Critical Care

RESEARCH

Open Access

Impact of lumbar cerebrospinal fluid drainage to control intracranial hypertension in patients with severe traumatic brain injury: a retrospective monocentric cohort

Geoffrey Dagod[1,2,3*], Marlène Laurens[1,2,3], Jean-Paul Roustan[1,2,3], Pauline Deras[1,2,3], Elie Courvalin[1,2,3], Mehdi Girard[1,2,3], Hugues Weber[1,2,3], Xavier Capdevila[1,2,3] and Jonathan Charbit[1,2,3]

Abstract

Background External lumbar drainage (ELD) of cerebrospinal fluid may help control intracranial pressure following a traumatic brain injury. We aimed to assess the efficacy and safety of ELD in post-traumatic intracranial hypertension (IH).

Methods This retrospective monocentric cohort study was conducted in the trauma critical care unit of the regional Level-I trauma centre between January 2012 and December 2022. All traumatic brain injury patients with IH (≥ 22 mmHg despite optimal sedation) were included. Data collection focused on the duration and management of IH, complications related to ELD, and outcomes (6-month Glasgow Outcome Scale [GOS]). The influence of ELD on the duration of IH was assessed using a multivariable Cox regression analysis, while its impact on the 6-month GOS ("unfavourable outcome" GOS 1–3, "good outcome" GOS 4–5) was evaluated using a multivariable logistic regression analysis.

Results Ninety patients (mean age 37 [SD, 16], injury severity score [ISS] 29 [IQR, 24–34]) were analyzed during the study period. Of these, 50 (56%) benefited from an ELD during their hospitalization (*ELD* group). The IH duration was significantly reduced in the *ELD* group (hazard ratio [HR] 1.74 [95% confidence interval (CI) 1.05–2.87; $p = 0.03$]). One patient (2%) experienced a cerebral herniation following ELD placement, and two others (4%) developed device-associated meningitis. The *ELD* group was significantly associated with a lower likelihood of an unfavourable outcome (OR 0.32 [95% CI 0.13–0.77]; $p = 0.011$) compared to the *no ELD* group.

Conclusion ELD appears in our cohort to be a safe and effective strategy to control post-traumatic IH, with an acceptable benefit-risk ratio. Our analysis even suggests a potential outcome improvement in patients treated by ELD compared with those having no cerebrospinal fluid drainage.

Keywords Cerebrospinal fluid, External lumbar drainage, External ventricular drainage, Intracranial hypertension, Management

*Correspondence:
Geoffrey Dagod
g-dagod@chu-montpellier.fr
Full list of author information is available at the end of the article

Background

Despite numerous advances in recent years, traumatic brain injury (TBI) remains a major public health and socioeconomic issue worldwide. The attributable mortality of severe TBI (sTBI) is estimated to range from 7 to 39%, depending on the severity [1, 2]. Furthermore, TBI is linked to a significant rate of lifelong disability among survivors. Accordingly, more than half of patients experiencing a sTBI will either die from it or survive with severe disabilities [3, 4].

Management of sTBI patients involves rapid haemodynamic and ventilatory stabilization, monitoring of intracranial pressure (ICP), and a tier-based approach structured to reduce intracranial hypertension while preventing secondary brain injury. This approach allows clinicians to escalate treatments in a systematic way. Monitoring and management of ICP is thus a crucial therapeutic objective. An increase in ICP is indeed central to the pathophysiological mechanisms of the injuries worsening following trauma; most TBI patients sustaining an unfavourable outcome experienced intracranial hypertension (IH) during the early phase of their management [5].

Most international guidelines [6] have thus integrated CSF drainage as a first-line therapy to treat IH when initial standard medical therapies have failed. Although the benefits in terms of outcome have not been clearly established, CSF drainage is widely used in a TBI context to avoid more invasive therapeutic options such as barbiturate-induced coma, hypothermia, or decompressive craniectomy. Regarding the pressure–volume ratio in the skull, withdrawing a small amount of CSF can significantly reduce ICP according to the Monro-Kellie doctrine. The gold standard for CSF drainage in TBI patients is ventriculostomy, also known as external ventricular drainage (EVD). However, EVD placement may be challenging or even infeasible in TBI patients with small ventricles or a shifted midline, making this clinical practice underused for controlling IH [7]. A CSF migration is thus observed in case of traumatic cerebral oedema from the lateral ventricles towards the subtentorial spaces and subarachnoid cisterns, making lumbar drainage an interesting alternative to EVD when CSF circulation is preserved.

External lumbar drainage (ELD) is technically simpler and can reduce most complications associated with ventriculostomy by avoiding the cerebral tissue. Observational retrospective studies evaluating ELD suggest it may be safe and effective in TBI patients when its use is appropriate [8, 9]. Some works in a traumatic context, with nevertheless methodological limitations, suggest that ELD would be associated with a lower ICP and a good long-term outcome [10]. Otherwise, in patients affected by an aneurysmal subarachnoid haemorrhage, a recent study also demonstrated a better neurological outcome at 6 months using prophylactic ELD [11]. A good global functional outcome should account for meaningful recovery, not just survival, and RESCUE-ICP trial [12] helps shift the focus toward interventions that improve both survival and quality of life. It appeared therefore important to assess in the traumatic context the relevance of an ELD strategy using a comparative group and a global functional endpoint.

The present study aimed to assess the efficacy and safety of a standardized protocol with CSF drainage with ELD to control ICP in sTBI patients. A secondary objective was to assess the influence of ELD on late neurological recovery.

Methods

Study design and setting

This monocentric cohort study was conducted over 10 years, between January 2012 and December 2022, in the trauma critical care unit of Lapeyronie University Hospital (Level-I Regional Trauma Centre – Montpellier, France – *OcciTRAUMA network*). All trauma patients suspected to have sustained severe trauma by a prehospital medical team were directly admitted to the emergency room of this unit, following the French guidelines for prehospital medical triage [13]. Retrospective identification of the study population was allowed by the trauma registry of our institution. For this retrospective analysis, patients consent was not considered as necessary by our local ethical committee.

Study population

The present study included all patients experiencing IH following a TBI. ICP was defined as elevated when its value exceeded 22 mmHg for at least 5 min with no stimulus, despite the optimization of sedation, correction of secondary brain insults and requiring additional specific therapy to control it.

Minors, patients with incomplete medical records, and those who prematurely died in the 48 h following admission or underwent an early decompressive craniectomy were excluded. Patients who had EVD were also excluded.

Management of patients

During the study period, all TBI patients benefited from standardized management according to international guidelines [14]. All patients undergoing ICP monitoring with an intraparenchymal probe were sedated and mechanically ventilated. Maintaining normocapnia and normoxia was a central goal during their initial management. Insulin was administered to control serum glucose

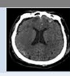
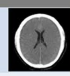
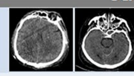
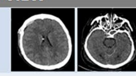
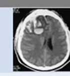
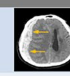
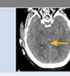
	GRADE 1 *Physiologic supratentorial reserve of CSF*	GRADE 2 *Reduced supratentorial reserve of CSF*	GRADE 3 *Infratentorial reserve of CSF only*	GRADE 4 *Small extra-axial lesion or operated or midline shift<5mm*	GRADE 5 *Focal intraparenchymal lesion or midline shift > 5mm*	GRADE 6 *Surgical extra-axial lesion or significative depressed skull fracture*	GRADE 7 *Diffuse brain swelling with loss of the supratentorial and infratentorial reserve of CSF*
SCAN VIEW							
CT scan							
Cortical folds	Physiologic	Reduced or missing	Missing	Grade **1** or **2**	Grade **1, 2** or **3**	Grade **1, 2** or **3**	Missing
Lateral ventricules	Physiologic	Reduced	Missing	Grade **1** or **2**	Grade **1, 2** or **3**	Grade **1, 2** or **3**	Missing
Basal cistern	Physiologic	Physiologic	Physiologic	Physiologic	Grade **1, 2** or **3**	Grade **1, 2** or **3**	Not discernible
TYPE OF INTRACRANIAL HYPERTENSION							
Type	Homogeneous IH	Homogeneous IH	Homogeneous IH	Homogeneous IH	Inhomogeneous IH	Inhomogeneous IH	Homogeneous IH
RISK INDUCED BY LUMBAR CEREBROSPINAL FLUID DRAINAGE							
Worsening of the lesion after decompression	–	–	–	++	+++++	+++++	–
Temporal or subfalcine herniation	–	–	–	–	+++++	+++++	–
Central herniation	–	–	+	–	+++	+++	+++++
INDICATIONS OF LUMBAR CEREBROSPINAL FLUID DRAINAGE							
	EARLY ELD → Standard target of ICP *[10-15 mmHg]*		Late ELD (Partial removal of CSF) → High target of ICP *[15-22 mmHg]*		Medical treatment - Rare surgery - Late ELD for rescue If ICP > 30 mmHg → High target of ICP *[15-22 mmHg]*	URGENT SURGERY Absolute contra-indication to the use of ELD	MEDICAL TREATMENT Absolute contraindication to the use of ELD Discuss decompressive craniectomy

Fig. 1 Classification of intracranial CSF reserve. ELD: External lumbar drainage, CSF: Cerebrospinal fluid, CT: Computed tomography, ICP: Intracranial pressure, IH: Intracranial hypertension

levels between 7 and 10 mmol/L. Patients were positioned supine with a 30-degree head-up tilt. Cerebral perfusion pressure (CPP) was maintained between 60 and 70 mmHg according to guidelines through vasoactive support with norepinephrine and, if necessary, plasma volume expansion with crystalloids [15]. The CPP could be adjusted via regular dynamic autoregulation assessments if necessary. For all patients, a cerebral CT scan was systematically performed on admission and 48–72 h after the injury to monitor lesion progression. Additional CT scans could be performed more closely based on clinical evolution or in cases of high risk of haemorrhage or complications.

Lumbar CSF drainage

ELD was introduced in 2012 as a rescue procedure for IH. It was thus used to reduce ICP to physiological levels when all conventional therapeutic procedures failed and in the absence of CT scan contraindications (*i.e.*, no discernible basal cisterns, midline shift > 10mm, presence of tonsillar herniation or significant mass lesion). Timing of ELD insertion was decided according to a local standardized protocol described in the Additional file 1. Since January 2018, a unit protocol was established to determine ELD indications, promote its use, and standardize the timing of its placement. This protocol was based on a CT scan classification according to several criteria, such as the amount of sub- and supratentorial CSF reserves, the presence of extra-axial haematomas or haemorrhagic contusions, and the obliteration of the basal cisterns. This classification integrated seven grades to allow the identification of the benefit-risk ratio for CSF drainage via the lumbar route. Homogeneous or inhomogeneous IH mechanisms and the potential for CSF drainage determined the possibility of ELD and its recommended timing (Fig. 1). To ensure the safety of procedure and to exclude a potential contraindication, a CT scan performed within the last 12 h and a coagulation status were necessary.

To avoid risks of cerebral hypotension and downward herniation caused by an excessive initial CSF withdrawal, our protocol recommended several safety measures associated with ELD placement. Firstly, ELD should be performed in the lateral position to limit pressure gradient between the spinal and cranial subarachnoid spaces. Secondly, ELD catheter should be inserted quickly into the needle after obtaining CSF reflux to reduce the drained volume. Thirdly, once the patient was repositioned with head elevation, a careful CSF withdrawal was achieved when the patient was repositioned in supine position, around 1 ml/minute, until ICP reaches the target level. Fourthly, a continuous bilateral pupillary examination was performed during initial CSF subtraction and then every hour. Thereafter, nurse protocol to control CSF drainage during critical phase was applied once the catheter was connected to a sterile collection bag allowing to collect, to measure and to set the pressure gradient of drainage. The drainage system was initially positioned 15 cm above the tragus to maintain safe and continuous drainage and was subsequently adjusted depending on the ICP targets. The target range for ICP was typically set between 10 and 20 mmHg. If the ICP remained above 20 mmHg, the drainage pressure gradient was increased by lowering the drainage level by -5 cm H_2O. Conversely, if the ICP dropped below 10 mmHg, the drainage was immediately stopped. When ICP increased to 15 mmHg, the drainage system was opened again and pressure gradient was reduced by increasing the drainage level by + 5 cm H_2O. In case of pupillary changes, the drainage was immediately stopped, and a brain CT scan was quickly performed. The lumbar CSF flow and pressure were monitored by nurses hourly to avoid the risk of overdrainage. If the CSF drainage rate was more than 10 ml per hour, the level of drainage was increased by + 5 cm H_2O. Weaning from ELD could be envisaged when the ICP remained within normal values for at least 12 h continuously with a + 20 cm H_2O drainage level. A clamping test for 24 h was then attempted and a CT scan performed to confirm the absence of ventricular dilatation. ELD could be removed in the case of good clinical evolution.

Data collection

The primary demographic data, Glasgow Coma Scale (GCS) on admission, cranial CT scan findings, and initial treatments, were documented for each patient. The Abbreviated Injury Scale (AIS) was calculated for each anatomical area, including the head, face, thorax, abdomen, extremities, and skin. All surgical interventions were collected. The ICP status was also recorded before and after implementing lumbar drainage. All CT scans were analyzed retrospectively for the present study by a radiologist blinded to the clinical outcome. All admission CT scan were analyzed to determine the Marshall score. Moreover, patients were classified according to our classification of the intracranial CSF reserve presented in Fig. 1. Seven grades are described, considering the presence of an intracranial injury, as well as the volumes of the basal cisterns and the lateral ventricles.

The occurrence and duration of IH phenomena were defined. The delay and duration of the ELD procedure were obtained in medical reports, as well as the initial volume of CSF drained. Any complications associated with lumbar drainage, such as infections, catheter occlusion, pupillary status, and cerebral complications, were also collected based on nurse ICU sheets and medical reports. All interventions to reduce the ICP, including measures to control body temperature, osmotherapy, and barbiturate administration, were also documented. Additionally, the duration of mechanical ventilation, sedation, and the length of stay in the ICU were collected. Finally, the neurological recovery of all patients was determined at ICU discharge and 6 months after the trauma, using the Glasgow Outcome Scale (GOS). This assessment was obtained from medical records.

Study definitions

The threshold used for the treatment of intracranial hypertension was 22 mmHg as recommended by the latest edition of Brain Trauma Foundation [14].

TBI severity was classified according to the GCS: mild TBIs had a GCS score of 14–15, moderate TBIs a GCS score of 9–13, and sTBI a GCS score of 3–8.

The critical CSF reserve represented the grade of our intracranial CSF reserve classification at the onset of IH.

The neurological outcomes were categorized based on the GOS [16]. Patients with GOS 4–5 were considered as having a "*good outcome*", while those with GOS 1–3 were classified as having an "*unfavourable outcome*".

Statistical analysis

The studied patients were initially divided into two groups, *ELD* and *no ELD*. Their clinical characteristics were initially presented and compared. Quantitative data were expressed as means (standard deviation [SD]) or median (interquartile range [IQR]) and compared using Student or Mann–Whitney *U* tests. Qualitative data were expressed as numbers (percentages) and compared using chi-square or Fisher tests.

Since the *ELD* and *no ELD* groups were not randomized and cannot be considered comparable, a propensity score was determined for each patient to account for potential confounding risk factors and reduce the expected selection bias. A *logit* score was thus established by multivariable logistic regression predicting ELD placement. This logistic model included the following variables determined a priori: age, diabetes insipidus, initial Marshall score, critical CSF reserve, osmotherapy, worst GCS, injury severity score (ISS), Simplified Acute Physiology Score (SAPS II), Revised Trauma Score (RTS), chest AIS, abdominal AIS, head AIS, face AIS, extremities AIS, skin AIS, mean arterial pressure, presence of tension pneumothorax on admission, or initial transfusion volume. This propensity score was compared between two groups as a quantitative variable and was also used as an adjustment variable in multivariable analysis to predict IH control and outcome.

Kaplan–Meier analysis was used to compare the cumulative incidence of normalization of ICP between the *ELD* and *no ELD* groups to study the delay in reaching IH control. Considering that early death was a possible clinical outcome and informative censoring, the *Fine and Grey* method was applied, classifying all dead patients as patients with persistent IH. The comparison between the groups was performed using the *Grey* test, which incorporates this competitive risk. Additionally, Cox proportional hazard regression analysis was conducted to assess whether an ELD was associated with faster normalization of ICP. The crude hazard ratio (HR) of ELD was provided with its 95% confidence interval (CI). Multivariable adjustment was then performed for potentially confusing risk factors determined a priori: age, initial Marshall score, initial and critical CSF reserve, GSC, ISS score, Simplified Acute Physiology Score, Revised Trauma Score, Trauma Injury Severity Score, chest/abdominal/extremities AIS score, mean arterial pressure, pneumothorax, initial transfusion, ventilation before admission, and the propensity score.

The influence of ELD on the final neurological recovery was ultimately assessed using a multivariable logistic regression analysis to predict the 6-month GOS (*good outcome*). Odds ratios (ORs) for ELD were thus provided with their 95% CI. Similarly to the previous analysis, multivariable adjustment was conducted using the same potentially confusing risk factors determined a priori, including the propensity score.

All statistical analyses were conducted using the software SAS online. A p-value below 0.05 was considered statistically significant.

Results

Study population

Between January 2012 and December 2022, 367 patients were admitted to our trauma centre with a sTBI. Among them, 104 patients surviving 48 h following admission experienced IH. Fourteen patients were excluded from the analysis due to an early decompressive craniectomy or an external ventricular drain (Additional file 2). A total of 90 patients were thus included in the study analysis. The mean age was 37 (SD, 16), and the majority were male (84%). The median GCS score was 6 (IQR, 3–8), and the median ISS was 29 (IQR, 24.5–34). The prehospital rate of mechanical ventilation was 84%. All patients had a head AIS $\geq$ 3, with a third (33%) having an extremities AIS $\geq$ 3, a quarter (27%) having a chest AIS $\geq$ 3 and one-tenth (10%) having an abdominal AIS $\geq$ 3. The most common cerebral injuries observed on the initial CT scan were subarachnoid haemorrhages (82%), cerebral contusions (80%), and subdural haematomas (70%). Additionally, 15 patients (17%) presented with brain herniation on admission. The median Marshall Score on admission CT-scan was 2 (IQR, 2–3). According to the CSF reserve classification, half of the patients were classified on admission as grade 1 or 2 (25% and 30%, respectively). Demographic data and patient characteristics are summarized in Table 1. Nine patients (10%) underwent early neurosurgery (eight craniotomies to evacuate extra-axial haematoma and one depressed skull fracture reduction). Thirty-four patients (38%) received osmotherapy during pre-hospital phase or in the emergency room.

During their ICU stay, 50 patients (56%) received an ELD (Additional file 1). No significant differences were found between the *ELD* and *no ELD* groups in terms of GCS, initial cerebral injuries, CSF reserve, or treatments. The AIS scores were comparable between the two groups, except for face AIS, which was higher in the *no ELD* group (Table 1).

IH occurrence

The median duration between admission and the onset of IH was 2 days (IQR, 1–5 days) for the overall population. In 50% of the patients, IH occurred within the first 2 days following admission, regardless of the group. IH occurred within 8 days of hospitalization for all patients except one (Additional file 3). No significant difference was found between the *ELD* and *no ELD* groups in terms of IH onset (3.5 days [IQR, 1.5–5.5 days] *versus* 2.5 days [IQR, 1–6 days], respectively; $p = 0.58$).

Intracranial CSF reserve on CT scan

On IH onset, 55% of patients were classified as grade 1 or 2 and 19% as grade 3 or 4 for the intracranial CSF reserve on the CT scan. As expected, grades 6 and 7 were more common in patients in the *no ELD* group (29% [9/40] *versus* 6% [3/50], respectively; $p = 0.022$). Other grades were comparable between the two groups (Additional file 4).

ELD use

The median day of ELD placement was 6 days (IQR, 3–8 days) following admission. All ELD were placed between the Day 1 and the Day 15. Only one patient (2%) in the *ELD* group failed in IH control, leading to brain death despite receiving maximal treatment. The median duration of CSF drainage was 8 days (IQR, 6–12 days). The median daily CSF volume drainage was 66 mL/day (IQR, 8–875 mL/day; Table 2).

ICP control and ELD

Using the *Fine and Grey* method, considering the competing risk of death, the *ELD* group experienced a significantly faster correction of IH ($p = 0.025$, Fig. 2).

Table 1 Baseline demographic and clinical characteristics of the 90 patients studied

	ELD (n = 50)	No ELD (n = 40)	Overall (n = 90)	*p* value
Gender, n (%)				0.65
Male	43 (88%)	33 (82%)	76 (84%)	
Female	7 (14%)	7 (17%)	14 (16%)	
Age (years), mean	36,7	37.5	37	
Glasgow coma scale, n (%)				0.70
13–15	6 (12%)	5 (12%)	11 (12%)	
9–12	3 (6%)	5 (12%)	8 (9%)	
6–8	20 (40%)	13 (32%)	33 (37%)	
3–5	21 (42%)	17 (42%)	38 (42%)	
AIS, n (%)				
Head AIS > 3	50 (100%)	40 (100%)	90 (100%)	1
Face AIS > 3	8 (16%)	14 (35%)	22 (24%)	0.04
Chest AIS > 3	14 (28%)	10 (25%)	24 (27%)	0.75
Abdominal AIS > 3	7 (14%)	2 (5%)	9 (10%)	0.15
Extremities AIS > 3	21 (42%)	9 (22%)	30 (33%)	0.05
Skin AIS > 3	10 (20%)	3 (7%)	13 (14%)	0.09
Severity scores, mean				
Simplified Acute Physiology	50.7	51.7	51.2	
Injury Severity	30.2	32.8	31.5	
Revised Trauma	5.3	4.9	5.1	
Initial Marshall CT Score, n (%)				0.22
Score 1	0 (0%)	0 (0%)	0 (0%)	
Score 2	36 (72%)	22 (55%)	58 (64%)	
Score 3	2 (4%)	5 (12%)	7 (8%)	
Score 4	3 (6%)	3 (8%)	6 (7%)	
Score 5	1 (2%)	1 (3%)	2 (2%)	
Score 6	8 (16%)	9 (22%)	17 (19%)	
Initial cerebral injury, n (%)				
Basal skull fracture	16 (32%)	18 (45%)	34 (38%)	0.21
Cranial vault fracture	16 (32%)	20 (50%)	36 (40%)	0.08
Extra-dural hematoma	11 (22%)	12 (30%)	23 (26%)	0.38
Subdural hematoma	36 (72%)	27 (67%)	63 (70%)	0.16
Subarachnoid hemorrhage	41 (82%)	33 (82%)	74 (82%)	0.95
Cerebral contusion	40 (80%)	32 (80%)	72 (80%)	1
Diffuse axonal injuries	10 (20%)	7 (17%)	17 (19%)	0.76
Midline shift > 5 mm	2 (4%)	4 (10%)	6 (7%)	0.49
Brain herniation	5 (10%)	10 (25%)	15 (17%)	0.06
Initial CSF reserve, n (%)				0.16
Grade 1	14 (28%)	9 (22%)	23 (25%)	
Grade 2	18 (36%)	9 (22%)	27 (30%)	
Grade 3	6 (12%)	4 (10%)	10 (11%)	
Grade 4	5 (10%)	2 (5%)	7 (8%)	
Grade 5	2 (4%)	5 (12%)	7 (8%)	
Grade 6	3 (6%)	8 (20%)	11 (12%)	
Grade 7	1 (2%)	3 (7%)	4 (4%)	
Initial treatment, n (%)				
Neurosurgery	4 (8%)	5 (12%)	9 (10%)	0.48
Osmotherapy upon admission	17 (34%)	17 (42%)	34 (38%)	0.41
Diabetes insipidus, n (%)	17 (34%)	15 (37%)	32 (36%)	0.73
Propensity score, median [IQR]	0.17 [− 0.62;1.46]	− 0.62[− 1.4;0.04]	1.15 [0.07;1.76]	< 0.0001

Table 1 (continued)

AIS, Abbreviated Injury Scale; CSF, Cerebrospinal fluid; CT, Computed Tomography; ELD, External lumbar drainage

Table 2 Data concerning ELD and related complications

ELD placed after injury (day)	**6.32**
ELD duration (day)	9.36
Mean CSF flow (mL/d)	
The first 24 h	43.6
Per day until removal	59.7
Complications, n (%)	
Pupillary changes	1 (2%)
ELD obstruction requiring catheter replacement	7 (14%)
Suspected CSF infection	2 (4%)
Subdural bleeding	1 (2%)
Cerebral herniation	1 (2%)

ELD, External lumbar drainage; CSF, Cerebrospinal fluid

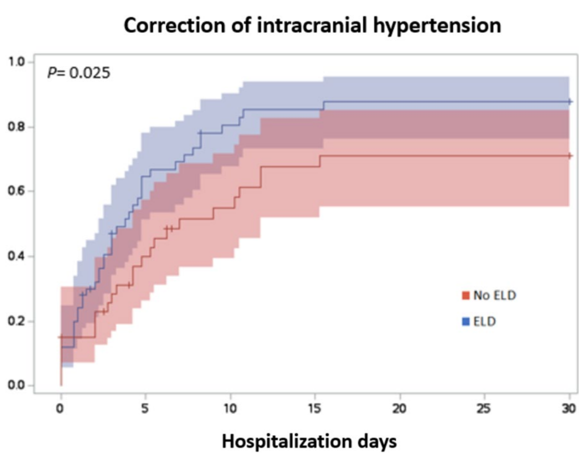


Fig. 2 Evolution of intracranial hypertension. Cumulative incidence of correction of IH in the groups with ELD (blue) and without (orange). The comparison between the groups was performed using the Grey test, which incorporates the competitive risk of death. ELD: External lumbar drainage, ICP: Intracranial pressure, IH: Intracranial hypertension

Similarly, Cox regression analysis demonstrated a significant association between ELD and a reduced duration of IH; the crude HR for the correction of IH was 1.74 (95% CI 1.05–2.88; $p=0.03$). This significant association was still observed after adjusting for many confounding factors, such as age, GCS, RTS, SAPS II, ISS, chest/abdominal/extremities AIS, mean arterial pressure, and admission pneumothorax (Fig. 3).

Safety of ELD

In the *ELD* group, one patient was classified as grade 7 for an intracranial CSF reserve (2%) developed after ELD placement and a central herniation leading to brain death within hours. An increase in a subdural haematoma was also observed in one patient (2%). The other complications related to ELD were a catheter occlusion requiring replacement of a lumbar drainage system in seven patients (14%) and a confirmed CSF infection in two patients (4%).

Neurological outcome and ELD

At ICU discharge, only four patients (4%) were classified as GOS 4 or 5, 63 patients (70%) GOS 2 or 3, while 23 patients (26%) were dead. The respective values 6 months after the trauma were 55 (62%), 10 (11%), and 25 (28%; Fig. 4). Patients with a *good outcome* at 6 months were significantly more numerous in the *ELD* group than in the *no ELD* group (72% versus 48%, $p=0.012$).

Following the same trend, ELD was associated in logistic regression analysis with a lower likelihood of an *unfavourable outcome* at 6 months (crude OR, 0.32 [95% CI 0.13 to 0.77]; $p=0.011$). This significant association was still observed after adjustment with all confounding variables, except for the propensity score (Fig. 3).

Discussion

In this retrospective study that studied a population of 367 sTBI over 10 years, we have described a safe and efficacy use of ELD in case of IH, with an acceptable rate of complications (4% of infections and 2% cerebral herniation) and a faster normalization of ICP. Furthermore, percutaneous placement of ELD and lumbar CSF drainage were associated in our analysis with a reduced likelihood of an unfavourable outcome at 6 months in comparison with a standard strategy without CSF drainage. This statistical association was observed after adjustment by most of confounding factors. Our findings support a favourable benefit-risk ratio of ELD in the management of IH in sTBI when it is included in therapeutic bundle and with a strict protocol. However, our conclusions should be interpreted cautiously because of the retrospective design of study and since our control group did not included CSF drainage by EVD.

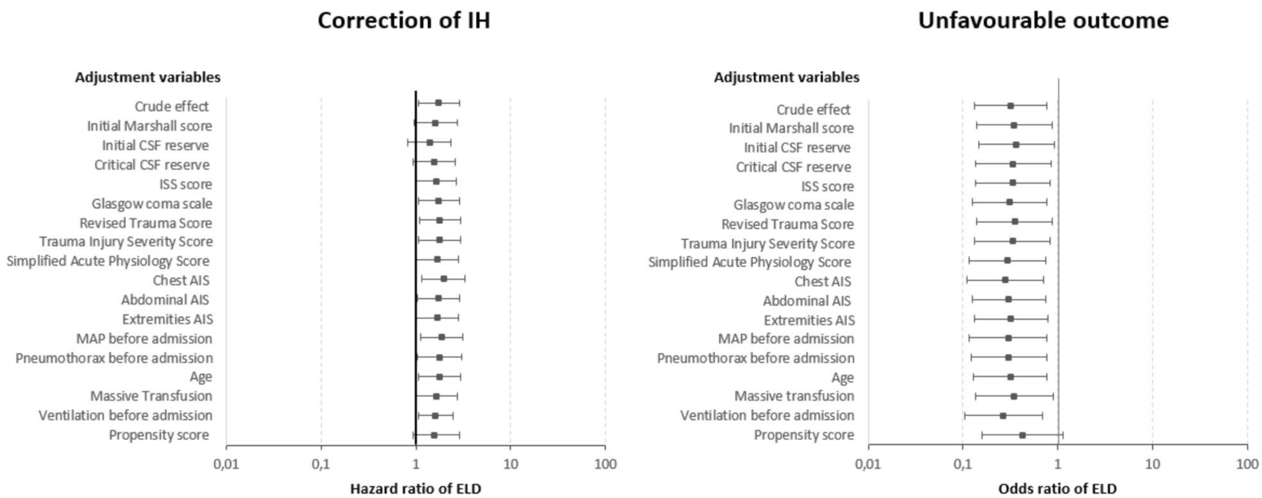


Fig. 3 Influence of ELD on ICP control (left) and Influence of ELD on outcome (right). Hazard ratio with its 95% confidence interval for the correction of IH. Odds ratio with its 95% confidence interval for the unfavourable outcome. Crude effect is presented as well as those adjusted for various confounding factors. AIS: Abbreviated Injury Scale, CSF: Cerebrospinal fluid, ELD: External lumbar drainage, ISS: Injury severity score, ICP: Intracranial pressure, IH: Intracranial hypertension, MAP: Mean arterial pressure

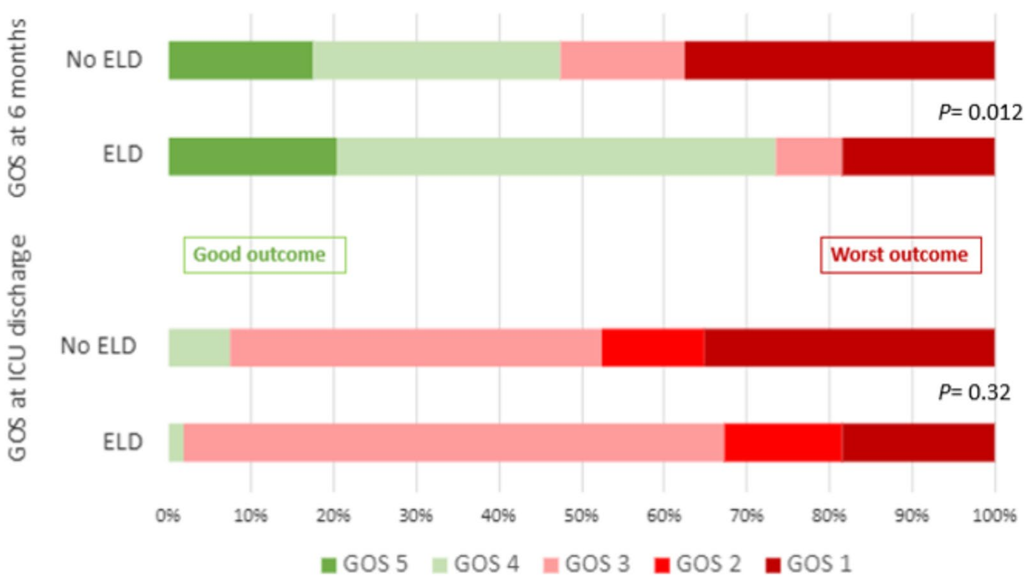


Fig. 4 ICU and long-term outcomes. Distribution of patients' GOS in the *ELD* and the *no ELD* groups, at ICU discharge (bottom) and 6 months after the trauma (top). A GOS of 4–5 was considered a "good outcome," while GOS of 1–3 was considered a "worst outcome." GOS: Glasgow Outcome Scale, ICU: Intensive care unit, ELD: External lumbar drainage

CSF drainage in TBI

CSF drainage plays a central role in the management of IH in severely brain-injured patients. The SIBICC guidelines recommend thus CSF drainage through a ventriculostomy as a first-tier therapy in the consensus-based algorithm [6]. However, in 2017, *Cnossen* et al. [7] revealed that EVD was poorly used in neurotrauma centres: in 27% as first-tier treatment of IH and in 33% as second-tier therapy. Several reasons may explain this underuse; firstly, the insertion of an EVD can be challenging or even infeasible in TBI patients with small ventricles or a midline shift. Secondly, even when ventricular dimensions are suitable for ventricular drainage, studies have reported 57% misplacement without neuronavigation [17]. Thirdly, placement and removal of an EVD risk haemorrhage, which may affect its efficacy or patient outcome. Finally, many concerns exist about the risk of [18]. EVD-related ventriculitis is indeed known to generate increased morbimortality, longer hospitalization, and higher healthcare costs [19]. Moreover, scientific evidence in the literature indicates the added value of ventricular CSF drainage in TBI patients is limited [14]. Therefore, it appears legitimate to explore reliable alternative approaches to CSF drainage during the management of traumatic IH.

Lumbar CSF drainage

Several experts have proposed ELD in TBI patient as an alternative to CSF drainage because of its technical simplicity. Different studies have thus reported a low complication rate for the ELD procedure, also suggesting its potential efficacy in IH control. However, works focused on the traumatic context studied small populations and did not include a control group [8]. Moreover, the studied populations were highly heterogeneous, justifying further studies to guarantee safe use. In contrast with previous works, the present study included a homogenous population (*i.e.*, patients with traumatic IH) and a control group. Thus, we observed that ELD enables a faster reduction in ICP than a strategy without CSF drainage. The findings are concordant with the existing literature [8–10]. *Ginalis* et al. indeed demonstrated in a meta-analysis that ELD allowed a rapid and prolonged control of IH, decreasing the need for sedatives, paralytics, and osmotherapy [8]. This decrease in the "hypertension dose" has been well-associated in many studies with neurological prognostic and overall outcome. Moreover, ELD strategy was observed in several studies to be associated with high rates of favourable outcome, with 62% of sTBI achieving a favourable outcome at five years in the study by *LLompart-Pou* et al. [10]. Similarly, our analysis found that in case of IH, ELD was associated with better outcomes compared to the absence of CSF drainage (72% of good outcome at 6 months versus 48%). This statistical association was also observed in multivariable analysis after adjustment by most of confounding factors. The adjustment with the propensity score had the same trend, but with a probable lack of statistical power.

Safe use of ELD

Several concerns are widespread regarding the lumbar CSF withdrawn in the presence of IH; the main one is the risk of central herniation. However, studies supporting this contraindication are old, conducted when CT scans and ICP monitoring were unavailable, and report uncontrolled CSF withdrawal in patients suffering from cerebral tumours with clinical signs of herniation [20–22]. More recent studies have demonstrated that in patients with elevated ICP, the risk of cerebral herniation associated with ELD was low if CT conditions were respected [23, 24]. CT criteria have been employed in various studies [23, 25] since *Munch* et al. [26] first described them, resulting in a low rate of complications. Expectedly, CSF subtraction leads to a slight displacement of brain structures toward the drained space. Therefore, it is necessary to verify the absence of mass lesions, clear visualization of basal cisterns, and a midline shift of less than 10 mm. With inhomogeneous IH, a large mass, deviation, or herniation, these phenomena will logically increase with CSF drainage, regardless of the route. The only patient experiencing cerebral herniation in our study corresponded to this case and had a CT contraindication for ELD (grade 7). Furthermore, CSF overdrainage may be avoided in determining the drainage pressure gradient by adjusting the drainage level in relation to the foramen of Monro. Therefore, our work introduced a CSF reserve classification detailed in Fig. 1 to assess the risk associated with ELD. This CT scan classification is based on criteria such as the presence and nature of intracranial injuries, the volume of basal cisterns and lateral ventricles, and the presence of a cerebral herniation. Our classification enables the determination of the intracranial CSF reserve and the graduating risk of herniation. This image-based scoring system will require external validation. Another non-negligible risk of ELD placement is the CSF infection, with an observed rate of 4% in our study. This incidence was similar to those reported in the literature with ELD use, ranging from 4 to 7% [9, 27].

Study limitations

Several potential limitations must be mentioned. Firstly, the retrospective data collection could have led to missing data. However, only one patient was excluded from our study due to incomplete information, minimizing any potential impact on the results. The location of our study at a single centre limits the extrapolation of our findings. Prospective multicentre studies would help to limit interpretation bias by establishing precise and reliable standards of care for ELD and control groups, determining timing of ELD use, and integrating ELD with various clinical practices across different trauma centres. Secondly, the control group in our analysis had no CSF drainage. Therefore, our results highlight the influence of CSF drainage and not only that of the lumbar route. A control group receiving external ventricular drainage would enable assessment of the specific influence of the lumbar route. Thirdly, CT scan follow-up was conducted in our series in accordance with the recommendations or when clinical situation required imaging control. However, closer monitoring would probably offer a better understanding of pathophysiological mechanisms and consequences of CSF drainage. Fourthly, ELD has contraindications that were listed in our unit protocol. Therefore, a difference between the two groups is expected, making a possible interpretation bias. We attempted to reduce this potential risk with a multiple variable adjustment including the propensity score, however an interpretation bias may still exist. Anyway, it is interesting to note that the observed difference between the ELD and no ELD groups is lower than that expected. This is probably due to the progressive implementation of ELD protocol in the first part of study period, making these two groups more comparable. Moreover, admission Marshall score were comparable between the two groups. Fifthly, ICP threshold defined into the recommendations has changed during the study period from 20 to 22 mmHg. This could have slightly influenced treatment decisions and outcomes. Instead of using a defined intracranial pressure threshold, it would also have been more interesting to consider cumulative ICP burden. Sixth, although 6-month functional outcome is commonly used to assess the prognosis of TBI patients, a longer follow-up would have allowed drawing more robust conclusions. The extended version of the GOS could also have provided a more detailed assessment of 6-month outcome. Furthermore, GOS, extracted from medical records, were not established by a blinded neurologist that might introduce a misclassification bias.

Conclusion

ELD appears in our cohort to be a safe and effective intervention in sTBI patients with intracranial hypertension. A strict compliance with CT scan indications before its placement and withdrawal modalities would guarantee safe use and a limited risk of complications, especially central herniation. Our findings suggest a significant association between ELD and a better outcome at 6 months in comparison with the absence of CSF drainage. However, the present work suffers from methodological limitations that require some caution. Prospective studies are therefore necessary to validate this strategy and recommend increased use of ELD in a traumatic context.

Abbreviations

AIS Abbreviated Injury Scale
CT Computed tomography
CPP Cerebral perfusion pressure
CR Crude ratio
CSF Cerebrospinal fluid
ELD External lumbar drainage
EVD External ventricular drainage
GSC Glasgow coma scale
GOS Glasgow outcome scale
HR Hazard ratio
IH Intracranial hypertension
ICP Intracranial pressure
ICU Intensive care unit
IQR Interquartile range
ISS Injury severity score
OR Odds ratio
SD Standard deviation
sTBI Severe traumatic brain injury
TBI Traumatic brain injury

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13054-024-05199-1.

Additional file 1: Local standardized protocol and timing of ELD insertion for the management of severe traumatic brain injury with intracranial hypertension. CPP: Cerebral Perfusion Pressure, ELD: External lumbar drainage, ICP: Intracranial pressure, PaCO2: arterial partial pressure of carbon dioxide.

Additional file 2: Flow chart of study population. TBI: Traumatic brain injury, ELD: External lumbar drainage, ICP: Intracranial pressure, EVD: External ventricular drainage.

Additional file 3: Intracranial hypertension occurrence. IH: Intracranial hypertension.

Additional file 4: Intracranial CSF reserve. On the left, distribution of intracranial CSF reserve grades in groups with ELD (blue) and without (orange), upon the onset of elevated ICP. On the right, distribution of intracranial CSF reserve grades in groups with ELD before lumbar CSF drainage. CSF: Cerebrospinal fluid, ELD: External lumbar drainage, ICP: Intracranial pressure.

Acknowledgements
None

Author contributions
Concept and design: GD, JC, JPR. Acquisition of data: ML, MG, HW. Interpretation of data, drafting and writing of the manuscript: GD, JC. Statistical analysis: JC. Critical revision of the manuscript for important intellectual content: All authors.

Funding
This work was supported by institutional sources.

Availability of data and materials
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The institutional trauma databank has been validated and follows the French rules relative to the nominative listings. It is declared and belongs to nominative lists of the Montpellier University Hospital. Following the French rules, all included patients and their relatives were informed that their data during and after their ICU stay could be anonymously used for analysis and medical publication. Thereby, in this retrospective analysis, no supplemental ethics Committee approval was necessary.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Trauma Critical Care Unit, Montpellier University Hospital, 34295 Cedex 5 Montpellier, France. [2]OcciTRAUMA Network, Regional Network of Medical Organization and Management for Severe Trauma in Occitanie, Montpellier, France. [3]Département d'Anesthésie Réanimation Lapeyronie, Hôpital Lapeyronie, 371 Avenue du Doyen G. Giraud, 34295 Montpellier, France.

Received: 8 September 2024 Accepted: 2 December 2024
Published online: 02 January 2025

References

1. Peeters W, van den Brande R, Polinder S, Brazinova A, Steyerberg EW, Lingsma HF, et al. Epidemiology of traumatic brain injury in Europe. Acta Neurochir (Wien). 2015;157(10):1683–96.
2. Roozenbeek B, Maas AIR, Menon DK. Changing patterns in the epidemiology of traumatic brain injury. Nat Rev Neurol. 2013;9(4):231–6.
3. Peterson AB Surveillance report of traumatic brain injury-related emergency department visits, hospitalizations, and deaths, United States, 2014 [Internet]. Available from: https://stacks.cdc.gov/view/cdc/78062/cdc_78062_DS1.pdf
4. Dewan MC, Rattani A, Gupta S, Baticulon RE, Hung YC, Punchak M, et al. Estimating the global incidence of traumatic brain injury. J Neurosurg. 2018;130(4):1080–97.
5. Balestreri M, Czosnyka M, Hutchinson P, Steiner LA, Hiler M, Smielewski P, et al. Impact of intracranial pressure and cerebral perfusion pressure on severe disability and mortality after head injury. Neurocrit Care. 2006;4(1):8–13.
6. Hawryluk GWJ, Aguilera S, Buki A, Bulger E, Citerio G, Cooper DJ, et al. A management algorithm for patients with intracranial pressure monitoring: the Seattle International Severe Traumatic Brain Injury Consensus Conference (SIBICC). Intensiv Care Med. 2019;45(12):1783–94.
7. Cnossen MC, Huijben JA, van der Jagt M, Volovici V, van Essen T, Polinder S, et al. Variation in monitoring and treatment policies for intracranial hypertension in traumatic brain injury: a survey in 66 neurotrauma centers participating in the CENTER-TBI study. Crit Care. 2017;21(1):233.
8. Ginalis EE, Fernández LL, Ávila JP, Aristizabal S, Rubiano AM. A review of external lumbar drainage for the management of intracranial hypertension in traumatic brain injury. Neurochirurgie. 2022;68(2):206–11.
9. Stevens AR, Soon WC, Chowdhury YA, Toman E, Yim S, Veenith T, et al. External lumbar drainage for refractory intracranial hypertension in traumatic brain injury: a systematic review. Cureus. 2022;14(10):e30033.
10. Llompart-Pou JA, Abadal JM, Pérez-Bárcena J, Molina M, Brell M, Ibáñez J, et al. Long-term follow-up of patients with post-traumatic refractory high intracranial pressure treated with lumbar drainage. Anaesth Intensiv Care. 2011;39(1):79–83.
11. Wolf S, Mielke D, Barner C, Malinova V, Kerz T, Wostrack M, et al. Effectiveness of lumbar cerebrospinal fluid drain among patients with aneurysmal subarachnoid hemorrhage: a randomized clinical trial. JAMA Neurol. 2023;80(8):833–42.
12. Hutchinson PJ, Kolias AG, Timofeev IS, Corteen EA, Czosnyka M, Timothy J, Anderson I, Bulters DO, Belli A, Eynon CA, Wadley J, Mendelow AD, Mitchell PM, Wilson MH, Critchley G, Sahuquillo J, Unterberg A, Servadei F, Teasdale GM, Pickard JD, Menon DK, Murray GD, Kirkpatrick PJ. Trial of Decompressive Craniectomy for Traumatic Intracranial Hypertension. New England J Med. 2016;375(12):1119–30.
13. Gauss T, Balandraud P, Frandon J, Abba J, Ageron FX, Albaladejo P, et al. Strategic proposal for a national trauma system in France. Anaesth Crit Care Pain Med. 2019;38(2):121–30.
14. Carney N, Totten AM, O'Reilly C, Ullman JS, Hawryluk GWJ, Bell MJ, et al. Guidelines for the management of severe traumatic brain injury. Fourth Ed Neurosurg. 2017;80(1):6–15.
15. Geeraerts T, Velly L, Abdennour L, Asehnoune K, Audibert G, Bouzat P, et al. Prise en charge des traumatisés crâniens graves à la phase précoce (24 premières heures). J Eur Urgences Réanimation. 2017;29(2):167–92.
16. Jennett B, Snoek J, Bond MR, Brooks N. Disability after severe head injury: observations on the use of the glasgow outcome scale. J Neurol Neurosurg Psychiatry. 1981;44(4):285–93.
17. Huyette DR, Turnbow BJ, Kaufman C, Vaslow DF, Whiting BB, Oh MY. Accuracy of the freehand pass technique for ventriculostomy catheter placement: retrospective assessment using computed tomography scans. J Neurosurg. 2008;108(1):88–91.
18. Ramanan M, Lipman J, Shorr A, Shankar A. A meta-analysis of ventriculostomy-associated cerebrospinal fluid infections. BMC Infect Dis. 2015;8(15):3.
19. Lyke KE, Obasanjo OO, Williams MA, O'Brien M, Chotani R, Perl TM. Ventriculitis complicating use of intraventricular catheters in adult neurosurgical patients. Clin Infect Dis. 2001;33(12):2028–33.
20. Hepburn HH. The risk of spinal puncture. Can Med Assoc J. 1938;39(5):449–50.
21. Sencer W. The lumbar puncture in the presence of papilledema. J Mt Sinai Hosp N Y. 1956;23(6):808–15.
22. Korein J, Cravioto H, Leicach M. Reevaluation of lumbar puncture; a study of 129 patients with papilledema or intracranial hypertension. Neurology. 1959;9(4):290–7.
23. Tuettenberg J, Czabanka M, Horn P, Woitzik J, Barth M, Thomé C, et al. Clinical evaluation of the safety and efficacy of lumbar cerebrospinal fluid drainage for the treatment of refractory increased intracranial pressure. J Neurosurg. 2009;110(6):1200–8.
24. Manet R, Schmidt EA, Vassal F, Charier D, Gergelé L. CSF lumbar drainage: a safe surgical option in refractory intracranial hypertension associated with acute posttraumatic external hydrocephalus. Acta Neurochir Suppl. 2016;122:55–9.
25. Abadal-Centellas JM, Llompart-Pou JA, Homar-Ramírez J, Pérez-Bárcena J, Rosselló-Ferrer A, Ibáñez-Juvé J. Neurologic outcome of posttraumatic refractory intracranial hypertension treated with external lumbar drainage. J Trauma Acute Care Surg. 2007;62(2):282–6.
26. Münch EC, Bauhuf C, Horn P, Roth HR, Schmiedek P, Vajkoczy P. Therapy of malignant intracranial hypertension by controlled lumbar cerebrospinal fluid drainage. Crit Care Med. 2001;29(5):976–81.
27. Citerio G, Signorini L, Bronco A, Vargiolu A, Rota M, Latronico N, et al. External ventricular and lumbar drain device infections in ICU patients: a prospective multicenter italian study. Crit Care Med. 2015;43(8):1630–7.

Publisher's Note