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Recommendations

Neurosurgical management of the acute phase of adult and pediatric traumatic brain injury: 2025 guidelines of the French Society of Neurosurgery

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ABSTRACT

Objective: To develop a multidisciplinary French framework addressing neurosurgical management in the initial phase of traumatic brain injury (TBI) in adults and children.

Design: A panel of 29 experts was formed at the request of the French Society of Neurosurgery (SFNC), with the participation of the French Society of Pediatric Neurosurgery (SFNCP), French Society of Private-Practice Neurosurgeons (SFNCL), French-Speaking Neurocritical Care and Neuro-Anesthesiology Society (ANARLF), French Society of Anesthesia, Critical Care and Perioperative Medicine (SFAR), French-Speaking Pediatric Emergency and Intensive Care Group (GFRUP), French Society of Neuroradiology (SFNR), French-Speaking Infectious Diseases Society (SPILF), and the French Society of Physical Medicine and Rehabilitation (SOFMER).

Methods: Questions were formulated using the PICO (Patients, Intervention, Comparison, Outcome) format, grouped into 7 categories: 1. Factors of poor prognosis, 2. Extradural hematoma, 3. Acute subdural hematoma, 4. Skull-base fracture and dural tear, 5. Penetrating traumatic brain injury, 6. Post-traumatic cerebrospinal fluid disorder, and 7. Pediatric specificities.

Results: Synthesis by the experts and application of the GRADE® method resulted in the formulation of 45 recommendations. Strong consensus was reached for all recommendations at the first round of rating,

Conclusion: There was a strong consensus among the experts on important interdisciplinary recommendations to improve the neurosurgical management of patients with TBI.

1. Introduction

Traumatic brain injury (TBI) is one of the most serious types of trauma, accounting for 30% of post-traumatic mortality in the United States [1] and 37% in Europe [2]. Annual incidence in Europe is approximately 250/100,000, with significant regional differences [3]. Despite major efforts in pre-hospital and in-hospital management, even mild TBI remains a source of disabling neurological sequelae.

Numerous national and international clinical guidelines and consensus statements have been developed to help practitioners adopt common decision-making rules in this area. Most were developed by professional societies in critical care and emergency medicine in collaboration with experts in neurosurgery, neuroradiology and rehabilitation. There are recommendations for the medical management of mild TBI (Glasgow Coma Score $\geq$13) and concussion [4,5], for severe (GCS $\leq$ 8) and moderate (GCS 9–12) TBI in adults [6,7] and for TBI in children [8], as well as recommendations for pre-hospital management [9] and for intracranial brain monitoring [10,11]. In addition, the Neurocritical Care Society issued recommendations on neuroprognosis in moderate and severe TBI [12].

Although neurosurgical procedures are an integral part of this management, the only guidelines developed specifically by neurosurgeons date back to 2006 [13]. Some surgical procedures were included in these recommendations, and not included in the present guidelines: external ventricular drainage (EVD) in adults [6,7] and children [8], and decompressive craniectomy in adults [6,7,14] and children [8]. However, the indications and modalities of neurosurgical treatment, regardless of the severity of TBI, for both adults and children are a broad area of debate. This is the subject of the present recommendations.

2. Methods

These guidelines were drawn up by a group of experts for the French Society of Neurosurgery (SFNC), in partnership with the French Society of Paediatric Neurosurgery (SFNCP), French Society of Private-Practice Neurosurgeons (SFNCL), French-Speaking Neurocritical Care and Neuro-Anesthesiology Society (ANARLF), French Society of Anesthesia, Critical Care and Perioperative Medicine (SFAR), French-Speaking Pediatric Emergency and Intensive Care Group (GFRUP), French Society of Neuroradiology (SFNR), French-Speaking Infectious Diseases Society (SPILF) and French Society of Physical Medicine and Rehabilitation (SOFMER).

The organizing committee compiled a list of questions to be addressed and designated experts for each question. Questions were formulated using the PICO (Patient Intervention Comparison Outcome) format.

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The GRADE® method was used to develop the guidelines. Following a quantitative analysis of the literature, the method determined the quality of evidence: i.e., the estimated confidence in the effect, and the level of recommendation. Quality of evidence was graded as:

- high: further research is very unlikely to change the confidence in the estimate of the effect;
- moderate: further research is likely to affect the confidence in the estimate of the effect and may change the estimate of the effect itself;
- low: further research is very likely to affect the confidence in the estimate of the effect and may change the estimate of the effect itself;
- very low: any estimate of the effect is very unlikely.

There are a large number of studies of neurosurgical management of head trauma in its early stages, but very few with a high level of evidence; thus, the "recommendations for professional practice" format is appropriate, allowing experts to make suggestions based on "expert opinion", even with very weak evidence. No level 1 recommendations were made. Recommendations were written using the following standard formulations: "It is probably advisable" for Grade 2 recommendations and "The experts suggest" for expert opinion. Each recommendation was then assessed by each of the experts and rated on a scale from 1 (strongest disagreement) to 9 (strongest agreement).

For a recommendation to be made, at least 50% of voters had to have an opinion, with fewer than 20% voting for the opposite proposal. A strong consensus required agreement by at least 70% of voters.

3. Results

The scope of these guidelines is the neurosurgical management of adult and pediatric TBI requiring neurosurgical intervention in the initial phase (days after trauma). A bibliographic search was performed using the PubMed and Cochrane databases. To be included in the analysis, publications had to be published after 2006, which is the date of the previous neurosurgical guidelines, or earlier if deemed important by the expert panel, in peer-reviewed journals, in English or French. A specific analysis of the pediatric literature was performed.

The experts selected 15 questions, covering areas related to the indications and modalities of neurosurgical procedures in the treatment of early-phase TBI: prognostic factors, extradural hematoma, acute subdural hematoma, depressed skull fracture and skull-base fracture associated with cerebrospinal fluid (CSF) fistula, penetrating TBI, post-traumatic CSF disorders, and pediatric specificities. Poor neurological outcome on the Glasgow Outcome Scale Extended (GOSE) [15] was used as the primary endpoint: death (GOSE 1) and severe neurological disability (GOSE 2–4) (see Appendix). For pediatric questions, GOSE was replaced by the Pediatric Cerebral Performance Category (PCPC) in some publications [16]; PCPC > 3 was considered pejorative. Central nervous system infections and epilepsy also counted as poor neurological outcomes.

After synthesizing the work of the experts and applying the GRADE methodology, 45 recommendations were formulated. These represent a collective effort on the part of practitioners to homogenize practice and provide arguments to support neurosurgical decision-making in individual cases, despite low levels of evidence in the literature.

The recommendations were summarized in two infographics (See Appendix).

1. Factors for poor prognosis when emergency neurosurgery is considered in adult patients with severe traumatic brain injury

Question 1: In patients with severe TBI for whom emergency neurosurgery is considered, should the decision to withhold or withdraw surgical treatment be discussed in a collegial multidisciplinary setting?

In neurosurgical emergencies, early neuroprognostication within the first 72 h is difficult. The surgical decision may have far-reaching and irreversible consequences. Given the risk of severe postoperative disability, there are situations of devastating brain injury in which abstention from surgery is indicated, withholding or withdrawing life-sustaining treatment: early life-sustaining treatment, within the first 72 h, is the leading cause of death after severe TBI, accounting for 45%–87% of in-hospital mortality [17]. Moreover, decompressive craniectomy protects the patient from death from intracranial hypertension, but at the potential cost of severe neurological disability [18]. However, the clinical and paraclinical variables to establish this prognosis at admission are limited: initial clinical examination may be carried out under uncertain conditions, the patient is not available to the neurosurgeon in case of telemedicine, and brain CT can be misleading if performed too early or may not fully explore the brainstem. Prognostic models for TBI do not accurately predict neurological outcome, explaining only 35% of variation in final prognosis [19]. A combination of a large number of modalities is necessary to refine neuro-prediction [20], and this is not feasible in very early phases.

In severe TBI, the patient is comatose and cannot take an active part in therapeutic decision-making. However, what constitutes poor prognosis is not only strictly medical and, may be judged differently by physicians, patients and relatives [21].

In practice, the surgical management of severe TBI is heterogeneous [17,22].

The framework for limitation and withdrawal of life-sustaining treatment in France and existing recommendations on prognosis and therapeutic limitations in patients with severe cerebral palsy are worth bearing in mind here.

Firstly, limitation and withdrawal of life-sustaining treatment are defined in French law: the "Kouchner law" (Act 200 2-3 03 of March 4, 2002), "Leonetti law" (Act 2005-370 of April 22, 2005) and "Claeys-Leonetti law" (Act 2016-87 of February 2, 2016) [23]. In emergency settings, strict application of the law can be difficult to enforce, and, in 2018, the French Society of Emergency Medicine (SFMU) and the French-Speaking Society of Intensive Care (SRLF) published recommendations, available online, on limitation and withdrawal of life-sustaining treatment in adults in emergency settings [24].

Secondly, the Neurocritical Care Society issued guidelines on the management of "devastating brain injury" [25], defined as any neurological condition on admission immediately threatening vital and functional prognosis and for which limitation of early intervention is envisaged [26]:

- *We recommend determining prognosis from repeated examinations over time to establish greater confidence and accuracy (strong recommendation, moderate quality of evidence).*
- *We recommend applying these guidelines in the early stages of devastating brain injury in order to maintain physiologic stability, even when early limitation of aggressive care is being considered. Such early implementation prevents unwarranted deterioration and allows sufficient opportunity for prognostic evaluation, care planning, and consideration of organ donation (strong recommendation, moderate quality of evidence).*
- *We recommend that clinicians consider all known prognostic variables in determining risk of death and that prognostication be based on individualized assessment of risk factors rather than on clinical scoring systems (strong recommendation, moderate quality of evidence).*

Recommendations

- **R 1.1: The experts suggest that, in patients with severe traumatic brain injury who require emergency neurosurgery (within the first 72 h) but present features of a devastating brain injury, any decision to withhold neurosurgical intervention should result from a collegial discussion involving, whenever possible, three senior physicians: a neurosurgeon, a specialist in anesthesiology and critical care (ideally with expertise in neurocritical care), and, preferably, a rehabilitation physician.**

EXPERT OPINION (STRONG AGREEMENT)

- **R 1.2: The experts suggest implementing a 'limited collegial decision-making process' during the period of permanent care, involving at least two senior physicians, including a neurosurgeon.**

EXPERT OPINION (STRONG AGREEMENT)

Question 2: In patients with severe TBI requiring emergency neurosurgery, is frailty associated with poor prognosis?

Frailty corresponds to age-related decline in multi-organ function, which is more or less rapid and intense depending on the individual, and better reflects the individual's vulnerability to stressors than age considered in isolation [27]. Several indices have recently been developed to assess frailty: the modified Frailty Index (mFI-11 [28]), and the shorter mFI-5 [29]), shown to be equally reliable in trauma patients [30]; the Clinical Frailty Scale (CFS) [31]; the Autonomy Maintenance Service Integration Research Program (*Programme de Recherche sur l'Intégration des Services de Maintien de l'Autonomie*: PRISMA 7) questionnaire [32]; and the Trauma-Specific Frailty Index (TSFI) [33]. These indices were shown to correlate with short- and medium-term mortality, complications, hospital stay, post-hospital functional decline and quality of life in many pathological contexts [34]. Frailty is a factor for poor prognosis independently of age in trauma patients [35].

These indices have rarely been applied in TBI: our literature review found only 3 non-randomized prospective studies [36–38], 10 retrospective studies [39–48] and 1 meta-analysis [49]. Several of these studies showed significant associations between age, frailty and neurological prognosis in TBI patients [36,39–41,49]. The CENTER TBI Frailty Index [36] is the only TBI-specific index. Although very accurate and well suited for research, its complexity precludes use in emergency settings, whereas mFI-5 ≥ 2 [37] and CFS ≥ 4 [48] are easy to determine and are reliable markers of pathological frailty in TBI patients.

Recommendations

- **R 2.1: In patients with severe TBI requiring emergency neurosurgery, it is probably advisable to consider frailty in neurosurgical decision-making.**

GRADE 2 (STRONG AGREEMENT)

- **R 2.2: The experts suggest that the following frailty scores should be considered pathological, in order to assess prognosis:**
  - **modified Frailty Index-5 (mFI-5) ≥2**
  - **Clinical Frailty Scale (CFS) ≥4**

EXPERT OPINION (STRONG AGREEMENT)

Question 3: In patients with severe TBI requiring emergency neurosurgery, is bilateral unreactive mydriasis associated with poor prognosis?

The literature reports overall poor prognosis, particularly in the absence of surgical intervention [50–59]. Most studies were subject to numerous biases, including the risk of self-fulfilling prophecy, as bilateral unreactive mydriasis is traditionally considered to have no hope of a favorable neurological outcome. Other causes of pupil dilation should be borne in mind: beta2-mimetics (salbutamol), levodopa, anticholinergic drugs (atropine, scopolamine, nefopam, serotonin reuptake inhibitors, imipramine), sympathomimetic drugs (adrenaline), central nervous system stimulants (amphetamines, cocaine), barbiturates, benzodiazepines, severe hypothermia, trauma to the eyeball and/or oculomotor nerves, etc. A recent study highlighted overestimation of mortality and of poor prognosis (GOSE ≤ 4) in the IMPACT and CRASH studies and the need to recalibrate these prognostic scores [60].

One meta-analysis [61] included 5 retrospective cohort studies for a total of 82 patients with bilateral unreactive pupils. Analysis showed favorable outcome (GOSE > 4) in 54.3% (95% CI 36.3%–71.8%) of patients with extradural hematoma and 6.6% (95% CI 1.8%–14.1%) of patients with acute subdural hematoma.

A systematic review of the literature including 22 studies and 503 patients, in mainly low-quality studies [62], suggested that patients presenting transtentorial herniation and bilateral unreactive mydriasis at initial management who underwent ultra-early ($\leq$2 h) decompression craniectomy or craniotomy had approximately a 1-in3 chance of survival and a 1-in-6 chance of achieving functional independence (GOSE > 4). In a few small retrospective studies, aggressive management combining osmotherapy and neurosurgical treatment within 2 h of trauma was associated with favorable neurological outcome (GOSE > 4) in 26.8–44.4 % of patients [63,64].

Recommendations

- **R 3: In patients with severe TBI requiring emergency neurosurgery, the experts suggest that bilateral unreactive mydriasis (ideally assessed on automated pupillometry) should be considered as a factor for poor prognosis, but should not, in isolation, contraindicate the procedure, particularly if the mydriasis lasts for less than 2 h.**

EXPERT OPINION (STRONG AGREEMENT)

Question 4: In patients with severe TBI who require emergency neurosurgery, is the interval to surgery associated with prognosis?

The literature reports divergent results regarding the association between time to surgery and prognosis in TBI patients.

Most studies [65–78] reported a negative impact of longer intervals, while

many retrospective studies with small numbers of patients found no association [79–90], as corroborated by other studies [91–96], questioning the concept of a 'golden hour' in TBI management [97].

Recommendations

- **R 4: In patients with severe TBI who require emergency neurosurgery, the experts suggest that time to treatment should not be considered in isolation when assessing prognosis and making neurosurgical decisions.**

EXPERT OPINION (STRONG AGREEMENT)

Question 5: In patients with severe TBI requiring emergency neurosurgery, is preoperative antithrombotic treatment associated with poor prognosis?

The head injury population, which is increasingly older, is often treated with antithrombotic (AT) agents, including antiplatelet agents (APA) and anticoagulants (AC), including direct oral anticoagulants (DOA).

In some studies, patients previously treated with dual APA [98] or a combination of AC and APA [99] had a more severe clinical and radiological presentation at admission after traumatic brain injury (TBI) than controls.

Overall, APA monotherapy is said not appear to affect prognosis in TBI. Many studies were imprecise and did not distinguish between the different APAs, and it seems that this statement concerns aspirin only. Other APAs, and especially clopidogrel, are probably associated with higher risk of intracranial bleeding.

A systematic review of the literature, including 2,447 TBI patients treated with APAs and 4,814 untreated TBI patients, found no difference in the mortality between the two groups [100]. Retrospective studies showed that outcome in patients treated with APAs or ACs who had neurosurgery for TBI did not differ compared to patients without ATs [101–103].

However, several studies found increased risk of mortality in TBI patients treated with ACs. In a retrospective study of 771 patients aged $\geq$65 years, use of AT agents was associated with a risk of lesions worsening and death (58% vs 26.7%, $p < 0.05$), particularly in the group with cerebral contusion [104]. In another retrospective cohort study of

1,365 patients aged ≥65 years, patients receiving ATs (n = 724) had more intracerebral hematomas (p < 0.0001), worse neurological prognosis (GOSE ≤ 4; p < 0.0001) and higher mortality (p < 0.0001). This increased mortality was found particularly in patients on dual APAs (odds ratio [OR], 4.66; 95% confidence interval [CI], 1.57–13.87), warfarin (OR 5.18; 2.15–12.51) and DOAs (OR 5.09; 1.37–18.87), but not in patients on APA mono-therapy [105]. In a third study, including 3,031 adult TBI patients, use of APAs (4% of patients) or ACs (11%) prior to TBI was independently associated with excess mortality (OR 1.62, 95% CI 1.02–2.58; and OR 1.43, 95% CI 1.06–1.94, respectively) [106]. In the subgroup aged ≥70 years, excess mortality at 1 year was even higher (OR 2.28, 95% CI 1.16–4.22; and OR 1.50, 95% CI 0.97–2.32, respectively). A retrospective analysis of a prospective cohort of 20,303 TBI patients aged ≥65 years also found a higher risk of mortality in those previously treated with ACs (OR = 1.306, p < 0.001) [107]. Similarly, in a retrospective cohort study of 8,312 patients aged ≥65 years, including 4,680 on ATs, risk of mortality or poor prognosis was higher in those treated with warfarin (OR 1.60; 95% CI 1.27–2.01), AC + APAs (OR 1.61; 95% CI 1.18–2.21) or DOAs (OR 1.67; 95% CI 1.07–2.59) compared with patients without ACs [108]. Finally, in a recent systematic review of the literature including 4,417 patients from 12 studies, prior treatment with ACs was associated with increased risk of mortality (OR 2.39; 95% CI 1.63–3.50) [109].

Use of ACs or APA + ACs prior to TBI was associated with an increased risk of poor neurological outcome (GOSE ≤ 4) in survivors [107,110–113], with increased risk of postoperative intracranial bleeding (OR 12.242; p = 0.0070) [114].

Recommendations

- **R 5.1: In patients with severe TBI who require emergency neurosurgery, particularly those over 65 years of age, it is probably advisable to consider the presence of anticoagulant treatment as an independent factor of poor outcome.**

GRADE 2 (STRONG AGREEMENT)

- **R 5.2: In patients with severe TBI requiring emergency neurosurgery, it is probably not advisable to consider the presence of anti-platelet monotherapy with aspirin as a poor prognostic factor.**

GRADE 2 (STRONG AGREEMENT)

2: EXTRA-DURAL HEMATOMA

Cyrille CAPEL, Jean Denis MOYER

Question 6: Is surgical evacuation of extra-dural hematoma associated with improved neurological outcome in TBI patients?

Initial Glasgow Coma Score (GCS) is one of the most important factors in surgical decision-making and prognosis [115–119]. A decrease of at least 2 points in GCS between admission and surgery is associated with poor prognosis (GOS (Glasgow Outcome Score) <4) [118].

The Brain Trauma Foundation guidelines [116] suggest that >30 mL extradural hematoma (EDH) should be managed surgically, regardless of clinical status. Several studies found that patients with EDH >25−30 mL were at greater risk of neurological deterioration [115, 119–123].

Frontotemporal and temporal locations are at greater risk of volume increase. Delayed surgical management was reported to be a factor for poor prognosis (22.7% GOS < 4) [115].

The swirl sign corresponds to hypodensity within the hyperdensity of the EDH, indicating active bleeding. It is present in 14–30% of EDHs [124,125] and is associated with poor prognostic signs (pupil dilation, impaired vigilance, large EDH volume) [124–126]. Mean GOS was 4.43 ± 1.25 in patients without swirl sign, compared to 3.58 ± 1.77 for those with [125].

For EDH located in posterior cerebral fossa, the Brain Trauma Foundation recommends surgery for volume >10 ml, thickness >15 mm or midline deviation >5 mm [127]. In cases of ventricular dilatation, external ventricular drainage or endoscopic ventriculocisternostomy should be considered in addition to surgical evacuation of the EDH. In these conditions, good outcome (GOS 4–5) was found in a majority of patients [128,129]. The best outcomes were in patients with a GCS ≥ 9 at the time of surgery.

EDH of venous origin (dural sinus wounds) can be difficult to evacuate and is usually managed conservatively, except in cases of large volume or neurological signs (impaired alertness, focal signs). The literature on this topic is limited. A review of the literature [130] and a retrospective study [131] found good prognosis (GOS 5) in operated patients.

With conservative treatment, the risk of poor outcome is higher if the CT scan is performed too early. In a 2002 analysis [132], trauma-to-scan time was shorter (1.3 vs. 2.3 h) in patients with volume change than in those without. Risk of poor outcome (GOS < 4) was greater if the scan was performed less than 6 h after trauma [118]. In a 2015 retrospective study of 797 patients with EDH, 98.1% of EDHs reached their final size within 5–6 h of trauma. If possible, it is therefore recommended to perform CT scan 6 h after TBI [116,118,133,134]. If the patient's condition deteriorates (impaired vigilance or focal neurological signs), the scan should be performed earlier, to guide surgical indications [118, 119]. Special attention should also be paid to conservatively treated EDH when a contralateral lesion was previously operated on, to prevent rapid worsening after surgical decompression [135].

Recommendations

- **R 6.1: The experts suggest that the emergency surgical evacuation of extradural hematoma can improve neurological outcome in TBI patients in the following circumstances:**
  - o **GCS ≤ 8;**
  - o **Pupil dilation;**
  - o **Estimated EDH volume >30 ml;**
  - o **Midline deviation >5 mm;**
  - o **Brainstem compression;**
  - o **Sign of active bleeding (swirl sign).**

EXPERT OPINION (STRONG AGREEMENT)

- **R 6.2: The experts suggest that conservative treatment of EDH of arterial origin should be considered in TBI patients in the absence of clinical or radiologic severity.**

EXPERT OPINION (STRONG AGREEMENT)

- **R 6.3: The experts suggest that individualized management of EDH of venous origin should be considered in TBI patients.**

EXPERT OPINION (STRONG AGREEMENT)

- **R 6.4: The experts suggest that follow-up of patients with non-operated EDH should be performed in a center with neurosurgical expertise.**

EXPERT OPINION (STRONG AGREEMENT)

- **R 6.5: In patients with post-traumatic EDH treated conservatively, it is probably advisable to perform systematic CT 6 h post-trauma if the initial CT scan was too early, even in the absence of subsequent clinical deterioration.**

GRADE 2 (STRONG AGREEMENT)

3: ACUTE SUBDURAL HEMATOMA

Matthieu FAILLOT, Stéphanie SIGAUT, Alice ROLLAND

Question 7: Is the surgical evacuation of acute subdural hematoma associated with improved neurological outcome in TBI

patients?

The Brain Trauma Foundation recommends evacuation of any acute subdural hematoma (ASDH) associated with a Glasgow Coma Score (GCS) ≤8 and/or with thickness >10 mm and/or with midline shift >5 mm [136]. These criteria were based on retrospective series [137–139] with young patients. Furthermore, the recommendations did not take account of negative criteria such as age, low GCS or the presence of bilateral unreactive pupils (see section 1). Overall, the management of patients with traumatic ASDH is heterogeneous [140].

In elderly patients, the risk-benefit ratio is difficult to establish. Early evacuation of SDH in these patients was associated with significant morbidity [141–144]. However, initial conservative management (which may be followed by burr-hole evacuation) might lead to significant neurological and/or systemic deterioration associated with prolonged hospital stay [145–147]. The biases of retrospective studies in older patients prevented demonstration of clear benefit of surgery in this population [142,143,145–147], as management was very heterogeneous [148]. The only randomized trial that might have addressed this issue [149] was halted due to recruitment difficulties [150]. In this context, there is no justification for withholding neurosurgical treatment in older patients with low frailty scores, particularly in the absence of associated intraparenchymal lesions. Regarding initial neurological status, patients operated on for ASDH with initial GCS of 3 showed very high mortality, at 65–100% [61,151,152]. Regarding patients operated for ASDH with bilaterally unreactive pupils, a systematic review found 66% mortality, and favorable neurological outcome in only 7% of patients [61].

In practice, studies found a trend for lower mortality with surgery, but no improvement in neurological outcome [153]. A meta-analysis found lower mortality in operated comatose patients (GCS ≤ 8) with an absolute risk reduction of 23%–40% [154]. Two recent studies [140, 155] found benefit of surgery in terms of reduced mortality but no improvement in neurological outcome.

Conservative treatment is suggested either for the least severe patients or for those considered to be beyond possible treatment [156]. Some authors suggested that, in patients with acute subdural hematoma for whom the neurosurgeon sees no clear advantage of acute surgery over conservative management, an initial conservative approach may be considered [139]. Hematoma size and mass effect were associated with failure of conservative management in some trials [157,158] but not in others [159].

Recommendations

- **R 7.1: The experts suggest that the emergency surgical evacuation of acute subdural hematoma can improve the neurological outcome in TBI patients under the following conditions:**
  - o **age <65 years OR 65–80 years but with low frailty score**

  AND

  - o **impaired consciousness (GCS ≤ 8 AND/OR loss of ≥2 GCS points) not explained by another mechanism OR intracranial hypertension refractory to medical treatment;**

  AND

  - o **ASDH with thickness >10 mm AND/OR midline shift >5 mm**

  EXPERT OPINION (STRONG AGREEMENT)

- **R 7.2: The experts suggest that later or less invasive surgery should be considered after ASDH if rebleeding is documented in chronic SDH.**

  EXPERT OPINION (STRONG AGREEMENT)

- **R 7.3: The experts suggest that conservative treatment should be considered in patients with ASDH outside the above circumstances. Follow-up with brain CT is recommended:**
  - o **urgently if clinical course deteriorates;**
  - o **at an early stage (7–10 days) if antiplatelet or anticoagulant treatment needs to be resumed;**
  - o **at a later stage (3–4 weeks) in other cases.**

  EXPERT OPINION (STRONG AGREEMENT)

4. DEPRESSED SKULL FRACTURE AND SKULL BASE FRACTURE ASSOCIATED WITH CEREBROSPINAL FLUID LEAKAGE

Edouard SAMARUT, Clémentine GALLET, Alexandre BANI-SADR, Marion LE MARECHAL, Romain MANET

Question 8: In TBI patients with depressed skull fracture, does surgical management improve neurological outcome?

In the absence of intracranial lesions, depressed skull fracture has good prognosis [160–164]. Dural tears must be excluded in case of open depressed skull fracture, which otherwise corresponds to penetrating TBI (pTBI) (see section 5). In a retrospective series of 128 patients treated for TBI associated with depressed skull fracture, the depth of the depressed skull fracture (OR 1.3; 95% CI 1.14–1.46), presence of pneumocephalus (OR 2.5; 95% CI 1.05–5.76) and adjacent contusion or hematoma (OR 5.5; 95% CI 1.57–8.82) were predictive of dural tear [165].

According to the Brain Trauma Foundation guidelines [166], neurosurgical indications include open depressed skull fracture associated with a contaminated wound, signs of local infection, uncontrollable bleeding, intracranial contusion or hematoma, cosmetic damage, signs of dural effraction, mass effect on the cerebral parenchyma, or depression depth >1 cm below the internal table. However, two studies, including 67 patients [162] and 232 patients [167], found no significant improvement in outcome in terms of neurological results, epilepsy or infection in patients treated surgically according to the BTF criteria compared with patients treated conservatively.

For uncontaminated skull fracture, wound excision and closure can be performed, not necessarily by a neurosurgeon. If neurosurgery is indicated, titanium osteosynthesis is preferred for reconstruction [168–170]. Depressed skull fracture is not an absolute emergency. Surgical treatment within 24 h is recommended [171].

Depressed skull fracture in the frontal sinus is associated with cosmetic damage, CSF rhinorrhea, short-term infectious complications (meningitis, empyema) and long-term complications (mucocele). In practice, two parameters need to be considered: integrity of the dura in the posterior wall, and integrity of the nasofrontal ducts. The frontal sinus should be preserved in the absence of major posterior wall defect, obvious dural tear or damage to the nasofrontal ducts. Otherwise, the procedure should be completed by obliteration or cranialization of the frontal sinus [171–175].

In depressed skull fracture exerting a mass effect on a venous sinus, several case reports [160,176–179] and a series of 13 cases [180] reported surgical treatment (direct fracture reduction, decompressive craniectomy, or CSF drainage) in cases of refractory intracranial hypertension.

Depressed skull fracture increases the risk of post-traumatic epilepsy (PTE) (OR 1.88, 95% CI 0.92–3.80; $p = 0.081$) [181]. PTE was reported in 16% of 333 patients in a retrospective cohort of patients treated for closed depressed skull fracture [182], and was related to initial clinical severity [162,181,182]. Although PTE was an independent factor for poor outcome [181], it was not influenced by surgical modalities for depressed skull fracture or antiepileptic prophylaxis [167,181]. Antiepileptic prophylaxis is therefore rarely prescribed in Europe (<20% of responders), in contrast to other parts of the world [183].

Recommendations

- **R 8.1: In a patient with traumatic brain injury associated with a depressed skull fracture, the experts suggest prompt neurosurgical management, within 24 h, in any of the following circumstances:**
  - o **complex or contaminated wound or evidence of local infection;**
  - o **suspected dural tear/pneumocephalus;**
  - o **CSF leakage;**
  - o **significant mass effect on brain parenchyma;**
  - o **other neurosurgical lesion(s);**
  - o **major cosmetic damage.**

EXPERT OPINION (STRONG AGREEMENT)

- **R 8.2: In a patient with traumatic brain injury associated with a depressed skull fracture involving the frontal sinus, the experts suggest surgical management with anterior wall reduction/osteosynthesis alone in the following circumstances:**
  - o **large posterior wall defect;**
  - o **obvious dural tear;**
  - o **nasofrontal canal involvement.**
  - o **Otherwise, the procedure must be completed with cranialization of the frontal sinuses.**

EXPERT OPINION (STRONG AGREEMENT)

- **R 8.3: In a patient with traumatic brain injury associated with depressed skull fracture and epileptic seizure, experts suggest initiating secondary antiepileptic prophylaxis. Primary antiepileptic prophylaxis should not be systematically prescribed in non-penetrating TBI associated with depressed skull fracture.**

EXPERT OPINION (STRONG AGREEMENT)

Question 9. In a patient with traumatic brain injury associated with skull base fracture and cerebrospinal fluid leakage, does surgical management improve neurological outcome?

Post-traumatic skull base cerebrospinal fluid (CSF) leakage occurs in 0.3%–39% of skull base fractures [184–186]. More than 50% of traumatic leaks occur within the first 48 h and 70% within the first 7 days. In the case of "true" tears, they occur almost systematically after 3 months [184,187–189]. Leakage mainly involves the frontal sinus (30% of cases), the sphenoidal sinus (11–30 %) or the ethmoid sinus (15–19%) [190,191]. Meningitis occurs in 0.2% of cases within the first 24 h after trauma, in 9% after the first week, and in 19% after the second week. The cumulative risk of meningitis is estimated to be about 1% per day for the first 2 weeks, then 7% per week for the first month [192,193]. Neurological outcome is mainly determined by the initial severity of TBI and not by the presence of CSF leakage [193,194].

Surgery is the preferred option if the leak persists after 3–7 days' well-conducted medical management [193–196]. Surgery reduces the overall risk of meningitis from 30% before surgery to 4% after. The 10-year cumulative risk also decreases, from 85% before surgery to 7% after. Recurrence despite surgery is estimated to be between 12.5% and 17%, with 1.3% mortality [197,198].

In case of associated intracranial lesions, craniotomy is preferred to endoscopic endonasal repair of the dural defect [185,193,196, 199–201]. In cases where emergency intracranial surgery is required for the initial trauma, some authors suggest closing the dural defect in the same step in the absence of intracranial hypertension (ICH). In case of ICH, a two-stage approach is recommended [193,194,201].

Small dural defects (diameter ≤1 cm) can be treated with an endonasal approach, but larger defects (>1 cm) require craniotomy [185, 193,194,196,201–203]. The location of the defect is an additional factor in the choice between an endonasal approach or craniotomy: medial defects can be easily treated with an endonasal approach, whereas lateral, very anterior or intermediate defects require craniotomy [185, 193,194,196,199–202,204].

Conservative treatment for post-traumatic skull-base CSF leakage includes bed rest (bedhead at 30 °) and laxatives, antitussives and antiemetics for at least 48–72 h. CSF leakage can thereby be stopped in 4–5 days in 60% of cases, and in 7 days in 85% [187,193,196,198,205]. In case of failure, 7–10 days' external (lumbar or ventricular) CSF drainage can be considered, with a target flow rate of 10–15 mL/hour. In most patients, this procedure was successful [195,205,206]. Postoperative external lumbar drainage can reduce the duration of rhinorrhea [207,208] although there is no evidence of impact on neurological outcome or risk of infection.

The SFAR/SPILF 2023 guidelines [209] do not recommend antibiotic prophylaxis for skull-base fractures. Antibiotic prophylaxis should be given for neurosurgical procedures only.

No studies compared the risk of long-term meningitis after dural tear in patients having received vaccination versus no vaccination. The epidemiology of meningitis cases was 50% *Streptococcus pneumoniae* and 20% *Haemophilus influenzae* [210].

The radiological location of a post-traumatic skull-base dural tear can be challenging. MRI and combined CT/MRI are more sensitive than conventional CT [211]. In a recent systematic review of the detection of CSF rhinorrhea [212], the sensitivity and specificity of the different detection methods were as follows: high-resolution CT: 0.93/0.50; MRI: 0.94/0.77, CT myelography: 0.95/1.00; isotopic cisternography: 0.90/0.50; MRI cisternography with contrast enhancement: 0.99/1.00; nasal endoscopy: 0.58/1.00; intrathecal fluorescein: 0.96/1.00.

Recommendations

- **R 9.1 In a patient with traumatic brain injury associated with skull-base fracture and cerebrospinal fluid leakage, the experts suggest prompt surgery (within 24 h) in case of major dural defect associated with abundant liquorrhea, to improve the neurological prognosis. If neurosurgery is indicated for other associated lesions, closure of the dural defect in the same step is not recommended in case of intracranial hypertension.**

EXPERT OPINION (STRONG AGREEMENT)

- **R 9.2: In a patient with traumatic brain injury associated with skull-base fracture and cerebrospinal fluid leakage, the experts suggest surgery in case of non-abundant liquorrhea refractory to conservative treatment for more than 7 days.**

EXPERT OPINION (STRONG AGREEMENT)

- **R 9.3: In a patient with traumatic brain injury associated with skull-base fracture and cerebrospinal fluid leakage, the experts suggest that conservative treatment of post-traumatic dural tears of the skull base should be combined with bed-rest at 30 ° and laxatives, cough suppressants and antiemetics for at least 72 h.**

EXPERT OPINION (STRONG AGREEMENT)

- **R 9.4: In a patient with traumatic brain injury associated with skull-base fracture and cerebrospinal fluid leakage, the experts recommend that vaccinations against pneumococcus,** Haemophilus influenzae **and meningococcus should be carried out or updated, to reduce the risk of meningitis:**
  - o **pneumococcal vaccination: 15-valent conjugate vaccine for under-18 year-olds (1 dose for over-2 year-olds) or 20-valent vaccine for over-18 year-olds (1 dose not followed by a non-conjugate vaccine);**
  - o **Haemophilus influenzae vaccination (1 dose);**
  - o **Meningococcus B and ACYW vaccination: catch-up according to general recommendations (meningococcal ABCYW before 2 years of age and meningococcal ACYW before 25 years of age).**

EXPERT OPINION (STRONG AGREEMENT)

- **R 9.5: In a patient with traumatic brain injury associated with skull-base fracture and cerebrospinal fluid leakage, the experts suggest screening for traumatic dural defect on bone-window CT scan with millimeter slices and MRI with high-resolution 3D T2 sequences. If in doubt, a CT-myelography can be performed, followed, if negative, by isotope cisternography, to improve diagnostic performance.**

EXPERT OPINION (STRONG AGREEMENT)

5. PENETRATING TRAUMATIC BRAIN INJURY

Arnaud DAGAIN, Christophe JOUBERT, Sébastien GAZZOLA, Pierre ESNAULT, Marion LE MARECHAL

Question 10. In a patient with penetrating traumatic brain injury, under what circumstances is neurosurgical treatment likely to improve neurological prognosis?

Penetrating traumatic brain injury (TBI) is associated with high mortality, up to 85% [213–219]. Aggressive management of these patients improves survival [218,220–222].

The following factors have been reported to be associated with high mortality: age over 35 years, unresponsive pupils, respiratory arrest or hypotension on admission, and bi-hemispheric (excluding bi-frontal), trans-hemispheric, transventricular or posterior fossa ballistic trajectories [214,219,223,224]. Factors moderately associated with higher mortality included ICP $>$ 20 mm Hg and Glasgow Coma Score (GCS) 3 or 4 at presentation [223]. On multivariate analysis, significant factors for mortality were bullet trajectory and pupillary response [223].

The 2 main predictive scores for mortality are the Maritzburg score and the SPIN score [225,226]. The Maritzburg score is based on 2 criteria: GCS $<$ 5 and externalization of the brain through the skin wound; presence of both has a positive predictive value of 92% (sensitivity 73%, specificity 98%). The SPIN score is based on a motor GCS subscore (mGCS), pupillary reactivity, absence of self-inflicted injury, transfer to a referral center, female gender, lower Injury Severity Score (ISS) and lower International Normalized Ratio (INR) (see Appendices), all shown to correlate strongly with survival [226]. These scores can be used for early prognostication, but should not be used in isolation to contraindicate aggressive management.

GCS at initial treatment is the most important clinical prognostic factor [213]. In particular, a GCS $<$ 5 is generally associated with very poor prognosis. Patients operated on for penetrating TBI with initial GCS 6-8 had better neurological prognosis than those treated conservatively (24% vs 0%) [227]. The rate of good neurological outcome in patients operated on with GCS $\geq$ 9 was high, at 77.8% [228]. These data suggest that neurosurgery should be widely used for patients with penetrating TBI.

Ideally, surgery should be performed within 5 h of trauma to reduce the risk of cerebro-meningeal infection [229,230,231]. In the absence of intracranial hypertension, surgery consists in plane-by-plane debridement, including watertight dural closure and skin closure if the scalp is not devitalized, to reduce the risk of infection, mainly from CSF fistulation [231–235]. Removal of bone fragments or bullets at a distance from the entry point, particularly in eloquent areas of the brain, is not systematic: it may reduce the risk of post-traumatic epilepsy [236], but at the cost of increased functional morbidity [231,232,235,237].

In case of extensive lesions or intracranial mass effect, surgery, combined with control of intracranial pressure and systemic aggression by intensive care, is part of a 'neuro-damage control' strategy aimed at reducing secondary cerebral lesions [238]: in addition to plane-by-plane debridement, evacuation of compressive hematomas and removal of accessible foreign bodies [229], or even decompressive craniectomy [239,240] with watertight dural closure, ideally with autologous augmentation plasty (galea or facia lata) if necessary [241,242].

Neurological outcome after superficial debridement was very heterogeneous, and essentially correlated with initial neurological severity as reflected by GCS [228,243]: the rate of good neurological prognosis varied from 0.8% to 75% [213,215,223,227], with 0% for an initial GCS 6–8, 50% for 9–11, and 95% for $\geq$12 [227]. Superficial debridement was therefore appropriate in selected patients with GCS $\geq$ 12, but offered limited benefit in more severe cases with intracranial hypertension, indicating more aggressive debridement in the latter.

Incidence of epileptic seizures in penetrating TBI within the first 7 days was high, ranging from 14% to 20% [244]. Patients with penetrating TBI were 3 times more likely to be readmitted to hospital within 2 years for concomitant seizure than patients with closed TBI [245,246]. Although incidence of early seizures was higher with penetrating TBI, incidence of late seizures did not differ [247]. Finally, incidence of epilepsy was unchanged by initial surgical treatment [242]. There are no randomized controlled trials of anticonvulsant prophylaxis in patients admitted for penetrating TBI; it appears to be acceptable in the first week, but not thereafter [247,248].

The SFAR / SPILF 2023 expert recommendations advocated antibiotic prophylaxis with 2 g amoxicillin-clavulanic acid, which can be continued for 24–48 h in penetrating TBI with a soiled wound [209].

No studies compared the long-term risk of meningitis with or without vaccination. The epidemiology of meningitis in cases of dura mater breach was 50% *Streptococcus pneumoniae* and 20% Haemophilus influenzae [210].

Recommendations

- **R 10.1: In a patient presenting with penetrating brain injury, experts suggest that the risk of mortality (SPIN score, Maritzburg score) should be assessed and taken into account, in a non-isolated manner, in the indication for emergency surgery.**

EXPERT OPINION (STRONG AGREEMENT)

- **R 10.2: In a patient presenting with penetrating brain injury, associated with Glasgow Coma Score ≥5, the experts suggest urgent neurosurgical management.**

EXPERT OPINION (STRONG AGREEMENT)

- **R 10.3: In a patient presenting with penetrating brain injury, associated with a Glasgow coma score ≤4, in absence of bilateral non-reactive mydriasis and of pejorative radiological criteria, the experts suggest evaluating the need for urgent neurosurgical management individually.**

EXPERT OPINION (STRONG AGREEMENT)

- **R 10.4: In a patient presenting with penetrating brain injury, the experts suggest that, in case of significant cortical damage, primary antiepileptic prophylaxis should be given for at least 7 days.**

EXPERT OPINION (STRONG AGREEMENT)

- **R 10.5: In a patient presenting with penetrating brain injury, the experts suggest that vaccinations against pneumococcus, meningococcus,** Haemophilus influenzae **and tetanus should be carried out or updated:**
  - o **in people who are not up-to-date: anti-tetanus vaccination combined with injection of 250 IU of anti-tetanus human immunoglobulin in case of extensive penetrating wound with foreign body or wound treated late;**
  - o **pneumococcal vaccination: 15-valent conjugate vaccine for under-18 year-olds (1 dose for over-2 year-olds) or 20-valent vaccine for over-18 year-olds (1 dose not followed by non-conjugate vaccine);**

- o **Meningococcus B and ACYW vaccination: catch-up according to general recommendations (meningococcus ABCYW before age 2 and meningococcus ACYW before age 25);**
- o **Haemophilus influenzae vaccination (1 dose)**

EXPERT OPINION (STRONG AGREEMENT)

Question 11. In a patient presenting with penetrating brain injury, when and how should screening for intracranial vascular lesions be performed?

Traumatic intracranial vascular lesions have been identified in up to 60% of patients with penetrating TBI [249,250].

Post-traumatic intracranial aneurysm (PTIA) is common in penetrating TBI, with incidence between 20% and 50% [214,218]. It is difficult to diagnose, associated with high mortality, and also poses the problem of choosing a treatment modality.

PTAI may occur in the first hours after trauma or later (several days to several weeks). Progression is uncertain, but PTAI is associated with intracranial hemorrhage in 80% of cases and subdural hematoma in 26% [214]. Ruptured PTAI is associated with high mortality, up to 50% [219].

Given the significant morbidity and mortality associated with failure to detect and treat PTAI, several authors recommended systematic screening for penetrating TBI [213,218,241]. Cerebral arteriography is the gold-standard for early detection of these lesions in penetrating TBI; cerebral CT-angiography has lower sensitivity [251,252]. Criteria for performing digital subtraction arteriography were defined by Bell [213,218,241]:

- o penetrating injury through the peritonsillar and orbitofrontal regions;
- o known cerebrovascular lesion with or without pseudoaneurysm observed on initial exploration;
- o blast injury with Glasgow score <8 (closed or penetrating);
- o evidence of vasospasm on transcranial Doppler;
- o Spontaneous unexplained decrease in cerebral tissue oxygen pressure (PtiO2).

To these criteria, the following may be added:

- o penetrating trajectory close to the main arterial axes;
- o multiple dural injuries;
- o intracerebral hematoma.

Early vascular imaging may be negative either because the lesion is too small to be detected on CT-angiography or because it appears to be secondary. If in doubt, follow-up imaging in 2–3 weeks should be considered.

Definitive multimodal treatment should be started immediately [214,219]. There is no evidence that surgical treatment is superior to endovascular treatment [241,253–255].

Recommendations

- **R 11.1: In a patient with a penetrating brain injury, the experts suggest systematic screening for intracranial vascular lesions on CT-angiography.**

EXPERT OPINION (STRONG AGREEMENT)

- **R 11.2: In a patient presenting with penetrating brain injury, the experts suggest that this examination be supplemented with a 6-axis digital subtraction cerebral arteriogram in case of one or more of the following:**
  - o **detection or suspicion of a vascular lesion on CT-angiography;**
  - o **penetrating injury in the periorbital and/or fronto-orbital region;**
  - o **multiple dural injuries;**
  - o **trajectory and/or hematoma close to the major vascular axes;**
  - o **penetrating or blast TBI with Glasgow score <8;**
  - o **detection of vasospasm on transcranial Doppler and/or spontaneous unexplained decrease in cerebral tissue oxygen pressure (PbtO2).**

EXPERT OPINION (STRONG AGREEMENT)

- **R 11.3: In patients presenting with penetrating TBI, associated with symptomatic or asymptomatic intracranial vascular injury at high risk of rupture and/or neurological worsening, the experts suggest that urgent treatment should be discussed.**

EXPERT OPINION (STRONG AGREEMENT)

- **R 11.4: No recommendations on modality (endovascular or surgical), which should be discussed collegially.**

NO RECOMMENDATION

- **R 11.5: In patients presenting with penetrating TBI, the experts suggest that, in the absence of proof of an initial intracranial vascular lesion, cerebrovascular imaging should be repeated approximately 14 days after trauma.**

EXPERT OPINION (STRONG AGREEMENT)

6. POST-TRAUMATIC CEREBROSPINAL FLUID DISORDERS

Romain MANET, Stéphane GOUTAGNY, Baptiste BALANCA, Vincent JECKO, Philippe DECQ, Arnaud DAGAIN

Question 12: In a patient with traumatic brain injury associated with post-traumatic peri-encephalic collections of cerebrospinal fluid, under what circumstances is surgical intervention likely to improve neurological outcome?

The pathophysiology of extra-axial cerebrospinal fluid (CSF) collections in adults is poorly understood. In practice, two entities can be distinguished. On the one hand, hygroma is thought to result from tearing of arachnoid layer adhesions to the dura mater [256,257] or, more rarely, from traumatic or iatrogenic rupture of an arachnoid cyst [258–261], leading to sequestration of CSF in the resulting subdural space. This passive accumulation, favored by post-traumatic atrophy [262], does not interfere with normal CSF circulation. Intracranial pressure (ICP) and neurological examination generally remain normal. The vast majority of hygromas are benign and are treated conservatively [263]. Conversely, external hydrocephalus involves 'active' sequestration of CSF within the subarachnoid spaces (SAS) as a result of resorption failure, favored by post-traumatic subarachnoid hemorrhage [264,265], which generally leads to an increase in ICP [266] and worsens the neurological condition of the patient [264]. Extra-axial CSF collection after decompressive craniectomy is very common and is often interpreted as hygroma [267–270], but may be more consistent with external hydrocephalus, with a risk of chronic post-traumatic hydrocephalus requiring definitive CSF shunting [264,267,268,271].

Management of peri-encephalic post-traumatic CSF collection has not been the focus of any guidelines. At the 2019 Seattle International Consensus Conference on the Management of Severe TBI, external lumbar drainage of CSF was not selected as a therapeutic measure for the management of post-traumatic intracranial hypertension [11]. Our systematic review of the literature on external lumbar drainage in TBI retrieved 10 original articles [265,272–280]. Three studies with interim results included in later publications [281–283] and 1 published in Hungarian [284] were not included in our analysis. Overall, our analysis included 221 patients with TBI, the majority of whom were adults. In 3 studies, no patients had previously received external ventricular drainage [275,277,278], which was performed systematically in 4 studies [272,276,279,280]; in the other 3 studies, it was used optionally. The weighted mean absolute and percentage reductions in ICP following external lumbar drainage were −17 mmHg and −59%, respectively. The meningitis rate was 6% (12/208), with tonsillar involvement in 7% of patients (21/295), primarily in studies where drainage protocols included counter-pressures of 0 or +5 cmH_2O (relative to the foramen of Monro), without the possibility of assessing the associated morbidity and mortality. To mitigate this risk, all authors relied on CT criteria, including the patency of the basal cisterns (particularly the prepontine and/or quadrigeminal cisterns), absence of lesions with significant mass effect, absence of midline shift >5 mm or >10 mm, absence of uncal or tonsillar herniation, and the 'Innsbruck intracranial reserve score,' which incorporates several of these elements [275]. In addition, one study proposed including a criterion of external hydrocephalus, defined by clinical features (delayed onset of intracranial hypertension and poor response to osmotherapy) and CT findings (progressive and paradoxical dilatation of the subarachnoid spaces, including the sylvian fissures, interhemispheric fissures and cortical sulci) [265]. Finally, to reduce the risk of a pressure gradient between the cranial and spinal compartments, the zero reference level for external lumbar drainage was set at the foramen of Monro (or the external auditory canal) in all studies.

Recommendations

Experts suggest distinguishing 2 types of post-traumatic peri-encephalic cerebrospinal fluid (CSF) collection:

- o **generally stable (rarely progressive) unilateral collection AND absence of neurological signs AND normal intracranial pressure = hygroma;**
- o **progressive collection on successive CT scans, generally bilateral AND neurological worsening AND/OR increased intracranial pressure = external hydrocephalus**
- **R 12.1: In patients presenting TBI associated with hygroma, the experts suggest conservative treatment in first line.**

EXPERT OPINION (STRONG AGREEMENT)

- **R 12.2: In patients presenting TBI associated with external hydrocephalus, experts suggest cerebrospinal fluid drainage, either by lumbar puncture or by external lumbar drainage, after CT confirmation of:**
- o **patency of the basal cisterns,**
- o **AND absence of midline deviation >10 mm,**
- o **AND absence of tonsillar involvement.**

In case of intracranial hypertension, this option should only be considered after 1st-line measures have failed.

EXPERT OPINION (STRONG AGREEMENT)

- **R 12.3: In patients presenting traumatic brain injury associated with external hydrocephalus treated by external lumbar drainage, the experts suggest placing the external lumbar drainage zero reference at the external auditory canal. In addition, in case of intracranial hypertension, intracranial pressure should be continuously monitored and the reference counter-pressure should not be lowered below 10 mmHg. Finally, if the pressure gradient between intracranial pressure and lumbar CSF pressure is greater than 5 mmHg, lumbar drainage should be discontinued.**

EXPERT OPINION (STRONG AGREEMENT)

7. SPECIFICS OF NEUROSURGICAL MANAGEMENT OF PEDIATRIC TRAUMATIC BRAIN INJURY

Nathalie CHIVORET, Andres COCA, Guillaume MORTAMET, Matthieu VINCHON

Question 13. In neonates less than 1 month of age with traumatic brain injury associated with extradural hematoma, under what circumstances is surgical intervention likely to improve neurological outcomes?

Neonatal extradural hematoma (EDH) is a recognized complication of forceps and vacuum-assisted delivery, but is rare. In recent studies, incidence of intracranial hemorrhage following instrumental delivery was 0.4–1%, and the incidence of neonatal EDH can be presumed to be considerably lower [285].

Neurological status at presentation, assessed on the Child Coma Scale (CCS) or GCS, is strongly prognostic. Children with CCS or GCS scores below 8 are subject to high mortality. In reported series, EDH was predominantly located in the parietal and temporoparietal regions, but no correlation was found between location and prognosis [286,287]. According to literature reviews, skull fracture does not significantly impact prognosis, including GOS score [287,288]. Neonates and infants are more resilient to acute elevations in ICP, owing to anatomical characteristics such as unfused cranial suture, open fontanelle, and relatively larger extracerebral spaces. Moreover, in contrast to adults, pediatric EDH is more frequently of venous origin [289].

It is generally accepted that many EDHs can be managed conservatively without need for surgery. This is especially true for neonatal EDH, which often resolves spontaneously. In neonates, EDH tends to liquefy more rapidly than in older age groups, and most analyses of contents found predominantly liquid blood [290,291].

A conservative approach is typically favored in patients with small hematoma (<20 mm in thickness), in the absence of midline shift or clinical deterioration, and with good neurological status (high GCS). Such cases require close monitoring in an intensive care setting, including regular neurological examinations and repeat imaging if deterioration is suspected.

The main indications for surgical management of EDH in neonates comprise substantial hematoma thickness, significant brain displacement, and depressed skull fracture or associated hydrocephalus. A review of the literature suggested that hematoma volume >30 mL, thickness >15 mm and midline shift >5 mm are strong indicators for surgical intervention [121,292]. The standard treatment is surgical evacuation, typically via craniotomy. However, in neonates, craniotomy is particularly invasive and associated with significant risks. Whenever feasible, less invasive approaches are preferred, to minimize surgical morbidity and optimize hematoma management. In cases where EDH is associated with a cephalohematoma, aspiration of the cephalohematoma may be considered. Alternatives such as skull fracture aspiration or direct epidural aspiration may be appropriate, particularly in EDH without associated skull fracture or cephalohematoma [293–295]. Craniotomy should be reserved for cases where less invasive techniques fail. In cases of liquefied hematoma, evacuation through a single burr-hole may be sufficient. If craniotomy is performed, osteosynthesis of the bone flap should be avoided, due to potential interference with subsequent skull growth.

Ongoing clinical and neurological monitoring is essential for managing EDH in infants under 1 year of age. These patients require close observation in an intensive care setting, with repeated neurological assessments and follow-up imaging when clinically indicated, mindful of the risks associated with cumulative ionizing radiation from CT scans.

Recommendations

- **R 13.1: In neonates with traumatic brain injury associated with extradural hematoma, the experts suggest emergency surgical evacuation in case of clinical or radiological signs of severity (>5 mm deviation of the midline or brainstem compression).**

EXPERT OPINION (STRONG AGREEMENT)

- **R 13.2: As there is no consensus on the optimal surgical technique, the experts suggest that less invasive approaches be considered before resorting to craniotomy. These strategies**

include aspiration of the cephalohematoma or other methods, such as puncture through a skull fracture or epidural puncture, particularly in cases of extradural hematoma without associated skull fracture or cephalohematoma.

EXPERT OPINION (STRONG AGREEMENT)

- **R 13.3: In neonates with traumatic brain injury associated with extradural hematoma, experts recommend a conservative approach in the absence of clinical or radiological signs of severity. In these cases, close monitoring in an intensive care unit is essential, including regular clinical examination and follow-up imaging.**

EXPERT OPINION (STRONG AGREEMENT)

Question 14. In infants under 2 years of age with non-accidental traumatic brain injury associated with subdural hematoma, under what circumstances is surgical treatment likely to improve neurological prognosis?

Non-accidental infantile TBI, commonly known as "shaken baby syndrome," is often associated with subdural hematoma (SDH), particularly in infants. Infantile SDH presents as a mixture of blood and cerebrospinal fluid; it is a frequent condition at this age and has no direct equivalent in adult pathology. Although often mistakenly referred to as chronic SDH, it typically develops within a few days of trauma and follows a relatively acute course. Prognosis correlates primarily with initial clinical severity ($p = 0.001$) and is not significantly influenced by shunt-related complications ($p = 0.27$) [296,297]. Overall incidence of complications was significantly associated with initial clinical severity ($p = 0.013$), preoperative hospital stay time ($p = 0.016$), and time between trauma and surgery ($p = 0.037$). Several studies confirmed that infant maltreatment and initial clinical severity, as indicated by stay in intensive care, are important independent prognostic factors [298]. Moreover, the morbidity and mortality associated with non-accidental pediatric TBI (maltreatment) are higher than in accidental TBI [298].

The primary goal of treatment is to relieve intracranial hypertension and prevent complications associated with SDH, such as cerebral atrophy, visual disorder and craniocerebral disproportion. Neurosurgical indications for emergency evacuation of the hematoma are typically based on clinical criteria, including GCS score ≤ 12 at admission, bulging fontanel or other signs of intracranial hypertension (e.g., on transcranial Doppler), which may improve neurological prognosis [297–300]. Initial treatment for intracranial hypertension may involve transfontanellar subdural puncture. However, intracranial hypertension is often only temporarily controlled by subdural puncture, which may need to be repeated. Although there is no definitive consensus on surgical techniques specific to non-accidental trauma, in retrospective studies analyzing large cohorts, subdural-peritoneal shunting, in addition to subdural puncture, was the most commonly employed treatment for SDH [296,297]. The role of decompressive craniectomy has been widely studied in accidental TBI [301–303], but results in infants with non-accidental TBI are uncertain, precluding any recommendation. The therapeutic window for intervention is especially limited in toddlers, and the presence of a 'big black brain' at admission is a contraindication. Other patients can typically be managed with intensive resuscitation, early monitoring of ICP, and CSF withdrawal via lumbar puncture if the cisterns are patent, or subdural drainage if they are not. Conservative treatment may be considered in cases of small (<10 mm), clinically well-tolerated SDH (including isolated seizure), with no signs of intracranial hypertension. However, there are no direct medical treatments for SDH [297]. Acute SDH, consisting of fresh clotted blood, comparable to the lesion seen in adults, is very rare in infants. The literature on this subject is extremely limited.

Recommendations

- **R 14.1: In infants with non-accidental traumatic brain injury associated with subdural hematoma, the experts suggest rapid surgical management, preferably by drainage.**

EXPERT OPINION (STRONG AGREEMENT)

- **R 14.2: No recommendations are made on decompressive craniectomy in non-accidental traumatic brain injury in infants.**

NO RECOMMENDATION

- **R 14.3: In infants with non-accidental traumatic brain injury associated with subdural hematoma, the experts suggest considering conservative management for chronic subdural hematomas with small thickness (<10 mm) that are clinically well-tolerated, accompanied by close surveillance and regular imaging monitoring.**

EXPERT OPINION (STRONG AGREEMENT)

Question 15. In infants under 2 years of age with ping-pong fracture, under what circumstances is surgical management likely to improve neurological outcome?

Delivery-related injuries include ping-pong fracture, occurring in 1–2.5 cases per 10,000 live births. This is characterized by a bony depression in the cranial vault without loss of continuity, and is rarely associated with intracranial lesions. There are no clearly identified predictive factors to determine which cases will resolve spontaneously and which will require intervention.

A recent systematic review, including 54 articles and 228 children under 20 months of age (excluding complex fractures associated with intracranial lesions) [304], reported that 30% of children received surgical management, 30% underwent interventional management (aspiration), and 40% were managed conservatively. The review found no significant difference in neurological outcome according to type of management, with favorable prognosis (no neurological deficit or epilepsy) in more than 96% of patients. The surgical indications reported were as follows:

- o presence of a foreign body;
- o wound contamination, infection or need for trimming;
- o neurological deficit;
- o signs of intracranial hypertension;
- o unsuccessful correction by external maneuver (aspiration);
- o risk of difficulty with close neurosurgical follow-up of conservative treatment;
- o intracranial hematoma;
- o hygroma;
- o major cosmetic concerns.

The authors recommended that infants with symptomatic ping-pong fracture undergo ultrasound examination, and those with an intracranial lesion visible on ultrasound or depression >1 cm undergo CT. Several of the included studies [304], as well as a recent retrospective series of 7 cases [305], advocated conservative treatment for fractures through external maneuvers (e.g., suction).

While the possibility of fracture reduction is emphasized, there is insufficient data on the impact of these procedures on neurological outcome. Consequently, the effectiveness of the maneuver remains uncertain.

Recommendations

- **R 15.1: In infants presenting ping-pong fracture, the experts suggest emergency surgery in the following situations:**
  - **o intracranial hypertension;**
  - **o significant mass effect on the parenchyma or intracranial hematoma or peri-encephalic CSF collection.**

EXPERT OPINION (STRONG AGREEMENT)

- **R 15.2: In infants presenting ping-pong fracture, the experts suggest that, in the absence of the above criteria, management should initially be conservative. Surgical management may be re-evaluated in the absence of favorable outcome.**

EXPERT OPINION (STRONG AGREEMENT)

Coordinators

Romain MANET (SFNC), Arnaud DAGAIN (SFNC)

Methodological supervision

Jean François PAYEN (SFAR, ANARLF), Hugues DE COURSON (CRC SFAR, ANARLF)

Experts

French Society of Neurosurgery (SFNC): Cyrille CAPEL (Amiens), Arnaud DAGAIN (Toulon), Philippe DECQ (Paris), Matthieu FAILLOT (Paris), Clémentine GALLET (Lyon), Vincent JECKO (Bordeaux), Stéphane GOUTAGNY (Paris), Christophe JOUBERT (Toulon), Romain MANET (Lyon), Édouard SAMARUT (Nantes)

French Society of Pediatric Neurosurgery (SFNCP): Nathalie CHIVORET (Nice), Andres COCA (Strasbourg), Mathieu VINCHON (Lyon)

French Society of Private-Practice Neurosurgeons (SFNCL): Alice ROLLAND (Montpellier)

French Society of Anesthesia, Critical Care and Perioperative Medicine (SFAR), and Neurocritical Care and French-Speaking Neuro Anesthesiology Society (**ANARLF):** Baptiste BALANCA (Lyon), Mickael CARDINALE (Toulon), Hugues DE COURSON (Bordeaux), Pierre ESNAULT (Toulon), Jean-Denis MOYER (Caen), Jean François PAYEN (Grenoble), Hervé QUINTARD (Genève), Stéphanie SIGAUT (Paris)

French-Speaking Group of Emergency and Intensive Care in Pediatrics (GFRUP): Guillaume MORTAMET (Grenoble)

French Society of Neuroradiology (SFNR): François COTTON (Lyon), Alexandre BANI-SADR (Lyon), Sébastien GAZZOLA (Toulon)

French-speaking Society of **Infectious Diseases (SPILF):** Marion LE MARECHAL (Grenoble)

French Society of Physical Medicine and Rehabilitation (SOFMER): Jacques LUAUTÉ (Lyon), Eric VERIN (Rouen)

Work groups

Prognostic factors to be considered when indicating emergency craniotomy in adult patients with traumatic brain injury
Romain MANET, Mickaël CARDINALE, François COTTON, Hervé QUINTARD, Jacques LUAUTE, Éric VERRIN, Arnaud DAGAIN

Extradural hematoma
Cyrille CAPEL, Jean Denis MOYER

Acute subdural hematoma
Matthieu FAILLOT, Stéphanie SIGAUT, Alice ROLLAND

Depressed fractures and skull base fractures associated with cerebrospinal fluid fistula
Edouard SAMARUT, Clémentine GALLET, Alexandre BANI-SADR, Marion LE MARECHAL, Romain MANET

Penetrating traumatic brain injury
Arnaud DAGAIN, Christophe JOUBERT, Sébastien GAZZOLA, Pierre ESNAULT, Marion LE MARECHAL

Post-traumatic cerebrospinal fluid disorders
Romain MANET, Stéphane GOUTAGNY, Baptiste BALANCA, Vincent JECKO, Philippe DECQ, Arnaud DAGAIN

Specifics of neurosurgical management of pediatric traumatic brain injury
Nathalie CHIVORET, Andres COCA, Guillaume MORTAMET, Matthieu VINCHON

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Declaration of competing interest

The authors declare having no conflicts of interest.

Appendices

Glasgow Outcome Scale Extended (GOSE) [15].

GOSE	**Poor neurological outcomes**
1 Death	
2 Vegetative State	
3 Lower Severe Disability	Totally dependent
4 Upper Severe Disability	Very dependent (but can be left alone several hours)
	Good neurological outcomes
5 Lower Moderate Disability	Partially dependent

(*continued on next page*)

(*continued*)

6 Upper Moderate Disability	Partial return to work (or school)
7 Lower Good Recovery	Mild sequelae
8 Upper Good Recovery	Complete recovery

Modified Frailty Index 5 **(mFI-5)** [29].

Items		Result	Interpretation
Functional dependency	+1	0	Non frail
History of diabetes	+1	1	Pre-frail
Chronic obstructive pulmonary disease	+1	≥2	Frail
Congestive heart failure within 30 days	+1		
Hypertension	+1		

Clinical Frailty Scale **(CFS)** [31].

Score	Category	Description
1	Very Fit	People who are robust, active, energetic, and motivated. These individuals typically exercise regularly and are among the fittest for their age.
2	Well	People who have no active disease symptoms but are less fit than category 1. They often exercise or are very active occasionally, e.g., seasonally.
3	Managing Well	People whose medical problems are well controlled, but are not regularly active beyond routine walking.
4	Vulnerable	While not dependent on others for daily help, often symptoms limit activities. They often complain of being "slowed up" or have disease symptoms.
5	Mildly Frail	People with limited dependence on others for instrumental activities of daily living (IADLs), such as shopping, transportation, and managing medications.
6	Moderately Frail	People who need help with all outside activities and with keeping house. They need help with both instrumental and non-instrumental activities of daily living (ADLs).
7	Severely Frail	People who are completely dependent on personal care, for most activities of daily living, from physical causes.
8	Very Severely Frail	People who are completely dependent, and can be difficult to engage or frequently seem unaware of their surroundings. They approach the end of life.
9	Terminally Ill	People with a life expectancy of less than six months, who are not otherwise evidently frail.

SPIN score (Penetrating brain injury severity criteria) [226].

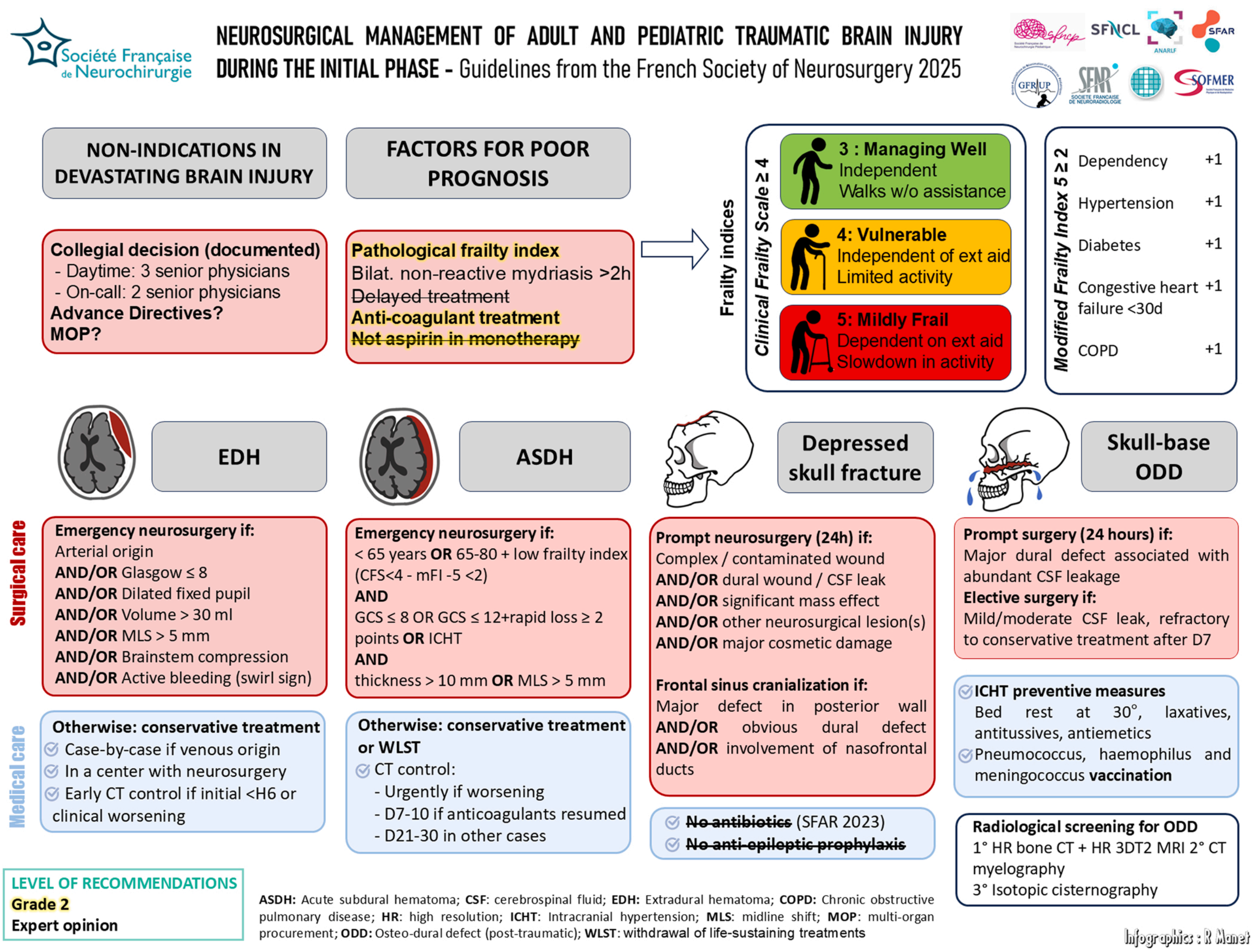
Survival score component	Points
motor Glasgow Coma Score	
5-Jan	0
6	9
Pupils	
Non-reactive bilaterally	0
Unequal	4
Globe rupture/non-visual	6
Equal and reactive bilaterally	9
Self-inflicted	
Yes	0
No	4
Transferred	
Yes	0
No	4
Sex	
Male	0
Female	4
Injury Severity Score (ISS)	
≥56	0
41–55	1
25–40	5
≤24	10
INR	
≥2,1	0
1,4–2	6
≤1,3	12

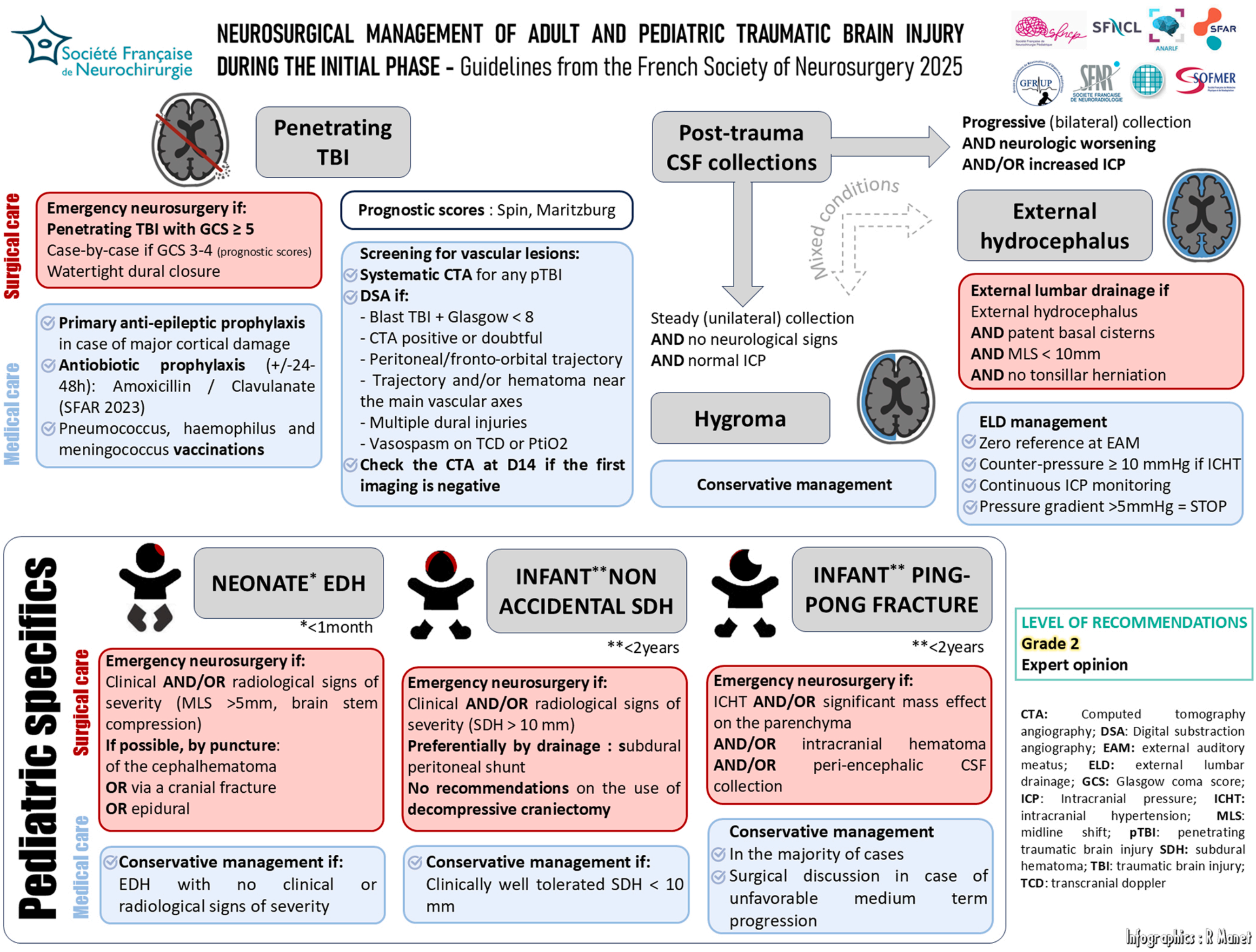
SPIN score ≥35: 98% survival. SPIN score ≤20: 3% survival.

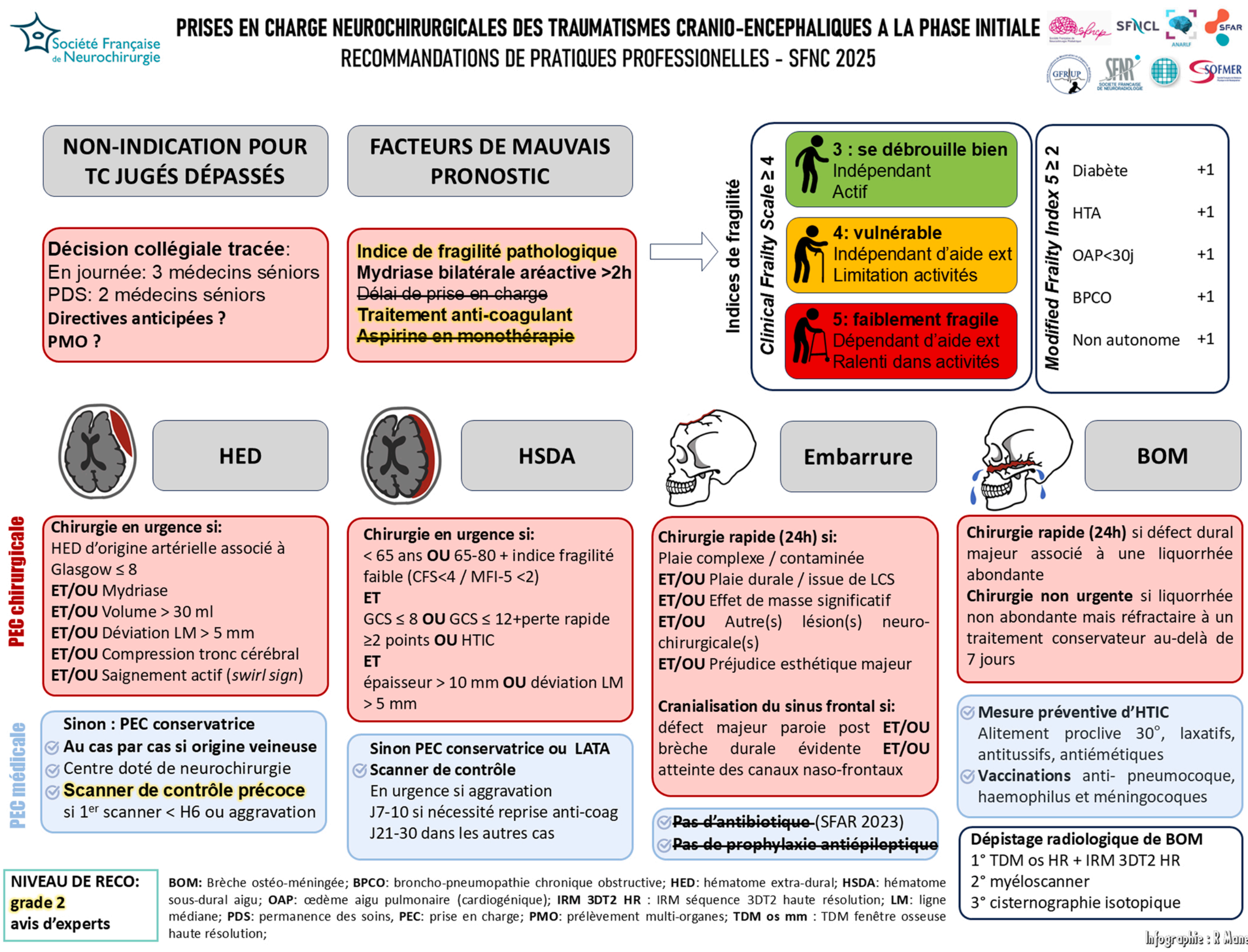
CT scan criteria for poor prognosis in penetrating traumatic brain injury [218,227].

- Multilobar or bihemispheric injury (except bi-frontal trajectory)
- Ventricular injury with hemorrhage
- Diffuse fragmentation
- Missile passing through the geographic center of the brain (i.e., involving the thalamus and basal ganglia)
  An area 4 cm above the dorsum sellae was described as the *zona fatalis*
- Trajectory crossing the x, y and z planes
- Midline shift (>10 mm on CT)
- Compressed or obliterated basal cisterns
- Large intracerebral hemorrhage
- Subarachnoid hemorrhage
- Large volume of contused brain
- Posterior fossa wound with brainstem involvement
- 'Tram track sign' hemorrhage on either side of a dark center track in a perforating injury

Figure. Infographic synthesis




Société Française de Neurochirurgie
NEUROSURGICAL MANAGEMENT OF ADULT AND PEDIATRIC TRAUMATIC BRAIN INJURY DURING THE INITIAL PHASE - Guidelines from the French Society of Neurosurgery 2025
sfncp
SFNCL
ANARLF
SFAR
GFRUP
SFNR SOCIETE FRANCAISE DE NEURORADIOLOGIE
SOFMER
Penetrating TBI
Surgical care
Emergency neurosurgery if:
Penetrating TBI with GCS ≥ 5
Case-by-case if GCS 3-4 (prognostic scores)
Watertight dural closure
Prognostic scores : Spin, Maritzburg
Medical care
Primary anti-epileptic prophylaxis in case of major cortical damage
Antibiotic prophylaxis (+/-24-48h): Amoxicillin / Clavulanate (SFAR 2023)
Pneumococcus, haemophilus and meningococcus vaccinations
Screening for vascular lesions:
Systematic CTA for any pTBI
DSA if:
- Blast TBI + Glasgow < 8
- CTA positive or doubtful
- Peritoneal/fronto-orbital trajectory
- Trajectory and/or hematoma near the main vascular axes
- Multiple dural injuries
- Vasospasm on TCD or PtiO2
Check the CTA at D14 if the first imaging is negative
Post-trauma CSF collections
Progressive (bilateral) collection
AND neurologic worsening
AND/OR increased ICP
Mixed conditions
External hydrocephalus
External lumbar drainage if
External hydrocephalus
AND patent basal cisterns
AND MLS < 10mm
AND no tonsillar herniation
ELD management
Zero reference at EAM
Counter-pressure ≥ 10 mmHg if ICHT
Continuous ICP monitoring
Pressure gradient >5mmHg = STOP
Steady (unilateral) collection
AND no neurological signs
AND normal ICP
Hygroma
Conservative management
Pediatric specifics
NEONATE* EDH
*<1month
Surgical care
Emergency neurosurgery if:
Clinical AND/OR radiological signs of severity (MLS >5mm, brain stem compression)
If possible, by puncture:
of the cephalhematoma
OR via a cranial fracture
OR epidural
Medical care
Conservative management if:
EDH with no clinical or radiological signs of severity
INFANT** NON ACCIDENTAL SDH
**<2years
Emergency neurosurgery if:
Clinical AND/OR radiological signs of severity (SDH > 10 mm)
Preferentially by drainage : subdural peritoneal shunt
No recommendations on the use of decompressive craniectomy
Conservative management if:
Clinically well tolerated SDH < 10 mm
INFANT** PING-PONG FRACTURE
**<2years
Emergency neurosurgery if:
ICHT AND/OR significant mass effect on the parenchyma
AND/OR intracranial hematoma
AND/OR peri-encephalic CSF collection
Conservative management
In the majority of cases
Surgical discussion in case of unfavorable medium term progression
LEVEL OF RECOMMENDATIONS
Grade 2
Expert opinion
CTA: Computed tomography angiography; DSA: Digital substraction angiography; EAM: external auditory meatus; ELD: external lumbar drainage; GCS: Glasgow coma score; ICP: Intracranial pressure; ICHT: intracranial hypertension; MLS: midline shift; pTBI: penetrating traumatic brain injury SDH: subdural hematoma; TBI: traumatic brain injury; TCD: transcranial doppler
Infographics : R Manet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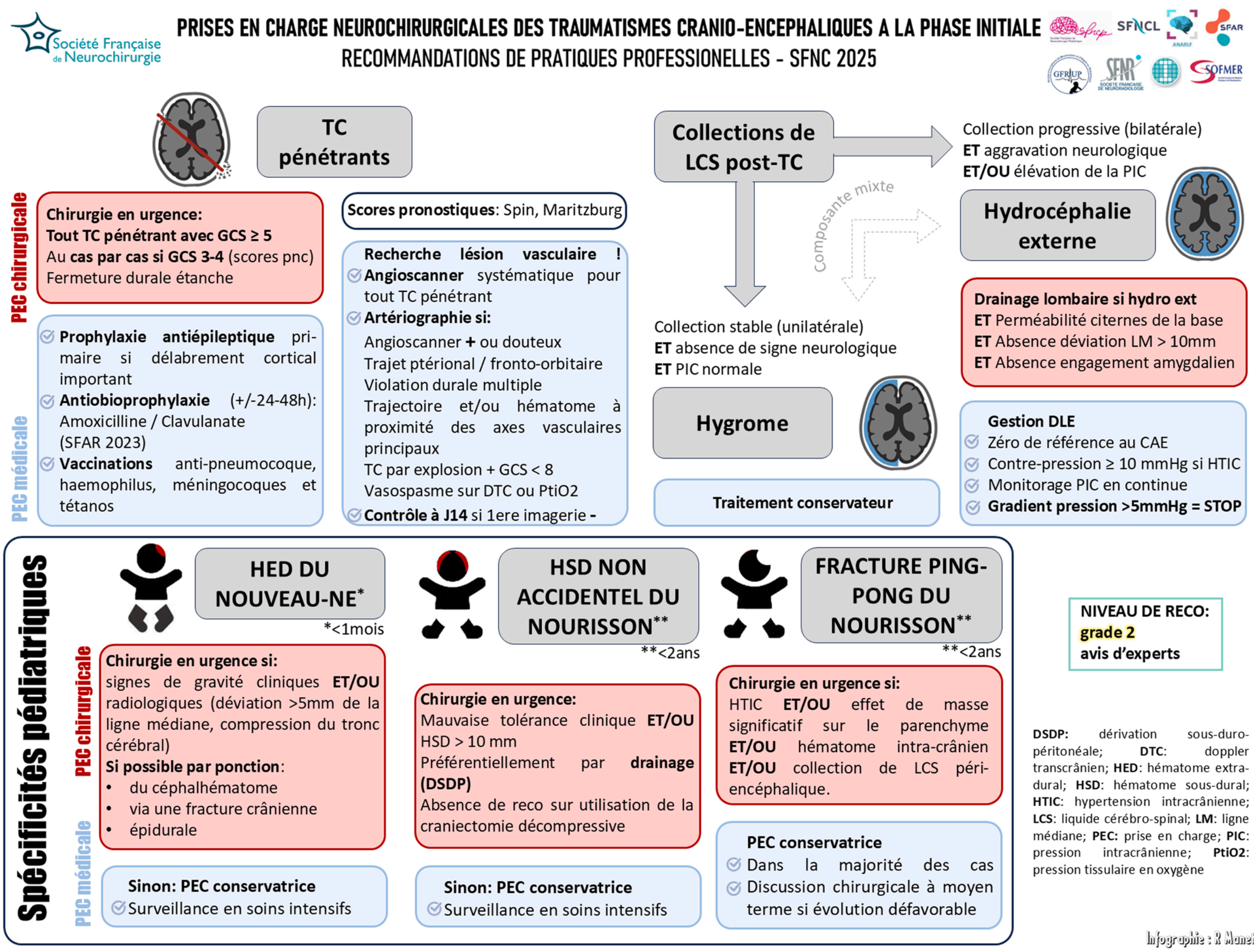
PRISES EN CHARGE NEUROCHIRURGICALES DES TRAUMATISMES CRANIO-ENCEPHALIQUES A LA PHASE INITIALE
RECOMMANDATIONS DE PRATIQUES PROFESSIONELLES - SFNC 2025
SFNCL
SFAR
GFRUP
SFNR
SOFMER
NON-INDICATION POUR TC JUGÉS DÉPASSÉS
Décision collégiale tracée:
En journée: 3 médecins séniors
PDS: 2 médecins séniors
Directives anticipées ?
PMO ?
FACTEURS DE MAUVAIS PRONOSTIC
Indice de fragilité pathologique
Mydriase bilatérale aréactive >2h
~~Délai de prise en charge~~
Traitement anti-coagulant
~~Aspirine en monothérapie~~
Indices de fragilité
Clinical Frailty Scale ≥ 4
3 : se débrouille bien
Indépendant
Actif
4: vulnérable
Indépendant d'aide ext
Limitation activités
5: faiblement fragile
Dépendant d'aide ext
Ralenti dans activités
Modified Frailty Index 5 ≥ 2
Diabète +1
HTA +1
OAP<30j +1
BPCO +1
Non autonome +1
HED
HSDA
Embarrure
BOM
PEC chirurgicale
Chirurgie en urgence si:
HED d'origine artérielle associé à Glasgow ≤ 8
ET/OU Mydriase
ET/OU Volume > 30 ml
ET/OU Déviation LM > 5 mm
ET/OU Compression tronc cérébral
ET/OU Saignement actif (*swirl sign*)
Chirurgie en urgence si:
< 65 ans OU 65-80 + indice fragilité faible (CFS<4 / MFI-5 <2)
ET
GCS ≤ 8 OU GCS ≤ 12+perte rapide ≥2 points OU HTIC
ET
épaisseur > 10 mm OU déviation LM > 5 mm
Chirurgie rapide (24h) si:
Plaie complexe / contaminée
ET/OU Plaie durale / issue de LCS
ET/OU Effet de masse significatif
ET/OU Autre(s) lésion(s) neuro-chirurgicale(s)
ET/OU Préjudice esthétique majeur
Cranialisation du sinus frontal si:
défect majeur paroie post ET/OU brèche durale évidente ET/OU atteinte des canaux naso-frontaux
Chirurgie rapide (24h) si défect dural majeur associé à une liquorrhée abondante
Chirurgie non urgente si liquorrhée non abondante mais réfractaire à un traitement conservateur au-delà de 7 jours
PEC médicale
Sinon : PEC conservatrice
Au cas par cas si origine veineuse
Centre doté de neurochirurgie
Scanner de contrôle précoce
si 1er scanner < H6 ou aggravation
Sinon PEC conservatrice ou LATA
Scanner de contrôle
En urgence si aggravation
J7-10 si nécessité reprise anti-coag
J21-30 dans les autres cas
~~Pas d'antibiotique~~ (SFAR 2023)
~~Pas de prophylaxie antiépileptique~~
Mesure préventive d'HTIC
Alitement proclive 30°, laxatifs, antitussifs, antiémétiques
Vaccinations anti- pneumocoque, haemophilus et méningocoques
Dépistage radiologique de BOM
1° TDM os HR + IRM 3DT2 HR
2° myéloscanner
3° cisternographie isotopique
NIVEAU DE RECO:
grade 2
avis d'experts
BOM: Brèche ostéo-méningée; **BPCO**: broncho-pneumopathie chronique obstructive; **HED**: hématome extra-dural; **HSDA**: hématome sous-dural aigu; **OAP**: œdème aigu pulmonaire (cardiogénique); **IRM 3DT2 HR** : IRM séquence 3DT2 haute résolution; **LM**: ligne médiane; **PDS**: permanence des soins, **PEC**: prise en charge; **PMO**: prélèvement multi-organes; **TDM os mm** : TDM fenêtre osseuse haute résolution;
Infographie : R Manet



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Romain Manet[a,b,*], Hugues de Courson[c,d], Cyrille Capel[e,f], Christophe Joubert[b,g], Nathalie Chivoret[h], Matthieu Faillot[i,j], Baptiste Balanca[k,l], Alexandre Bani-Sadr[m,n], Mickael Cardinale[g,o], Andres Coca[p], François Cotton[n,q], Pierre Esnault[o], Clémentine Gallet[a], Sébastien Gazzola[r], Stéphane Goutagny[i,s], Vincent Jecko[t,u], Marion le Marechal[v,w], Jacques Luauté[x,y], Guillaume Mortamet[w,z], Jean-Denis Moyer[A], Hervé Quintard[B], Alice Rolland[C], Édouard Samarut[D,E], Stéphanie Sigaut[F,G], Eric Verin[H,I], Mathieu Vinchon[J], Philippe Decq[i,K], Jean-François Payen[w], Arnaud Dagain[b,g]

[a] *Service de Neurochirurgie Crânienne, Hôpital Neurologique Pierre Wertheimer, Hospices Civils de Lyon, Bron, France*
[b] *Service de Neurochirurgie, Hôpital National d'Instruction des Armées Saint-Anne, Toulon, France*
[c] *Département d'Anesthésie-Réanimation, Hôpital Pellegrin, CHU de Bordeaux, Bordeaux, France*
[d] *Université de Bordeaux, INSERM UMR 1219, Bordeaux, France*
[e] *Service de Neurochirurgie, CHU Amiens-Picardie, Amiens, France*
[f] *CHIMERE UR UPJV 7516, Université de Picardie Jules Verne, Amiens, France*
[g] *Ecole du Val de Grâce, Académie de Santé des Armées, Paris, France*
[h] *Service de Neurochirurgie, CHU de Nice, Nice, France*
[i] *Service de Neurochirurgie, Hôpital Beaujon, Assistance Publique Hôpitaux de Paris, Clichy, France*
[j] *Université Paris-Cité, Laboratoire CEA/Service Hospitalier FrédéricJoliot/BioMaps, Paris, France*
[k] *Service d'Anesthésie Réanimation Neurologique, Hôpital Neurologique Pierre Wertheimer, Hospices Civils de Lyon, Bron, France*
[l] *Centre de Recherche en Neurosciences, INSERM U1028/CNRS, UMR 5292, Université de Lyon 1, Lyon, France*
[m] *Service de Neuroradiologie, Hôpital Neurologique Pierre Wertheimer, Hospices Civils de Lyon, Bron, France*
[n] *CREATIS-LRMN, CNRS/UMR/5220-INSERM U630, Université Lyon 1, Lyon, France*
[o] *Service de Réanimation, Hôpital National d'Instruction des Armées Sainte Anne, Toulon, France*
[p] *Service de Neurochirurgie, Hôpital Hautepierre, CHU Strasbourg, Strasbourg, France*
[q] *Service de Radiologie, Centre Hospitalier Lyon Sud, Hospices Civils de Lyon, Lyon, France*
[r] *Service de Neurologie, Hôpital National d'Instruction des Armées Sainte Anne, Toulon, France*
[s] *Université Paris Cité, Inserm UMRS1144, Paris, France*
[t] *Service de Neurochirurgie A, Hôpital Pellegrin, CHU Bordeaux, Bordeaux, France*
[u] *Université de Bordeaux, CNRS UMR, INCIA, Bordeaux, France*
[v] *Service de Maladies Infectieuses, CHU Grenoble Alpes, Grenoble, France*
[w] *Université Grenoble-Alpes, Grenoble, France*
[x] *Service de Médecine Physique et Réadaptation, Hôpital Henry Gabrielle, Hospices Civils de Lyon, Saint-Genis-Laval, France*
[y] *Centre de Recherche en Neurosciences de Lyon, U1028, UMR5229, équipe Trajectoires, Université Lyon 1, Lyon, France*
[z] *Service de Soins Critiques Pédiatriques, CHU de Grenoble, Grenoble, France*
[A] *Département d'Anesthésie-Réanimation, CHU de Caen Normandie, Caen, France*
[B] *Département d'Anesthésiologie, de Pharmacologie Clinique, de Soins Intensifs et de Médecine d'Urgence, Hôpitaux Universitaires de Genève, Genève, Switzerland*
[C] *Service de Neurochirurgie, Clinique du Millénaire, Montpellier, France*
[D] *Service de Neurochirurgie, CHU de Nantes, Nantes, France*
[E] *Nantes Université, INSERM, CRCI2NA, Nantes, France*
[F] *Service d'Anesthésie Réanimation, Hôpital Beaujon, Assistance Publique Hôpitaux de Paris, Clichy, France*
[G] *Université Paris Cité, INSERM, NeuroDiderot, Paris, France*
[H] *Service de Médecine Physique et Réadaptation, CHU de Rouen, Rouen, France*
[I] *Université de Rouen, Rouen, France*
[J] *Service de Neurochirurgie Pédiatrique, Hôpital Femme Mère Enfant, Hospices Civils de Lyon, Bron, France*
[K] *Institut de Biomécanique Humaine Georges Charpak, Arts et Métiers ParisTech et Université de Paris, Paris, France*

* Corresponding author.
E-mail address: romain.manet@chu-lyon.fr (R. Manet).