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Consensus-based recommendations for diagnosis and surgical management of cranioplasty and post-traumatic hydrocephalus from a European panel

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A R T I C L E I N F O

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A B S T R A C T

Introduction: Planning cranioplasty (CPL) in patients with suspected or proven post-traumatic hydrocephalus (PTH) poses a significant management challenge due to a lack of clear guidance.
Research question: This project aims to create a European document to improve adherence and adapt to local protocols based on available resources and national health systems.
Methods: After a thorough non-systematic review, a steering committee (SC) formed a European expert panel (EP) for a two-round questionnaire using the Delphi method. The questionnaire employed a 9-point Likert scale to assess the appropriateness of statements inherent to two sections: "Diagnostic criteria for PTH" and "Surgical strategies for PTH and cranial reconstruction."
Results: The panel reached a consensus on 29 statements. In the "Diagnostic criteria for PTH" section, five statements were deemed "appropriate" (consensus 74.2–90.3 %), two were labeled "inappropriate," and seven were marked as "uncertain."
In the "Surgical strategies for PTH and cranial reconstruction" section, four statements were considered "appropriate" (consensus 74.2–90.4 %), six were "inappropriate," and five were "uncertain."
Discussion and conclusion: Planning a cranioplasty alongside hydrocephalus remains a significant challenge in neurosurgery. Our consensus conference suggests that, in patients with cranial decompression and suspected hydrocephalus, the most suitable diagnostic approach involves a combination of evolving clinical conditions and neuroradiological imaging. The recommended management sequence prioritizes cranial reconstruction, with the option of a ventriculoperitoneal shunt when needed, preferably with a programmable valve. We strongly recommend to adopt local protocols based on expert consensus, such as this, to guide patient care.

1. Introduction

Following the International Consensus Conference on post-traumatic cranioplasty (CPL) in 2018, there is still a clear need for clinical studies of high methodological quality evaluating cerebral spinal fluid (CSF) disorders following decompressive craniectomy (DC) and the impact this has on cranial reconstruction. In patients with suspected or proven post-traumatic hydrocephalus (PTH) and where a CPL is planned, the management remains empirical and widely variable, reflecting the absence of definitive diagnostic criteria and the lack of consensus on the most appropriate surgery in terms of timing and technique (Mavrovounis et al., 2021).

Building consensus when dealing with complex and controversial health issues lacking high-quality evidence has been widely adopted as a practical and effective solution in patients with severe traumatic brain injury (TBI).

2. Methods

2.1. Consensus document's focus and target population

The focus is on the management of CPL in adult patients with a suspected or proven PTH at the time of planning cranial reconstruction, with the target population being those who have undergone DC following TBI and require CPL.

2.2. Aim

Providing pragmatic and easy-to-follow clinical guidelines for managing PTH in the context of CPL with the hope that an appropriate diagnostic approach and a clear surgical strategy become integral in managing cranial reconstruction.

It is important to note that this document does not cover managing other types of hydrocephalus and CPL except for PTH and associated CPL. Additionally, the document does not address specific subsets of the CPL population based on the material used for CPL, as these topics are beyond its scope.

2.3. Delphi survey and panel composition

A steering committee (SC) comprised selected members (FS, CI, SC, TS, IT, HM) from European Neurosurgical Centers in France, Germany, Italy, and the UK. The committee members were selected based on their recognized expertise in the field and their involvement in national registries on CPL.

To enable the two-round voting process, the SC identified a European panel (EP) comprising 25 experts in neurotrauma. The panel members were chosen based on their extensive publication record in the field and their relevant clinical and academic experience. The final composition of the EP included six neurosurgeons from Italy and the UK, two neurosurgeons each from Greece, Romania, Sweden, and Germany, and one neurosurgeon each from the Netherlands, Croatia, Finland, Spain and Belgium (Appendix 1).

2.4. Literature search

An extensive non-systematic review of the literature from 18 January to November 22, 2022 was performed via electronic databases (MEDLINE, EMBASE, and Cochrane Library Central Registry) by non-panelist authors (IZ, SF) and study coordinators; only articles describing human subjects and published in English were included. Uncontrolled clinical trials, case series, retrospective studies, expert opinions, clinical trials, meta-analyses, case series, preclinical studies, and practice guidelines were considered eligible for inclusion.

The Medical Subject Heading (MeSH) terms used for the literature search are listed in Appendix 2.

The quality of available studies underwent double-blind evaluation, and when available, relevant articles published in the last five years resulting from the literature search on the diagnostic approaches and surgical strategies were embedded in the relative survey questions (Tables 1 and 2).

This time frame followed the recent update on this topic reported in the international consensus on post-traumatic CPL (Iaccarino et al., 2021), where the same research method had been adopted.

2.5. Survey development

The SC identified the main gaps and clinical questions (reported in

Supplementary Data 1) for the development of two theme-based blocks: 1. "Diagnostic criteria" and 2. "Surgical strategies". Each question addressed the relevant population and explored alternative management strategies encompassing diagnosis and surgery.

2.5.1. -diagnostic criteria

- ○ Differentiation between ventriculomegaly, brain bulging, and clinically relevant hydrocephalus.
- ○ CSF tests:
- - When to perform tests: before or following CPL
- - Dynamic studies:
  - ● CSF infusion test
  - ● Tap test
- ○ Electrophysiological testing
- ○ Imaging
- - CT scan measures
- - MRI findings
- - Perfusion imaging
- - Nuclear medicine imaging

2.5.2. -surgical strategy

- ○ Transitory shunts
- - Use of external ventricular drainage (EVD)
- - Use of external lumbar drainage (ELD)
- - Time of implementation:
  - - Before CPL
  - - One-step surgery with CPL
  - - Following CPL
- ○ Definitive Shunts
- - Ventriculoperitoneal shunt (VPS)
- - Lumboperitoneal shunt (LPS)
  - ●Time of implementation
  - ● Before CPL
  - ● One-step surgery with CPL
  - ● Following CPL

The SC convened a meeting to pool all the statements and validate the voting. The final questionnaire voted on in the first round contained the following.

Table 1
Outline of the references provided to the panelists about diagnostic approaches.

Diagnostic approach	Main focus: PTH/iNPH	Relevant indications	Focus on PTH and CPL	Author
Clinical prediction model	Predicting the outcomes of shunt implantation in patients with PTH and severe conscious disturbance	- Independent predictors for the long-term prognosis of shunt: age <50 years, mild hydrocephalus, GCS scores 9–12, shunting <3 months after trauma - Not useful for predicting the occurrence of PTH	Yes	Wang et al., 2020
Practical nomogram	Predicting the occurrence of PTH after DC for TBI	Predictors: SAH, type of DC, transcalvarial herniation volume, subdural hygroma, functional outcome	Yes	Zhuo et al., 2022
Diagnostic criteria	Differentiation of PTH from ventriculomegaly and identification of patients eligible for CSF diversion	Approaches to differentiate PTH from ventriculomegaly: clinical signs or, in their absence, lumbar infusion studies	Yes, unless DC with contusion or bilateral DC	Rufus et al., 2021
Gudeman's criterion, (enlargement of cerebral ventricles) on serial CT scans), Evans index, clinical characteristics of PTH	Risk factors affecting the prognosis of PTH in patients with TBI	Risk factors: the disappearance of cisterna ambiens, long-lasting coma (>2 months), high plasma fibrinogen, and VPS implantation. DC and cranioplasty did not influence the outcome of PTH	Yes, partially	Sun et al., 2019
Prognostic factors	Clinical outcome and prognostic factors for patients who received a VPS due to PTH	Predictors of greatest improvement: post-traumatic ventriculomegaly with impeded neurological recovery, low- or high-pressure hydrocephalus symptoms Predictors of unresponsiveness to shunt implantation: - Poor neurological condition with concurrent ventricular dilatation - Infusion tests are more reliable after CPL	Yes, partially	Svedung Wettervik et al., 2022
Transcranial Doppler ultrasonography	Characterization of CBF in hydrocephalus patients through mathematical models	Alterations in CBF dynamics identified by mathematical models represent a complementary source of information.	No	Kazimierska et al., 2021
CT perfusion and cardiac gated cine phase MRI	Effects of CPL on cerebro-hemodynamics and their co-relationship with neurocognitive outcome	CPL improves cortical perfusion and correlates with cognitive outcome.	No	Panwar et al., 2019
Perfusion imaging, CBF quantification, MRI	Understanding the vascular and glymphatic factors related to iNPH pathogenesis	Neuroimaging detection of alterations in CBF and glymphatic flow facilitates the differential diagnosis and the identification of patients eligible for shunt surgery.	No	Soldozy et al., 2022
Presenting clinical features ELD, IT, ICPM, TT	Predicting shunt responsiveness in iNPH	Efficacy of diagnostic tests: Intraparenchymal ICPM > ELD > IT > TT TT and IT: recommended as the first line due to higher accessibility.	No	Thavarajasingam et al., 2021
Constant rate infusion tests	CSF dynamics in post-acute, post-traumatic ventriculomegaly with normal baseline intracranial pressure	Resistance to CSF outflow and CSF pulse amplitude are lower in PTH compared to iNPH. Ventricular enlargement degree ≠ altered CSF dynamics degree	Excluded criteria PTH and DC	Lalou et al., 2020
Infusion techniques	CSF dynamics to differentiate between iNPH and brain atrophy	Review of results from infusion studies for evaluating CSF dynamics at the bedside	Excluded criteria PTH and DC	Papaioannou et al., 2022

CBF: cerebral blood flow, CPL: Cranioplasty, CSF: Cranio-Spinal Fluid, CT: Computed tomography, DC: Decompressive Craniectomy, ELD: external lumbar drainage, GCS: Glasgow Coma Scale, ICPM: intracranial pressure monitoring, iNPH: idiopathic Normal Pressure Hydrocephalus, PTH: Post Traumatic Hydrocephalus, SAH: subarachnoid hemorrhage TBI: traumatic brain injury, TT: Tap Test, VPS: Ventriculo-Peritoneal Shunt.

Table 2
Outline of the references provided to the panelists about surgical strategies.

Surgical strategy	Main focus Hydrocephalus and CPL	Relevant indications	PTH and CPL	Author
One-staged: CPL + VPS vs staged CPL→VPS or VPS→CPL	Superiority of one-staged vs. staged strategy	In the case of persistent hydrocephalus, but no considerations about diagnosis	Yes	Rosinski et al., 2020
		- Ipsilateral VPS recommended over contralateral one - Ventricular/biparietal ratio >0.26 indicates hydrocephalus	Yes	Yan et al., 2022
	Inferiority of one-staged vs staged strategy	- Between VPS→CPL vs CPL + VPS - Between CPL→VPS vs CPL + VPS - Complication rate: one-staged surgery 33.3 % vs. staged surgery 9.6 % ($p < 0.01$)	Yes	Gill et al., 2021
		CPL + VP overall higher incidence of infections	Yes	Zhang et al., 2022
	Non-superiority of one-staged vs. staged strategy	Between VPS→CPL, CPL→VPS vs CPL + VPS in terms of complications	Yes	Ting et al., 2020
Definitive CSF shunt Wait for CPL VPS →CPL	Superiority of initial VPS placement	VPS→CPL Lower revision rate vs CPL→VPS	Yes	Gill et al., 2021
	Inferiority of initial VPS placement	VPS→CPL higher complications vs CPL→VPS	Yes	Zhang et al., 2022
		VPS→CPL - Higher overall complications ($p < 0.010$), excluding infection and seizures - Higher risk for sunken skin flap ($p < 0.001$) - Independent risk factors for postoperative extradural collection (odds ratio 17.714, $p < 0.001$) have been reported	Yes, partially	Zheng et al., 2019
Temporary external CSF shunt	Inferiority of initial VPS placement	Intraoperative ELD vs. preoperative VPS	Yes, partially	Dang et al., 2021
Fixed pressure valves	Inferiority of fixed pressure valves over programmable ones	Fixed VPS →CPL Higher risk with VPS placement during rehabilitation	Yes, partially	Castellani et al., 2021
Timing CPL	Superiority of early CPL in reducing PTH risk	Early CPL (≤2 months after DC) (sensitivity: 0.800, specificity: 0.703)	Yes	Ozoner et al., 2020
	Inferiority of early CPL in reducing PTH risk	Early CPL (≤3 months after DC) PTH risk: early 11.1 % vs late 2.0 % [OR]: 6.03, 95 % CI 1.80–20.19 ($p = 0.003$) Higher complication rate: Early CPL 32.1 % vs late CPL 12.7 % [OR]: 3.27, $p < 0.001$	Yes, partially	Tora et al., 2021

CPL: Cranioplasty, CSF: Cranio-Spinal Fluid, DC: Decompressive Craniectomy, LPS: lumbar-peritoneal shunt, OR: Odds ratio, VPS: Ventriculo-Peritoneal Shunt, →: followed by.

- Three general questions on the appropriateness of neuroradiological examinations, clinical assessment, and neurophysiological examinations as first diagnostic approaches, followed by consensus statements on the appropriateness of diagnostic tools (eight items) and of shunt responsiveness tools (three items).
- Consensus statements about first-line surgical treatments (five items), CSF withdrawal techniques relative to the different surgical approaches (five items), and different options for definitive CSF shunt (five items).

2.6. Data collection and analysis

A two-round survey was conducted by a questionnaire using Survey Monkey (cloud-based online survey software). The link was active between 03/11/22 and 28/11/22 and between 11/01/23 and 27/01/23 for the first and second rounds, respectively. Responses were independent and anonymous, with only the independent study moderator having access to the individual responses.

The panelists evaluated the items using a single 9-point Likert scale. The level of appropriateness was classified as follows.

- ***1, 2, 3 = inappropriate***
  - *1 = totally inappropriate, 2 = inappropriate, 3 = slightly inappropriate*
- ***4, 5, 6 = uncertain***
  - *4 = very uncertain, 5 = uncertain, 6 = slightly uncertain*
- ***7, 8, 9 = appropriate***
  - *7 = slightly appropriate, 8 = appropriate, 9 = totally appropriate*

2.7. Voting criteria

- *"appropriate" = votes ≥70 %*
- *"uncertain" = inappropriate votes <30 % and appropriate votes <70 %*
- *"inappropriate" = inappropriate votes ≥30 %*
- *Statement to be revoted automatically: appropriate votes ≥60 and < 70 %*
- *Statement to be revoted, according to the steering committee: appropriate votes ≥50 % (taking into consideration the suggestions received from the EP).*

2.8. Delphi rounds

Once completed, each item's median values and standard deviation were calculated. The results were analyzed by determining the percentage of votes for each degree of appropriateness. The results were shared with the panelists as anonymous statistical summaries representing overall responses.

Between rounds, the SC convened to discuss the results and identify statements that required a revote. During this discussion, the EP actively participated remotely, offering suggestions for modifications and rephrasing the statements that needed improvement.

Questions that did not reach a consensus in the first round were carried forward to the second round. Following the EP discussion, some questions were reformulated to enhance clarity and precision. Thus, experts were asked to vote again, following published guidelines (Hasson et al., 2000). One of the 25 panelists did not participate in the second round.

2.9. Consensus process

The final criteria for assessing the appropriateness remained, and each statement was scored against this and reviewed by the SC to see if a consensus had been reached. There was sufficient convergence of voting following round 2 to generate specific recommendations, and no further rounds of voting were necessary.

No ethical approval was required for the present study as it only requested the opinions of clinicians, and no patient-specific data were involved.

Fig. 1 summarizes the principal steps of the Delphi process as it was performed in this study.

3. Results

Consensus opinions on 29 statements were generated from two rounds of the Delphi from 31 invited participants. Response rates were 100 % (31 out of 31) in round 1 and 96.7 % (30 out of 31) in round 2. The 29 statements were grouped into two main themes – 1. "Diagnostic criteria" and 2. "Surgical strategies"; both were organized into three linked sessions.

3.1. Theme 1: diagnostic criteria

There were 14 questions about the appropriateness of three main first diagnostic approaches (first session), eight different diagnostic tools (second session), and three about shunt-responsiveness tools (third session).

A strong consensus on the appropriateness of "neuroradiology" and "clinical examination" as first diagnostic approaches (90.3 % and 87.1 %, respectively) was reached. Out of the six diagnostic neuroradiological tools (Evans index, brain bulging, CT perfusion, SPECT brain perfusion, phase contrast MRI, and Diffusion Tensor Imaging [DTI]), only "Evans index" reached consensus following a revote and panel discussion.

The clinical diagnostic tools "GCS trend" and "change in cognition" were rated as appropriate (86.67 % and 80 %, respectively). "Neurophysiological examinations" were rated as an inappropriate criterion as a first diagnostic approach by 48.5 % of panelists. Regarding the shunt-responsiveness tool, the "tap test" was considered appropriate (74.2 %), while the "infusion test" and "external lumbar drainage" remained uncertain.

Table 3 includes the statements in a collapsed form and the results of the Delphi survey for the diagnostic theme block. The statements in full with the percentage agreement/disagreement are reported in Supplementary Table 1.

3.2. Theme 2: surgical strategies

There were 15 questions in total. The first session contained five statements on the appropriateness of different combined surgical strategies of cranial reconstruction and PTH treatment as the first choice. The second session included five statements on the appropriateness of different approaches for CSF withdrawal management. The third session included five statements on the appropriateness of different options for definitive CSF shunt.

A high rate of agreement on the appropriateness of the option "Cranioplasty" as a first surgical approach followed by observation and a definitive shunt if indicated was reached (77.4 %). In this case, the CSF withdrawal management was rated as appropriate (74.2 %), with

Table 3
Results of the Delphi survey for each statement belonging to the diagnostic criteria theme block.

Diagnostic Criteria	Appropriateness
SESSION 1: Rate the appropriateness as the first diagnostic approach for:	
Neuroradiology	Appropriate
Clinical	Appropriate
Neurophysiology	Inappropriate
SESSION 2: Rate the appropriateness as a diagnostic tool for:	
Evans index	Uncertain
Brain Bulging	Uncertain
CT perfusion	Uncertain
SPECT brain perfusion	Uncertain
Phase contrast MRI	Uncertain
DTI	Inappropriate
GCS trend	Appropriate
Change in cognition (MMSE/MOCA)	Appropriate
SESSION 3: Rate the appropriateness as a shunt-responsiveness tool for:	
Tap test	Appropriate
Infusion test	Uncertain
External lumbar drainage	Uncertain

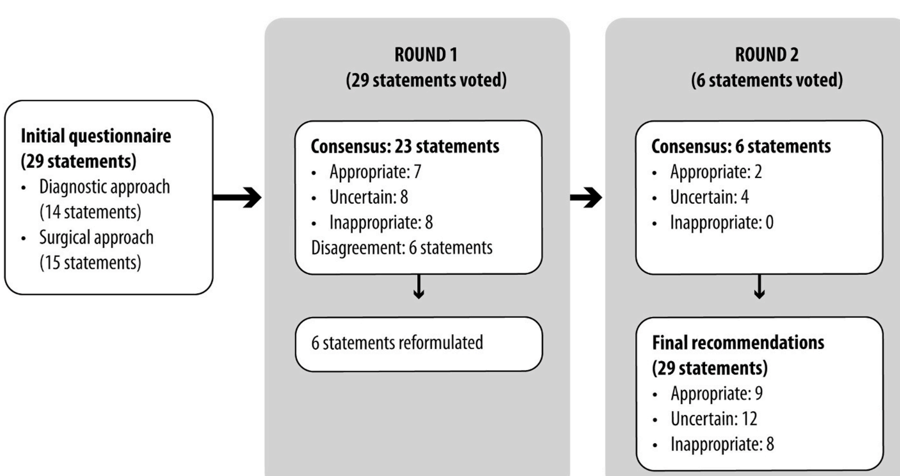

Fig. 1. Delphi flow chart. Outline of the principal steps of the Delphi process as it was performed in this study.

intraoperative drainage and waiting for postoperative clinical and radiological observations being factors to help decide on the indication of a definitive shunt.

The option of a staged strategy with a first surgical step with CPL and temporary external CSF shunt reached an uncertain agreement with 42 % appropriate and 38.7 % uncertain. Likewise, the external lumbar drainage also reached an uncertain agreement (63.3 %) despite a revote in the second round. The external ventricular drainage was considered inappropriate for 32.3 % and inappropriate for 29.1 % of panelists, and the one-step surgery with contemporary CPL and definitive shunt was rated inappropriate.

A staged strategy of both a temporary and a definitive shunt positioning in a decompressed patient waiting for a second surgery with CPL was rated inappropriate in almost all steps. The options of definitive shunt received 22.6 % and 38.8 % of votes as appropriate or inappropriate, respectively. The options of temporary external shunt received 42 % of both appropriate and inappropriate votes. In this setting, a temporary external lumbar shunt received 48.4 % of votes as appropriate and 28.7 % as uncertain, while a temporary external ventricular shunt was voted as inappropriate by 32.3 % and uncertain by 38.6 %.

Among the different options for definitive CSF shunt, the ventriculoperitoneal shunt and adjustable pressure valve were rated as appropriate (90.4 % and 87.2 %), while the lumbar-peritoneal shunt and fixed pressure valve were rated as inappropriate (41.9 % and 45.2 %) with the CSF flow control valve did not reach a consensus.

3.3. *Additional surgical strategies*

During discussions, two additional surgical strategies were proposed - "In the case of definitive CSF shunt, rate the appropriateness of additional gravitational/anti-siphoning system" and "Following just CPL, rate the appropriateness of intraparenchymal ICP monitoring to confirm indication of definite CSF shunt positioning." Since the surgical strategies included in the new statements were deemed to be beyond the scope of this consensus, the SC decided to exclude them from the official list of the statements but still investigate the opinion of the EP. Following discussion and voting, both were deemed inappropriate.

Table 4 includes the statements in a collapsed form and the results of the Delphi survey for the surgical strategies theme block. The statements in full, with the percentage agreement/disagreement for each statement, are reported in Supplementary Table 2.

Table 4
Results of the Delphi survey for each statement belonging to the surgical strategies theme block.

Surgical strategies	Appropriateness
SESSION 1: Rate the appropriateness as the first choice of treatment for:	
STAGED STRATEGY: Cranioplasty • I surgery: CPL • II surgery: definitive shunt following observation if indicated	Appropriate
STAGED STRATEGY: Cranioplasty + temporary external CSF shunt • I surgery: CPL and external shunt • II surgery: definitive shunt following observation if indicated	Uncertain
STAGED STRATEGY: Temporary external CSF shunt • I surgery: external shunt • II surgery: CPL according to brain/ventricle state ± definitive shunt (or III surgery)	Inappropriate
STAGED STRATEGY: Definitive CSF shunt • I surgery: definitive shunt • II surgery: CPL according to brain/ventricle state	Inappropriate
ONE-STEP STRATEGY: Cranioplasty + definitive shunt • One-step surgery CPL and definitive shunt	Inappropriate
SESSION 2: Rate the appropriateness of CSF withdrawal management for:	
Intraoperative CSF drainage after CPL	Appropriate
External lumbar drainage with CPL, waiting for definitive CSF shunt, if indicated	Uncertain
External ventricular drainage with CPL waiting for definitive CSF shunt, if indicated	Uncertain
External lumbar drainage waiting for CPL and for definitive CSF shunt, if indicated	Uncertain
External ventricular drainage waiting for CPL and for definitive CSF shunt, if indicated	Inappropriate
SESSION 3: Rate the appropriateness of the definitive CSF shunt when indicated for:	
VENTRICULOPERITONEAL SHUNT as the definitive CSF shunt	Appropriate
LUMBOPERITONEAL SHUNT as the definitive CSF shunt	Inappropriate
ADJUSTABLE PRESSURE VALVE as the definitive CSF shunt	Appropriate
FIXED PRESSURE VALVE as the definitive CSF shunt	Inappropriate
CSF-FLOW CONTROL VALVE as the definitive CSF shunt	Uncertain

4. Discussion

4.1. *Delphi process*

There is a distinction between guidelines and consensus statements. For most neurosurgical issues about management, even for PTH and CPL, the evidence is weak for guidelines, and the expert opinions vary. The challenges of such an endeavor are very well known (Bellander et al., 2004; Chesnut et al., 2020; Hawryluk et al., 2019; Hutchinson et al., 2019; Picetti et al., 2019; Stocchetti et al., 2014; Wiegele et al., 2019). Despite consensus statements being more subjective as they reflect the attitudes of individual participants and the group dynamics challenges, the development of common clinical recommendations seems to be an appropriate method in striving for consistency. The lack of a complete analysis of cost, implementation of local adaptation challenges, and monitoring method is a limit of a Consensus Conference (Fitch et al., 2001).

Guideline developers are strongly urged to use GRADE (Grading of Recommendations Assessment, Development, and Evaluation; www.gradeworkinggroup.org) to evaluate the quality of evidence and propose recommendations with different strengths (Andrews et al., 2013). Application of the GRADE system requires training; there is confusion regarding how "imprecision" results should be presented and interpreted and how to integrate more than one intervention. Moreover, the inflexibility of the GRADE approach with regard to the hierarchy of evidence is the main limitation. Anything but a randomized trial is considered "not-high-quality" evidence. However, randomized trials are not feasible in certain complex situations, given the often complex practical and/or ethical considerations, such as in TBI and/or related occurrences, such as PTH (Langhoff-Roos and Shah, 2016). Therefore, in this setting, the discrepancy between the evidence and the strength of the recommendation could be the subject of serious considerations with highly heterogeneous problems. It is confusing to try to indicate the quality of the evidence as "low" but make a "strong" recommendation. Therefore, in clinical practice, it may be possible to misinterpret this approach as legitimizing interventions without evidence; however, this is not the intended purpose (Movsisyan et al., 2016a, 2016b). In this context, the scientific community has arrived at its current position to treat the recommendations as a "consensus" of a panel of experts and recognize that future evidence is likely to influence the strength of the evidence.

Despite the focused discussion, the rate of uncertain statements reached 41 % (12/29), indicating that the ideal approach to define and treat PTH and CPL remains unclear for the EP. These results can be compared to the last international consensus conference on the same topic (Iaccarino et al., 2021) held in 2018 in Naples, where the international worldwide assembly concluded that there is inadequate evidence for determining the best imaging method and optimal management.

Therefore, in the absence of definitive evidence to support a specific algorithm for performing a definitive CSF shunt before, during, or after CPL, surgeons may rely on their personal expertise and patient requirements to guide their choice of strategy (Peraio et al., 2017; Rosinski et al., 2020).

4.2. Diagnostic algorithm

Although the best imaging technique or neurodiagnostic score remains uncertain, neuroradiology is considered an appropriate first diagnostic approach. The degree of ventricular enlargement is inconsistent with the altered CSF dynamics (Table 1) (Lalou et al., 2020). Wang et al. (2020) proposed a three-scale scoring model to correlate clinical features and long-term prognosis, but unfortunately not effective in predicting PTH in decompressed patients scheduled for a CPL (Table 1).

The EP emphasized the dynamic nature of PTH, which renders it difficult to define with a static morphologic tool, and suggested that a clinical trend, as indicated by serial GCS or MMSE/MOCA evaluations, should be considered alongside neuroimaging findings to support the diagnosis. EP recommended modifying the statement from "GCS" to "GCS trend" and from "MMS/MOCA" to "Change in cognition MMS/MOCA" to emphasize the significance of neuro-worsening.

When ventricular enlargement is detected, several authors advocate for a progressive observation approach, considering both radiological and clinical findings to confirm the diagnosis of PTH (Tables 1 and 2) (Rufus et al., 2021; Sun et al., 2019; Svedung Wettervik et al., 2022; Ting et al., 2020). Symptoms such as new-onset neurological deficits, raised intracranial pressure, scalp fullness, and a lack of neurological progress over time can help define PTH when correlated with radiological evidence.

Evan's ratio of >0.3 is commonly used as an initial step to define ventriculomegaly and diagnose PTH (Tables 1 and 2) (Wang et al., 2020; Rufus et al., 2021; Svedung Wettervik et al., 2022; Ozoner et al., 2020; Soldozy et al., 2022; Zhuo et al., 2022). However, the degree of appropriateness or inappropriateness of this ratio and brain bulging in predicting PTH in decompressed patients was uncertain and needed to be revoted in the second round without reaching the threshold for appropriateness as a single neurodiagnostic tool.

This uncertainty likely explains the ambiguous ratings of EP for neuroradiological tools, such as "CT perfusion," "SPECT brain perfusion," "Phase contrast MRI," and the inappropriate rating for DTI in predicting PTH in DC patients.

Considering the significant effects of DC on pressure-volume compensation, the EP rated the appropriateness of infusion tests and ELD as shunt-responsiveness tools as uncertain. Due to these effects, decompressed patients should be excluded from this evaluation (Lalou et al., 2020). Surprisingly, this Consensus Conference rated the Tap Test as an appropriate shunt-responsiveness tool. While measurements of opening pressure via lumbar puncture and spinal tap tests are often used to detect PTH (Table 1) (Lalou et al., 2020), they are not diagnostically accurate due to abnormal resistance to CSF outflow (ROut). Nonetheless, short-term manometric assessment via lumbar puncture is still suggested (Lalou et al., 2020).

Considering the limited clinical improvement and the risk of shunt complications in patients with poor neurological conditions, additional diagnostic assessments involving cerebrospinal fluid pressure dynamics may be necessary to improve patient selection for shunt treatment.

Nevertheless, evaluating CSF resistance outflow alone cannot guide the decision about definitive shunt placement, and infusion tests are more reliable after cranioplasty (Svedung Wettervik et al., 2022). Consequently, when the surgical strategy represents the final step in the diagnostic process, the surgical resolution of PTH and CPL as a single-stage strategy was less preferred.

In this setting, the staged surgery could represent a more appropriate strategy to differentiate a post-traumatic ventriculomegaly with no need for a definitive shunt from an altered CSF dynamic, which can benefit from a restored CSF circulation following CPL or indicate a definitive CSF shunt, following a period of observation.

4.3. Surgical algorithm

A relevant result of this European Consensus Conference has been the clearer perspective of EP to prefer performing CPL before a definitive CSF shunt, as expressed in the previous worldwide consensus. In the last five years, a few authors have proposed a one-stage strategy of CPL and VPS as the first choice (Table 2). Rosinski et al. (2020) found a trend toward a lower incidence of reoperation rate and a significantly lower incidence of hospital-acquired infection with concurrent CPL and VPS. Nevertheless, no relevant consideration has been reported about diagnostic proof of ongoing PTH (Table 2). Yan et al. (2022) reported the ventricular/biparietal (V/Bp) ratio >0.26 as an assessment of the degree of hydrocephalus and to drive surgery. The authors reported the one-staged operation conducive to early recovery, especially with ipsilateral VPS (Table 2) (Yan et al., 2022).

Few authors focused on the best strategy when a defined PTH is not proven. Ozoner et al. (2020) suggested timing ≤2 months after DC to reduce the risk of PTH (Table 2). Conversely, Tora et al. (2021) reported the inferiority of early CPL (≤3 months after DC) in reducing complications and hydrocephalus rate (Table 2). In the literature, there is still inconsistency in supporting the ideal timing of CPL, even regarding the relationship with PTH.

In the surgical algorithm, the EP expressed a firm inappropriateness regarding the treatment of PTH before or in one-staged surgery with CPL; even the appropriateness of a temporary external CSF shunt placement with CPL has been rated uncertain. Only the two-staged surgical strategy, first with CPL, then definitive CSF shunt if indicated, has been voted as appropriate, most probably due to the consideration of the lack of evidence about the best neuroradiological tool and the not reliability of the infusion tests before CPL. Maybe the risk of overtreatment of ventriculomegaly rather than PTH could have driven the EP opinion.

Ting et al. (2020) reported staged surgery in 22 patients with CPL following VPS and ten patients with VPS following CPL, but a distinguished subanalysis among these two groups has not been reported.

Regarding staged surgery, Gill et al. (2021) reported better results for CPL after VPS compared to VPS after CPL in terms of revision surgery, and one-staged surgery showed higher complication rates than staged surgery (Table 2). Conversely, Zhang et al. (2022) reported the initial VPS placement was associated with a significantly higher risk of overall complications, while for the one-staged surgery, a significantly higher rate of infections was observed. The same observation has been analyzed by Zheng et al. (2019), with pre-CPL VPS positioning associated with a greater overall complication rate and a higher risk of developing a sunken skin flap and postoperative extradural collection (Table 2).

Thus, when indicated, a specific strategy for cranial reconstruction and hydrocephalus treatment is still debated. No specific study has focused on the most appropriate management for the temporary external CSF drainage. Dang et al. (2021) described using perioperative lumbar or cisternal puncture in case of brain bulging.

The EP rated the use of programmable valves as inappropriate for the fixed valve, reflecting the literature data available (Ting et al., 2020; Gill et al., 2021; Zhang et al., 2022; Castellani et al., 2021). This indication is reasonably related to the possibility of hypershunting due to a modification of CSF dynamics that can occur during the postoperative follow-up or due to the presence of an overtreated ventriculomegaly. Thus, the pressure valve setting will be adapted to the patient's requirement up to a complete stop of CSF outflow, if necessary.

Traditional valve has been reported as an additional option in fewer reports (Zhang et al., 2022; Castellani et al., 2021) (Table 2). A recent systematic review and meta-analysis conducted by Ahmed et al. (2023) revealed that the summary of the proportions of the incidence rate of complications was less for Adjustable Differential Pressure Valves (ADPV) as compared to Fixed Differential Pressure Valves (FDVP), but the confidence intervals overlapped. The incidence of complications was low in the population implanted with DPV along with gravitational or anti-siphon unit (GASU) (Ahmed et al., 2023). Nevertheless, in 2020, Garegnani et al. (2020), in the Cochrane Database of Systematic Reviews, performed a Synthesis Without Meta-analysis (SWiM) incorporating GRADE for the quality of the evidence due to the scarcity of data. The authors concluded that standard shunt valves for idiopathic hydrocephalus compared to anti-siphon or self-adjusting CSF flow-regulating valves might cause little to no difference on the main outcomes of this review; however, uncertainty remains due to the low evidence available (Garegnani et al., 2020).

The use of the anti-siphon unit is still under debate for treating idiopathic normal pressure hydrocephalus. Poca et al. (2021) reported how the correct function of any gravitational device depends on adequate device implantation along the vertical body axis. Misalignment from the vertical axis equal to or more than 45 might eliminate the beneficial effect of these devices (Poca et al., 2021). Still, a matter of debate is the opportunity to include continuous intracranial pressure monitoring as a diagnostic tool, as Reilly (2001) reported in normal pressure hydrocephalus. Thus, during the second round, following the discussion, the EP agreed to rate the appropriateness of these devices but without the scope to express any recommendation because specific considerations in the PTH setting have not been clearly reported.

The main take-home messages from the discussion are summarized in Supplementary Data 2.

5. Conclusion

The reader of this paper should consider that the recommendations in this document represent a 'consensus' of the EP around the table. It is important to note that further evidence will likely influence our suggestions' strength.

The most appropriate approach to defining and treating PTH and CPL remains unclear, and the best imaging technique or neurodiagnostic score is still uncertain.

PTH is a dynamic condition, and neuroradiological findings must be correlated with ongoing clinical assessments. Evan's ratio >0.3 is the most commonly reported index for hydrocephalus. However, in decompressed patients, it has been challenging to measure accurately, leading the EP to label its appropriateness as "uncertain."

New-onset neurological deficits, elevated intracranial pressure, scalp fullness, and a lack of neurological improvement over time are all suggestive of PTH diagnosis. The EP emphasized the importance of observing a trend of neuro-worsening rather than relying on a single observation.

In cases with a high risk of definitive shunt failure or low certainty of PTH, especially in patients with poor health, dynamic CSF studies to confirm suspected PTH should be extended after CPL. Prior to CPL, evaluating CSF outflow resistance alone cannot determine the decision about a definitive shunt. Infusion tests are more reliable after CPL.

Staged surgery may offer a more suitable approach, allowing ample time to distinguish between post-traumatic ventriculomegaly not requiring a permanent shunt and altered CSF dynamics that could benefit from improved CSF circulation after cranioplasty. It also provides the opportunity for a definitive CSF shunt decision following a period of observation.

The adjustable/programmable valve in VPS is considered the most suitable choice for a definitive shunt, primarily because of the potential variability in CSF dynamics and the uncertainty of treating ventriculomegaly rather than PTH in some cases.

Relying on documents such as this expert consensus, the strong recommendation is to implement local protocols for managing these patients. Given the absence of conclusive evidence and the uncertainty surrounding many diagnostic and surgical choices, establishing a systematic local protocol becomes invaluable. Such a protocol facilitates data collection and positively influences patient outcomes, as widely reported in the literature.

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Authors' contributions

Study conception and design: FS, CI, HM; collection and interpretation of data: FS, CI, SC, TS, IT, HM; statistical analysis: FS, CI; manuscript drafting: FS, CI; manuscript editing: FS, CI, SC, TS, IT, HM; approval to submit: FS, CI, SC, TS, IT, HM.

Declaration of competing interest

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Appendix A. Supplementary data

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