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# Role of brain tissue oxygenation ($PbtO_2$) in the management of subarachnoid haemorrhage: a scoping review protocol

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## ABSTRACT

**Introduction** In patients with subarachnoid haemorrhage (SAH), the initial brain oedema and increased blood volume can cause an increase in intracranial pressure (ICP) leading to impaired cerebral perfusion and tissue hypoxia. However, ICP monitoring may not be enough to detect tissue hypoxia, which can also occur in the absence of elevated ICP. Moreover, some patients will experience tissue hypoxia in a later phase after admission due to the occurrence of delayed cerebral ischaemia. Therefore, the measurement of brain oxygenation using invasive techniques has become of great interest. This scoping review seeks to examine the role of brain tissue oxygenation in the management of patients with SAH, mapping the existing literature to identify areas for future research.

**Methods and analysis** This scoping review has been planned following the Joanna Briggs Institute recommendations and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. The literature search will be performed using several databases: Medline, EMBASE, the Cochrane Central Register of Controlled Trials and Grey literature. The database searches are planned from the inception to May 2020. Two reviewers will independently screen titles and abstracts, followed by full-text screening of potentially relevant articles with a standardised data extraction. Articles eligible for the inclusion will be discussed with a third reviewer.

**Ethics and dissemination** This paper does not require ethics approval. The results of our evaluation will be disseminated on author's web sites. Additional dissemination will occur through presentations at conferences, such as courses and science education conferences, regionally and nationally, and through articles published in peer-reviewed journals.

**Scoping review registration** Open Science Framework Registration: https://doi.org/10.17605/OSF.IO/ZYJ7R. Trial registration number ClinicalTrials.gov Identifier: NCT03754114.

## Strengths and limitations of this study

- This scoping review will map 'the state of the art' on brain tissue oxygenation ($PbtO_2$) in the management of subarachnoid haemorrhage and will identify knowledge gaps.
- The findings from this scoping review could guide the development of more specific, clinical questions highlighting potential opportunities for future research.
- The review will be restricted to articles having an English title/abstract, which may potentially prevent some $PbtO_2$ studies from being detected.
- No quality appraisal of included studies will be completed, precluding conclusions about the effectiveness of different $PbtO_2$ use.

## BACKGROUND

Subarachnoid haemorrhage (SAH) is a devastating acute neurological disease that affects many people worldwide.[1] An estimated 25% of patients with SAH admitted to the hospital will eventually die, while half of the survivors will experience long-term neurological disabilities.[2] The most important cause of non-traumatic SAH is aneurysm rupture, representing 5% of all strokes[3] and 85% of all non-traumatic SAH.[3] The incidence of aneurysmatic SAH (aSAH) varies significantly depending on region, gender, age, time period, smoking habits and blood pressure levels.[4] A recent meta-analysis has shown a decrease of 40% in the incidence of aSAH since 1980, estimating to be around 6% in 2010.[5 6]

Immediately after blood is spilled in the subarachnoid space, there is an elevation in intracranial pressure (ICP), a decrease in cerebral perfusion and possibly ischaemia.[7] This causes neuronal death and endothelial damage, resulting in cytotoxic oedema.[8] Furthermore, there is brain blood barrier rupture, which aggravates the development of vasogenic oedema.[9] This process is responsible for further ICP increase. Moreover, the activated inflammatory response[10] increases brain injury and contributes to microcirculatory failure and microthrombi formation, which further deteriorates ischaemia.[11] These events are responsible for the so-called 'early

brain injury' after SAH. Without a specific and prompt intervention, these phenomena will lead to irreversible brain damage and neuronal death. However, monitoring of ICP/cerebral perfusion pressure may not be enough to prevent cerebral complications. Although therapies aimed at reducing elevated ICP may decrease the risk of early death, the effectiveness of ICP monitoring and ICP-driven therapies have not significantly increased the probability of good neurological recovery in this setting.[12 13] Additionally, tissue hypoxia can occur in the absence of elevated ICP and can significantly impact patients' outcome.[14 15] Therefore, measurement of brain tissue oxygenation ($PbtO_2$) has become of great interest in the early phase of aSAH.

After the initial phase of SAH pathogenesis, patients become susceptible to secondary brain injury, such as hydrocephalus, cerebral vasospasm and delayed cerebral ischaemia (DCI). DCI occurs in 30%[16] of patients with aSAH and is the most important preventable cause of death and poor neurologic recovery in this setting.[17–19] DCI has a complex pathogenesis that includes vasospasm of large vessels leading to low perfusion as well as neuro-inflammatory injury leading to microthrombi formation and microcirculatory failure. Moreover, electric phenomena such as cortical spread depolarisation[20] seem to play a role in the pathogenesis of DCI. Early recognition of DCI is essential for timely intervention to minimise brain damage. This can be challenging, especially in patients with poor clinical status because of the difficulty to perform clinical examination and detect neuro-worsening. In this setting, multimodal neuromonitoring can help identify patients suffering from DCI and optimise treatment.[21] Indeed, $PbtO_2$ can be relevant in detecting episodes of brain tissue hypoxia.[22 23]

In other acute brain injury disorders, such as traumatic brain injury (TBI), $PbO_2$/ICP combined therapies seem to improve long-term outcomes when compared with ICP-guided therapy.[24–27] A phase 2 randomised controlled trial suggests that $PbtO_2$ monitoring reduces the duration of brain hypoxia.[25] A phase 3 trial with a similar design is actually recruiting patients to demonstrate an effect of such approach on the neurological outcome of patients with TBI. The ongoing trials on the use of transcranial oxygen saturation measurement in TBI and SAH are summarised in table 1.

Our scoping review will assess most of the existing literature on this topic (ie, $PbtO_2$ and SAH); this scoping review will ask the following question based on the PCC (population, concept and context) elements of the

**Table 1** Ongoing trials on the use of transcranial oxygen saturation measurement in severe brain injury, TBI and SAH

| Study title | ClinicalTrials.gov identifier | Status | Condition(s) | Intervention(s) |
|---|---|---|---|---|
| Cerebral autoregulation in patients with aneurysmal subarachnoid haemorrhage | NCT03987139 | Recruiting | aSAH | O: Hypertension<br>O: Hyper- and hypoxia<br>O: Hyper- and hypocapnia |
| Study of $PtiO_2$ variation by body temperature and capnia in severe head trauma patients with intracranial refractory hypertension treated with targeted temperature control (TODAY) | NCT04109430 | Recruiting | Severe brain injury | NS |
| Brain oxygen optimisation in severe TBI (BOOST3): a comparative effectiveness study to test the efficacy of a prescribed treatment protocol based on monitoring the partial pressure of brain tissue oxygen | NCT03754114 | Recruiting | TBI | O: ICP +$PbtO_2$ guided management strategy<br>O: ICP guided management strategy |
| Impact of early optimisation of brain oxygenation on neurological outcome after severe traumatic brain injury | NCT02754063 | Recruiting | TBI | D: $PbtO_2$ probes<br>O: No $PbtO_2$ probes |
| NSI pulsed electromagnetic field (PEMF) biomarker study | NCT03654014 | Recruiting | TBI | D: SofPulse |
| Lactate therapy after traumatic brain injury | NCT01573507 | Recruiting | SAH<br>TBI | O: sodium lactate infusion |
| Non-invasive near-infrared spectroscopy (NIRS) vs invasive licox intracranial pressure | NCT04247321 | Not yet recruiting | Brain injuries | D: Licox brain tissue oxygen monitoring system<br>D: NIRS |

Search strings: "PbtO2" OR "Brain Tissue Oxygenation". Recruitment status limited to a.Not yet recruiting b.Recruiting c.Enrolling by invitation d.Active, not recruiting. Eligibility criteria: adult (18–64) and older adult (65+) (accessed on February 19, 2020).
aSAH, aneurysmatic subarachnoid haemorrhage; D, device; NIRS, near-infrared spectroscopy; NS, not specified; O, other; TBI, traumatic brain injury.

inclusion: 'What is the role of $PbtO_2$ in SAH management of adult patients?'.[28]

We will explore the existing and emerging evidence in the literature, with different levels of quality, from several databases. We will summarise the main results and discuss the limitations of the studies retrieved in order to map 'the state of the art' on the subject and identify knowledge gaps. These findings could be helpful to understand the actual knowledge for brain oxygen monitoring in patients with SAH and to guide the development of future, more specific, therapeutic protocols integrating this monitoring tool into dedicated algorithms. Since a scoping review aims to identify the nature of a broad field of evidence, this approach may help our research group to develop more specific questions to which a subsequent systematic review and meta-analysis will try to answer.[29]

## METHODS

### Protocol design

The scoping review has been planned according to the five stages framework proposed by Arksey and O'Malley[30] and Guidance of Peters *et al*,[31] which has been further developed by Levac *et al*[32] and the Joanna Briggs Institute[28]: (1) identifying the review question, (2) identifying relevant studies, (3) study selection, (4) charting the data and (5) collating, summarising and reporting the results. Furthermore, it will be conducted in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[33] The protocol was registered prospectively with the Open Science Framework on 4 November 2019.[34]

### Patient and public involvement

Patients and public were not involved in the preparation of this protocol.

### Stage 1: identifying the research question

The aim of this review is to map the available literature on $PbtO_2$ regarding the management of patients with SAH. To achieve this objective, the following research questions will be addressed:

1. Which patient with SAH benefit the most from $PbtO_2$ monitoring (ie, clinical and imaging severity, ICP levels)?
2. What is the rationale behind this technique (eg, $PbtO_2$ physiology, etc)?
3. Where is this technique performed (eg, mixed intensive care unit, neurological intensive care unit, etc)?
4. When is the technique implemented and when should it be stopped (eg, at hospital admission, at worsening of neurological conditions, etc)?
5. Why is the technique performed (diagnostic, predictive, prognostic)? Which are the major indications? Can $PbtO_2$ monitoring help detect brain injury (both early brain injury and DCI)? Can $PbtO_2$ monitoring help prevent brain injury? Can $PbtO_2$ monitoring guide therapy and improve mortality or neurologic outcome?
6. How is $PbtO_2$ monitoring performed (device insertion, device site, calibration, etc)?
7. How to apply this technique in the clinical practice? Is there a specific therapeutic protocol driven by $PbtO_2$? How to quantify the burden of hypoxia and what thresholds for brain hypoxia were applied in different studies?

### Stage 2: identifying relevant studies

#### Eligibility criteria

This scoping review will consider all the studies focusing on $PbtO_2$ in the management of adult patients with SAH (≥18 years old).

In order to maximise the gathering of data, we will include both full peer-reviewed articles and grey literature (conference publications, abstracts, dissertations, etc). There will be no limitations regarding the year of publication. We will include all publications that have English title/abstract. There will be no language limitation

### Search strategy

We plan to follow a three-step search strategy to find and analyse fully published studies. First, we will conduct a limited search on Medline and CINAHL. This preliminary search will be followed by the analysis of the text words contained in the title and abstract and of the index terms used to describe articles. This information will allow us to develop a complete search strategy and tailored to each information source. A proposed search strategy for Medline is detailed in table 2. A subsequent search using keywords and index terms will then be started using the following databases: Medline, EMBASE and the Cochrane Central Register of Controlled Trials.

Regarding the analysis of grey literature, we will consult the following sources: Google Scholar, Conference Proceedings Citation Index via Web of Science, Dissertation Abstracts via ProQuest, Networked Digital Library of Theses and Dissertations, Open DOAR and Open Grey. Finally, we will use the reference list of all identified reports and articles to identify additional eligible studies.

### Stage 3: study selection

The screening will be performed in two phases, namely 'initial screening' based on title and abstract, followed by a 'full-text screening" of the eligible articles for final inclusion. Duplicates will be excluded. Two authors (EB and MF) will independently evaluate the titles and abstracts of potentially eligible studies. The authors of the screened studies will be contacted in the case of missing data.

### Stage 4: data charting

We will identify and retrieve the following data:

1. Study population description: age, gender, comorbidities, Glasgow Coma Scale[35] at admission, Fisher scale or modified Fisher scale,[36] Hunt-Hess scale,[37] world federation of neurological surgeons scale,[38] aetiology

Table 2 Scoping review search strategy. Ovid medline search strategy (24 May 2020)

| Searches | | Results |
|---|---|---|
| 1. | (pbtO2 or licox or NeuroTrend).mp. | 279 |
| 2. | Oxygen/ | 163 532 |
| 3. | (oxygen or oxygenation or O2).mp. | 697 827 |
| 4. | 2 or 3 | 697 827 |
| 5. | exp Monitoring, Physiologic/ | 173 039 |
| 6. | monitor*.mp. | 957 907 |
| 7. | 5 or 6 | 991 601 |
| 8. | exp brain/ or exp meninges/ | 1 217 704 |
| 9. | (cerebral or cerebrovascular or brain or meninge* or arachnoid* or subarachnoid*).mp. | 1 744 487 |
| 10. | Cerebrovascular Circulation/ | 54 723 |
| 11. | 8 or 9 or 10 | 2 106 957 |
| 12. | Hemorrhage/ or aneurysm/ or aneurysm, ruptured/ or exp hypoxia/ | 166 271 |
| 13. | exp Subarachnoid Hemorrhage/ | 21 143 |
| 14. | 4 and 7 and 11 | 7128 |
| 15. | 1 or 14 | 7239 |
| 16. | 11 and 12 | 22 575 |
| 17. | 13 or 16 | 40 694 |
| 18. | 15 and 17 | 653 |

The search strategies for the other databases will be similar in structure with similar search terms and synonyms.

of SAH (aneurysmal, arteriovenous malformation, sine materia, etc).

2. Intervention: indication for $PbtO_2$ catheter insertion; timing of testing of the catheter's function; which devices were included in multimodal monitoring strategy (ICP monitoring, continuous EEG monitoring, microdialysis); comparison between $PbtO_2$ and other techniques in the detection of brain hypoxia (ICP, near-infrared spectroscopy; jugular bulbous venous saturation); thresholds commonly used in the clinical practice to define brain hypoxia; when to start treatment based on $PbtO_2$ values. What targets of $PbtO_2$ should be sought to guide intervention.
3. Complications: bleeding due to catheter insertion, ischemia due to catheter insertion, malfunctional or incorrectly inserted catheter, infections.
4. Outcomes: burden of hypoxia (how low was $PbtO_2$ and for how long), neurologic outcome, mortality (intensive care mortality, hospital mortalit, 30-day mortality)

Data will be extracted independently using the Joanna Briggs Institute (JBI) Data Extraction Form for Experimental/Observational Studies and the results will be cross checked. Any disagreements on study eligibility or data extraction will be resolved according to a third reviewer's opinion.

Studies considered as potentially relevant will be analysed in full, and their reference list will be imported into the Joanna Briggs Institute's System for the Unified Management, Assessment and Review of Information.[32] The selected citations' full text will be assessed in detail against the inclusion criteria by two independent reviewers. Reasons for exclusion of full-text studies not meeting the inclusion criteria will be recorded and reported in this scope review. Any conflict arising between the reviewers at any stage of the study selection process will be resolved through debate or by a discussion with a third reviewer. The results of each step of the planned search will be reported in detail in the closing report and presented in a PRISMA-Extension for Scoping Reviews (PRISMA-ScR) flow diagram.[33] The references of the included studies will be screened and hand-searching of journals will be performed. Citations of eligible studies retrieved in full will be imported into JBI System for the Unified Management, Assessment and Review of Information (SUMARI).[32]

### Stage 5: collating, summarising and reporting the results

The JBI template study details, characteristics and results extraction instrument will be used to record the critical information of the source, such as: author(s), year of publication, origin/country of origin (where the study was published or conducted), aims/purpose, study population and sample size, methodology/methods, intervention type, details of the intervention, duration of the intervention, outcomes and details of the outcomes and other key findings related to the scoping review question. The reviewers will keep careful records to identify each study. Each reviewer will chart each study for a more comprehensive analysis of the collected data.

No evaluation of the quality of the studies will be made because the purpose of a scoping review is not to use the findings to make recommendations for policy/practice.[39] We will acknowledge this as a limitation in the discussion of the full manuscript.

## DISCUSSION

To our knowledge, this is the first attempt to map all existing literature on the topic. $PbtO_2$ monitoring is an invasive technique that is not easily available worldwide. In order to use $PbtO_2$ correctly, it is mandatory to know why, when and how to implement it in patients with SAH. Furthermore, it is essential to understand how to use the information available to detect neuro-worsening and to potentially guide therapy. This review will aim to clarify these topics and hopefully guide potential randomised clinical trials on the use of $PbtO_2$-guided therapy in patients with SAH.

### Ethics and dissemination

This paper does not require ethics approval as data will be obtained through review of primary studies already

published. This project will serve as a pilot for other reviews from our research group. The results of our evaluation will be disseminated on the author's web sites. Additional dissemination will occur through presentations at conferences and through articles published in peer-reviewed journals. Finally, the investigators will use their networks to encourage broad dissemination of results.

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**Competing interests** None declared.

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