Critical Care

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Individualized mean arterial pressure targets in critically ill patients guided by non-invasive cerebral-autoregulation: a scoping review

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Abstract

Background Current guidelines recommend a uniform mean arterial pressure (MAP) target for resuscitating critically ill patients; for example, 65 mmHg for patients with sepsis and post-cardiac arrest. However, since cerebral autoregulation capacity likely varies widely in patients, uniform target may be insufficient in maintaining cerebral perfusion. Personalized MAP targets, based on a non-invasive determination of cerebral autoregulation, may optimize perfusion and reduce complications.

Objectives This scoping review summarizes the numerical values, feasibility, and clinical data on personalized MAP targets in critically ill patients. The focus is on non-invasive monitoring, such as near-infrared spectroscopy and transcranial doppler ultrasound, due to their safety, practicality and applicability to patients with- and without brain injury.

Methods Following PRISMA-ScR guidelines, a systematic search of Ovid MedLine, Embase (Ovid), and the Cochrane Library (Wiley) was conducted on September 28, 2023. Two independent reviewers screened titles, abstracts, and full texts for eligibility and manually reviewed references.

Results Of 7,738 studies were identified, 49 met the inclusion criteria. Of these, 45 (92%) were observational and 4 (8%) were interventional. Patient populations included cardiac surgery (26, 53%), non-cardiac major surgery (4, 8%), cardiac arrest (8, 16%), brain injury (7, 14%), respiratory failure and shock (3, 6%), and sepsis (3, 6%). Optimal MAP was reported in 24 (49%), lower limit of autoregulation in 23 (47%), and upper limit of autoregulation in 10 studies (20%). Thirty-four studies reported partial data loss due to software failures, anomalous data, insufficient natural MAP fluctuation, and workflow barriers. Available randomized controlled trials (RCT) identified challenges with maintaining patients within their target range. Studies explored the associations between personalized MAP targets and a wide range of neurological and non-neurological outcomes, with the most significant and consistent associations identified for acute kidney injury and major morbidity and mortality. Ten studies investigated demographic predictors identifying only few predictors of personalized targets.

Conclusion Preliminary investigations suggest considerable variability in personalized MAP targets, which may explain differences in clinical outcomes among critically ill populations. Key gaps remain, including a lack of observational studies in critically ill subpopulations other than cardiac surgery and well-designed RCTs. Resolving identified feasibility barriers might be crucial to successfully carrying out future studies.

Keywords Precision medicine, Near-infrared spectroscopy, Transcranial Doppler ultrasonography, Autoregulation, Cerebral vascular circulation, Arterial pressure, Big data

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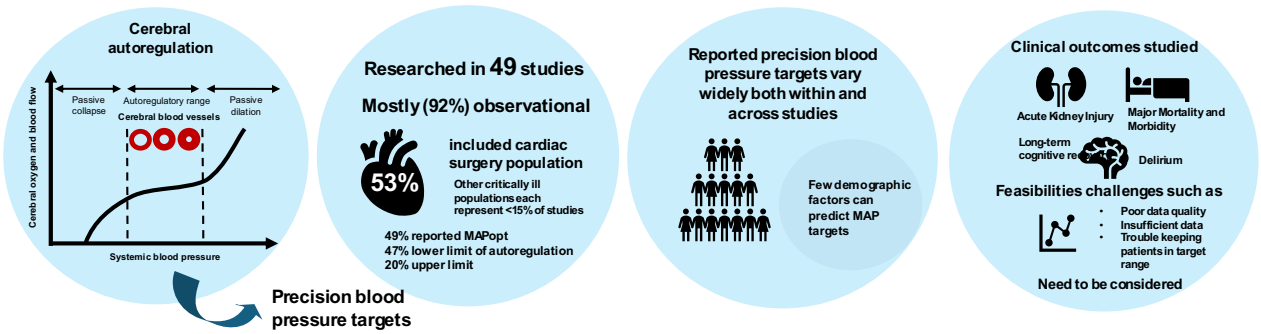
Graphical Abstract



Background

Cerebral autoregulation refers to the brain's intrinsic ability to maintain stable cerebral blood flow despite fluctuations in systemic blood pressure [1]. This is a vital homeostatic mechanism that protects the brain from ischemia at low pressures and hyperemia at high pressures [1]. However, autoregulation may be impaired in critically ill adults, particularly those with traumatic brain injury (TBI), stroke, subarachnoid hemorrhage (SAH), or sepsis [2–4]. This dysfunction renders cerebral perfusion pressure-passive, meaning fluctuations in MAP can directly compromise cerebral blood flow and oxygen delivery, exacerbating neurologic injury and increasing mortality risk [5–7].

Current clinical guidelines have relied on fixed MAP or cerebral perfusion pressure (CPP = MAP—ICP [intracranial pressure]) thresholds to prevent hypoperfusion. For example, a MAP greater than 65 mmHg is suggested for patients with sepsis [8], post-cardiac arrest [9], and in the perioperative period [10, 11]. However, these thresholds were determined predominantly using population-based studies and might not account for the increasingly recognised, considerable inter-individual variability in cerebral autoregulation capacity in critically ill populations [12, 13].

Cerebral autoregulation can be conceptualized as comprising static and dynamic components, existing in a continuum of the pace of cerebrovascular change to systemic blood pressure fluctuations [14–18]. Static autoregulation reflects the brain's ability to maintain cerebral blood flow across steady-state changes in MAP over minutes to hours. In contrast, dynamic autoregulation refers to the brain's rapid vascular responses to transient or spontaneous changes in MAP occurring within seconds. Dynamic autoregulation is especially relevant in critical care, where patients are hemodynamically unstable (have large and rapid changes in cardiovascular status) and are closely monitored. Both static and dynamic assessments could inform actionable MAP or CPP targets in the clinical setting. To assess dynamic autoregulation, a variety of analytical methods can be employed, including frequency-domain spectral analyses (e.g., transfer-function analysis applied to both induced and spontaneous BP oscillations), time-domain techniques (e.g., correlation-based methods and the autoregulation index), and non-linear approaches [17, 19–21]. Correlation-based methods are among the least computationally intensive and thus most readily translatable to real-time bedside monitoring. When implemented at the bedside, autoregulation-guided perfusion monitoring offers a physiologically grounded strategy to tailor blood-pressure management to each patient's needs.

Invasive multimodal neuromonitoring, particularly the use of ICP monitoring to calculate the slow-wave correlations that result in pressure reactivity index (PRx), has allowed clinicians to estimate a patient-specific "optimal CPP" or "optimal MAP" (CPPopt or MAPopt), defined as the pressure at which autoregulatory capacity is maximal. In addition, the upper and lower limits of autoregulation (ULA and LLA) can be derived, representing the boundaries beyond which autoregulation becomes impaired. Observational studies have suggested that maintaining perfusion near these individualized targets is associated with improved neurologic outcomes, particularly in TBI [22]. However, the risks and expertise required for ICP monitoring limits its utility to select populations, leaving

a gap in individualized perfusion strategies for broader critically ill cohorts [23].

To address this, non-invasive techniques, such as near-infrared spectroscopy (NIRS) and transcranial doppler ultrasound (TCD), have been explored as alternatives to assess cerebral autoregulation and guide personalized MAP titration [24]. NIRS monitoring uses forehead sensors that emits and detects light absorption at a particular depth to measure regional cerebral oxygen saturation (rSO_2) in the cortex. NIRS provides a continuous estimate of cerebral oxygen balance (delivery vs. utilization) in the sampled region, which is influenced by cerebral blood flow. TCD provides a non-invasive window into cerebral blood flow by measuring blood velocity in the cerebral arteries (usually the middle cerebral artery). These methods, when correlated with MAP generate surrogate indices of dynamic autoregulation (e.g., cerebral oximetry index [COx], mean blood velocity index [Mx]) that can enable the estimation of individualized blood pressure targets without the risks of invasive monitoring. Early studies suggest these modalities may be feasible and clinically informative across a range of intensive care unit (ICU) populations, including cardiac surgery, cardiac arrest and sepsis [24].

While there is growing interest in using non-invasive autoregulation monitoring to personalize blood pressure targets in critical care, no comprehensive synthesis currently exists to examine what methods have been applied, what MAPopt values they yield, how feasible they are to use in practice, and what clinical outcomes or predictors have been associated with their use. Understanding these dimensions is essential to bridge the gap between emerging research and clinical translation and to guide future studies on precision hemodynamic management.

Methods

This review was reported in accordance with Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) [25] and preregistered January 2nd 2024 on PROSPERO (ID:CRD42024500484).

Literature search

The literature search strategy was designed in collaboration with a clinical research librarian who has expertise in literature review. On September 28, 2023, a comprehensive journal/white-paper literature search was conducted across Ovid MedLine, Embase (Ovid platform), Cochrane Library CENTRAL (Wiley platform) using a combination of subject headings and key words (see Additional file 1). Relevant articles from the search and those discovered throughout the review process (e.g., by exploring bibliographies from selected articles) were reviewed.

Eligibility

We included studies that (1) are interventional or observational design, or case series, (2) written in English, (3) include adult patients with surgical or medical diagnoses that warrant ICU admissions (4) indicate that they have calculated MAPopt or ABPopt (optimal arterial blood pressure) or limits/thresholds of autoregulation based on non-invasive neuromonitoring. Studies were excluded if (1) they were conference abstracts, case reports, reviews, or editorial/commentaries, (2) animal or paediatric studies, (3) studies in healthy volunteers. Reviews were tagged at the screening stage and read to search for additional references.

Selection of sources of interest

Abstract and full-text screening were carried out in pairs among all authors (JX, AC, AA, and JGB). Disagreements were solved by consensus or by involving a third reviewer. Covidence was used to manage references and facilitate the screening. For missing or incomplete information, we contacted the corresponding authors by email.

Data abstraction and synthesis

Data charting was done using a pre-formatted excel template and modified iteratively throughout the review process. JX and AC independently completed critical appraisal using the Newcastle–Ottawa Scale for observational studies, JBI checklist for case series for case series studies, and Cochrane RoB2 for interventional studies. Disagreements were solved by consensus or by involving a third reviewer. Due to the heterogeneity in study designs and the scoping intention of our review, the analysis is descriptive. ChatGPT was used to improve writing clarity and grammar.

Results

Study characteristics

Our search resulted in 7,738 studies with 49 remaining after the independent screening process (Fig. 1 PRISMA diagram). Table 1 reports the distribution of included studies by study design, publication year, setting, population, objectives, and quality. In total, 45 observational studies, 2 interventional physiology studies, 2 randomized controlled studies were included. There is a growing number of studies on this subject while over half of the included studies are in patients receiving cardiac surgery. Most studies have a low to moderate risk of bias (Additional file 2).

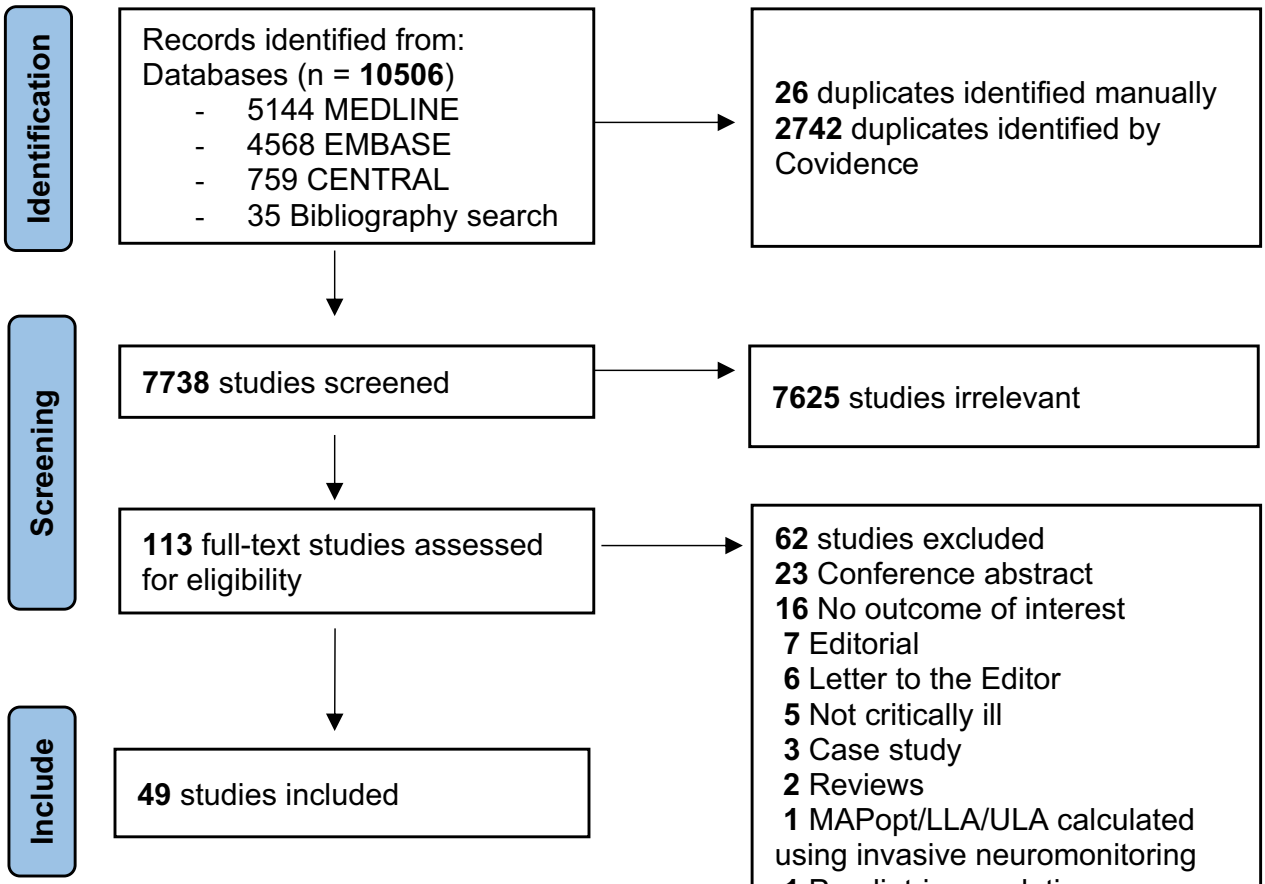


Fig. 1 PRISMA Flow chart

Absolute personalized target values

MAPopt, LLA, and ULA were reported in 24, 23, 10 studies respectively. These are summarized in Fig. 2 (MAPopt), Additional file 3 (LLA), and Additional file 4 (ULA). Notably, as shown in Fig. 2, values of MAPopt vary within and across studies and all studies reported a mean/median MAPopt over 65 mmHg.

We also summarized the width of the MAP range (ULA-LLA) in available studies. As shown in Fig. 3, widths vary within and across studies.

The magnitude of deviation and/or the duration of time patients spent outside of their personalized MAP range was reported in 23 studies (Additional file 5). Within these studies, 11 studies reported time or deviation alone. Others reported the product of both time and deviation (ie. area outside personalized MAP range), some further standardized this metric by adjusting for the differences in monitoring duration across patients.

Methods of target determination

Autoregulation assessment

In most studies, monitoring occurred throughout the surgery or early upon ICU admissions. The duration of autoregulation monitoring is mostly consistent in cardiac surgery studies, typically spanning the full surgery or the cardiopulmonary bypass (CPB) period only. However, it varies in post-operative and ICU studies, ranging from the first few hours after surgery [27–29], to a single measurement within 24 h after resuscitation [30], to consecutive daily measurements lasting over one hour [31–33], to discountinous recordings over several timepoints or days [34–36], continuous monitoring from 8 h up to 1 week [37–49]. Importantly, while most often MAPopt is calculated with the unit of patients, in some studies MAPopt is calculated per recordings, when there are several recordings per patient [32–34, 36], or every pre-determined partial recording duration (every hour [39], every 4 h [48], or every 12 h [42]) within continous recordings. Most studies used a correlation-based approach to assess autoregulation (45/49), though also with variations. For

Table 1 Included studies' characteristics

Study characteristics	No. of studies, *n* (%)
Total number of included studies	49 (100)
Study design	
Observational	45 (92)
Interventional physiology	2 (4)
Randomized controlled trial	2 (4)
Publication year	
2000–2009	3 (6)
2010–2014	10 (20)
2015–2019	20 (41)
2020–2023	16 (32)
Setting*	
Operating room (OR)	29 (59)
Intensive Care Unit (ICU)	17 (35)
Neurocritical Care Unit (NCCU)	5 (10)
Unknown/Department of Infectious Disease	1 (2)
Patients Characteristics	
Cardiac Surgery	26 (53)
Non-Cardiac Major Surgery	4 (8)
Cardiac Arrest	7 (14)
Brain Injury	5 (10)
Respiratory Failure & Shock	3 (6)
Sepsis	2 (4)
Acute Bacterial Meningitis	1 (2)
Mixed	1 (2)
Study Objectives as Relates to Personalized MAP targets**	
Characterize personalized targets or the feasibility of identifying personalized targets	12 (24)
Test and compare methods to improve personalized targets parameters calculations	15 (31)
Compare personalized targets parameters by setting or intervention (ICU vs operative room, HCA, sevoflurane anesthesia, temporality of surgery/disease stage)	8 (16)
Test the association between personalized targets parameters and clinical characteristics or outcomes	24 (49)
Test the underlying physiology of personalized target parameters (e.g., vascular biomarkers, left–right lobe differences)	3 (6)
Newcastle–Ottawa Scale/JBI/Cochrane Risk of bias Score***	
Low	22
Mid	25
High	2

*This refers to the setting where monitoring necessary for personalized target identification was performed. In some studies, multiple settings were possible (e.g., patient was monitored both in the OR and ICU and one target were calculated for each setting)

**These may not be the primary objectives of the studies, and some studies have multiple objectives

***For Newcastle–Ottawa Scale, scores ≥ 7–9, 4–6, < 4 are considered low, intermediate, and high risk, respectively [26]. For JBI checklist, "Yes" answers for ≥ 8, 5–8, < 5 items are considered low, intermediate, and high risk, respectively

example, the majority uses Pearson correlation (42/45), while three studies applied Spearman correlation [40, 41, 43]. Autoregulation indices are calculated every few minutes within the recordings. If the duration used for calculation is too short (e.g., < 1 min), the algorithm generates a noisy autoregulation signal that is indistinguishable across patients. Conversely, if the duration used is too long, the algorithm smoothens the autoregulation signal and diminishes the detection of dynamic changes. Although most studies calculate autoregulation indices every 5-min, others opted for alternative lengths, such as 30secs [50] or 30 min [43], to better distinguish the signals across their select populations. Three studies incorporated multi-window weighting algorithms to improve MAPopt yield [32, 37, 38]. Before the calculation of these correlation indices, signals sampled are usually averaged

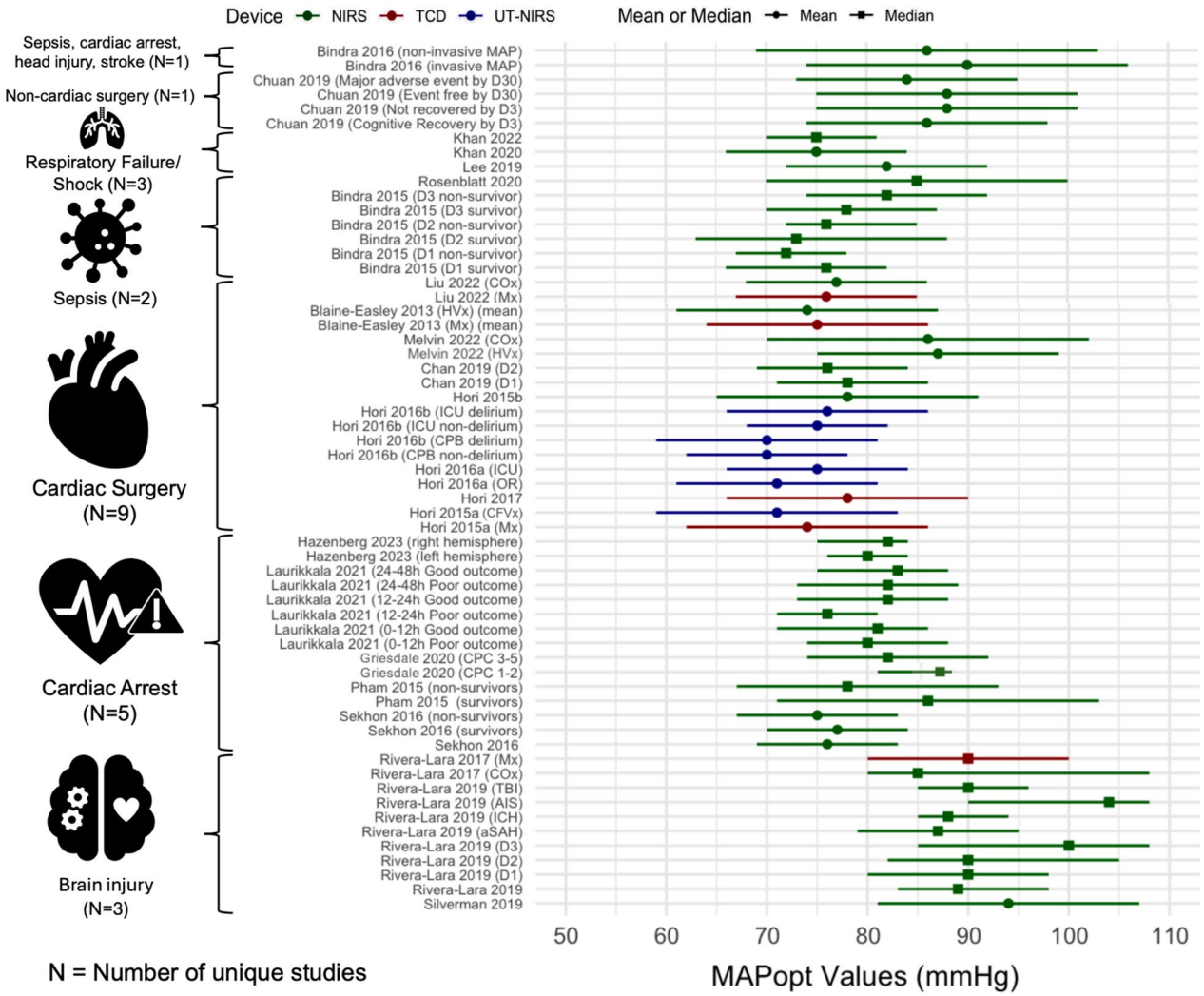


Fig. 2 MAPopt values reported across studies. Note that some studies reported multiple values corresponding to different participant sub-groups/MAPopt calculation methods used. Secondary aggregation of these datapoints to one single value are oftentimes not possible or appropriate, hence they are listed as reported in the study. D = Day, Cox = Cerebral Oximetry Index, Mx = Mean Blood Velocity Index, HVx = Haemoglobin Volume Reactivity Index, CFVx = Cerebral Flow Velocity Index, CPC = Cerebral Performance Category, TBI = Traumatic Brain Injury, AIS = Acute Ischemic Stroke, ICH = Intracranial Hemorrage, aSAH = Aneurysmal Subarachnoid Hemorrhage, TCD = Transcranial Doppler Ultrasound, NIRS = Near Infared Spectroscopy, UT-NIRS = Ultra-sound tagged Near Infared Spectoscopy

over 10 s to filter out high-frequency components caused by respiration and pulse waveforms but two studies also studied the reliability of a short averaging duration (Mx2s vs. Mx10s) to improve the speed of identifying the LLA [51, 52].

Within the correlation-based group, MAPopt was most commonly defined as the MAP associated with the lowest autoregulation index (nadir) or the vertex of a second-order polynomial curve fit, after averaging COx by 5 mmHg length MAP bins. However, three studies [40, 41, 43] averaged MAP values by COx bins to improve MAPopt identification rate in their ICU respiratory failure/shock population. This approach reduces the impact of uneven MAP sampling and may be more robust to noise and variability in COx signals. It does not require the identification of a single nadir of the COx curve, which is not identifiable in a significant proportion of patients [37].

Among the four studies that did not use a correlation-based method, three employed regression-based techniques [35, 49, 53]. In these studies, cerebral signals were plotted against MAP. Two models were fitted to the data: a linear and a horizontal model for MAP values below and above the LLA respectively. The point where these

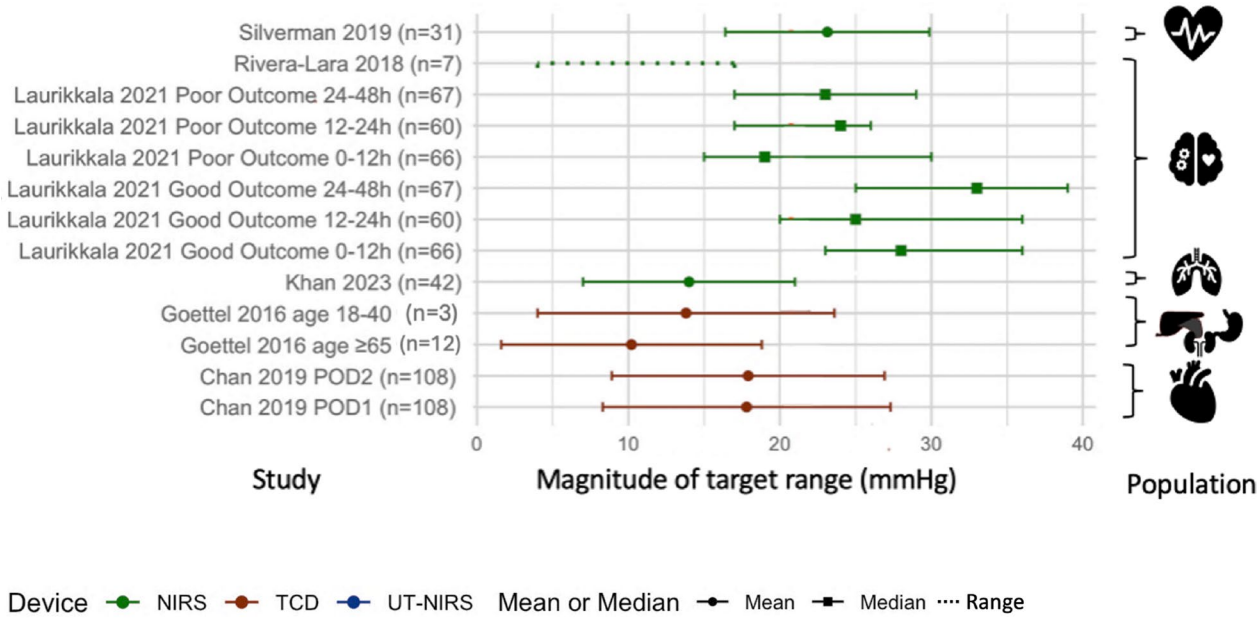


Fig. 3 The magnitude of target MAP range reported across studies. POD = post-operative day. For which day 1 is the day patients complete their surgery

two models intersect or transition marks the LLA. One study [39] uses a wavelet-based method, which is a newer approach that considers correlations between signals in both the time and frequency domains simultaneously.

For studies determining the limits of autoregulation, the most frequently used method was to apply a threshold to the correlation index (e.g., COx > 0.3), with the corresponding MAP at threshold crossing defined as the LLA or ULA. Threshold values ranged from 0.3 to 0.45, with 0.3 being the most common. A few studies employed alternative approaches, including threshold adjusted for End Tidal CO_2 [54], visual identification [44, 55, 56], regression-analysis [35, 49, 53], and MAP range where COx is ± 1 SD of the lowest [40, 41, 43]. Methods and autoregulation limits of each studies are detailed in Additional file 3 and 4.

Correlation-index value/monitoring technology

As outlined in Fig. 2 and Additional file 3 and 4, NIRS is the most commonly used technology to approximate cerebral perfusion in non-surgical populations (16/19). When studying surgical populations, TCD is more commonly used (17/30). Seven studies have compared the consistency in personalized targets determined by different non-invasive monitoring technologies and thereby correlation index. This includes Mx (TCD) vs COx (NIRS – regional cerebral oxygen saturation) [33, 57–59], Mx vs HVx (NIRS – relative tissue hemoglobin density) [60], and Mx vs CFVx (Ultrasound-tagged NIRS) [61, 62]. These studies found that population-level agreement is generally high. However, limits of agreement are broad, suggesting that there is a high degree of inter-individual variability. Most of these studies were conducted in cardiac surgery populations, with only one notable exception in patients with brain injury [33].

Consistency between MAPopt and autoregulatory limits derived from non-invasive versus invasive metrics was evaluated in three studies: Silverman et al. [48] (COx vs PRx [ICP] in aneurysmal SAH [aSAH]), Zweifel et al.[36] (THx [NIRS—total hemoglobin index] vs PRx in TBI), and Hoiland et al.[39] (COx vs PRx, PRx vs JvPRx [Jugular Venous Oxygen Saturation], PRx vs $JvsaO_2Rx$ [Jugular Venous Blood Pressure] in Hypoxic-Ischemic Brain Injury [HIBI]). Silverman et al. [48] and Zweifel et al.[36] found strong agreement, with 75% MAPopt, LLA, and ULA values within ± 7 mmHg of PRx-derived targets. In contrast, Hoiland et al. [39] observed wide limits of agreement (± 25 mmHg) despite a low mean bias and a poor AUC for MAPopt, LLA, and ULA detection in PRx by other metrics, raising concerns about COx and other non-invasive metrics' accuracy in HIBI. This variability was attributed by Hoiland et al. [39] to NIRS-specific technical limitations, physiological assumptions, and diffusion-limited oxygen transport in HIBI.

Common barriers to target identification

Thirty-four studies described participants/data lost due to feasibility barriers. Feasibility barriers were categorized as barriers to data acquisition and target calculation when data is sufficient. Specific challenges cited in each category and the number of studies cited are listed in Table 2.

Personalized targets and clinical outcomes

Twenty-one studies examined the association between personalized MAP targets and clinical outcomes. Findings vary by patient population and outcome measure. In cardiac surgery patients, particularly those undergoing CPB, MAP values below the LLA have been consistently linked to adverse outcomes such as acute kidney injury (AKI) and major morbidity and mortality (MMOM) in observational studies [27, 55, 58, 65, 68, 69]. Associations with stroke [58, 60, 63, 65, 67] and delirium have also been reported [28, 29, 32, 70], though findings are less consistent. Available randomized controlled trials (RCT) have largely failed to confirm the associations [71, 72]. A large RCT designed to determine the effects of maintaining the MAP above LLA on neurological outcomes as well as AKI and MMOM did not find a significant effect, although the intervention did not consistently keep the target MAP above LLA [71]. However, a nested cohort within the same study did demonstrate an effect on reducing the incidence and odds of delirium after effectively decreasing time and magnitude below LLA [72].

In patients with acute brain injury (e.g., aSAH, TBI, intracerebral hemorrhage), personalized MAP targets may have prognostic value. Duration spent and/or deviation outside the autoregulatory range have been associated with worse neurological outcomes [45, 48] and increased mortality [45] even when the absolute values of ULA, LLA, and MAPopt do not significantly differ between patients with favorable and unfavorable outcomes.

By contrast, in patients recovering from cardiac arrest, studies have not demonstrated a strong relationship between personalized MAP targets and long-term cognitive recovery [37, 42]. Similarly, in patients with sepsis [31] or respiratory failure-related shock [41], neither absolute MAPopt values nor deviations from autoregulation limits have shown associations with mortality or delirium. However, these findings should be interpreted cautiously, as significantly fewer studies have been conducted in these populations. Additionally, there is variability in how personalized MAP targets are calculated and measured across studies, whether as discrete MAPopt, LLA, or ULA values, or as cumulative measures such as time, deviation of an absolute magnitude, or the product of both outside autoregulatory limits (see Additional File 5 for different metrics of exposure to MAP targets studied). This variability limits the ability to directly compare the studies.

Overall, while observational data suggest that variations from personalized MAP targets may have an association with clinical outcomes, particularly in surgical and neurocritical care populations, interventional trials have yet to demonstrate consistent benefits [71, 73]. Additionally, research in other critically ill populations is in its early stages and requires further replication, testing, and refinement.

Demographic predictors of personalized targets

Ten studies examined demographic and clinical predictors of personalized MAP targets to answer the question whether targets could be approximated using other parameters and further contextualize the underpinning biology of these targets [29, 41, 42, 45, 54, 63, 67, 68, 74, 75]. They found that most common demographic, lifestyle, and clinical factors do not significantly predict individualized cerebral autoregulatory targets like MAPopt, LLA, or ULA (Fig. 4). Only a few associations were statistically significant, and even these demonstrated small effect sizes or marginal clinical relevance. Moreover, surgical and intraoperative variables had only minor predictive value in isolated models that explained little variance.

Discussion

This scoping review summarizes the absolute values, methods, feasibility, and clinical data on cerebral autoregulation-based personalized MAP targets in critically ill patients using non-invasive neuromonitoring techniques. We identified 49 studies that calculated personalized MAP targets, most of which were observational. Across these studies, the average MAPopt consistently exceeded 65 mmHg. The confidence intervals within study and variability across studies were high. Most personalized MAP targets are determined via correlation-based methods, although there are some variabilities in its application. Several feasibility challenges with current methods are reported, from issues with data acquisition, target calculation, to target maintenance. The association between personalized MAP targets and outcomes was assessed primarily in observational studies. There is strongest evidence supporting potential benefits in AKI prevention and reducing MMOM in cardiac surgery patients and emerging evidence improving neurological outcomes and mortality in patients with acute brain injury , asides from HIBI. Evidence in other outcomes or patient populations remains preliminary or inconsistent. Despite the diverse factors investigated, few predictors of MAPopt have been identified and have not yet been externally validated.

Table 2 Barriers to target identification referenced across studies

Category	Issue	N of studies	Measures taken or recommended	Impact on study or clinical application*
Data acquisition				
TCD	Anomalous/contaminated data (e.g., movement, electrocautery, physiologically impossible velocity)	7	Manual removable of artifacts, utilize only unilateral recordings, or patient exclusion	In cardiac surgery, this affects pre/post-CPB periods more due to high electrocautery activity. Patient attrition and signal loss related to this cause were up to 23% [51] and 36% respectively [60]. In brain injury, attrition rate related to this cause was 7% [33]. Manual removal might not perfectly rule out contaminated signals. [52, 56, 57, 62]
	Lack of transcranial window	4	Patient exclusion	Minimally impacts recruitment rate (4–7% of recruited patients) and could be identified early in the research [33, 61–63]
	Forehead obstruction (e.g., monitors, dressing, hemicraniectomy)	1	Patient exclusion or use only unilateral recordings	Specific prevalence was not reported [33]
NIRS	Contaminated signals (metabolic/physiological changes incompatible with the recording mechanism)	2	Patient exclusion	Patient attrition related to this cause was few (6%) [53]; could be inherent to the technology thereby impact is masked, specific populations might be more affected and should be identified [44] 5/6/2025 7:19:00 PM
	Sensor adhesion issues	1	Remove recordings	Specific prevalence was not reported [39]
	Optode malfunction	1	Patient exclusion or use only unilateral recordings	Affected 1% of patients [38]
	Recording failure	1		Specific prevalence was not reported [37]
	Equipment unavailability	1		Specific prevalence was not reported [40]
MAP	Anomalous or contaminated data	3	Manual or auto/algorithmic MAP cleaning	Affected up to 15% of participants [40, 41, 43]
	Software failure (loss of continuous MAP data)	1	Patient exclusion and data cleaning	Affected up to 23% participants [62]
Other or unspecified	Equipment unavailability, no high-fidelity recording, data loss while transferring, or protocol miscommunication	4	Patient exclusion, re-training and equipping sites, extract data immediately after recording, review protocol and improve documentation	Affected 3% to 53% of eligible participants depending on when the protocol is reviewed and revised [37, 40, 43, 48]
	Anomalous or contaminated data	3	Data cleaning or patient exclusion	Affected 14% of data recorded [37] and 23–26% of participants [55, 58]
	Damaged recordings or other recording complications	2	Patient exclusion	Affected 9% [45] and 4% of all eligible participants [37]
	ICU discharge before study completion	1	Modify study design/timing	Specific prevalence was not reported [48]
Target calculation				

Table 2 (continued)

Category	Issue	N of studies	Measures taken or recommended	Impact on study or clinical application*
	No observable MAP limits—MAP always above/outside acceptable thresholds	15	Define LLA as the lowest COx above the threshold, adjusting threshold values	Affected 2–100% participants depending on study methods. Gergelé et al.[52] tried calculating LLA with 15-min long recording and was unsuccessful. Møller et al.[35] tried calculating LLA in patients with bacterial meningitis in the first 24 h after diagnostic lumbar puncture and was also unsuccessful until later in their recovery. Asides from these two studies, loss related to this cause is lower than 35%. Yield appears lower for ULA vs LLA [29]. [33, 43–45, 49, 51, 53, 54, 63, 65–67]
	No observable MAP limits—MAP always below/within acceptable thresholds	7	No steps needed as assumed part of healthy variation; prevalence should be transparently reported	Affected 2–60% of participants, regression studies more heavily affected; threshold values influenced detection rates; surgical studies generally had better identification rates than ICU studies (2–18% loss versus 26–27% [correlation approach only]) [29, 43, 49, 53, 54, 63, 67]
	Short recording duration	5	Attempts made to calculate but if unsuccessful patients will be excluded	Affected 10% of participants [33, 34, 38, 44, 54]
	Fluctuating thresholds	1	N/A	Affected 15% (Mx2s) and 16% (Mx10s) of participants [51]

*Prevalence only cited if directly identified as associated with listed causes in the table. Sometimes the prevalence of the issue is aggregated with other causes. In these cases, we decided not to report the aggregated prevalence to not misinterpret the findings

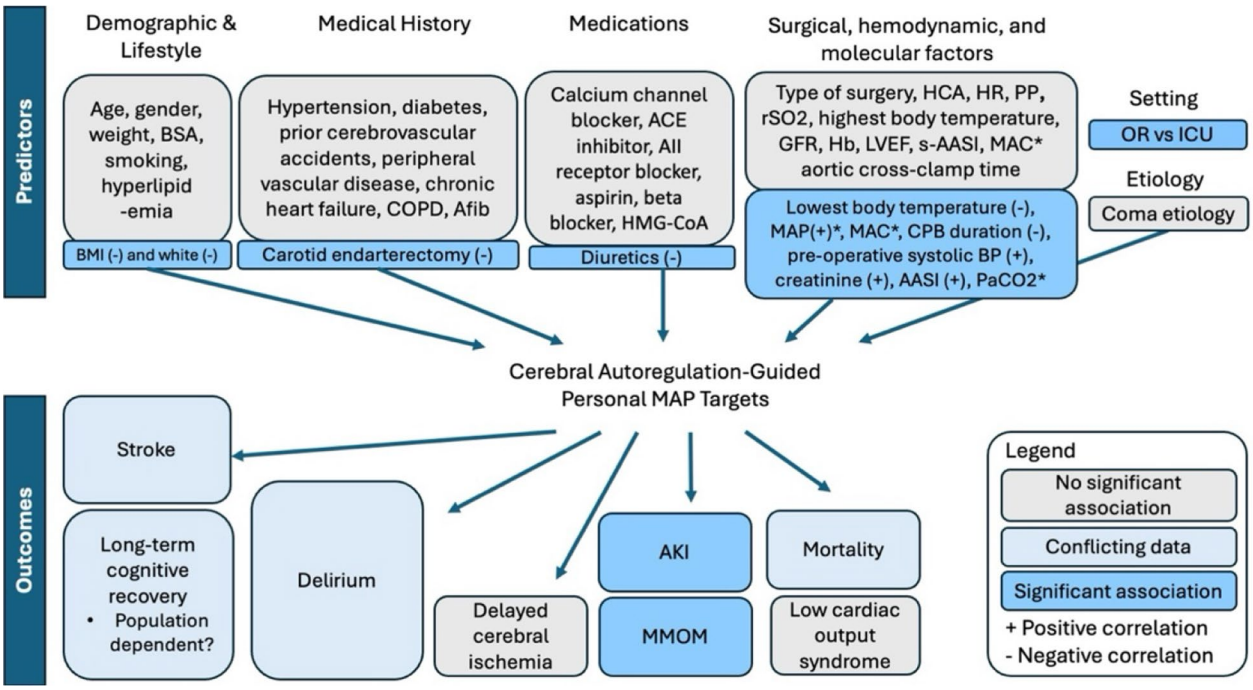


Fig. 4 Diagram overview of factors associated with autoregulation-guided MAP targets. *MAC positively correlates with ULA but not LLA. Low PaCo2 and high MAP treatment associates with a larger MAP area below LLA

Several trials investigated the impact of higher versus lower blood pressure targets on mortality and morbidity but found no significant effects [76–78]. Recent meta-analyses [79, 80] suggested potential benefits of lower MAP targets. However, confidence intervals were wide, and conclusions were described as imprecise and inconsistent with prior recommendations. This may stem from a lack of individualized approaches to blood pressure management. In our review, we observed within- and between-study variability in MAPopt, LLA, ULA. Blaine-Easley et al. [60] reported a deviation of median MAP-opt as large as -20 mmHg/+15 mmHg (range), while River-Lara et al. [45] documented an median MAPopt of 100 mmHg in 89 patients comatose from brain injury. MAP associated with intact autoregulation may also differ by sub-populations (e.g., higher in patients with brain injury) as shown by the unweighted mean plots in our results and supplement. Diagnosis-specific changes in MAPopt is an interesting hypothesis that warrants further assessment.

Individualized resuscitation using NIRS and TCD has demonstrated feasibility in the ICU and OR despite the complexity of these settings. However, several challenges remain. Fluctuating or unidentifiable autoregulatory curves due to poor signal quality and natural biological variations (or lack thereof) are commonly cited as challenges. These challenges, as described in our summary of the feasibility of these techniques, can prevent the identification of personalized targets in over half of the study population. New methods or approaches, such as a multi-window weighted calculations [81], inverted COx-MAP binning [43], automated MAP signal cleaning [64], and increasing the MAP within 1h from 65 to 95 mmHg using norepinephrine to quickly detect MAPopt [82] is increasingly studied and could be considered in future trials to improve target identification rates. Researchers might also anticipate challenges with maintaining patients in their target range. In our scoping review, only two RCTs were identified [71, 73]. The larger of the two examined multiple outcomes (selected on the basis of prior observational data). However, the intervention to keep patients at or near MAPopt did not reduce the area under the LLA. As a result, no definitive conclusions could be drawn about whether targeting individualized MAPopt improves clinical outcomes. Studies examining higher vs lower blood pressure targets in the ICU reported clinicians' reluctance to decrease vasopressor infusion rates at a lower MAP [76] due to concern for patient's clinical condition, following other targets or clinical priorities, and inadequate trial awareness [77]. There is a dearth of RCTs designed to test the effectiveness of personalized targets, but the feasibility issues outlined above will need to be addressed before initiating large-scale interventional trials.

Currently, autoregulation-based MAP targets are studied using a variety of calculation methods and experimental paradigm. These include different MAPopt, LLA, ULA calculation approaches, neuromonitoring technology used, and different duration and onset of autoregulation monitoring. It is unknown what methods best balance the clinical feasibility and the benefits of such targets. The most suitable methods might differ by critically ill sub-population due to differences in practice setting and pathophysiology. Patterns of blood pressure fluctuations may differ between the ICU and OR, affecting the yield and prognostic abilities of different target identification approaches. Some studies challenge the accuracy of existing algorithm and NIRS in measuring autoregulation in patients who experienced cardiac arrest due to potential impairments in oxygen diffusion and metabolism in this population [83]. Future studies might take inspiration from studies in critically ill populations broadly, considering the large quantity of research conducted in cardiac surgery and patients with brain injury, however, researchers should be sensitive to the differences in setting and pathophysiology and a likely need to adapt approaches to their critical ill sub-populations.

Our assessment of demographic predictors highlighted that were few consistent predictors of autoregulation-guided MAP targets, despite the wide range of factors studied in relation to cerebral autoregulation. This may reflect the fact that different autoregulation monitoring methods are not fully interchangeable, or that MAP targets are highly individualized and dynamic. It also highlights the complexity of cerebrovascular control, which is influenced by multiple interacting physiological processes, such as autoregulatory function, cerebral metabolism, and systemic variables, that may not follow linear or easily modeled relationships. For example, recent research shows that cerebral autoregulation is more effective during rising MAP than falling MAP over short timescales (10–60 s), possibly due to differing myogenic and sympathetic activity [84]. This suggests a potential limitation of correlation-based methods, though it's unclear if directional sensitivity persists at the slower timescales used to calculate correlation-based indices (e.g., 5 min). Future work should aim to better understand the biological basis of autoregulation estimates and how they relate to other physiological markers, to guide the development of more reliable and personalized clinical applications.

One of the strengths of this review is its broad scope. We included diverse patient populations across varying clinical settings. We have also captured multiple metrics of individualized blood pressure targets (i.e. MAPopt, LLA, ULA). Furthermore, we have performed a risk of bias assessment for included studies, which improves the ability to interpret the captured data.

Our review also has several limitations. First, scoping review methodology precluded the ability to perform meta-analyses that could further allow the comparison of findings and address specific questions of interest (e.g., the frequency of hypo- vs hypertension or variations in MAPopt across populations). Second, our search was limited to English-language publications, potentially excluding relevant studies in other languages.

Conclusion

Technological advancements have made it feasible to determine personalized MAP targets in critically ill patients. Most evidence in this emerging field is observational and shows high variability in MAP values associated with intact autoregulation. While some studies suggest associations with clinical outcomes, methodological inconsistencies and feasibility challenges, such as signal loss, variable calculation methods, and inability to keep MAP above LLA, limit interpretability and generalizability. To move the field forward, future studies should prioritize validating algorithms across diverse patient populations, standardizing within critically ill sub-populations, and identifying strategies to overcome practical barriers to implementation. Efforts should be tailored to the unique physiological profiles of critically ill sub-groups and will likely lead to a better understanding of the complex, multifactorial nature of cerebrovascular regulation.

Abbreviations

TBI	Traumatic brain injury
SAH	Subarachnoid hemorrhage
CPP	Cerebral perfusion pressure
ICP	Intracranial pressure
MAP	Mean arterial pressure
CPPopt	Optimal cerebral perfusion pressure
MAPopt	Optimal mean arterial pressure
LLA	Lower limit of autoregulation
ULA	Upper limit of autoregulation
NIRS	Near-infrared spectroscopy
TCD	Transcranial doppler ultrasound
rSO_2	Regional cerebral oxygen saturation
COx	Cerebral oximetry index
Mx	Mean blood velocity index
ICU	Intensive care unit
PRISMA-Scp	Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Scoping Reviews
JBI	Joanna Briggs Institute
RoB2	Risk of Bias 2 tool
HVx	Hemoglobin volume index
CFVx	Cerebral flow volume index
PRx	Pressure reactivity index
aSAH	Aneurysmal subarachnoid hemorrhage
JvPRx	Jugular venous pressure reactivity index
$JvsaO_2Rx$	Jugular venous saturation pressure reactivity index
HIBI	Hypoxic-ischemic brain injury
AUC	Area under the curve
AKI	Acute kidney injury
MMOM	Major mortality and morbidity

RCT	Randomized controlled trial
MAC	Minimum alveolar concentration

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13054-025-05432-5.

Additional file 1: Search strategy. Search strategy used for this review.

Additional file 2: Risk of bias assessment of all included studies.

Additional file 3: LLA values reported in included studies. An unweighted mean plot of LLA values reported in included studies.

Additional file 4: ULA values reported in included studies. An unweighted mean plot of ULA values reported in included studies.

Additional file 5: Duration and/or magnitude outside of LLA/ULA/MAPopt reported across studies. A chart with all the time and/or deviation spent outside LLA or ULA reported across studies.

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Author contributions
JX ARW JGB contributed to the conception and design of the study. JX AC AA JGB performed the title and abstract screening. JX and AC performed the data extraction. JX and JGB summarized and analyzed the data. JX wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

Availability of data and materials
The datasets used and/or analyzed during this study are available as supplementary files or can be obtained from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
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Competing interests
The authors declare no competing interests.

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