Perioperative Medicine

REVIEW

Open Access

Goal-directed therapy: what is the goal again?

Amy Yerdon[1*], Ken Taylor[2], Katie Woodfin[1], Ryan Richey[1], Susan McMullan[1] and Desirée Chappell[3]

Abstract

Recent attention has focused on intraoperative hypotension (IOH) and hemodynamic instability. This enhanced awareness to limit IOH, combined with fluid restriction and increased vasopressor use, has been associated with an increase in postoperative acute kidney injury. Recent literature supports improved intraoperative monitoring of mean arterial pressure (MAP), fluid management, and appropriate use of vasopressors and inotropic support for hemodynamic management. Implementing an algorithm to manage the causes of IOH minimizes iatrogenic harm by guiding anesthesia clinicians to select the appropriate interventions at the optimal time. This ensures a comprehensive evaluation of contributing factors such as fluid deficits, myocardial depression, and vasodilation. Shifting attention from the MAP displayed on the physiologic monitor to more individualized care with a goal-directed therapy approach may improve patient outcomes.

Keywords Goal-directed therapy, Hemodynamic instability, Intraoperative hypotension, Hemodynamic management, Individualized care

Numerous recent studies have demonstrated an association of intraoperative hypotension (IOH) with negative patient outcomes, such as mortality, acute kidney injury (AKI), myocardial injury after non-cardiac surgery (MINS), stroke, postoperative cognitive dysfunction/delirium, and mortality (Cai et al. 2023; Calvo-Vecino et al. 2018; Chiu et al. 2022; Duan et al. 2023; French & Scott 2022; Gregory et al. 2020; Maheshwari et al. 2020a; Martin et al. 2020; Salmasi et al. 2017; Stapelfeldt et al. 2021; Sessler et al. 2019; Wesselink et al. 2018). Increased IOH severity and/or duration is associated with increased risk of these negative outcomes (French et al. 2021; Futier et al. 2017; Gregory et al. 2020; Putowsky et al. 2021; Salmasi et al. 2017; Sessler et al. 2019; Wesselink et al. 2018). Many recent observational cohort studies describe associations between hemodynamic instability, hemodynamic management, and patient outcomes. This lower to moderate-quality supporting evidence cannot be used at this time to ascertain the cause of patient morbidity and mortality. It is unknown if the increased risk of negative outcomes is due to the advanced age or increased co-morbidities of the current patient population, anesthetic practice, or any combination of these. Although causal evidence is currently insufficient, anesthesia clinicians should proactively take measures to prevent or treat significant IOH while awaiting interventional trials.

Anesthesia clinicians should minimize the occurrence, severity, and duration of IOH. However, recent anesthetic practice trends of fluid restriction and increased vasopressor use have been associated with increased risk of patient morbidity and mortality (Chiu et al. 2022). Recommendations for intraoperative fluid administration and hemodynamic management have evolved over the last several years, yet tremendous variation persists in clinical practice (Ariyarathna et al. 2022; Christensen et al. 2021; Perel 2020; Saasouh et al. 2023; Shah et al.

*Correspondence:
Amy Yerdon
ady0002@uab.edu
[1] University of Alabama at Birmingham BSN-DNP Nurse Anesthesia Pathway, Birmingham, AL, USA
[2] St. Vincent's East Hospital in Birmingham, Birmingham, AL, USA
[3] Northstar Anesthesia, Louisville, KY, USA

2020). Goal-directed therapy (GDT) strategies optimize patient hemodynamic status, prevent organ hypoperfusion, and are associated with decreased length of stay (LOS) and perioperative complications, such as AKI, surgical site infections (SSIs), pneumonia, ileus, postoperative nausea and vomiting (PONV), and mortality (Calvo-Vecino et al. 2018; French et al. 2021; Futier et al. 2017; Giglio et al. 2019; Jessen et al. 2022; Miller & Myles 2019; Perel 2020; Ripollés et al. 2016; Sun et al. 2017; Zhang et al. 2018). Implementing GDT protocols may help reduce clinical practice variation and associated negative outcomes, thereby improving patient safety (Boekel et al. 2021; de Keijzer et al. 2023).

The causes of derangements of hemodynamic instability producing IOH must remain the priority for anesthesia clinicians to choose the most appropriate treatments at the right time. A review of recent evidence on appropriate hemodynamic management strategies may assist anesthesia clinicians in caring for the increasingly challenging patient population to improve outcomes. This narrative review aims to bridge a potential gap between anesthesia clinicians' awareness of negative postoperative effects associated with intraoperative hemodynamic mismanagement and evidence-based strategies to improve outcomes for surgical patients. Additionally, real-world application of GDT strategies will be discussed to aid the frontline anesthesia clinician in incorporating its use.

Traditional endpoints and their challenges

The historical practice of calculating intraoperative fluid requirements as the sum of hourly maintenance, NPO deficits, blood loss, and evaporative loss is based on incorrect, antiquated assumptions and led to many adverse postoperative outcomes (Corcoran et al. 2012). This strategy was also guided by traditional indicators of hypovolemia, including heart rate, blood pressure (BP), urine output, or central venous pressure. However, changes in these parameters are late indicators of hypovolemia (Davies & Mythen 2021; Hamilton-Davies et al. 1997). Heart rate and BP are unreliable because they may change in response to surgical stimulation and medications, may not change in patients taking cardiovascular medications such as beta-blockers, or may remain within normal limits until a 25% reduction in volume occurs (Davies & Mythen 2021). Urine output is an unreliable indicator of hypovolemia because surgical stimulation causes antidiuretic hormone excretion, which reduces urine output. Central venous pressure indicates the pressure of the right atrium, not volume status, and may remain normal even after heart rate and BP finally change in response to significant hypovolemia. These traditional endpoints are static measures of cardiovascular function and poor indicators of fluid requirements (Martin et al. 2020).

History of goal-directed therapy

Whereas traditional and restrictive therapies are based on calculations and use ineffective traditional endpoints, goal-directed therapy (GDT) strategies incorporate an advanced hemodynamic monitor and use a specific endpoint or goal to guide optimal timing and administration of fluids, inotropes, and vasopressors to optimize tissue oxygen delivery (Calvo-Vecino et al. 2018; Ripollés et al., 2016; Tote & Grounds 2006). GDT may be conceptualized as a broad category encompassing the subcategories of goal-directed fluid therapy (GDFT) and goal-directed hemodynamic therapy (GDHT). Figure 1 depicts the recent GDT concept and its components.

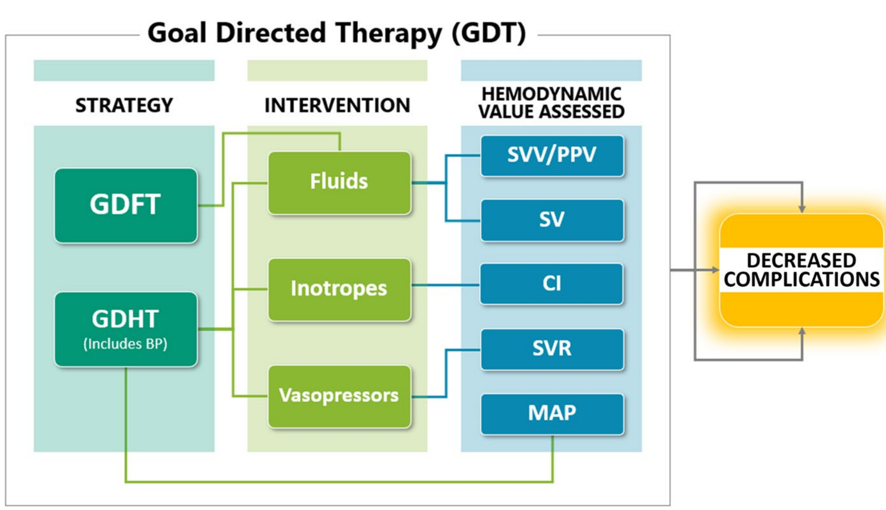

Fig. 1 Goal-directed therapy (GDT) concept and components

GDFT was the first iteration of a goal-directed strategy concept and was introduced within Enhanced Recovery After Surgery (ERAS) protocols to help minimize fluid overload by using a monitor to guide fluid bolus administration and evaluate fluid responsiveness. After the publication of conflicting evidence regarding the GDFT effect on patient outcomes, the benefits of this strategy were questioned, and initial implementation slowed (French & Scott 2022). The lack of evidence supporting GDFT benefits was most likely due to numerous benefits observed from ERAS protocol components, including surgical advancements, avoidance of preoperative dehydration, and avoidance of fluid overload (Brandstrup et al. 2012; Miller et al. 2015; Srinivasa et al. 2013). The implementation of GDFT was hindered by insufficient evidence, which led to a lack of support from anesthesia clinicians. This challenge was further complicated by a knowledge gap concerning optimal fluid administration and the absence of advanced hemodynamic monitors and protocols to facilitate their use (Boekel et al. 2021).

Note. The figure depicts the concept of GDT encompassing the sub-categories of goal-directed fluid therapy (GDFT) and goal-directed hemodynamic therapy (GDHT) strategies. The figure suggests targeted interventions based on correcting the specific hemodynamic values of stroke volume variation (SVV), pulse pressure variation (PPV), stroke volume (SV), cardiac index (CI), systemic vascular resistance (SVR), and mean arterial pressure (MAP). Managing intraoperative hemodynamics with a comprehensive focus on overall perfusion rather than solely on fluid optimization is associated with a reduction in postoperative complications.

In addition to embodying the core concepts of GDFT, GDHT incorporates hemodynamic optimization to maintain BP and avoid IOH (Calvo-Vecino et al. 2018; Tote & Grounds 2006). Recently, GDHT and GDFT conceptually merged into the more comprehensive, modern idea of GDT. Multiple recent studies demonstrate the superiority of GDT over traditional approaches and support its use to reduce postoperative morbidity and mortality in low-, moderate-, and high-risk procedures (Calvo-Vecino et al. 2018; Futier et al. 2017; Zhang et al. 2018). Despite this evidence, confusion may persist for many anesthesia clinicians about the benefits and how to incorporate advanced hemodynamic monitoring. Another challenge appears to be appropriately interpreting the monitor information to tailor the administration of fluids, inotropes, and vasopressors in a GDT strategy (Martin et al. 2020). The merging and interchanging of terms may contribute to the current confusion regarding the benefits of GDT (French & Scott 2022). Anesthesia clinicians may consider GDT the original GDFT concept, which showed conflicting results within ERAS protocols.

Adding to the confusion, some trials reported no significant difference in patient morbidity, mortality, or length of stay in GDHT groups, yet the GDHT protocol used lacked a stepwise approach to treating the cause of hemodynamic instability (Pearse et al. 2014; Pestaña et al. 2014). After the first fluid challenge, the OPTIMISE trial intraoperative protocol relied on a continuous infusion of dopexamine, a beta-2 and dopamine-1 agonist with vasodilatory effects and no direct beta-1 properties (Pearse et al. 2014). The OPTIMISE II trial had similar limitations to OPTIMISE I and used a continuous dobutamine infusion in a stroke volume (SV)-guided protocol (OPTIMISE II Trial Group 2024). While these studies followed a form of GDT, they did not incorporate a fully comprehensive hemodynamic optimization strategy (OPTIMISE II Trial Group 2024; Pearse et al. 2014). In contrast, GDT protocols associated with reductions in postoperative complications consider the entire hemodynamic picture and optimize preload, contractility, and afterload status by considering factors affecting each in a stepwise approach (Calvo-Vecino et al. 2018; Futier et al. 2017; Martin et al. 2020; Miller & Myles, 2019; Perel 2020; Zhang et al. 2018). OPTIMISE II did not actively apply the principles of targeting vasopressors and inotropes at specific endpoints, making it a limited representation of a comprehensive GDT strategy.

Three systematic reviews and meta-analyses of GDHT effects in non-cardiac surgery reported reductions in postoperative morbidity and mortality (Jessen et al. 2022; Sun et al. 2017) or significant reductions in complications but no difference in mortality (Ripollés et al. 2016). Jessen et al. (2022) described their results as imprecise and with low certainty of evidence and recommended larger trials for confirmation. One limitation of this systematic review is the heterogeneity of the included trials. Many trials in this review used protocols focusing on fluid optimization alone rather than overall hemodynamic optimization by incorporating indicators of contractility and afterload. Conversely, numerous trials with protocols encompassing preload, contractility, and afterload were associated with reduced postoperative complications, mortality, or length of stay (Benes et al. 2010; Calvo-Vecino et al. 2018; Colantonio et al. 2015; Kim et al. 2018; Luo et al. 2017; Salzwedel et al. 2013; Zhang et al. 2018; Zheng et al. 2013). Furthermore, a meta-analysis on GDHT and postoperative kidney injury found significant reductions in AKI in studies that utilized the hemodynamic targets of cardiac output and oxygen delivery, while also incorporating both fluids and inotropes as interventions (Giglio et al. 2019). Recognizing that not all GDT protocols are the same is crucial for anesthesia clinicians to support changes in clinical practice. GDT strategies that incorporate a protocol that optimizes intraoperative hemodynamics by considering the entire picture of perfusion (i.e., preload, contractility, afterload) are associated with decreased postoperative complications.

Evidence-based GDT strategies

Increased awareness of the benefits of GDT, how to use advanced monitors appropriately to guide care, and the simplified method of optimizing hemodynamic status through an algorithmic approach may improve outcomes for the surgical patient (Calvo-Vecino et al. 2018; Futier et al. 2017; Martin et al. 2020; Miller & Myles, 2019; Perel 2020; Zhang et al. 2018). Blood pressure alone is an unreliable indicator of hemodynamic instability, but advanced hemodynamic parameters do indicate when a problem exists. GDT strategies include using a monitor with advanced hemodynamic parameters that provide preload, contractility, and afterload information, most importantly SV, stroke volume variation (SVV), pulse pressure variation (PPV), CO, CI, and systemic vascular resistance (SVR). The dynamic values offered by the GDT monitor are based on concepts of the Frank-Starling relationship and accurately predict fluid responsiveness (Martin et al. 2020). Protocols involving continuous assessment and individualized optimization of these multiple dynamic parameters reflect the definition of a GDT strategy by targeting specific endpoints at the most appropriate time. OPTIMISE II primarily focused on SV optimization without systematically incorporating these additional hemodynamic targets. Furthermore, using a fixed low-dose dobutamine infusion rather than titrating inotropic and vasopressor therapy to real-time physiological needs limited its applicability.

Using a protocol to treat the causes of instability and IOH with a stepwise approach improves hemodynamic status by optimizing the physiologic determinants of SV (Calvo-Vecino et al. 2018; Kouz et al. 2023a; Saugel et al. 2024; Scott & APSF, 2024). Recent studies incorporating a GDT protocol for intraoperative hemodynamic management demonstrated improved patient outcomes, fewer complications, and less IOH (Boekel et al. 2021; Calvo-Vecino et al. 2018; Futier et al. 2017; Wijnberge et al. 2020; Zhang et al. 2018). The GDT protocols used in these studies guide the anesthesia clinician in assessing and treating causes of IOH by first optimizing preload, contractility, and afterload, in this order. Addressing preload first by correcting intravascular volume deficits with fluid moves the patient upward on their Frank-Starling curve, therefore improving SV (Martin et al. 2020; Miller et al. 2015). A resultant increase in SV of about 10% indicates the patient is fluid-responsive (Martin et al. 2020; Miller et al. 2015; Vincent et al. 2020). Once fluid needs are met, contractility is addressed next. Inotropes should be given to treat myocardial depression or reductions in CI (Saugel et al. 2024). After SV has been optimized by addressing preload and contractility, attention may then be focused on afterload (French et al. 2021). Vasoplegia, indicated by decreased SVR, is treated with vasopressors (Calvo-Vecino et al. 2018). Yerdon et al. (2024) illustrated this concept with their "Fill, Flow, Pressure" infographic for Certified Registered Nurse Anesthetists (CRNA) education on progressing through optimizing preload with volume administration (i.e., "Fill"), contractility and end-organ perfusion with inotropes (i.e., "Flow"), and afterload with vasopressors (i.e., "Pressure"). Figure 2 provides a practical clinical application of this stepwise approach in a GDT protocol. Following this algorithm in treating causes of IOH avoids iatrogenic harm by choosing the wrong treatment, such as giving vasopressors to improve IOH without correcting fluid deficits or myocardial depression. In the context of GDT, anesthesia clinicians should recall and address the potential reversible causes of hemodynamic

SV DETERMINANT	HEMODYNAMIC VALUE	TREATMENT THRESHOLD	INTERVENTION	INTERVENTION EXAMPLE	ASSESSMENT OF INTERVENTION
PRELOAD	SV, SVI, SVV, PPV	↓ SV/SVI ↑ SVV (≥ 13%) ↑ PPV (≥ 12%)	Fluid bolus	200-250 mL crystalloid or colloid*	SV ↑ by 10% ↓ SVV ↓ PPV
CONTRACTILITY	CI	↓ CI (< 2.5 liters per min)	Inotrope	Ephedrine or calcium	↑ CI
AFTERLOAD	SVR, SVRI	↓ SVR/SVRI	Vasopressor	Phenylephrine or norepinephrine	↑ SVR/SVRI

Fig. 2 Practical clinical application of goal-directed therapy (GDT) protocol

instability, such as reducing the anesthetic level if too deep, releasing pneumoperitoneum, or changing patient position. Once known causes of hemodynamic instability are corrected, anesthesia clinicians may consider the "fill, flow, pressure" algorithm.

Note. The figure provides an example of a stepwise approach in a GDT protocol addressing preload, contractility, and then afterload, and includes monitored values, interventions, and reassessments (Calvo-Vecino et al. 2018; Futier et al. 2017; Wijnberge et al. 2020; Yerdon et al. 2024).

Hemodynamic values include stroke volume (SV), stroke volume index (SVI), stroke volume variation (SVV), pulse pressure variation (PPV), cardiac index (CI), systemic vascular resistance (SVR), and systemic vascular resistance index (SVRI).

*Lower volume (e.g., 100 mL) may be appropriate for patients with renal or heart failure (Martin et al. 2020).

GDT experience and protocol compliance

Using standardized GDT protocols helps clinicians incorporate advanced hemodynamic parameters into evidence-based fluid and hemodynamic strategies, improves end-user buy-in, and is associated with reduced patient complications (Boekel et al. 2021; Calvo-Vecino et al. 2018; Martin et al. 2020). One study evaluated the impact of an educational intervention and protocol implementation on IOH (de Keijzer et al. 2023). They found that while the surveyed clinicians believed they possessed adequate knowledge and skills to treat IOH before the educational intervention, the duration and severity of IOH were worse in the baseline group compared to the test group with education and a protocol (de Keijzer et al. 2023). Additionally, more inotropes were administered in the protocol test group, suggesting that protocol adherence may be associated with IOH reductions (de Keijzer et al. 2023). Other studies attributed the positive impact of GDT protocol implementation on minimizing IOH to the clinicians' skills and prior experience (Frassanito et al. 2023; Lorente et al. 2023).

Another study that found no benefit in using an intraoperative GDT protocol in minimizing IOH discussed the possible contributing factors of clinician mistrust and difficulty using the protocol, which led to clinicians ignoring alerts and poor protocol compliance (Maheshwari et al. 2020b). These researchers recommended emphasizing education on protocol compliance and providing treatment guidance for future trials (Maheshwari et al. 2020b). In another study assessing the effect of GDT protocol compliance on postoperative outcomes, researchers reported that high protocol compliance was associated with reductions in severity and overall postoperative complications (Boekel et al. 2021). These recent studies suggest that clinician education and protocol compliance are vital to improving patient outcomes.

Which patients/procedures need GDT?

Adding a GDT monitor and required disposables is associated with additional costs, which vary depending on the manufacturer, compared with traditional monitoring without this technology. Miller and Myles (2019) suggested a risk-adapted matrix for determining which patients and procedures should receive GDT management. GDT strategies are associated with the greatest improvement in patient outcomes when used in moderate to high-risk patients (e.g., American Society of Anesthesiologists [ASA] Physical Status ≥ III or IV) or moderate-to-high-risk procedures. These procedures involve a greater risk for fluid shifts and/or blood loss, such as major abdominal surgery or multiple-level spinal fusions. Additionally, GDT should be considered in moderate to high-risk patients having lower-risk procedures not associated with fluid shifts and/or blood loss (e.g., an ASA IV patient with an ejection fraction of 10% having a laparoscopic cholecystectomy) (Miller & Myles 2019). If blood samples are not needed for intraoperative labs, the risks of placing an arterial line can be avoided by choosing a non-invasive finger cuff for GDT and continuous BP monitoring. If both the patient and procedure are considered moderate to high-risk (e.g., an ASA IV patient having a liver resection), intraoperative GDT is recommended, and postoperative admission to the intensive care unit should be considered. GDT is not indicated for a healthy ASA I patient having a low-risk procedure.

Alternatives for clinicians without access to GDT monitors

Many anesthesia clinicians may not have the advanced technology available, making GDT strategies challenging without the additional hemodynamic values to assist in treatment decisions and assessment of those treatments. In this situation, anesthesia clinicians may consider the recommendations from the RELIEF trial, which compared liberal and restrictive fluid approaches (Myles et al. 2018). The conclusion of this trial was that restrictive approaches are associated with a greater risk of AKI and SSI. The authors recommended a moderately liberal fluid strategy, defined as 10–12 mL/kg/hr or a net balance of positive one to 2 L for major surgery and half to 1 L in minor outpatient procedures. Recently published consensus recommendations support this strategy aiming for 1–2 L of positive balance by the end of the surgical procedure (Ostermann et al. 2024). Anesthesia clinicians without access to advanced hemodynamic technology should recall the various causes of IOH and hemodynamic instability, such as anesthetic effects, myocardial depression, hypovolemia, vasodilation, or bradycardia, and address all aspects of flow to enhance perfusion (Saugel et al. 2024; Scott & APSF, 2024). Recent consensus recommendations for managing hemodynamic instability include using a logical approach with fluid, blood products, inotropes, and vasopressors so that interventions most effectively address the problem and do not harm patients (Saugel et al. 2024; Scott & APSF, 2024). Incorporating the "fill, flow, pressure" algorithm may help guide intraoperative hemodynamic management, even in the absence of advanced hemodynamic technology (Yerdon et al. 2024).

Prevention of IOH and hemodynamic instability

IOH is overt hemodynamic instability, and traditional hemodynamic management involves the reactive treatment of IOH after organ hypoperfusion is already occurring. Mounting recent evidence touts the need to correct underlying hemodynamic instability and reduce the incidence, severity, and duration of IOH. Considering the harmful patient effects and the associated healthcare system burden, anesthesia clinicians should consider surpassing the traditional reactive strategy and transitioning to a proactive approach by preventing instability and IOH (Gregory et al. 2020; Kouz et al. 2023a; Saugel et al. 2019). Recent innovations in advanced hemodynamic monitoring using artificial intelligence and machine learning make this possible (Davies et al. 2020; Edwards Lifesciences 2024; Frassanito et al. 2023; Hatib et al. 2018; Kouz et al. 2023b; Li et al. 2022; Saugel et al. 2019; Wijnberge et al. 2020). Numerous contemporary studies demonstrate this technology's sensitivity, specificity, and validity in accurately predicting IOH and reducing hypotensive events through prevention (Davies et al. 2020; Frassanito et al. 2023; Hatib et al. 2018; Kouz et al. 2023b; Li et al. 2022; Ranucci et al. 2019; Wijnberge et al. 2020). This technology uses an early warning system called the Hypotension Prediction Index (HPI) to alert the user to impending hypotensive events (Edwards Lifesciences 2024). The monitor incorporates information from the patient's arterial waveform and detects instability in the cardiovascular system that may lead to IOH. HPI is a unitless number on a scale from zero to 100, with higher numbers (e.g., > 80–85) indicating a higher probability of IOH within a shorter time frame (Edwards Lifesciences 2024). When the clinician is alerted to a high HPI indicating imminent IOH, additional information regarding the probable cause is available on a secondary screen. This information details the components of BP, highlighting the physiologic cause of IOH, such as hypovolemia, myocardial depression, or vasoplegia (Kouz et al. 2023a; Wijnberge et al. 2020; Yerdon et al. 2024). Incorporating this information aids anesthesia clinicians in choosing appropriate interventions targeting the future IOH cause, thereby preventing it from occurring (Kouz et al. 2023b; Wijnberge et al. 2020; Yerdon et al. 2024).

However, one large randomized controlled trial on the effect of HPI-guided intraoperative management did not reduce the amount of IOH (Maheshwari et al. 2020b). The authors reported clinician difficulty implementing the complex treatment algorithm, clinicians ignoring alarms, and protocol non-compliance as possible explanations for the lack of demonstrated benefit. Additionally, there is an ongoing debate on the degree to which HPI is superior to MAP and reports of moderate-to-low accuracy in predicting IOH (Mukkamala et al. 2024; Vistisen & Enevoldsen 2024; Yang et al. 2023). These uncertainties underscore the need for robust assessments of the effect of this predictive technology on patient-centered outcomes. Of note, HPI is one of several hemodynamic values available within a broader collection of monitoring parameters designed to guide clinical decision-making. HPI is an early warning indicator for impending IOH, but anesthesia clinicians should incorporate this value alongside other hemodynamic parameters like CO, SV, and SVR. HPI alerts should prompt clinicians to evaluate these additional data points to identify and manage instability accurately. Relying solely on HPI is not equivalent to trending MAP as effective hemodynamic management requires integrating this parameter with a comprehensive set of data rather than alone.

Closed-loop systems

Closed-loop systems are an emerging technology designed to enhance patient care by maintaining a target variable within a specified set point (Coeckelenbergh et al. 2024). Automated closed-loop systems in anesthesia consist of a sensor for monitoring vital signs, a controller for interpreting data and correcting discrepancies, and an effector for precise medication administration (Coeckelenbergh et al. 2024). These systems have been shown to reduce clinician workload, increase protocol compliance, and are associated with decreases in errors or deviations caused by distraction or fatigue (Coeckelenbergh et al. 2024; Spataru et al. 2024). Multiple studies demonstrate the ability of closed-loop systems to improve intraoperative hemodynamic management—with fluids and/or vasoactive medications—in patients undergoing major surgeries while providing a level of protocol compliance that is challenging to achieve with routine care (Joosten et al. 2021a, 2021b; Kumar et al. 2022). A study on closed-loop-assisted GDFT in major abdominal surgery reported a reduction in net fluid balance, which was associated with fewer postoperative complications and a shorter length of stay (Joosten et al. 2018). In other studies on computer-assisted vasoactive medication administration in patients undergoing intermediate and high-risk procedures, the use of a closed-loop system significantly reduced IOH incidence (Joosten et al. 2021a, 2021b). More studies are needed, but anesthesia clinicians would be prudent to stay abreast of the benefits of this emerging technology on patient care.

Summary

Incorporating intraoperative GDT protocols that optimize the entire picture of perfusion is associated with reductions in decreased LOS, healthcare costs, and perioperative complications, such as AKI, SSIs, pneumonia, ileus, PONV, and mortality. Reviewing the concepts of the various causes of IOH and hemodynamic instability and methods for correcting these with targeted treatments may benefit patients and reduce adverse outcomes. Interventions must target the root IOH cause using a GDT strategy rather than simply improving the MAP value displayed on the physiologic monitor. This strategy allows for a more individualized approach, which may improve patient outcomes. Anesthesia clinicians need to recognize the variability of GDT protocols in published trials, as this understanding will empower them to interpret the evidence and facilitate meaningful changes in clinical practice. Additional strategies for improving patient outcomes include raising awareness to limit IOH tolerance and practice variation, collaborating with perioperative departments to measure postoperative AKI, reporting outcomes to frontline clinicians, ongoing education on IOH and GDT strategies, incorporating continuous BP monitoring where feasible, using advanced technology to prevent IOH, and GDT protocol implementation to reduce practice variation and patient harm.

Abbreviations

AKI	Acute kidney injury
ASA	American Society of Anesthesiologists
BP	Blood pressure
CI	Cardiac index
CO	Cardiac output
ERAS	Enhanced Recovery After Surgery
GDT	Goal-directed therapy
GDFT	Goal-directed fluid therapy
GDHT	Goal-directed hemodynamic therapy
HPI	Hypotension Prediction Index
IOH	Intraoperative hypotension
LOS	Length of stay
MAP	Mean arterial pressure
MINS	Myocardial injury after non-cardiac surgery
PONV	Postoperative nausea and vomiting
PPV	Pulse pressure variation
SSI	Surgical site infection
SV	Stroke volume
SVI	Stroke volume index
SVR	Systemic vascular resistance
SVRI	Systemic vascular resistance index
SVV	Stroke volume variation

Acknowledgements
The authors would like to thank Lauren Antia for her adaptation and creation of Figures 1 and 2.

Authors' contributions
A.Y. and D.C. developed the objectives for the manuscript. A.Y., D.C., and K.T. performed the literature review. All authors made substantial contributions to the work or substantively revised it. All authors read and approved the final manuscript.

Funding
Not applicable.

Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
Amy Yerdon, DNP, MNA, CRNA, CNE, CHSE, is a member of the speaker's bureau for Edwards Lifesciences. Desiree Chappell, MSNA, CRNA, FAANA, is the Editor-in-chief and lead Anchor, TopMedTalk, a member of the speakers' bureau for Edwards Lifesciences and Medtronic, and a member of the Provation Advisory Board.

Received: 4 June 2024 Accepted: 19 April 2025
Published online: 16 May 2025

References

Ariyarathna D, Bhonsle A, Nim J, Huang CKL, Wong GH, Sim N, Hong J, Nan K, Lim AKH. Intraoperative vasopressor use and early postoperative acute kidney injury in elderly patients undergoing elective noncardiac surgery. Ren Fail. 2022;44(1):648–59. https://doi.org/10.1080/0886022X.2022.2061997.

Benes, J., Chytra, I., Altmann, P., Hluchy, M., Kasal, E., Svitak, R., Pradl, R., & Stepan, M. (2010). Intraoperative fluid optimization using stroke volume variation in high risk surgical patients: results of prospective randomized study. Critical Care (London, England). 14(3), R118. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1186/cc9070

Boekel MF, Venema CS, Kaufmann T, van der Horst ICC, Vos JJ, Scheeren TWL. The effect of compliance with a perioperative goal-directed therapy protocol on outcomes after high-risk surgery: a before-after study. J Clin Monit Comput. 2021;35(5):1193–202. https://doi.org/10.1007/s10877-020-00585-w.

Brandstrup, B., Svendsen, P. E., Rasmussen, M., Belhage, B., Rodt, S. Å., Hansen, B., Møller, D. R., Lundbech, L. B., Andersen, N., Berg, V., Thomassen, N., Andersen, S. T., & Simonsen, L. (2012). Which goal for fluid therapy during colorectal surgery is followed by the best outcome: near-maximal stroke volume or zero fluid balance? British J Anaesthesia. 109(2), 191–199. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1093/bja/aes163

Cai J, Tang M, Wu H, Yuan J, Liang H, Wu X, Xing S, Yang X, Duan XD. Association of intraoperative hypotension and severe postoperative complications during non-cardiac surgery in adult patients: a systematic review and meta-analysis. Heliyon. 2023;9(5): e15997. https://doi.org/10.1016/j.heliyon.2023.e15997.

Calvo-Vecino, J. M., Ripollés-Melchor, J., Mythen, M. G., Casans-Francés, R., Balik, A., Artacho, J. P., Martínez-Hurtado, E., Serrano Romero, A., Fernández Pérez, C., Asuero de Lis, S., & FEDORA Trial Investigators Group. Effect of goal-directed haemodynamic therapy on postoperative complications in low-moderate risk surgical patients: a multicentre randomised controlled

trial (FEDORA trial). Br J Anaesth. 2018;120(4):734–44. https://doi.org/10.1016/j.bja.2017.12.018.
Chiu C, Fong N, Lazzareschi D, Mavrothalassitis O, Kothari R, Chen LL, Pirracchio R, Kheterpal S, Domino KB, Mathis M, Legrand M. Fluids, vasopressors, and acute kidney injury after major abdominal surgery between 2015 and 2019: a multicentre retrospective analysis. Br J Anaesth. 2022;129(3):317–26. https://doi.org/10.1016/j.bja.2022.05.002.
Christensen AL, Jacobs E, Maheshwari K, Xing F, Zhao X, Simon SE, Domino KB, Posner KL, Stewart AF, Sanford JA, Sessler DI. Development and evaluation of a risk-adjusted measure of intraoperative hypotension in patients having nonemergent, noncardiac surgery. Anesth Analg. 2021;133(2):445–54. https://doi.org/10.1213/ANE.0000000000005287.
Coeckelenbergh, S., Boelefahr, S., Alexander, B., Perrin, L., Rinehart, J., Joosten, A., & Barvais, L. (2024). Closed-loop anesthesia: foundations and applications in contemporary perioperative medicine. J Clin Monitor Comput. 38(2), 487–504. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1007/s10877-023-01111-4
Colantonio, L., Claroni, C., Fabrizi, L., Marcelli, M. E., Sofra, M., Giannarelli, D., Garofalo, A., & Forastiere, E. (2015). A randomized trial of goal directed vs. standard fluid therapy in cytoreductive surgery with hyperthermic intraperitoneal chemotherapy. J Gastrointestinal Surg: Official J Soc Surg Alimentary Tract. 19(4), 722–729. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1007/s11605-015-2743-1
Corcoran T, Rhodes JE, Clarke S, Myles PS, Ho KM. Perioperative fluid management strategies in major surgery: a stratified meta-analysis. Anesth Analg. 2012;114(3):640–51. https://doi.org/10.1213/ANE.0b013e318240d6eb.
Davies SJ, Mythen M. Hemodynamic and Intestinal Microcirculatory Changes in a Phenylephrine Corrected Porcine Model of Hemorrhage. Anesth Analg. 2021;133(4):1060–9. https://doi.org/10.1213/ANE.0000000000005388.
Davies SJ, Vistisen ST, Jian Z, Hatib F, Scheeren TWL. Ability of an arterial waveform analysis-derived hypotension prediction index to predict future hypotensive events in surgical patients. Anesth Analg. 2020;130(2):352–9. https://doi.org/10.1213/ANE.0000000000004121.
Duan W, Zhou CM, Yang JJ, Zhang Y, Li ZP, Ma DQ, Yang JJ. A long duration of intraoperative hypotension is associated with postoperative delirium occurrence following thoracic and orthopedic surgery in elderly. J Clin Anesth. 2023;88:111125. https://doi.org/10.1016/j.jclinane.2023.111125.
de Keijzer IN, Vos JJ, Yates D, Reynolds C, Moore S, Lawton RJ, Scheeren TWL, Davies SJ. Impact of clinicians' behavior, an educational intervention with mandated blood pressure and the hypotension prediction index software on intraoperative hypotension: a mixed methods study. J Clin Monitor Comput. 2023;38(2):325–35. https://doi-org.uab.idm.oclc.org/, https://doi.org/10.1007/s10877-023-01097-z
Edwards Lifesciences. (2024, April 11). *Acumen IQ sensor: unlock continuous access to predictive decision support.* https://www.edwards.com/healthcare-professionals/products-services/predictive-monitoring/acumen-iq-sensor
Frassanito, L., Giuri, P. P., Vassalli, F., Piersanti, A., Garcia, M. I. M., Sonnino, C., Zanfini, B. A., Catarci, S., Antonelli, M., & Draisci, G. (2023). Hypotension prediction index guided goal directed therapy and the amount of hypotension during major gynaecologic oncologic surgery: a randomized controlled clinical trial. J Clin Monitor Comput. 37(4), 1081–1093. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1007/s10877-023-01017-1
French WB, Rothstein WB, Scott MJ. Time to use peripheral norepinephrine in the operating room. Anesth Analg. 2021;133(1):284–8. https://doi.org/10.1213/ANE.0000000000005558.
French WB, Scott M. Fluid and hemodynamics. Anesthesiol Clin. 2022;40(1):59–71. https://doi.org/10.1016/j.anclin.2021.11.002.
Futier, E., Lefrant, J. Y., Guinot, P. G., Godet, T., Lorne, E., Cuvillon, P., Bertran, S., Leone, M., Pastene, B., Piriou, V., Molliex, S., Albanese, J., Julia, J. M., Tavernier, B., Imhoff, E., Bazin, J. E., Constantin, J. M., Pereira, B., Jaber, S., & INPRESS Study Group. Effect of individualized vs standard blood pressure management strategies on postoperative organ dysfunction among high-risk patients undergoing major surgery: a randomized clinical trial. J Am Med Assoc. 2017;318(14):1346–57. https://doi.org/10.1001/jama.2017.14172.
Giglio, M., Dalfino, L., Puntillo, F., & Brienza, N. (2019). Hemodynamic goal-directed therapy and postoperative kidney injury: an updated meta-analysis with trial sequential analysis. Critical Care (London, England). 23(1), 232. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1186/s13054-019-2516-4
Gregory A, Stapelfeldt W, Khanna A, et al. Intraoperative hypotension is associated with adverse clinical outcomes after noncardiac surgery. Anesth Analg. 2020;x(x):1–12. https://doi.org/10.1213/ANE.0000000000005250
Hamilton-Davies C, Mythen MG, Salmon JB, Jacobson D, Shukla A, Webb AR. Comparison of commonly used clinical indicators of hypovolaemia with gastrointestinal tonometry. Intensive Care Med. 1997;23(3):276–81. https://doi.org/10.1007/s001340050328.
Hatib F, Jian Z, Buddi S, Lee C, Settels J, Sibert K, Rinehart J, Cannesson M. Machine-learning algorithm to predict hypotension based on high-fidelity arterial pressure waveform analysis. Anesthesiology. 2018;129(4):663–74. https://doi.org/10.1097/ALN.0000000000002300.
Jessen, M. K., Vallentin, M. F., Holmberg, M. J., Bolther, M., Hansen, F. B., Holst, J. M., Magnussen, A., Hansen, N. S., Johannsen, C. M., Enevoldsen, J., Jensen, T. H., Roessler, L. L., Lind, P. C., Klitholm, M. P., Eggertsen, M. A., Caap, P., Boye, C., Dabrowski, K. M., Vormfenne, L., Høybye, M., … Andersen, L. W. (2022). Goal-directed haemodynamic therapy during general anaesthesia for noncardiac surgery: a systematic review and meta-analysis. British J Anaesthesia. 128(3), 416–433. https://doi.org/10.1016/j.bja.2021.10.046
Joosten, A., Coeckelenbergh, S., Delaporte, A., Ickx, B., Closset, J., Roumeguere, T., Barvais, L., Van Obbergh, L., Cannesson, M., Rinehart, J., & Van der Linden, P. (2018). Implementation of closed-loop-assisted intra-operative goal-directed fluid therapy during major abdominal surgery: a case-control study with propensity matching. European J Anaesthesiolo. 35(9), 650–658. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1097/EJA.0000000000000827
Joosten, A., Chirnoaga, D., Van der Linden, P., Barvais, L., Alexander, B., Duranteau, J., Vincent, J. L., Cannesson, M., & Rinehart, J. (2021a). Automated closed-loop versus manually controlled norepinephrine infusion in patients undergoing intermediate- to high-risk abdominal surgery: a randomised controlled trial. British J Anaesthesia. 126(1), 210–218. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1016/j.bja.2020.08.051
Joosten, A., Rinehart, J., Van der Linden, P., Alexander, B., Penna, C., De Montblanc, J., Cannesson, M., Vincent, J. L., Vicaut, E., & Duranteau, J. (2021b). Computer-assisted individualized hemodynamic management reduces intraoperative hypotension in intermediate- and high-risk surgery: a randomized controlled trial. *Anesthesiology, 135*(2), 258–272. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1097/ALN.0000000000003807
Kim, H. J., Kim, E. J., Lee, H. J., Min, J. Y., Kim, T. W., Choi, E. C., Kim, W. S., & Koo, B. N. (2018). Effect of goal-directed haemodynamic therapy in free flap reconstruction for head and neck cancer. Acta Anaesthesiol Scandinavica. 62(7), 903–914. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1111/aas.13100
Kouz K, Brockmann L, Timmermann LM, Bergholz A, Flick M, Maheshwari K, Sessler DI, Krause L, Saugel B. Endotypes of intraoperative hypotension during major abdominal surgery: a retrospective machine learning analysis of an observational cohort study. Br J Anaesth. 2023a;130(3):253–61. https://doi.org/10.1016/j.bja.2022.07.056.
Kouz K, Monge García MI, Cerutti E, Lisanti I, Draisci G, Frassanito L, Sander M, Ali Akbari A, Frey UH, Grundmann CD, Davies SJ, Donati A, Ripolles-Melchor J, García-López D, Vojnar B, Gayat É, Noll E, Bramlage P, Saugel B. Intraoperative hypotension when using hypotension prediction index software during major noncardiac surgery: a European multicentre prospective observational registry (EU HYPROTECT). British Journal of Anesthesia Open. 2023b;6: 100140. https://doi.org/10.1016/j.bjao.2023.100140.
Kumar, S., Puri, G. D., Mathew, P. J., & Mandal, B. (2022). Evaluation of indigenously developed closed-loop automated blood pressure control system (claps): a preliminary study. J Clin Monitor Computing. 36(6), 1657–1665. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1007/s10877-022-00810-8
Li W, Hu Z, Yuan Y, Liu J, Li K. Effect of hypotension prediction index in the prevention of intraoperative hypotension during noncardiac surgery: a systematic review. J Clin Anesth. 2022;83: 110981. https://doi.org/10.1016/j.jclinane.2022.110981.
Lorente, J., Ripollés-Melchor, J., Jiménez, I., Becerra, A., Mojarro, I., Fernández-Valdes-Bango, P., Fuentes, M., Moreno, A., Agudelo, M., Villar-Pellit de la Vega, A., Ruiz-Escobar, A., Cortés, A., Venturoli, R., Quintero, A., Acedo, G., Abad-Motos, A., Gómez, P., Abad-Gurumeta, A., & Monge-García, M. (2023). Intraoperative hemodynamic optimization using the hypotension

prediction index vs. goal-directed hemodynamic therapy during elective major abdominal surgery: the predict-H multicenter randomized controlled trial. Front Anesthesiol. 2:1193886. https://doi.org/10.3389/fanes.2023.1193886

Luo, J., Xue, J., Liu, J., Liu, B., Liu, L., & Chen, G. (2017). Goal-directed fluid restriction during brain surgery: a prospective randomized controlled trial. Ann Intensive Care. 7(1), 16. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1186/s13613-017-0239-8

Maheshwari K, Ahuja S, Khanna AK, Mao G, Perez-Protto S, Farag E, Turan A, Kurz A, Sessler DI. Association between perioperative hypotension and delirium in postoperative critically ill patients: a retrospective cohort analysis. Anesth Analg. 2020a;130(3):636–43. https://doi.org/10.1213/ANE.0000000000004517.

Maheshwari, K., Shimada, T., Yang, D., Khanna, S., Cywinski, J. B., Irefin, S. A., Ayad, S., Turan, A., Ruetzler, K., Qiu, Y., Saha, P., Mascha, E. J., & Sessler, D. I. (2020b). Hypotension prediction index for prevention of hypotension during moderate- to high-risk noncardiac surgery. Anesthesiol. 133(6), 1214–1222. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1097/ALN.0000000000003557

Martin, G. S., Kaufman, D. A., Marik, P. E., Shapiro, N. I., Levett, D. Z. H., Whittle, J., MacLeod, D. B., Chappell, D., Lacey, J., Woodcock, T., Mitchell, K., Malbrain, M. L. N. G., Woodcock, T. M., Martin, D., Imray, C. H. E., Manning, M. W., Howe, H., Grocott, M. P. W., Mythen, M. G., Gan, T. J., … Miller, T. E. (2020). Perioperative Quality Initiative (POQI) consensus statement on fundamental concepts in perioperative fluid management: fluid responsiveness and venous capacitance. Perioperative Medicine (London, England). 9, 12. https://doi.org/10.1186/s13741-020-00142-8

Miller TE, Myles PS. Perioperative Fluid Therapy for Major Surgery. Anesthesiology. 2019;130(5):825–32. https://doi.org/10.1097/ALN.0000000000002603.

Miller, T. E., Roche, A. M., & Mythen, M. (2015). Fluid management and goal-directed therapy as an adjunct to Enhanced Recovery After Surgery (ERAS). Canadian J Anesthesia. 62(2), 158–168. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1007/s12630-014-0266-y

Mukkamala, R., Schnetz, M. P., Khanna, A. K., & Mahajan, A. (2024). Intraoperative hypotension prediction: current methods, controversies, and research outlook. *Anesthesia and Analgesia*, https://doi.org/10.1213/ANE.0000000000007216. Advance online publication. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1213/ANE.0000000000007216

Myles, P. S., Bellomo, R., Corcoran, T., Forbes, A., Peyton, P., Story, D., Christophi, C., Leslie, K., McGuinness, S., Parke, R., Serpell, J., Chan, M. T. V., Painter, T., McCluskey, S., Minto, G., Wallace, S., & Australian and New Zealand College of Anaesthetists Clinical Trials Network and the Australian and New Zealand Intensive Care Society Clinical Trials Group. Restrictive versus liberal fluid therapy for major abdominal surgery. N Engl J Med. 2018;378(24):2263–74. https://doi.org/10.1056/NEJMoa1801601.

OPTIMISE II Trial Group. Cardiac output-guided haemodynamic therapy for patients undergoing major gastrointestinal surgery: OPTIMISE II randomised clinical trial. Br Med J (Clin Res Ed). 2024;387: e080439. https://doi.org/10.1136/bmj-2024-080439.

Ostermann, M., Auzinger, G., Grocott, M., Morton-Bailey, V., Raphael, J., Shaw, A. D., Zarbock, A., & POQI XI Investigators (2024). Perioperative fluid management: evidence-based consensus recommendations from the international multidisciplinary PeriOperative Quality Initiative. British J Anaesthesia. 133(6), 1263–1275. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1016/j.bja.2024.07.038

Pearse, R. M., Harrison, D. A., MacDonald, N., Gillies, M. A., Blunt, M., Ackland, G., Grocott, M. P., Ahern, A., Griggs, K., Scott, R., Hinds, C., Rowan, K., & OPTIMISE Study Group (2014). Effect of a perioperative, cardiac output-guided hemodynamic therapy algorithm on outcomes following major gastrointestinal surgery: a randomized clinical trial and systematic review. J American Med Assoc. 311(21), 2181–2190. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1001/jama.2014.5305

Perel A. Using dynamic variables to guide perioperative fluid management. Anesthesiology. 2020;133(4):929–35. https://doi.org/10.1097/ALN.0000000000003408.

Pestaña, D., Espinosa, E., Eden, A., Nájera, D., Collar, L., Aldecoa, C., Higuera, E., Escribano, S., Bystritski, D., Pascual, J., Fernández-Garijo, P., de Prada, B., Muriel, A., & Pizov, R. (2014). Perioperative goal-directed hemodynamic optimization using noninvasive cardiac output monitoring in major abdominal surgery: a prospective, randomized, multicenter, pragmatic trial: POEMAS Study (PeriOperative goal-directed therapy in Major Abdominal Surgery). Anesthesia and Analgesia. 119(3), 579–587. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1213/ANE.0000000000000295

Putowski Z, Czajka S, Krzych ŁJ. Association between intraoperative blood pressure drop and clinically significant hypoperfusion in abdominal surgery: a cohort study. J Clin Med. 2021;10(21):5010. https://doi.org/10.3390/jcm10215010.

Ranucci, M., Barile, L., Ambrogi, F., Pistuddi, V., & Surgical and Clinical Outcome Research (SCORE) Group (2019). Discrimination and calibration properties of the hypotension probability indicator during cardiac and vascular surgery. Minerva Anestesiol. 85(7), 724–730. https://doi.org/10.23736/S0375-9393.18.12620-4

Ripollés, J., Espinosa, A., Martínez-Hurtado, E., Abad-Gurumeta, A., Casans-Francés, R., Fernández-Pérez, C., López-Timoneda, F., Calvo-Vecino, J. M., & EAR Group (Evidence Anestesia Review Group). Intraoperative goal directed hemodynamic therapy in noncardiac surgery: a systematic review and meta-analysis. Brazilian Journal of Anesthesiology (Elsevier). 2016;66(5):513–28. https://doi.org/10.1016/j.bjane.2015.02.001.

Tote, S. P., & Grounds, R. M. (2006). Performing perioperative optimization of the high-risk surgical patient. British J Anaesthesia. 97(1), 4–11. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1093/bja/ael102

Salzwedel, C., Puig, J., Carstens, A., Bein, B., Molnar, Z., Kiss, K., Hussain, A., Belda, J., Kirov, M. Y., Sakka, S. G., & Reuter, D. A. (2013). Perioperative goal-directed hemodynamic therapy based on radial arterial pulse pressure variation and continuous cardiac index trending reduces postoperative complications after major abdominal surgery: a multi-center, prospective, randomized study. Critical Care (London, England). 17(5), R191. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1186/cc12885

Saugel, B., Fletcher, N., Gan, T. J., Grocott, M. P. W., Myles, P. S., Sessler, D. I., & PeriOperative Quality Initiative XI (POQI XI) Workgroup Members (2024). PeriOperative Quality Initiative (POQI) international consensus statement on perioperative arterial pressure management. British J Anaesthesia. 133(2), 264–276. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1016/j.bja.2024.04.046

Saugel B, Kouz K, Hoppe P, Maheshwari K, Scheeren TWL. Predicting hypotension in perioperative and intensive care medicine. Best Pract Res Clin Anaesthesiol. 2019;33(2):189–97. https://doi.org/10.1016/j.bpa.2019.04.001.

Saasouh W, Christensen AL, Xing F, Chappell D, Lumbley J, Woods B, Mythen M, Dutton RP. Incidence of intraoperative hypotension during non-cardiac surgery in community anesthesia practice: a retrospective observational analysis. Perioperative Medicine (London, England). 2023;12(1):29. https://doi.org/10.1186/s13741-023-00318-y.

Salmasi V, Maheshwari K, Yang D, Mascha EJ, Singh A, Sessler DI, Kurz A. Relationship between intraoperative hypotension, defined by either reduction from baseline or absolute thresholds, and acute kidney and myocardial injury after noncardiac surgery: a retrospective cohort analysis. Anesthesiology. 2017;126(1):47–65. https://doi.org/10.1097/ALN.0000000000001432.

Scott, M. J., & Anesthesia Patient Safety Foundation (APSF) Hemodynamic Instability Writing Group. Perioperative patients with hemodynamic instability: consensus recommendations of the anesthesia patient safety foundation. Anesth Analg. 2024;138(4):713–24. https://doi.org/10.1213/ANE.0000000000006789.

Sessler DI, Bloomstone JA, Aronson S, Berry C, Gan TJ, Kellum JA, Plumb J, Mythen MG, Grocott MPW, Edwards MR, Miller TE, Perioperative quality initiative-3 workgroup, POQI chairs, Miller, T. E., Mythen, M. G., Grocott, M. P., Edwards, M. R., Physiology group, Preoperative blood pressure group, Intraoperative blood pressure group, … Postoperative blood pressure group,. Perioperative Quality Initiative consensus statement on intraoperative blood pressure, risk and outcomes for elective surgery. Br J Anaesth. 2019;122(5):563–74. https://doi.org/10.1016/j.bja.2019.01.013.

Shah NJ, Mentz G, Kheterpal S. The incidence of intraoperative hypotension in moderate to high risk patients undergoing non-cardiac surgery: a retrospective multicenter observational analysis. J Clin Anesth. 2020;66: 109961. https://doi.org/10.1016/j.jclinane.2020.109961.

Spataru, A., Eiben, P., & Pluddemann, A. (2024). Performance of closed-loop systems for intravenous drug administration: a systematic review and meta-analysis of randomised controlled trials. J Clin Monitor Comput.

38(1), 5–18. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1007/s10877-023-01069-3
Srinivasa, S., Taylor, M. H., Singh, P. P., Yu, T. C., Soop, M., & Hill, A. G. (2013). Randomized clinical trial of goal-directed fluid therapy within an enhanced recovery protocol for elective colectomy. The British J Surg. 100(1), 66–74. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1002/bjs.8940
Stapelfeldt WH, Khanna AK, Shaw AD, Shenoy AV, Hwang S, Stevens M, Smischney NJ. Association of perioperative hypotension with subsequent greater healthcare resource utilization. J Clin Anesth. 2021;75: 110516. https://doi.org/10.1016/j.jclinane.2021.110516.
Sun, Y., Chai, F., Pan, C., Romeiser, J. L., & Gan, T. J. (2017). Effect of perioperative goal-directed hemodynamic therapy on postoperative recovery following major abdominal surgery-a systematic review and meta-analysis of randomized controlled trials. Critical Care (London, England). 21(1), 141. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1186/s13054-017-1728-8
Vincent, J. L., Cecconi, M., & De Backer, D. (2020). The fluid challenge. Critical Care (London, England). 24(1), 703. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1186/s13054-020-03443-y
Vistisen, S. T., & Enevoldsen, J. (2024). CON: the hypotension prediction index is not a validated predictor of hypotension. Europ J Anaesthesiol. 41(2), 118–121. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1097/EJA.0000000000001939
Wesselink EM, Kappen TH, Torn HM, Slooter AJC, van Klei WA. Intraoperative hypotension and the risk of postoperative adverse outcomes: a systematic review. Br J Anaesth. 2018;121(4):706–21. https://doi.org/10.1016/j.bja.2018.04.036.
Wijnberge M, Geerts BF, Hol L, Lemmers N, Mulder MP, Berge P, Schenk J, Terwindt LE, Hollmann MW, Vlaar AP, Veelo DP. Effect of a machine learning-derived early warning system for intraoperative hypotension vs standard care on depth and duration of intraoperative hypotension during elective noncardiac surgery: the HYPE randomized clinical trial. Journal of American Medical Association. 2020;323(11):1052–60. https://doi.org/10.1001/jama.2020.0592.
Yang, S. M., Cho, H. Y., Lee, H. C., & Kim, H. S. (2023). Performance of the Hypotension Prediction Index in living donor liver transplant recipients. Minerva Anestesiol. 89(5), 387–395. https://doi-org.uab.idm.oclc.org/https://doi.org/10.23736/S0375-9393.23.16710-1
Yerdon A, Woodfin K, Richey R, McMullan S. Predicting intraoperative hypotension (IOH): an intraoperative case report. American Association of Nurse Anesthesiology Journal: In press; 2024.
Zhang N, Liang M, Zhang DD, Xiao YR, Li YZ, Gao YG, Cai HD, Lin XZ, Lin CZ, Zeng K, Wu XD. Effect of goal-directed fluid therapy on early cognitive function in elderly patients with spinal stenosis: a case-control study. International Journal of Surgery (London, England). 2018;54(Pt A):201–5. https://doi.org/10.1016/j.ijsu.2018.04.007.
Zheng, H., Guo, H., Ye, J. R., Chen, L., & Ma, H. P. (2013). Goal-directed fluid therapy in gastrointestinal surgery in older coronary heart disease patients: randomized trial. World J Surg. 37(12), 2820–2829. https://doi-org.uab.idm.oclc.org/https://doi.org/10.1007/s00268-013-2203-6

Publisher's Note