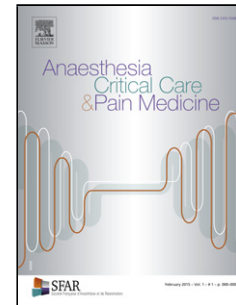


Journal Pre-proof

Continuous versus intermittent non-invasive blood pressure monitoring and intraoperative hypotension: a systematic review and meta-analysis

Pasquale Rinaldi, Marta Di Folco, Vincenzo Fotticchia



PII: S2352-5568(26)00167-0

DOI: <https://doi.org/10.1016/j.accpm.2026.101909>

Reference: ACCPM 101909

To appear in: *Anaesthesia Critical Care & Pain Medicine*

Accepted Date: 12 August 2026

Please cite this article as: Rinaldi P, Di Folco M, Fotticchia V, Continuous versus intermittent non-invasive blood pressure monitoring and intraoperative hypotension: a systematic review and meta-analysis, *Anaesthesia Critical Care and Pain Medicine* (2026), doi: <https://doi.org/10.1016/j.accpm.2026.101909>

This is a PDF file of an article that has undergone enhancements after acceptance, such as the addition of a cover page and metadata, and formatting for readability, but it is not yet the definitive version of record. This version will undergo additional copyediting, typesetting and review before it is published in its final form, but we are providing this version to give early visibility of the article. Please note that, during the production process, errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

© 2026 Published by Elsevier Masson SAS on behalf of Société française d'anesthésie et de réanimation (SFAR).

Continuous Versus Intermittent Non-invasive Blood Pressure Monitoring and Intraoperative Hypotension: A Systematic Review and Meta-analysis

Pasquale Rinaldi¹, Marta Di Folco², Vincenzo Fotticchia^{3*}

¹ Department of Anesthesiology, Unit of Emergency Anesthesia, Burn Intensive Care and Poison Control Center, AORN Antonio Cardarelli, Naples, Italy

² Unit of Anesthesiology and Intensive Care, IRCCS Regina Elena National Cancer Institute, Rome, Italy

³ Department of Clinical Medicine and Surgery, Section of Infectious Diseases, University of Naples Federico II, Naples, Italy

E-mail:

¹ pasquale.rinaldi1994@gmail.com

² marta.difolco@ifo.it

³ vincenzo.fotticchia@unina.it * [corresponding author]

Registration: PROSPERO (CRD420261415758).

ABSTRACT

Background: Intraoperative hypotension is associated with postoperative morbidity and mortality. Standard intermittent oscillometric blood pressure monitoring may fail to detect short-lived hypotensive episodes occurring between measurement cycles. Continuous non-invasive finger-cuff monitoring provides beat-to-beat arterial pressure assessment and may reduce cumulative hypotension exposure. This systematic review and meta-analysis evaluated the effect of continuous versus intermittent non-invasive blood pressure monitoring on intraoperative hypotension and related perioperative outcomes.

Methods: A systematic search of PubMed/MEDLINE, Scopus, and Web of Science was conducted in June 2026. Randomized controlled trials comparing continuous non-invasive finger-cuff blood pressure monitoring with intermittent oscillometric upper-arm cuff monitoring in adults undergoing procedures under anesthesia or procedural sedation were included. Random-effects meta-analyses were performed for outcomes with sufficiently comparable data. Effect estimates were reported as risk ratios (RRs) for dichotomous outcomes and standardized mean differences (SMDs) for continuous outcomes. Risk of bias was assessed using the Cochrane RoB 2 tool, and certainty of evidence was evaluated using GRADE.

Results: Twelve randomized controlled trials were included, enrolling 1,466 randomized patients, of whom 1,340 contributed to the eligible comparison arms. Ten studies including 1,126 patients contributed to the meta-analysis of intraoperative hypotension incidence. Continuous monitoring was not associated with a statistically significant reduction in the incidence of intraoperative hypotension compared with intermittent oscillometric monitoring (RR 0.90, 95% CI 0.77–1.04; $p = 0.141$; $I^2 = 58.2\%$). However, it was associated with a lower time-weighted average of hypotension (SMD -0.42 , 95% CI -0.64 to -0.20 ; $p = 0.0002$; $I^2 = 56.5\%$) and lower AUT/AUC-derived hypotension burden (SMD -0.40 , 95% CI -0.58 to -0.23 ; $p < 0.0001$; $I^2 = 29.9\%$). Postoperative nausea was not significantly reduced (RR 0.81, 95% CI 0.51–1.28; $p = 0.288$), whereas postoperative vomiting was less frequent with continuous monitoring (RR 0.62, 95% CI 0.42–0.92; $p = 0.027$), although event

numbers were low. Treatment-related and safety outcomes were summarized narratively because of heterogeneous reporting. The certainty of evidence ranged from very low to low.

Conclusions: Continuous non-invasive finger-cuff blood pressure monitoring did not significantly reduce the binary incidence of intraoperative hypotension compared with intermittent oscillometric monitoring. However, it was associated with lower cumulative hypotension exposure, as reflected by TWA and AUT/AUC-based metrics. These findings suggest that continuous monitoring may improve the recognition and management of intraoperative hypotension, although the certainty of evidence remains limited. Further high-quality randomized trials using standardized hypotension definitions are warranted.

KEYWORDS: Intraoperative hypotension; Continuous blood pressure monitoring; Finger-cuff technology; Oscillometric monitoring; Hemodynamic monitoring; Meta-analysis

Introduction

Maintaining intraoperative hemodynamic stability is essential during perioperative care, as fluctuations in blood pressure can severely compromise tissue perfusion. Among these, intraoperative hypotension (IOH) represents a critical challenge; a meta-analysis of 130,862 patients by Wijnberge *et al.* [1] demonstrated that IOH during non-cardiac surgery is associated with adverse postoperative outcomes. The risk appears to be related to both the severity and duration of hypotension.

Indeed, Gu *et al.* [2] confirmed IOH as an independent predictor of short-term 30-day mortality and major adverse cardiac events. Regarding the duration of hypotension, An *et al.* [3] revealed that a mean arterial pressure (MAP) dropping below 60 mmHg for as little as 1 to 5 minutes is associated with an increased risk of acute kidney injury and myocardial injury, with this association becoming stronger as exposure exceeds 5 minutes. These findings highlight the importance of timely detection and management of intraoperative hypotension, while suggesting that both the severity and duration of hypotensive episodes may be clinically relevant.

Standard intermittent non-invasive blood pressure monitoring via an automated oscillometric upper-arm cuff remains the conventional approach in most clinical settings, typically cycling at 3-to-5-minute intervals. However, this intermittent tracking creates temporal blind spots, leaving rapid drops in MAP undetected between inflation cycles. Continuous non-invasive hemodynamic monitoring technologies have been developed to overcome these limitations. Utilizing a finger-cuff based on automated volume-clamp technology, these devices provide real-time, beat-by-beat monitoring of arterial pressure [4]. This continuous tracking facilitates shorter response times to acute hemodynamic changes without the vascular and infectious risks associated with invasive arterial lines. Furthermore, beyond standard blood pressure metrics, these systems track advanced parameters such as stroke volume and stroke volume variation, which can guide intraoperative fluid and vasopressor administration.

Evidence from non-intensive care hospital wards suggests that continuous vital sign monitoring significantly improves patient outcomes, showing a 39% reduction in mortality risk compared to standard intermittent assessments [5]. However, the clinical impact of continuous beat-to-beat monitoring specifically within the intraoperative setting remains debated, with individual trials reporting conflicting results regarding the total burden of hypotension and subsequent fluid or vasopressor management. Although continuous finger-cuff technologies offer a clear theoretical advantage in preventing hidden hypotensive windows, a comprehensive synthesis of their efficacy and safety during anesthesia is still lacking. Therefore, this systematic review and meta-analysis aims to evaluate the effect of continuous finger-cuff monitoring compared to standard intermittent

oscillometric cuffs on the overall burden of intraoperative hypotension, fluid and vasopressor administration, and device-related safety in adult patients undergoing anesthesia.

Methods

Study design and registration

This study was conducted according to PRISMA guidelines [6] and registered in the PROSPERO database (CRD420261415758). The framework of the review was structured around following PICO components as follow: (population) adult patients aged 18 years or older, undergoing surgical or non-surgical procedures requiring general anesthesia, regional anesthesia, or procedural sedation across any hospital clinical setting; (intervention) continuous non-invasive arterial blood pressure monitoring using finger-cuff technology (*e.g.*, ClearSight, CNAP), providing real-time, beat-to-beat hemodynamic data to clinicians during the procedure; (comparator) standard intermittent non-invasive blood pressure monitoring using an automated oscillometric upper-arm cuff; (outcomes) overall burden of intraoperative hypotension, intraoperative management (fluid and vasopressor administration), hemodynamic stability metrics, and device performance/safety.

Eligibility criteria

Peer-reviewed research articles were selected for eligibility based on the following inclusion criteria: 1) randomized controlled trials (RCTs); 2) adult patients undergoing procedures under general anesthesia, regional anesthesia, or procedural sedation; 3) studies comparing continuous finger-cuff technologies directly against standard intermittent oscillometric upper-arm cuffs.

Studies were excluded if they evaluated intensive arterial lines without a finger-cuff continuous non-invasive comparator arm. Case series, case reports, retrospective cohort studies, letters to the editor, conference reports, and abstracts were excluded. Only studies published in the English language were sought.

Search strategy

A systematic search was conducted in the PubMed/MEDLINE, Scopus, and Web of Science databases in June 2026. No restrictions were applied regarding publication date. Only full-text articles published in English were eligible for inclusion. The following search strategy was used: ("finger cuff" OR "continuous non-invasive" OR "continuous noninvasive" OR ClearSight OR Nexfin OR CNAP OR Finapres) AND ("intermittent" OR "NIBP" OR "oscillometr*" OR "blood pressure cuff"). The compilation of articles retrieved from the systematic search was uploaded to Rayyan (<https://www.rayyan.ai>) and screened independently by at least two reviewers to resolve potential differences. After the automatic elimination of duplicates, the remaining titles and abstracts were independently checked by the reviewers. Potentially eligible articles meeting the predefined criteria were selected for full-text screening, which was conducted independently by two reviewers. Any disagreements during the screening and eligibility phase were discussed and resolved by a third experienced reviewer. The final eligibility list was checked by all authors, and the reasons for study exclusions were thoroughly recorded.

Data extraction

Data from the eligible published papers were extracted independently by two authors using a standardized data collection form, with a process to resolve differences through team consensus. When necessary, study investigators were contacted to request required data that were unclear or unavailable in the published reports.

The following information was systematically recorded:

- Study characteristics: Authors, publication years, study design, country, setting and type of procedure (*e.g.*, operating theater, intervention suites, acute care), anesthesia type, and sample size;

- Demographic characteristics: Age, sex, ASA physical status, hypertension, and diabetes when reported;
- Intervention details: Specific finger-cuff device used and cycling intervals of the control intermittent cuff;
- Main outcomes: intraoperative hypotension-related outcomes, including the incidence of patients experiencing at least one hypotensive episode, the time-weighted average (TWA) of hypotension below predefined blood pressure thresholds, and hypotension burden assessed through area under the curve (AUC) or area under the threshold (AUT) metrics. When reported, cumulative duration of hypotension, number of hypotensive episodes, time below threshold, and time to detection or treatment of hypotension were also extracted;
- Additional outcomes: Intraoperative therapeutic interventions (cumulative vasopressor/inotrope doses, total volume of intravenous fluid crystalloids or colloids infused); hemodynamic stability metrics (incidences of severe hypertension, tachycardia, or bradycardia requiring intervention); and device performance/safety (frequency of local finger pain, skin lesions, or technical signal failure rates).

Risk of bias assessment

The methodological quality and risk of bias of the included RCTs were assessed independently by two reviewers using the Cochrane Risk of Bias 2.0 (RoB 2) tool. The assessment covered the five standard domains: randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result. Each domain was rated as *low risk of bias*, *some concerns*, or *high risk of bias* based on standard signaling questions and domain-level algorithms. An overall risk of bias judgement was produced for each study. Disagreements between reviewers were resolved by discussion or by consulting a third reviewer. Risk of bias assessments were summarized visually using traffic-light and summary plots. All randomized studies included in the systematic review underwent risk-of-bias assessment using the RoB 2 tool, including studies summarized narratively.

Statistical analysis

Quantitative synthesis was planned for outcomes where data were extracted in a sufficiently comparable format across trials. Consistent with the registered protocol, the primary outcome was the overall burden of intraoperative hypotension, assessed using the hypotension-related metrics available across studies. Quantitative synthesis was feasible for three primary hypotension-related outcomes: incidence of intraoperative hypotension, time-weighted average of hypotension, and AUT/AUC-derived hypotension burden. Among additional outcomes, postoperative nausea and postoperative vomiting were sufficiently comparable across studies to be meta-analysed. Other predefined additional outcomes, including vasopressor or inotrope use/dose, fluid administration, haemodynamic stability metrics, clinical complications, and device-related safety or performance outcomes, were summarized narratively because of heterogeneity in definitions, measurement units, time windows, clinical thresholds, and reporting. For continuous outcomes, the primary meta-analysis was based on means and standard deviations. Mean differences (MDs) or standardized mean differences (SMDs) with corresponding 95% confidence intervals (CIs) were calculated according to the comparability of measurement scales across studies. When means and standard deviations were not directly reported, they were estimated from medians, ranges, and/or interquartile ranges using the method proposed by Wan *et al.* [7]. Sensitivity analyses using median differences were conducted when sufficient median-based summary data were available. For dichotomous outcomes, risk ratios (RRs) with 95% CIs were computed. Statistical significance for all pooled estimates was defined as a two-sided p -value < 0.05 . Due to anticipated clinical diversity arising from variations in surgical

cohorts, anesthesia techniques, and procedural settings, a random-effects model was selected as the primary approach to pool data and account for between-study variance. Between-study heterogeneity was formally assessed and quantified using the I^2 statistic and Cochran's Q test. Studies that reported valuable clinical findings but presented data using non-standardized metrics or formats incompatible with quantitative pooling were not eligible for quantitative synthesis and were therefore summarized using a structured narrative approach based on population, intervention, comparator, and outcome domains. Publication bias was assessed through visual inspection of funnel plots and Egger's regression asymmetry test only when at least 10 studies were available for a specific synthesis. All analyses were performed using R software, version 4.4.2 (2024-10-31; R Foundation for Statistical Computing, Vienna, Austria).

Certainty of evidence

The certainty of evidence for the outcomes included in the Summary of Findings table was independently evaluated by the reviewers using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach. This framework considers five domains that may lead to downgrading the certainty of evidence: risk of bias, inconsistency, indirectness, imprecision, and publication bias. Potential downgrades of one or two levels were applied based on domain-specific assessments. Any disagreements during the grading process were resolved through discussion or by consultation with a third reviewer. The final certainty of evidence was categorized as high, moderate, low, or very low. Studies summarized narratively were not included in the GRADE assessment because they did not contribute data to the pooled outcome estimates included in the Summary of Findings table.

Results

Study selection

A total of 712 records were initially identified from PubMed/MEDLINE, Scopus, and Web of Science. After removing 241 duplicates, 471 records were screened by title and abstract (Fig. 1). Of these, 457 records were excluded because they did not meet the predefined eligibility criteria. Fourteen full-text reports were sought for retrieval, and all were successfully obtained. After full-text assessment, two reports were excluded: one because it was not written in English and one because the intervention was based on a predictive machine-learning algorithm rather than continuous non-invasive finger-cuff blood pressure monitoring alone. Therefore, 12 randomized controlled trials were included in the systematic review.

Study characteristics

The main characteristics of the included studies are summarized in Table 1. All included studies were randomized controlled trials comparing continuous non-invasive arterial pressure monitoring with intermittent oscillometric upper-arm cuff monitoring, published between 2014 [8] and 2026 [9,10] and conducted across Europe [8,11–15], Asia [9,10,16,17], and the United States [18,19]. Overall, 1,466 patients were randomized across the included trials, and 1,340 patients from eligible comparison arms were included in the analyses summarized in this review. The included trials covered heterogeneous perioperative settings, including elective cesarean delivery [9–11,16,18], non-cardiac surgery [12,19], orthopedic surgery [14], spinal surgery [13], shoulder arthroscopy [15], surgery in the upright position [8], and total knee arthroplasty [17]. Continuous monitoring was performed using finger-cuff technologies, mainly ClearSight, CNAP, Acumen IQ/HemoSphere, or related platforms, and was compared with intermittent oscillometric upper-arm cuff monitoring at

intervals ranging from 1 to 5 minutes, sometimes adjustable according to clinical instability. Of the 12 studies included in the systematic review, 10 were included in the quantitative synthesis for the primary dichotomous outcome. Two studies were summarized narratively because their outcome data were not suitable for pooling in the primary meta-analysis. In particular, Meidert *et al.* [14] reported hypotensive readings rather than patient-level event data, while Kukralova *et al.* [13] evaluated an individualized goal-directed haemodynamic management strategy based on extended continuous monitoring. Shih *et al.* [10] was the only three-arm randomized trial; for the quantitative synthesis, only the continuous monitoring and oscillometric monitoring arms were included, while the HPI-guided arm was excluded from the main analysis because it represented a predictive haemodynamic management strategy. Further baseline characteristics, including the number of male participants, ASA physical status distribution, and the prevalence of hypertension and diabetes, are provided in Supplementary Table S1.

Definitions of intraoperative hypotension and extracted outcome domains varied substantially across studies. Hypotension definitions included absolute MAP thresholds, relative reductions from baseline SAP or SBP, and study-specific haemodynamic targets. The hypotension definitions, main hypotension outcomes, treatment-related outcomes, and clinical/safety outcomes extracted from each study are mapped in Supplementary Table S2.

Studies included in the qualitative synthesis only

Two randomized studies were included in the systematic review but were not included in the quantitative synthesis because their outcome data were not suitable for pooling. Meidert *et al.* [14] evaluated continuous non-invasive blood pressure monitoring with ClearSight compared with intermittent oscillometric monitoring in 160 patients with chronic hypertension undergoing orthopedic surgery under general anesthesia. Continuous monitoring was associated with improved early intraoperative blood pressure stability: MAP values were higher in the continuous monitoring group at 12 and 15 minutes after induction, and hypotensive MAP readings below 55 mmHg occurred less frequently than in the intermittent monitoring group. However, the study reported hypotensive readings rather than patient-level hypotension events, precluding inclusion in the dichotomous meta-analysis of intraoperative hypotension incidence. Fluid administration was lower in the continuous monitoring group, whereas norepinephrine dosage did not differ significantly between groups. Overall, this study supported a potential benefit of continuous monitoring on early blood pressure stability, but its outcome format was not compatible with quantitative pooling. Kukralova *et al.* [13] randomized 50 patients undergoing elective spinal surgery in the prone position to an extended continuous haemodynamic monitoring strategy based on ClearSight/EV1000 or to standard intermittent oscillometric monitoring. The intervention group had more detected hypotensive episodes per patient, higher ephedrine use, greater total fluid administration, and a more positive fluid balance, while norepinephrine use and postoperative outcomes did not differ between groups. Because the intervention combined continuous monitoring with individualized goal-directed haemodynamic management, and because the reported hypotension outcome was not directly comparable with the pooled patient-level incidence, TWA, or AUT/AUC outcomes, the study was summarized narratively.

Risk of bias assessment

Overall, 6 studies were judged to be at low risk of bias [8,9,12,15,16,19], 2 studies raised some concerns [10,17], and 4 studies were judged to be at high risk of bias [11,13,14,18]. The main methodological concerns were related to deviations from intended interventions and outcome measurement, mainly reflecting the difficulty of blinding clinicians to the assigned monitoring

strategy and the potential influence of visible continuous blood pressure values on intraoperative management. The risk of bias assessment is shown in Figure 2.

Incidence of intraoperative hypotension

Ten studies including 1,126 patients were included in the meta-analysis of intraoperative hypotension incidence (Figure 3). Compared with intermittent oscillometric upper-arm cuff monitoring, continuous non-invasive blood pressure monitoring was associated with a non-significant reduction in the risk of intraoperative hypotension (RR 0.90, 95% CI 0.77–1.04; $p = 0.141$). Between-study heterogeneity was moderate to substantial ($I^2 = 58.2\%$; Cochran's $Q p = 0.010$). The confidence interval crossed the line of no effect, indicating no statistically significant difference between groups for this dichotomous outcome.

Publication bias was assessed only for the incidence of intraoperative hypotension, as this was the only outcome including at least 10 studies. Visual inspection of the funnel plot did not suggest marked asymmetry, and Egger's regression test did not provide evidence of small-study effects ($p = 0.166$; Figure S1).

A sensitivity analysis excluding Gupta *et al.* 2016 [18], in which all patients in both groups experienced the event, yielded similar results (RR 0.88, 95% CI 0.74–1.05; $p = 0.127$; $I^2 = 59.2\%$; Cochran's $Q p = 0.012$; Figure S2). Therefore, removal of this trial did not materially change the overall conclusion.

Subgroup analysis according to anesthesia type is shown in Figure S3. Among studies conducted under spinal anesthesia [9–11,16,18], continuous monitoring was not associated with a reduction in intraoperative hypotension compared with intermittent oscillometric monitoring (RR 0.99, 95% CI 0.84–1.17; $I^2 = 38.9\%$). Among studies conducted under general anesthesia [8,12,15,17,19], the pooled estimate did not show a statistically significant difference between continuous and intermittent monitoring (RR 0.83, 95% CI 0.66–1.06; $I^2 = 66.8\%$). However, the test for subgroup differences was not statistically significant ($p = 0.097$), indicating no clear evidence that anesthesia type modified the effect of continuous monitoring on hypotension incidence.

Time-weighted average of hypotension

Five studies [9,10,12,15,19] including 867 patients contributed to the standardized meta-analysis of the time-weighted average of hypotension (Figure 4). For studies reporting this outcome as medians with interquartile ranges [9,10,15,19], means and standard deviations were estimated before pooling. Continuous monitoring was associated with a lower time-weighted average of hypotension compared with intermittent oscillometric monitoring (SMD -0.42 , 95% CI -0.64 to -0.20 ; $p = 0.0002$). Between-study heterogeneity was moderate ($I^2 = 56.5\%$; Cochran's $Q p = 0.056$). This finding should be interpreted cautiously because hypotension thresholds were not fully homogeneous across studies, with Kim *et al.* [9] using SAP $<80\%$ of baseline rather than an absolute MAP-based threshold.

A sensitivity analysis based on median differences was restricted to four studies reporting medians and interquartile ranges for TWA MAP <65 mmHg [10,12,15,19], excluding Kim *et al.* [9] because of the different hypotension threshold (Figure S4). This analysis also favoured continuous monitoring, showing a lower median TWA of hypotension in the continuous monitoring group (median difference -0.26 mmHg, 95% CI -0.50 to -0.02 ; $p = 0.037$). However, heterogeneity remained substantial ($I^2 = 66.8\%$; Cochran's $Q p = 0.020$).

Area-based hypotension exposure

Five studies [9,10,12,15,19] including 862 patients were included in the standardized meta-analysis of area-based hypotension exposure, expressed as area under the hypotension threshold or area under

the curve (Figure 5). For studies reporting area-based outcomes as medians with interquartile ranges [9,10,15,19], means and standard deviations were estimated before pooling. Continuous monitoring was associated with lower area-based hypotension exposure compared with intermittent oscillometric monitoring (SMD -0.40 , 95% CI -0.58 to -0.23 ; $p < 0.0001$). Between-study heterogeneity was low to moderate ($I^2 = 29.9\%$; Cochran's Q $p = 0.222$). This finding should be interpreted cautiously because the pooled analysis combined related but not identical area-based metrics, including different blood pressure thresholds and time windows. In particular, Kim *et al.* [9] used SAP $<80\%$ of baseline, whereas Kouz *et al.* [12] assessed area under MAP <65 mmHg only within the first 15 minutes after induction.

A sensitivity analysis restricted to three studies [10,15,19] reporting comparable median area-based hypotension exposure values did not show a statistically significant difference between groups (median difference -22.30 mmHg $\times$ min, 95% CI -46.18 to 1.58 ; $p = 0.067$; Figure S5). Heterogeneity was moderate ($I^2 = 58.7\%$; Cochran's Q $p = 0.084$). Overall, the primary standardized analysis showed a statistically significant reduction in area-based hypotension exposure, whereas the median-based sensitivity analysis did not reach statistical significance.

Secondary outcomes

Six studies [8–11,16,18], including 484 patients, reported postoperative nausea (Figure 6 A). Continuous monitoring was not associated with a statistically significant reduction in postoperative nausea compared with intermittent oscillometric monitoring (RR 0.81 , 95% CI 0.51 – 1.28 ; $p = 0.288$). Between-study heterogeneity was low to moderate ($I^2 = 25.6\%$; Cochran's Q $p = 0.243$). The confidence interval crossed the line of no effect, indicating no clear difference between groups.

The same six studies, including 484 patients, reported postoperative vomiting (T 6 B). Continuous monitoring was associated with a lower risk of postoperative vomiting compared with intermittent oscillometric monitoring (RR 0.62 , 95% CI 0.42 – 0.92 ; $p = 0.027$). No statistical heterogeneity was observed ($I^2 = 0.0\%$; Cochran's Q $p = 0.946$). This finding should be interpreted cautiously because the total number of events was low, with 38 vomiting events across all included studies. Additional treatment-related and clinical outcomes were extracted and summarized narratively. Fluid administration was reported in several studies [9–11,13–18], but definitions varied and included total intraoperative fluids, infusion volume, intravenous fluid amount, crystalloids, colloids, and pre- or post-delivery fluid administration. Similarly, vasopressor and vasoactive drug outcomes were reported using heterogeneous measures, including use or dose of ephedrine [11,13,15–19], phenylephrine [9,16–19], norepinephrine [10,12–15], atropine [10,13], and nicardipine [17], with some studies reporting timing-specific values during induction, surgery, or before and after delivery. Because these outcomes differed across trials in terms of drug type, unit of measurement, timing of assessment, and reporting format, they were not considered suitable for quantitative pooling.

Clinical and safety outcomes were also variably reported. Blood loss was reported in a limited number of studies [13–14,16–19], while other outcomes included bleeding [8], ventilation [8], intraoperative nausea and vomiting [18], breathlessness [9], bradycardia [9,10], shivering [10], and finger-cuff skin lesions [18]. Overall, no consistent pattern of device-related harm was identified across the included studies. However, these findings should be interpreted cautiously because reporting was sparse and event numbers were low for several safety outcomes.

Certainty of evidence

The certainty of evidence ranged from very low to low across outcomes (Table 2). For the incidence of intraoperative hypotension, the certainty of evidence was rated as very low because of concerns regarding risk of bias, inconsistency, and imprecision. For the time-weighted average of

intraoperative hypotension, certainty was rated as very low because of risk of bias, inconsistency, and indirectness related to differences in hypotension thresholds across studies. For area-based hypotension burden, certainty was rated as low because of risk of bias and indirectness, as studies combined related but not identical AUC/AUT-based metrics with different thresholds and time windows. Certainty was low for postoperative nausea and postoperative vomiting, mainly because of risk of bias and imprecision.

Discussion

The aim of this systematic review and meta-analysis was to evaluate whether continuous non-invasive arterial pressure monitoring using finger-cuff technology reduces intraoperative hypotension (IOH) compared with standard intermittent oscillometric blood pressure monitoring. The pooled analysis of the primary dichotomous outcome demonstrated no statistically significant difference in the binary incidence of IOH between groups (RR=0.90, 95% CI [0.77,1.04]; $p=0.14$), with moderate between-study heterogeneity ($I^2=58.2\%$, $p=0.0104$). This finding remained consistent across the subgroup analyses of spinal anesthesia and general anesthesia. The general anesthesia subgroup exhibited substantial heterogeneity, suggesting that differences in patient populations, surgical procedures, anesthetic management, and hypotension definitions may have contributed to variability across studies.

However, interpretation of these findings depends considerably on the metric used to quantify hypotension. Whereas dichotomous outcomes only capture whether at least one hypotensive episode occurred, continuous measures such as Time-Weighted Average (TWA) and Area Under the Curve (AUC) incorporate both the duration and severity of hypotension and may therefore provide a more clinically informative assessment of hemodynamic exposure. These endpoints should therefore be interpreted as complementary rather than interchangeable measures, as binary incidence reflects the occurrence of hypotension, whereas TWA and AUC/AUT quantify cumulative exposure to hypotension. In the present analysis, continuous monitoring was associated with a moderate but statistically significant reduction in cumulative hypotension burden, with pooled standardized mean differences of -0.42 for TWA (95% CI $[-0.64, -0.20]$; $p=0.0002$) and -0.40 for AUC (95% CI $[-0.58, -0.23]$; $p<0.0001$). Although the magnitude of these effects should be interpreted in the context of variability in hypotension definitions and reporting, the consistency across continuous hypotension metrics suggests a potentially clinically relevant reduction in hemodynamic exposure.

The apparent discrepancy between the neutral binary incidence outcome and the favorable TWA and AUT/AUC-derived hypotension burden findings may reflect inherent differences in event detection between monitoring modalities. Intermittent oscillometric devices typically measure blood pressure at intervals of 3 to 5 minutes and may therefore fail to capture transient hypotensive episodes occurring between measurements. In contrast, finger-cuff systems provide continuous beat-to-beat assessment and are capable of detecting short-lived fluctuations in arterial pressure with substantially greater temporal resolution. Consequently, the higher temporal resolution of beat-to-beat tracking may allow detection of transient, short-lived pressure drops that could remain undetected with intermittent measurements. One possible explanation is that continuous monitoring may facilitate earlier recognition of hypotensive episodes and thereby allow more timely intervention. However, this represents a plausible mechanistic explanation rather than a demonstrated mechanism, as the present analysis could not quantitatively assess the timing or intensity of treatment interventions. Consistent with this interpretation, Phan *et al.* [20] reported earlier and more frequent detection of hypotension with continuous monitoring in an observational study conducted during digestive endoscopy.

From a clinical perspective, these findings may be consistent with a potential benefit of continuous monitoring in facilitating earlier recognition and treatment once hypotension develops, rather than

necessarily preventing the initial occurrence of hypotension. However, this interpretation remains uncertain because treatment-related outcomes, including vasopressor and fluid administration, were reported heterogeneously and could not be quantitatively synthesized. This concept shifts attention from binary event occurrence toward cumulative hypotension burden, an increasingly recognized determinant of perioperative organ perfusion and postoperative outcomes. In this regard, the current findings extend observations from non-intensive care hospital settings, where continuous physiological monitoring has been associated with earlier detection of clinical deterioration and improved patient outcomes [5].

The reduction in cumulative hypotension burden observed in the intervention group was accompanied by differences in postoperative gastrointestinal outcomes. Postoperative nausea was not significantly different between groups (RR=0.81, 95% CI [0.51,1.28]; $p=0.29$). In contrast, postoperative vomiting was significantly less frequent among patients receiving continuous monitoring (RR=0.62, 95% CI [0.42,0.92]; $p=0.027$), with no evidence of statistical heterogeneity ($I^2=0.0\%$, $p=0.96$). Previous physiological studies have suggested that prolonged or severe hypotension may compromise regional tissue perfusion, which has been implicated in mechanisms contributing to postoperative PONV [21]. Consequently, it is conceivable that the reduction in cumulative hypotension burden contributed to the lower incidence of postoperative vomiting observed in the intervention group. However, causality cannot be inferred from the available evidence, and alternative explanations cannot be excluded.

Importantly, although the effect estimate for postoperative vomiting was consistent across studies, the total sample size remained limited, and the certainty of evidence for this outcome should therefore be interpreted cautiously pending confirmation from larger randomized trials.

To preserve methodological homogeneity and evaluate the isolated effect of continuous reactive monitoring, studies incorporating machine-learning-guided predictive algorithms, specifically the Hypotension Prediction Index (HPI), were excluded from the quantitative synthesis. Accordingly, the study by Aloziem *et al.* [22] was not included because it exclusively evaluated HPI-guided management, while only the conventional continuous monitoring and oscillometric control groups from the multi-arm trial by Shih *et al.* [10] were extracted for analysis. Nevertheless, these investigations provide useful insight into potential future directions for perioperative hemodynamic management.

Unlike conventional continuous monitoring, predictive algorithms are designed to identify hemodynamic instability before clinically significant hypotension occurs. By analyzing subtle arterial waveform characteristics, these systems may provide clinicians with advance warning of impending hypotension, potentially allowing earlier intervention than is achievable through reactive monitoring alone. Preliminary findings from Shih *et al.* and Aloziem *et al.* suggest that predictive monitoring strategies may further reduce hypotension burden. However, the current evidence base remains limited, and robust conclusions regarding their comparative effectiveness cannot yet be drawn. Future adequately powered randomized trials and dedicated systematic reviews are required before routine implementation can be recommended.

The clinical implications of the present findings should also be considered within the broader context of invasive and non-invasive blood pressure monitoring strategies. Invasive arterial catheterization remains the reference standard for continuous blood pressure monitoring and offers additional advantages, including arterial blood gas sampling and reliable performance during profound hemodynamic instability. However, arterial catheter placement is associated with procedural complexity and catheter-related complications. Recent evidence from critical care settings, including the EVERDAC trial [23], has demonstrated that a non-invasive blood pressure management strategy using automated brachial cuffs is non-inferior to early arterial catheterization in patients with septic shock. While the EVERDAC trial confirmed the safety of avoiding early invasive placement, it also highlighted a higher incidence of patient discomfort with repeated cuff inflations compared to an indwelling line. Although these findings originate from critically ill populations rather than surgical patients, they support the broader safety of non-invasive blood pressure strategies while highlighting some practical disadvantages associated with repeated cuff inflation. In this context, continuous

finger-cuff technology represents a potentially valuable intermediate strategy, reducing the discomfort and temporal gaps of automated cuffs while preserving a safe, non-invasive profile.

In the perioperative setting, this clinical paradigm must be tailored to surgical complexity and risk. Continuous finger-cuff technology represents a compelling intermediate approach, particularly for patients undergoing low- to intermediate-risk procedures.

Conversely, invasive arterial monitoring remains indispensable in major high-risk surgery, severe hemodynamic instability, massive hemorrhage, and conditions associated with marked peripheral vasoconstriction, where continuous non-invasive technologies may exhibit reduced reliability.

Several limitations should be considered when interpreting the findings of this review. First, finger-cuff monitoring relies on the volume-clamp principle and photoplethysmographic signal acquisition, making measurement accuracy dependent on adequate peripheral perfusion. Severe hypothermia, advanced peripheral vascular disease, and high-dose vasopressor therapy may impair signal quality and increase calibration interruptions, potentially limiting applicability in selected high-risk populations.

Second, substantial heterogeneity existed in the definition and reporting of intraoperative hypotension across the included studies. Trials used different haemodynamic thresholds, including absolute MAP-based definitions and relative reductions from baseline blood pressure. Although data extraction focused on clinically relevant and commonly used thresholds, particularly MAP <65 mmHg and SAP <80% of baseline, residual heterogeneity in outcome definitions, treatment protocols, patient populations, anesthetic techniques, and surgical settings likely contributed to variability across analyses.

Third, several continuous outcomes required estimation of means and standard deviations from medians and interquartile ranges. Although established statistical methods were used, these conversions may have introduced additional uncertainty, particularly for skewed outcomes such as hypotension burden, TWA, AUT/AUC, vasopressor dose, and fluid administration. Fourth, several additional outcomes, including vasopressor use, fluid administration, haemodynamic stability metrics, clinical complications, and device-related safety outcomes, were reported heterogeneously and could only be summarized narratively. This limited the ability to draw robust conclusions regarding treatment-related effects and safety. Finally, the certainty of evidence was low or very low across all outcomes, mainly because of risk of bias, inconsistency, indirectness, and imprecision. Therefore, the findings should be interpreted as suggestive rather than definitive and should be confirmed by larger, methodologically robust randomized trials using standardized hypotension definitions and reporting frameworks.

In conclusion, continuous non-invasive finger-cuff monitoring was not associated with a statistically significant reduction in the binary incidence of intraoperative hypotension compared with intermittent oscillometric monitoring. However, the pooled analyses suggested lower cumulative hypotension burden, as reflected by lower TWA and AUT/AUC values, although these findings should be interpreted cautiously because of heterogeneity in hypotension definitions and observation windows, the conversion of medians and interquartile ranges to means and standard deviations in several studies, the non-significant median-based sensitivity analysis for AUT/AUC, and the low or very low certainty of evidence. These findings may be consistent with a potential role for continuous monitoring in facilitating earlier recognition and treatment of hypotensive episodes rather than preventing their initial occurrence; however, this remains a plausible explanation rather than a demonstrated mechanism, given the heterogeneous reporting of treatment-related outcomes and the limitations of the available evidence. The observed reduction in postoperative vomiting further supports the potential clinical relevance of this strategy, although confirmation in larger studies is warranted. Overall, finger-cuff technology may represent a useful adjunct for enhancing hemodynamic surveillance in appropriately selected surgical patients, whereas invasive arterial catheterization remains the preferred monitoring modality in patients at high risk of severe hemodynamic instability.

DECLARATIONS

Author contributions

Conceptualization: Rinaldi, Di Folco.
Methodology: Rinaldi, Di Folco, Fotticchia.
Investigation and data curation: Rinaldi, Fotticchia.
Formal analysis: Fotticchia.
Visualization: Fotticchia.
Writing – original draft: Rinaldi, Fotticchia.
Writing – review & editing: Rinaldi, Fotticchia.
Supervision: Rinaldi.
All authors read and approved the final version of the manuscript.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

ETHICAL STATEMENT

This study is a systematic review and meta-analysis based exclusively on data extracted from previously published studies. No new data involving human participants or animals were collected or generated. Therefore, ethical approval and informed consent were not required. The review protocol was prospectively registered in the PROSPERO international database of systematic reviews under the registration number CRD420261415758

Vincenzo Fotticchia
Department of Clinical Medicine and Surgery,
Section of Infectious Diseases,
University of Naples Federico II,
via Pansini 5, 80131 Naples, Italy
vincenzo.fotticchia@unina.it

10/08/2026

Funding: No external funding was received.

Acknowledgements

None.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Informed consent

Not applicable.

Declaration of generative AI and AI-assisted technologies

During the preparation of this work, the author(s) used ChatGPT, developed by OpenAI, to support language editing, improve readability, and refine the presentation of methodological and statistical content. The tool was not used to generate original data, perform the statistical analyses, or make decisions regarding study eligibility, risk of bias, or certainty of evidence. The author(s) reviewed and edited the output as needed and take full responsibility for the content of the published article.

References

- [1] Wijnberge M, Schenk J, Bulle E, Vlaar AP, Maheshwari K, Hollmann MW, et al. Association of intraoperative hypotension with postoperative morbidity and mortality: systematic review and meta-analysis. *BJS Open* 2021;5:zraa018. <https://doi.org/10.1093/bjsopen/zraa018>.
- [2] Gu W-J, Hou B-L, Kwong JSW, Tian X, Qian Y, Cui Y, et al. Association between intraoperative hypotension and 30-day mortality, major adverse cardiac events, and acute kidney injury after non-cardiac surgery: A meta-analysis of cohort studies. *Int J Cardiol* 2018;258:68–73. <https://doi.org/10.1016/j.ijcard.2018.01.137>.
- [3] An R, Pang Q-Y, Liu H. Association of intra-operative hypotension with acute kidney injury, myocardial injury and mortality in non-cardiac surgery: A meta-analysis. *Int J Clin Pract* 2019;73. <https://doi.org/10.1111/ijcp.13394>.
- [4] Gellert G, Bramlage P. Use of the ClearSight® System for Continuous Noninvasive Hemodynamic Monitoring during Heart Valve Interventions: Review of the Literature and Single-Site Experience. *Heart Surg Forum* 2018;21:E476–83. <https://doi.org/10.1532/hsf.2177>.
- [5] Sun L, Joshi M, Khan SN, Ashrafian H, Darzi A. Clinical impact of multi-parameter continuous non-invasive monitoring in hospital wards: a systematic review and meta-analysis. *J R Soc Med* 2020;113:217–24. <https://doi.org/10.1177/0141076820925436>.
- [6] Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JPA, et al. The PRISMA Statement for Reporting Systematic Reviews and Meta-Analyses of Studies That Evaluate Health Care Interventions: Explanation and Elaboration. *PLoS Med* 2009;6:e1000100. <https://doi.org/10.1371/journal.pmed.1000100>.
- [7] Wan X, Wang W, Liu J, Tong T. Estimating the sample mean and standard deviation from the sample size, median, range and/or interquartile range. *BMC Med Res Methodol* 2014;14:135. <https://doi.org/10.1186/1471-2288-14-135>.
- [8] Benes J, Simanova A, Tovarnicka T, Sevcikova S, Kletecka J, Zatloukal J, et al. Continuous non-invasive monitoring improves blood pressure stability in upright position: randomized controlled trial. *J Clin Monit Comput* 2015;29:11–7. <https://doi.org/10.1007/s10877-014-9586-2>.
- [9] Kim Y, Kim H, Yoo S, Kim J-T, Gim DY, Park S-K. Non-invasive continuous versus intermittent oscillometric arterial pressure monitoring and maternal hypotension during cesarean delivery: a randomized controlled trial. *Sci Rep* 2026;16:16124. <https://doi.org/10.1038/s41598-026-47307-x>.

- [10] Shih P, Wei T, Lee C, Kang J, Shih M, Chen Y, et al. Proactive haemodynamic management using the hypotension prediction index during caesarean section: a randomised controlled study. *Anaesthesia* 2026;81:924–32. <https://doi.org/10.1111/anae.70161>.
- [11] Ayhan A, Akovali N, Camkiran Fırat A. Can Hypotension Episodes that were not Identified in the Non-Invasive Blood Pressure be Detected during Cesarean Section? A Randomized Controlled Trial. *Balk Med J* 2022;39:358–65. <https://doi.org/10.4274/balkanmedj.galenos.2022.2022-3-130>.
- [12] Kouz K, Weidemann F, Naebian A, Lohr A, Bergholz A, Thomsen KK, et al. Continuous Finger-cuff versus Intermittent Oscillometric Arterial Pressure Monitoring and Hypotension during Induction of Anesthesia and Noncardiac Surgery: The DETECT Randomized Trial. *Anesthesiology* 2023;139:298–308. <https://doi.org/10.1097/ALN.0000000000004629>.
- [13] Kukralova L, Dostalova V, Cihlo M, Kraus J, Dostal P. The Impact of Individualized Hemodynamic Management on Intraoperative Fluid Balance and Hemodynamic Interventions during Spine Surgery in the Prone Position: A Prospective Randomized Trial. *Medicina (Mex)* 2022;58:1683. <https://doi.org/10.3390/medicina58111683>.
- [14] Meidert AS, Nold JS, Hornung R, Paulus AC, Zwißler B, Czerner S. The impact of continuous non-invasive arterial blood pressure monitoring on blood pressure stability during general anaesthesia in orthopaedic patients: A randomised trial. *Eur J Anaesthesiol* 2017;34:716–22. <https://doi.org/10.1097/EJA.0000000000000690>.
- [15] Vergari A, Frassanito L, Piersanti A, Vassalli F, Pitoni S, Ruggiero E, et al. Continuous versus intermittent noninvasive blood pressure monitoring during beach chair position for shoulder surgery: A randomised controlled trial. *Eur J Anaesthesiol* 2026;43:139–48. <https://doi.org/10.1097/EJA.0000000000002259>.
- [16] Juri T, Suehiro K, Kimura A, Mukai A, Tanaka K, Yamada T, et al. Impact of non-invasive continuous blood pressure monitoring on maternal hypotension during cesarean delivery: a randomized-controlled study. *J Anesth* 2018;32:822–30. <https://doi.org/10.1007/s00540-018-2560-2>.
- [17] Juri T, Suehiro K, Kimura A, Mukai A, Tanaka K, Yamada T, et al. Impact of continuous non-invasive blood pressure monitoring on hemodynamic fluctuation during general anesthesia: a randomized controlled study. *J Clin Monit Comput* 2018;32:1005–13. <https://doi.org/10.1007/s10877-018-0125-4>.
- [18] Gupta D, SoSkin V, MarjanoVic M. Continuous non-invasive arterial pressure deviCe as an adjunCt to reCognize fluCtuating blood pressures during eleCtive Cesarean seCtion under subaraChnoid bloCkade (sab) 2016.
- [19] Maheshwari K, Khanna S, Bajracharya GR, Makarova N, Riter Q, Raza S, et al. A Randomized Trial of Continuous Noninvasive Blood Pressure Monitoring During Noncardiac Surgery. *Anesth Analg* 2018;127:424–31. <https://doi.org/10.1213/ANE.0000000000003482>.
- [20] Phan A-D, Neuschwander A, Perrod G, Rahmi G, Cellier C, Cholley B. Noninvasive continuous monitoring versus intermittent oscillometric measurements for the detection of hypotension during digestive endoscopy. *PLOS ONE* 2020;15:e0240241. <https://doi.org/10.1371/journal.pone.0240241>.
- [21] Goss S, Jedlicka J, Strinitz E, Niedermayer S, Chappell D, Hofmann-Kiefer K, et al. Association between intraoperative hypotension and postoperative nausea and vomiting: a retrospective cohort study. *Curr Med Res Opin* 2024;40:1439–48. <https://doi.org/10.1080/03007995.2024.2373885>.
- [22] Aloziem O, Lin H-HS, Kelly K, Nicholas A, Romeo RC, Smith CT, et al. Feasibility of Hypotension Prediction Index-Guided Monitoring for Epidural Labor Analgesia: A Randomized Controlled Trial. *J Clin Med* 2025;14:5037. <https://doi.org/10.3390/jcm14145037>.
- [23] Muller G, Contou D, Ehrmann S, Martin M, Andreu P, Kamel T, et al. Deferring Arterial Catheterization in Critically Ill Patients with Shock. *N Engl J Med* 2025;393:1875–88. <https://doi.org/10.1056/NEJMoa2502136>.

LEGEND

Figure 1. PRISMA flow diagram of the study selection process.

The diagram shows the identification, screening, eligibility assessment and inclusion of studies in the systematic review and meta-analysis.

PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only

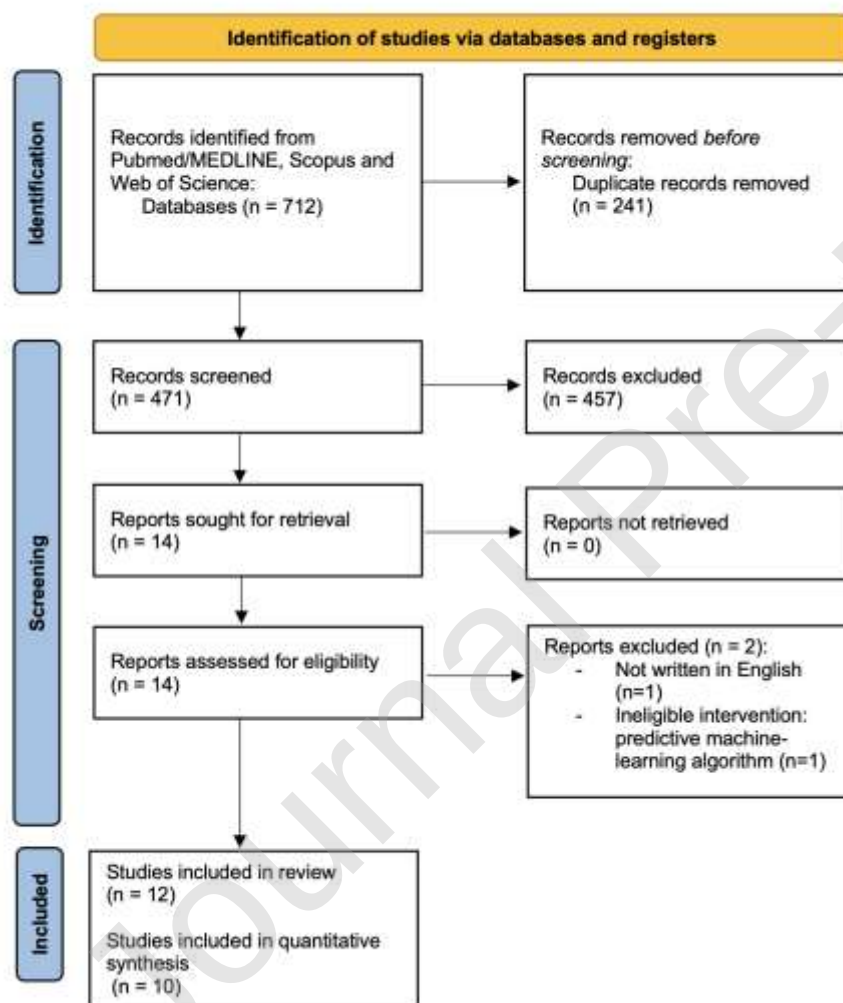


Figure 2. Risk-of-bias assessment of the included randomized controlled trials.

Risk of bias was assessed using the revised Cochrane risk-of-bias tool for randomized trials (RoB 2). The left panel shows study-level judgements across the five RoB 2 domains and the overall judgement. The right panel summarizes the distribution of risk-of-bias judgements across studies.

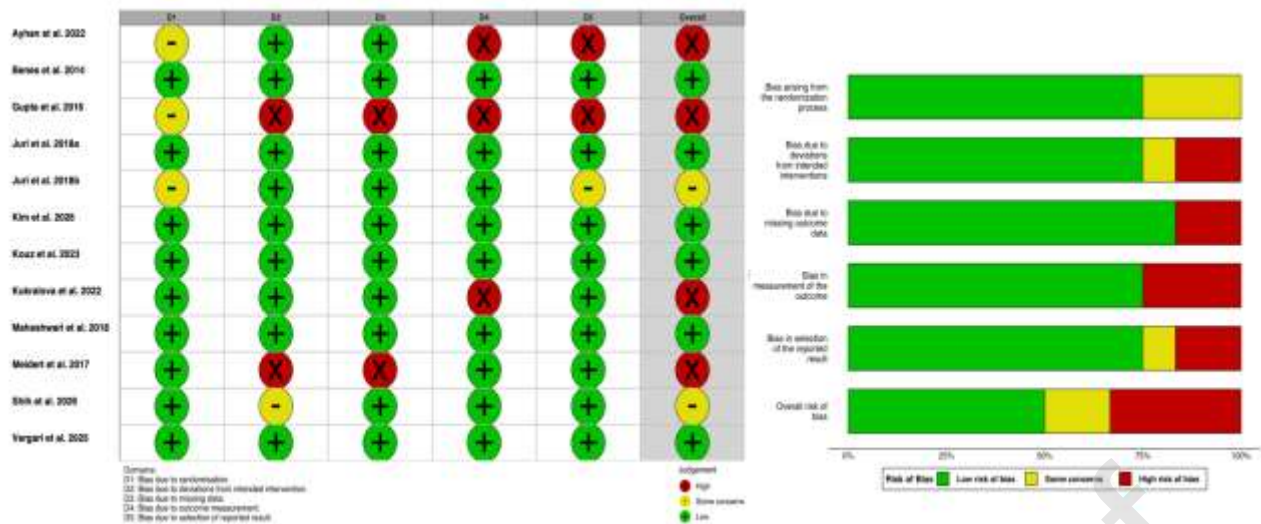


Figure 3. Forest plot of the incidence of intraoperative hypotension.

Risk ratios were calculated comparing continuous non-invasive blood pressure monitoring with intermittent oscillometric upper-arm cuff monitoring. Values lower than 1 favour continuous monitoring. The pooled estimate was calculated using a random-effects model.

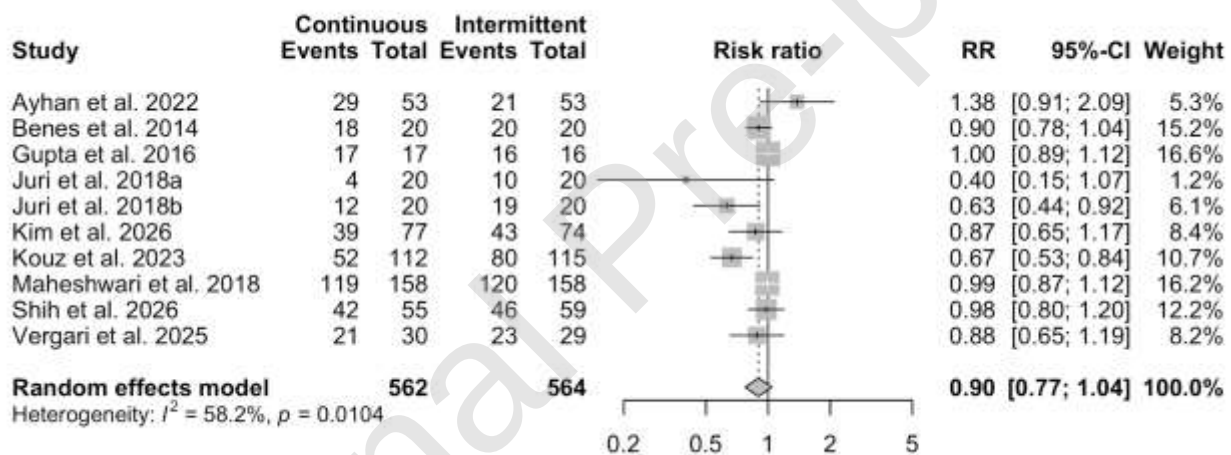


Figure 4. Forest plot of time-weighted hypotension burden.

Standardized mean differences were calculated comparing continuous non-invasive blood pressure monitoring with intermittent oscillometric upper-arm cuff monitoring. Means and standard deviations were estimated from medians and interquartile ranges when not directly reported.

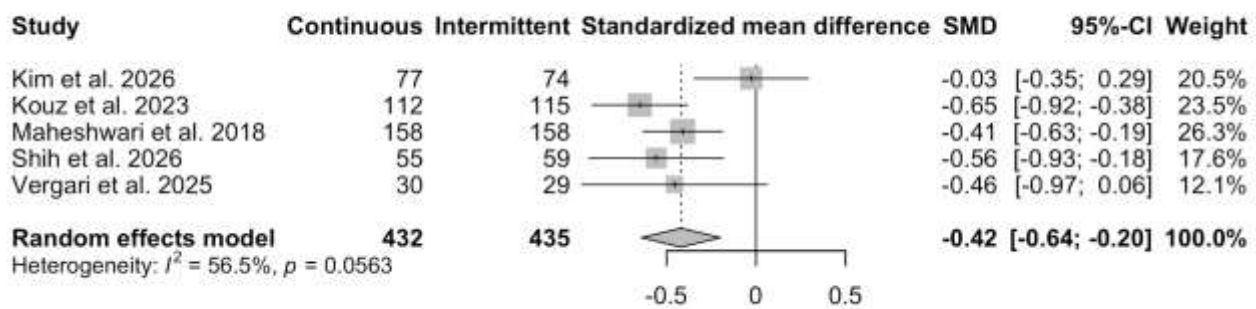


Figure 5. Forest plot of area-based hypotension exposure.

Standardized mean differences were calculated comparing continuous non-invasive blood pressure monitoring with intermittent oscillometric upper-arm cuff monitoring. Means and standard deviations were estimated from medians and interquartile ranges when not directly reported. Values lower than 0 favour continuous monitoring.

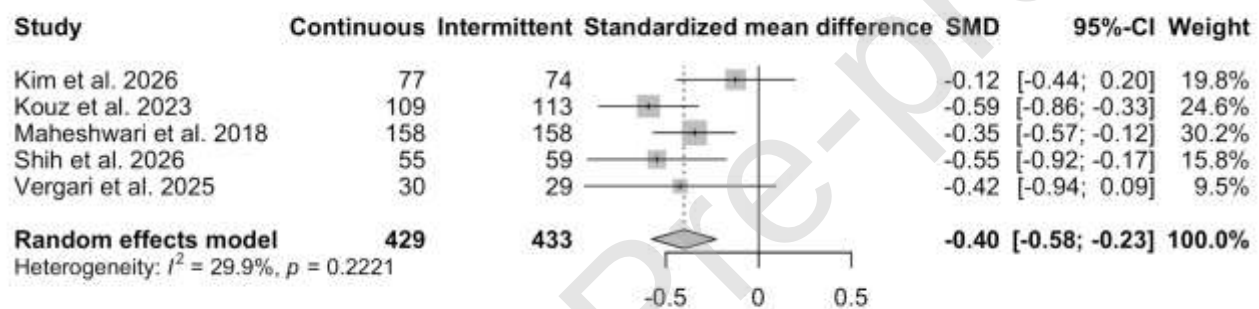
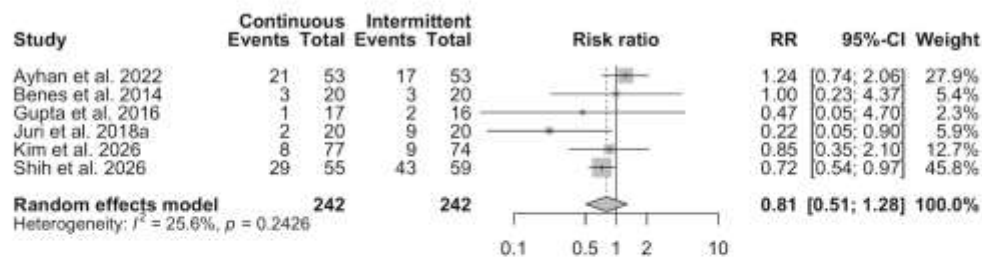


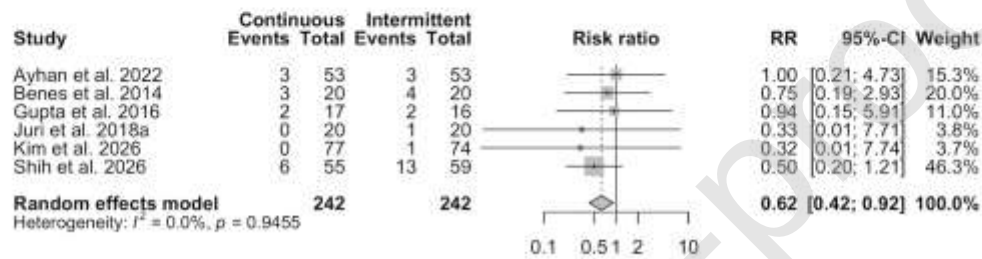
Figure 6. Forest plots of nausea and vomiting.

Panel A shows the pooled risk ratio for nausea, and Panel B shows the pooled risk ratio for vomiting. Risk ratios were calculated comparing continuous non-invasive blood pressure monitoring with intermittent oscillometric upper-arm cuff monitoring. Values lower than 1 favour continuous monitoring.

A. Postoperative nausea



B. Postoperative vomiting



LEGEND

Table 1. General characteristics of studies included in the systematic review and meta-analysis

First Author and Year	Country	Number of Patients			Age		Setting	Anesthesia Type	Intervention	Control
Ayhan et al. 2022	Turkey	T 106	I 53	C 53	I 32 (5)	C 32 (5)	Elective cesarean delivery	Spinal anesthesia	Infinity® CNAP™ / Dräger	Oscillometric upper-arm cuff (Every 3 min for the first 15 min; every 5 min thereafter)
Benes et al. 2014	Czech Republic	40	20	20	56 (15)	59 (12)	Surgery in upright position	General anesthesia	CNAP® Monitor / CNSystems	Oscillometric upper-arm cuff (Every 5 min)
Gupta et al. 2016	USA	33	17	16	28 (6)	30 (6)	Elective cesarean delivery	Spinal anesthesia	CNAP Monitor 500 / CNSystems	Oscillometric upper-arm cuff (Every 1 min pre-delivery; every 2.5 min post-delivery)
Juri et al. 2018a	Japan	40	20	20	34 (4)	34 (5)	Elective cesarean delivery	Spinal anesthesia	ClearSight™ / Edwards Lifesciences	Oscillometric upper-arm cuff (Every 1 min until delivery; every 5 min after delivery)
Juri et al. 2018b	Japan	40	20	20	72 (10)	76 (5)	Total knee arthroplasty	General anesthesia	ClearSight™ / Edwards Lifesciences	Oscillometric upper-arm cuff (Every 1 min during induction/ emergence; every 5 min intraoperatively)
Kim et al. 2026	South Korea	151	77	74	36 [34–40]	35 [33–38]	Elective cesarean delivery	Spinal anesthesia	ClearSight System / Edwards Lifesciences	Oscillometric upper-arm cuff (Every 1 min until delivery)

Kouz et al. 2023	Germany	231	114	117	59 [53–68]	61 [52–70]	Elective non-cardiac surgery	General anesthesia	ClearSight system / Edwards Lifesciences	Oscillometric upper-arm cuff (Every 2.5 min; adjustable by clinicians)
Kukralova et al. 2022*	Czech Republic	50	25	25	58 (15)	55 (15)	Elective spinal surgery	General anesthesia	ClearSight / EV1000 platform / Edwards Lifesciences	Oscillometric upper-arm cuff (Every 5 min; every 2 min if instability was expected or detected)
Maheshwari et al. 2018	USA	316	158	158	60 (9)	62 (9)	Non-cardiac surgery	General anesthesia	ClearSight™ / Edwards Lifesciences	Oscillometric upper-arm cuff (Every 5 min; adjustable by clinicians)
Meidert et al. 2017*	Germany	160	77	83	69 [62–75]	73 [69–78]	Orthopaedic surgery	General anesthesia	ClearSight™ / Edwards Lifesciences	Oscillometric upper-arm cuff (Every 3 min)
Shih et al. 2026	Taiwan	114	55	59	37 (5)	38 (4)	Elective caesarean section	Spinal anesthesia	HemoSphere / Edwards Lifesciences	Oscillometric upper-arm cuff (Every 2.5 min)
Vergari et al. 2025	Italy	59	30	29	60 [52–67]	63 [58–67]	Arthroscopic shoulder surgery	General anesthesia	ClearSight / HemoSphere / Edwards Lifesciences	Oscillometric upper-arm cuff (Every 3 min)

Abbreviations: T, total number of patients analyzed; I, number of patients in the intervention group; C, number of patients in the control group.

Notes: Age is reported as mean (SD) or median [IQR], according to the original study. Studies marked with an asterisk were included in the systematic review but not in the quantitative synthesis because comparable data suitable for pooling were not available. For Kouz et al. 2023, the numbers reported in Table 1 refer to the overall analyzed population for baseline characteristics: continuous finger-cuff monitoring, n = 114; intermittent oscillometric monitoring, n = 117. For the primary and secondary intraoperative outcomes relevant to the quantitative synthesis, the analyzed sample was n = 112 in the continuous monitoring group and n = 115 in the intermittent monitoring group.

Table 2. GRADE summary of findings for continuous versus intermittent non-invasive blood pressure monitoring and intraoperative hypotension-related outcomes

Certainty assessment							№ of patients		Effect		Certainty	Importance
№ of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	Continuous non-invasive blood pressure monitoring	Intermittent oscillometric non-invasive blood pressure monitoring	Relative (95% CI)	Absolute (95% CI)		
Incidence of intraoperative hypotension (assessed with: Number of patients experiencing at least one episode of intraoperative hypotension)												
10	randomised trials	serious ^a	serious ^b	not serious	serious ^c	none	353/562 (62.8%)	398/564 (70.6%)	RR 0.90 (0.77 to 1.04)	71 fewer per 1000 (from 162 fewer to 28 more)	⊕○○○ ○ Very low ^{a,b,c}	CRITICAL
Time-weighted average of intraoperative hypotension (assessed with: Time-weighted average of hypotension using SAP <80% of baseline or MAP <65 mmHg thresholds, analysed using standardized mean difference)												
5	randomised trials	serious ^f	serious ^g	serious ^h	not serious	none	432	435	-	SMD 0.42 SD lower (0.64 lower to 0.2 lower)	⊕○○○ ○ Very low ^{f,g,h}	CRITICAL
Intraoperative hypotension burden (assessed with: Area under the hypotension threshold or area under the curve/time, including AUC/AUT-based measures of MAP or SAP hypotension, analysed using standardized mean difference)												
5	randomised trials	serious ^d	not serious	serious ^e	not serious	none	429	433	-	SMD 0.40 SD lower (0.58 lower to 0.23 lower)	⊕⊕○○○ ○ Low ^{d,e}	CRITICAL
Post-operative nausea (assessed with: Number of patients experiencing nausea)												
6	randomised trials	serious ⁱ	not serious	not serious	serious ^j	none	64/242 (26.4%)	83/242 (34.3%)	RR 0.81 (0.51 to 1.28)	65 fewer per 1000 (from 168 fewer to 96 more)	⊕⊕○○○ ○ Low ^{i,j}	IMPORTANT
Post-operative vomiting (assessed with: Number of patients experiencing postoperative vomiting)												

6	randomised trials	serious ^k	not serious	not serious	serious ^l	none	14/242 (5.8%)	24/242 (9.9%)	RR 0.62 (0.42 to 0.92)	38 fewer per 1000 (from 58 fewer to 8 fewer)	⊕⊕○○ Low ^{k,l}	IMPORTANT
---	-------------------	----------------------	-------------	-------------	----------------------	------	------------------	------------------	----------------------------------	--	----------------------------	-----------

Abbreviations: CI: confidence interval; RR: risk ratio; SMD: standardised mean difference

Explanations

- a. Downgraded by one level because several included randomized trials had methodological concerns related to lack of blinding, potential performance bias, and clinical management influenced by the monitoring strategy. Intraoperative hypotension and its treatment may be affected by whether continuous blood pressure values are visible to clinicians.
- b. Downgraded by one level because there was moderate-to-substantial heterogeneity across studies. The pooled analysis showed $I^2 = 58.2\%$ and a statistically significant test for heterogeneity ($Q = 21.55$, $p = 0.0104$), with study-specific effects ranging from clear benefit to no effect or possible harm.
- c. Downgraded by one level because the 95% confidence interval crossed the line of no effect and was compatible with both a clinically relevant reduction in intraoperative hypotension and little or no effect. The pooled estimate was RR 0.90 (95% CI 0.77 to 1.04).
- d. Downgraded by one level because several included randomized trials had methodological concerns related to lack of blinding and potential performance bias. In addition, for this continuous outcome, some means and standard deviations were estimated from medians and interquartile ranges, introducing additional uncertainty in the study-level estimates.
- e. Downgraded by one level because the pooled outcome combined related but not identical measures of intraoperative hypotension burden, including AUT and AUC. Although both measures reflect the magnitude and duration of hypotension, differences in operational definitions and scales required the use of standardized mean differences.
- f. Downgraded by one level because several included randomized trials had methodological concerns related to lack of blinding and potential performance bias. In addition, for this continuous outcome, some means and standard deviations were estimated from medians and interquartile ranges, introducing additional uncertainty in the study-level estimates.
- g. Downgraded by one level because there was moderate heterogeneity across studies ($I^2 = 56.5\%$; Q test $p = 0.0563$), with variation in the magnitude of effect across trials. Although most estimates favoured continuous monitoring, the degree of benefit was not fully consistent.
- h. Downgraded by one level because the pooled outcome combined related but not identical TWA-based measures of intraoperative hypotension. Studies used different blood pressure thresholds and definitions, including SAP <80% of baseline and MAP <65 mmHg. These differences required use of standardized mean differences and limit direct comparability across studies.
- i. Downgraded by one level because several included randomized trials had methodological concerns related to lack of blinding and potential performance bias. Postoperative nausea is a subjective outcome and its reporting or ascertainment may have been influenced by perioperative clinical management and awareness of the allocated monitoring strategy.
- j. Downgraded by one level because the 95% confidence interval crossed the line of no effect and was compatible with both a reduction and an increase in postoperative nausea. The pooled estimate was RR 0.81 (95% CI 0.51 to 1.28).
- k. Downgraded by one level because several included randomized trials had methodological concerns related to lack of blinding and potential performance bias. Postoperative vomiting is a clinical adverse event that may be influenced by perioperative management, antiemetic use, and awareness of the allocated monitoring strategy.
- l. Downgraded by one level because the total number of events was low and several studies had very few or zero events, making the estimate potentially fragile despite the confidence interval excluding the line of no effect. The pooled estimate was RR 0.62 (95% CI 0.42 to 0.92).