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Intraoperative hypotension and postoperative risks in non-cardiac surgery: a meta-analysis

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Abstract

Background Postoperative complications are often associated with the severity and duration of intraoperative hypotension. However, the optimal approach for managing intraoperative hypotension remains controversial. The aim of this meta-analysis of randomized controlled trials was to compare the incidence of common postoperative complications with different treatment threshold of hypotension.

Methods We searched PubMed, the Cochrane Database, and Embase from August 2014 to August 2024 for studies comparing different treatment threshold of hypotension (low [mean arterial pressure < 60 mmHg], moderate [60–75 mmHg], and high [> 75 mmHg]). Only randomized controlled trials conducted during 2014–2024 were included in this meta-analysis without language restrictions. Studies with the following characteristics were included: randomized controlled study; involved non-cardiac, non-obstetric surgery; included different blood pressure management strategies; evaluated major postoperative complications; and included acute kidney injury, myocardial injury, altered consciousness, or infection. Data included patient age, type of surgery, group criteria, and adverse events. Mantel–Haenszel method was used for analysis. The primary outcomes were postoperative complications, including acute kidney injury. The secondary outcomes included length of hospital stay and all-cause mortality.

Results Of the 2160 studies identified, eight randomized controlled trials with 9108 participants were included. No significant differences in postoperative complications were observed between the moderate and high mean arterial pressure treatment threshold groups (risk ratio = 1.0, 95% confidence interval = 0.86–1.18, *P* = 0.96). Sensitivity analysis confirmed these findings. Length of hospitalization was not significantly different between the groups (standardized mean difference = -0.39; 95% confidence interval = -0.69 to 1.31; *P* = 0.03). Limited data prevented meta-analysis of mean arterial pressure management at lower treatment thresholds.

Conclusion The results of this meta-analysis suggest no significant differences in postoperative complications between moderate and high mean arterial pressure management.

Keywords Intraoperative hypotension, Target management, Postoperative complication

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Background

Hypotension during surgery is strongly associated with serious complications, such as ischemia of vital organs (i.e., the heart, brain, and kidney), a condition termed "intraoperative hypotension" (IOH) [1–4]. Studies suggest that the complication risk increases with the severity and duration of IOH, and IOH management can help reduce the risk of postoperative organ dysfunction. Currently, measuring mean arterial pressure (MAP) remains a key component of perioperative care, whereas organ perfusion monitoring is not commonly performed in non-cardiac surgery [5, 6]. Common therapeutic approaches include a combination of vasoactive agent (especially vasopressors) administration and fluid therapy to achieve hemodynamic stability during surgery and anesthesia.

The duration of IOH treatment should be carefully controlled to ensure patient safety. A systematic review and meta-analysis [7] reported that 10 min of MAP < 80 mmHg, shorter durations of MAP < 70 mmHg, and any exposure to MAP < 55 mmHg are associated with end-organ injury in non-cardiac surgery. However, the optimal treatment threshold of hypotension remain uncertain. Therefore, we conducted a meta-analysis of randomized controlled studies to determine the optimal threshold associated with lower incidences of complications and improved outcomes.

Methods

Search strategy and selection criteria

The bibliographic search and analysis for this meta-analysis were conducted according to the guidelines of the Cochrane Handbook for systematic reviews of intervention and the QUORUM statements [8]. We searched various databases, including PubMed, Embase, and the Cochrane Database, using the following predefined terms:

#1: "hypotension" or "low blood pressure" or "slight pressure".

#2: "intraoperative" or "intraoperation" or "perioperative" or "operation" or "surgery" or "surgical" or "procedure".

#3: "target" or "targets" or "targeting" or "targeted" or "management" or "goal" or "mark" or "purpose".

#4: "complication" or "neopathy" or "adverse effect" or "myocardial injury" or "acute renal injury" or "kidney injury" or "death" or "mortality" or "delirium" or "cognitive dysfunction" or "stroke" or "end-organ injury" or "mortality" or "atrial fibrillation" or "myocardial infarction" or "transfusion" or "mechanical ventilation".

#5: #1 and #2 and #3 and #4.

Only randomized controlled trials conducted over the last 10 years (2014–2024) were included in this meta-analysis, as we aimed to capture the latest advancements in clinical pressure research. We did not restrict language and made every effort to obtain full text versions of the articles, including contacting the authors via email in cases where the original text was difficult to access. Additionally, we manually searched the references cited in the selected articles.

Studies with the following characteristics were included for further analysis:

1. Randomized controlled study.
2. Involved non-cardiac, non-obstetric surgery.
3. Included different blood pressure treatment thresholds.
4. Evaluated major postoperative complications, including at least one of the following: acute kidney injury, myocardial injury, altered consciousness, or infection.

The search was concluded in August 2024. Quality evaluation and data extraction were performed by two independent authors. Collected data included patient age, type of surgery, group criteria, and actual number of adverse events. We evaluated and integrated the original group criteria from each study and distinguished them as follows: (i) low threshold of hypotension group (blood pressure < 60 mmHg); (ii) moderate threshold of hypotension group (blood pressure of 60–75 mmHg); and (iii) high threshold of hypotension group (blood pressure > 75 mmHg).

In cases of conflicting results, the article was reviewed by two authors, and the reasons for the exclusion of ineligible studies were recorded. The selection process was recorded, and a study selection flow diagram was constructed (Fig. 1).

Outcomes

Primary outcome

The primary outcome, indicated as a composite outcome, was any postoperative adverse event being recorded during the duration of hospital stay, including acute kidney injury, myocardial injury, altered consciousness, and post-surgical infection.

Secondary outcomes

The secondary outcomes included the individual components of the combined outcome: all-cause mortality within 30 days following surgery and the average length of hospital stay.

Statistical analysis

Statistical analysis was performed using Review Manager 5 (RevMan 5; The Cochrane Collaboration, Oxford, the UK). The incidence of outcomes was analyzed using the risk ratio (RR) computed using the Mantel–Haenszel

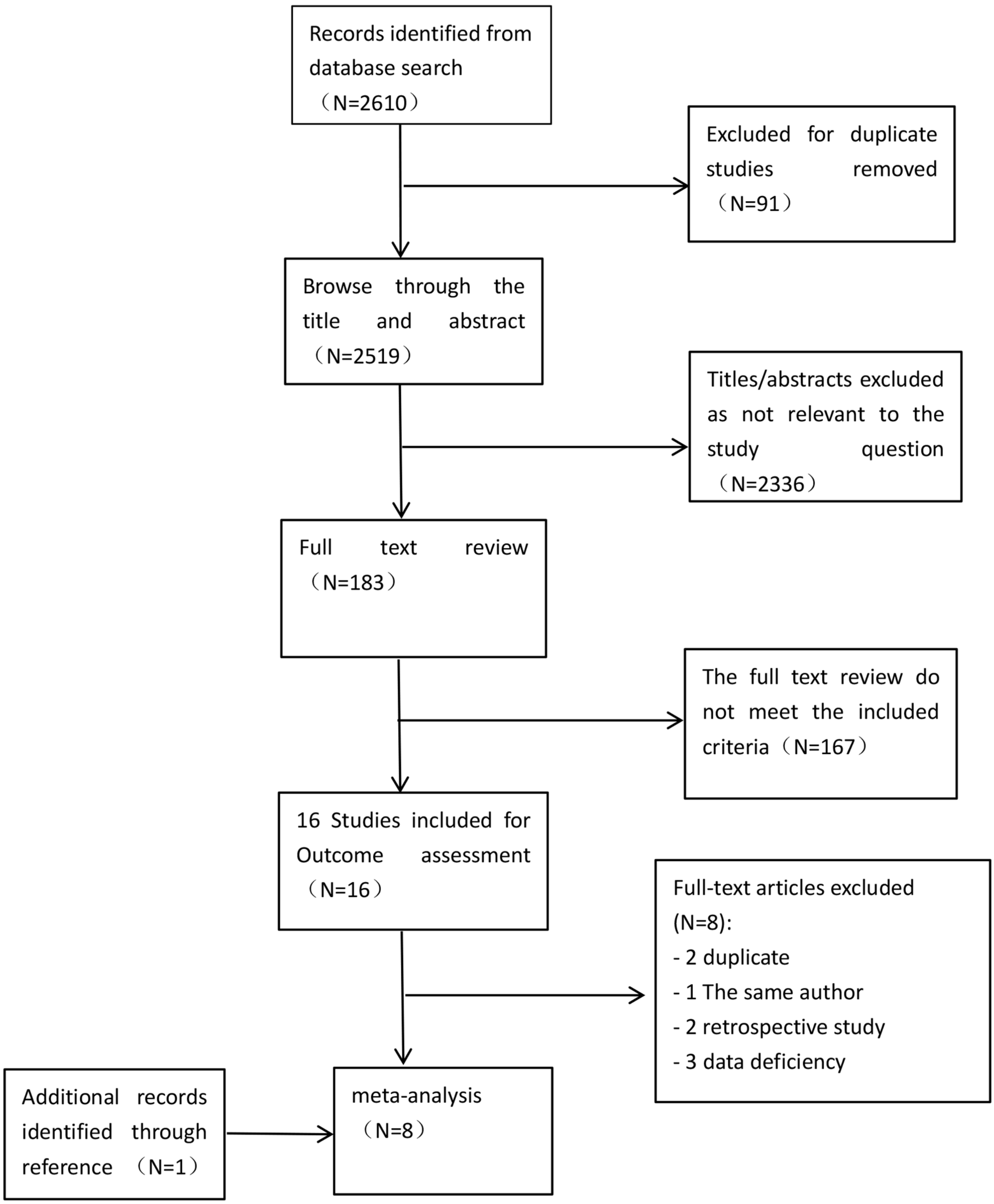

Fig. 1 Flow diagram: PRISMA diagram showing the selection of articles for review

method (random models). RR represents the odds of outcomes occurring in one group compared with that in the other. A confidence interval (CI) for the RR that does not include a value of one indicates a significant difference. For continuous variables, the standard mean difference with a 90% credibility interval was calculated using the Mantel–Haenszel method (random models). To assess the effect of study heterogeneity on the results of the meta-analysis, we adjusted the RR values by excluding studies with large ($N > 1000$) or small ($N < 100$) cohorts to reduce potential bias across studies. We also used I^2 in the analysis to assess the heterogeneity of the included studies, with a fixed model used if I^2 was less than 50% and random model used if I^2 was 50% or greater. For comparisons involving high heterogeneity, the source of consistency was verified by sequentially removing individual studies, and changes in heterogeneity were observed by removing studies with either large or small samples.

When statistical heterogeneity was detected, a sensitivity analysis was performed by removing individual studies based on their research design. Studies with statistical heterogeneity were further analyzed to identify differences in design and results. For unexplained heterogeneity, we explored rational interpretations by reviewing the studies. The results are expressed as RR (95% CI), I^2, and *P*-value for heterogeneity. Reporting bias was assessed using a funnel plot.

Results

We retrieved 2160 studies from PubMed/Medline, EMBASE, and the Cochrane Database. Ultimately, eight randomized controlled trials involving 9108 participants were identified and included in this systematic review and meta-analysis (Fig. 1). All studies included in the analysis were designed as randomized, controlled, or double-blind trials. In seven studies, participant age was ≥60 years, whereas in one study, participant age was 14–45 years [9]. After reviewing the treatment thresholds of hypotension in each group, participants were randomized into three groups: low treatment threshold of hypotension (<60 mmHg; $N=101$; 2 studies), moderate treatment threshold of hypotension (60–75 mmHg; $N=4547$; 8 studies), and high treatment threshold of hypotension (>75 mmHg; $N=4460$; 7 studies). The characteristics of the included studies are summarized in Table 1.

Seven studies evaluated the primary outcome. The incidence of the primary combined outcome was 17.4% (783/4465) in the moderate treatment threshold group and 17.4% (777/4460) in the high treatment threshold group. The RR between the groups was 1.0 (95% CI: 0.86 to 1.18), $I^2=66\%$, and $P=0.96$. No significant differences were observed between the groups (Table 2 and Forest Plot S1).

Five studies evaluated the length of hospitalization. The standard mean difference for length of hospitalization between the moderate threshold ($N=4224$) and high threshold ($N=4219$) groups was −0.3 (95% CI: -0.57 to -0.03; $I^2=92\%$; $P=0.07$). Because the CI does not include "0," this difference was considered statistically significant. After removing a large sample study, the standard mean difference changed to -0.39 (95% CI: -0.69 to -0.00; $P=0.03$; Table 2 and Forest Plot S7a and b).

There were no significant differences in the other secondary outcomes, and the results did not change following adjustment. The results are summarized in Table 2 and Forest Plots S2–S7b.

Only two studies evaluated postoperative complications at a low treatment threshold of hypotension, and it was impossible to complete the meta-analysis owing to incomplete reports and inconsistent results. We attempted to obtain raw data from the authors; unfortunately, we received no response.

In the funnel plot of primary outcome analysis, the effect estimates of eight studies are evenly distributed around the relative risk of 0, including one large study and one small study. Therefore, removing large or small studies when conducting sensitivity analysis may be effective for identifying sources of heterogeneity.All funnel plots used for bias assessment are available in the Supplementary Materials, and no significant publication bias was observed (Funnel Plots S1–S7).

Discussion

Whether hypotension causes postoperative complications or is merely an associated phenomenon remains unclear. Therefore, determining the optimal treatment threshold of hypotension is essential.

Our meta-analysis confirmed the absence of a significant difference in postoperative complications between moderate and high treatment thresholds of hypotension. A few randomized studies have confirmed the effect of different treatment threshold of hypotension on clinical outcomes, largely because maintaining MAP over a relatively narrow range is challenging in clinical practice. We found similar results in two studies on the management of blood pressure in patients with shock [12, 13]. In the study conducted by Lamontagne et al., the risk of cardiac arrhythmias in lower and higher MAP arms was 20% and 36%, respectively [10]. Similarly, Asfar et al. found no significant difference in the overall incidence of serious adverse events between the moderate and high treatment threshold of hypotension ($P=0.64$) [11].

Unexpectedly, a recent meta-analysis reported that a lower treatment threshold of hypotension is associated with a reduction in hospital stay compared with a higher treatment threshold [12]. However, these findings remain controversial. Payne et al. [13] suggested that this discrepancy may stem from the inclusion of the POISE-3 study, which involved some patients who did not require general anesthesia. Nonetheless, even after excluding this study, the results remained unchanged. This phenomenon is difficult to explain, and future prospective studies are required to clarify the issue.

Only two studies have compared treatment threshold of hypotension with MAP<60 mmHg [10, 11], and each study used different variables. Yajuan et al. assessed

Table 1 Research characteristic

Research	Features of study design	Nation	Study population	Type of surgery	Group(target)			Outcomes
					Target <60mmhg	Target 60-75mmhg	Target>75mmhg	
An-Min Hu 2021 [7]	Single center RCT	China	Age ≥ 60y	non-cardiothoracic surgery	N/A	MAP (60–70 mmHg)	MAP (90–100 mmHg)	postoperative delirium, length of hospital stay
Emmanuel Futier 2017 [8]	multicenter RCT	France	Age>65y	abdominal operation (>90%)	N/A	Individualized blood pressure Management (10% of reference value)	Standard blood pressure Management (≥ 80mmhg)	composite of systemic inflammatory response syndrome and dysfunction of at least 1 organ system of the renal, respiratory, cardiovascular, coagulation, and neurologic systems postoperative
Julia Y 2024 [9]	Single center RCT	Germany	Age ≥ 60y	major noncardiac surgery	N/A	MAP>65mmhg	baseline MAP ± 10 mm Hg	Neurocognitive disorders, glomerular filtration rate, acute kidney injury, acute myocardial injury, hospital length of stay, all-cause mortality
Maura Marcucci 2023 [10]	multicenter RCT	International	Age ≥ 60y	noncardiac surgery	N/A	MAP>60mmhg	MAP>80mmhg	A composite of vascular death and nonfatal myocardial injury after noncar diac surgery, stroke, and cardiac arrest at 30 days.
Xiaodong Qiu 2021 [11]	Single center RCT	China	Age ≥ 60y	posterior lumbar fusion	N/A	MAP>65mmhg	MAP>75mmhg	kidney functions, Postoperative adverse reactions included pulmonary complications, gastrointestinal complications.
Yajuan Zhao 2022 [12]	Single center RCT	China	Aged 55–70 y	total knee arthroplasty	MAP ± 30%	Map ± 20%	MAP ± 10%	Postoperative Hb, CRP after operation, MMSE score at 1, 3, and 7 days after operation and PACU residence time
Matthew M 2015 [13]	Single center RCT	USA	Aged 14–45 y	gunshot wounds (76%) and stab wounds (24%)	MAP 50mmhg	Map 65mmhg	N/A	acute myocardial infarction, stroke, any renal failure coagulopathy, infection and Acute renal injury
Patrick M. Wanner 2021 [14]	Single center RCT	Switzerland	Age ≥ 60y	noncardiac surgery	N/A	MAP>65mmhg	MAP>75mmhg	acute myocardial injury, acute kidney injury, all-cause mortality

changes in postoperative cognitive function under different treatment threshold using the Mini-Mental State Examination (MMSE) scale; the MMSE scores were lower in the group with MAP < 60 mmHg. However, a lower score does not indicate a functional change, and none of the participants experienced postoperative changes in cognitive function [10]. Therefore, without access to the raw data, we were unable to perform a meta-analysis of

Table 2 Comparison of common postoperative complications managed by different intraoperative MAP targets

Outcomes	Study	Events/total		Risk Ratio/ Std mean difference(95%CI)	Adjust Risk Ratio (1)/Std mean difference(95%CI)	Adjust Risk Ratio (2)/Std mean difference(95%CI)	I^2	*p*	Adjust *p* value 1	Adjust *p* value 2
		Target 60-75mmhg group	Target >75mmhg group							
the composite primary outcome.	7	783(4465)	777(4460)	1.00[0.86,1.18]	1.02[0.80,1.31]	1.02[0.80,1.20]	66%	0.96	0.88	0.86
Acute kidney injury	4	166(678)	179(691)	0.91[0.66,1.25]	N/A	N/A	65%	0.63	N/A	N/A
Acute myocardial injury	6	576(4445)	570(4445)	1.05[0.96,1.15]	1.24[0.99,1.55]	1.05[0.96,1.15]	0%	0.41	0.12	0.41
Postoperative consciousness changed	4	65(451)	59(465)	1.00[0.44,2.25]	N/A	N/A	86%	0.99	N/A	N/A
Postoperative infection	4	88(4058)	89(4062)	0.94[0.62,1.41]	0.78[0.47,1.31]	1.01[0.61,1.65]	50%	0.80	0.43	0.98
All-cause mortality	4	56(4279)	59(4278)	0.93[0.68,1.26]	1.28[0.63,2.59]	N/A	0%	0.68	0.56	N/A
Length of hospitalization	5	4224	4219	-0.3[-0.57,-0.03]	-0.39[-0.69,-0.10]	-0.30[-0.59,0.00]	92%	0.07	0.03	0.1

these two studies; unfortunately, our request for the data was not granted. However, moderate variability was also noted in our analysis, with I^2 of 66% for the primary outcomes. The funnel plot did not suggest significant publication bias, and this difference may have to be explained both in light of our results and from a clinical perspective. First, we used a composite index as the primary outcome. Second, during the review of the studies, we found that all included studies were randomized, controlled, and double-blinded. Thus, differences in trial design such as age, surgery type, intervention time, dosage, administration method, and evaluation criteria may be the primary source of heterogeneity. Nonetheless, these results require confirmation through prospective studies.

This study had certain limitations. First, the standard blood pressure thresholds in some studies [9, 14–17] were individualized, making it difficult to establish fixed criteria for grouping. Instead, we defined the grouping criteria using an interval based on the need for clinical benefits. Therefore, our primary findings may have been biased owing to the variability in real-word clinical settings. Second, it was impossible to analyze all results of each study; we selected commonly reported indicators for analysis to obtain results that more closely reflect actual clinical situations. As the follow-up period extends, mortality may become more susceptible to influence by other factors.

Conclusions

There is no significant difference in postoperative complications between moderate and high treatment thresholds of hypotension. A higher treatment threshold during non-cardiac surgery does not significantly improve short-term prognosis compared with a moderate threshold. However, concerning the significant heterogeneity, further exploration and research are essential. Additionally, long-term follow-up data are crucial for assessing the impact of various blood pressure thresholds on long-term outcomes. Consequently, future research should focus on these factors. A moderate treatment threshold of hypotension appeared to reduce the length of hospital stay. However, the low treatment threshold of hypotension cannot be adequately explained by the available data and may pose potential risks.

Abbreviations

IOH	intraoperative hypotension
MAP	mean arterial pressure
RR	risk ratio
CI	confidence interval
MMSE	Mini-Mental State Examination

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12871-025-02976-5.

Supplementary Material 1

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None.

Author contributions

YG supervised and contributed to all aspects from study design through manuscript writing and critical revisions. GQ contributed to study design, literature search, data collection, data analysis, data interpretation, and critical revisions. MD contributed to data collection and data analysis. KY contributed to literature search, data analysis, and data interpretation. All authors have read and agreed to the published version of the manuscript.

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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
The authors declare no competing interests.

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