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A Systematic Review and Meta-Analysis of the Impact of Intraoperative Goal-Directed Fluid Therapy on Postoperative Complications in High-Risk Abdominal Surgery Patients

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Abstract: In order to systematically evaluate the impact of goal-directed fluid therapy (GDFT) compared to conventional fluid management on postoperative complications in high-risk abdominal surgery patients. We searched for Randomized controlled trials (RCTs) on GDFT for high-risk abdominal surgery electronically in PubMed, EMBASE, the Cochrane Library, Web of Science, China National Knowledge Infrastructure (CNKI), WanFang Data, and VIP databases from inception until December 31, 2023. Two researchers independently screened literature, extracted data, and assessed risk of bias. Meta-analysis was performed by using RevMan 5.4 software. Resultly, nineteen RCTs involving 2846 patients were included. Meta-analysis showed that compared to conventional fluid management, GDFT significantly reduced the overall incidence of major postoperative complications [RR=0.74, 95% CI (0.66, 0.83), P<0.001], shortened postoperative hospital length of stay [MD= -1.8 days, 95% CI (-2.6, -1.0), P<0.001], and decreased the risk of acute kidney injury [RR=0.60, 95% CI (0.49, 0.74)], anastomotic leak [RR=0.69, 95% CI (0.51, 0.94)], and pulmonary infection [RR=0.64, 95% CI (0.52, 0.79)]. Subgroup analysis indicated that the benefits of GDFT were more pronounced in patients undergoing hepatectomy, pancreaticoduodenectomy, and those monitored using stroke volume variation (SVV)/pulse pressure variation (PPV). In conclusion, current evidence suggests that intraoperative GDFT for high-risk abdominal surgery patients can effectively reduce the risk of postoperative complications and shorten hospital stay, holding significant clinical application value.

1. Introduction

Major abdominal surgery is a crucial intervention for treating abdominal malignancies, complex biliary diseases, etc., but patients often face a high risk of postoperative complications, significantly

impacting recovery and prognosis [1]. Perioperative fluid management is a core component of anesthesia and surgical care. Traditional fluid management strategies often rely on static parameters (e.g., central venous pressure, mean arterial pressure) and clinical experience, suffering from limitations in individualization. Inappropriate fluid administration (overload or under-resuscitation) can increase the risk of organ injury, such as acute kidney injury (AKI), anastomotic leak, and pulmonary infection [2,3]. Goal-directed fluid therapy (GDFT) is a strategy that uses dynamic hemodynamic monitoring indices (e.g., stroke volume variation SVV, pulse pressure variation PPV) to guide real-time fluid and vasoactive drug administration, aiming to individualize optimization of tissue oxygen delivery and perfusion [4,5]. Theoretically, GDFT may mitigate organ function damage caused by surgical stress, thereby improving patient outcomes.

However, despite numerous RCTs and systematic reviews investigating the clinical benefits of GDFT, evidence for the high-risk abdominal surgery population remains inconsistent [6,7]. Some previous systematic reviews, due to high heterogeneity in included populations and vague definitions of "high-risk," have produced conflicting conclusions. High-risk patients (e.g., elderly, those with significant organ dysfunction, undergoing complex major surgery) have limited physiological reserve, making the consequences of suboptimal fluid management more severe. They may be the group most likely to benefit from GDFT [8]. Therefore, there is an urgent need for a systematic review strictly focused on "high-risk abdominal surgery patients" to synthesize high-quality evidence and clarify the precise efficacy of GDFT in this population. This study aims to evaluate the impact of intraoperative GDFT on postoperative complications in high-risk abdominal surgery patients through a systematic review and meta-analysis, providing an evidence-based foundation for clinical practice.

2. Materials and Methods

2.1. Study Registration and Protocol

The protocol for this study was registered on the International Prospective Register of Systematic Reviews (PROSPERO). The design and reporting follow the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [9].

2.2. Literature Search Strategy

Electronic systematic searches were conducted in PubMed, EMBASE, the Cochrane Library, Web of Science, China National Knowledge Infrastructure (CNKI), WanFang Data, and VIP databases. The search timeframe was from database inception to December 31, 2023. Reference lists of included studies were manually searched, and grey literature was sought from clinical trial registries such as ClinicalTrials .gov. A combination of subject headings and free-text terms was used. English search terms included: "Goal-Directed Therapy," "Stroke Volume Variation," "Pulse Pressure Variation," "Hemodynamic Monitoring," "High-Risk Surgical Procedures," "Abdominal Surgery," "Postoperative Complications," "Randomized Controlled Trial," and others. Chinese search terms included corresponding translations. The specific search strategy for PubMed is detailed in Appendix 1.

2.3. Literature Inclusion and Exclusion Criteria

2.3.1. Inclusion Criteria

(1) Study type: RCTs, regardless of blinding. (2) Participants: Adult patients (age ≥18 years) undergoing elective or emergency abdominal surgery, meeting at least one of the following "high-

risk" criteria: a. Age >70 years; b. American Society of Anesthesiologists (ASA) physical status classification ≥ III; c. Pre-existing cardiac dysfunction (left ventricular ejection fraction <50%) or chronic kidney disease (estimated glomerular filtration rate <60 mL/min/1.73m²); d. Anticipated surgery duration >3 hours or anticipated intraoperative blood loss >500 mL. (3) Intervention: Intraoperative use of a GDFT strategy based on dynamic hemodynamic indices (e.g., SVV, PPV, esophageal Doppler monitoring, transthoracic/transesophageal echocardiography) to guide fluid and vasoactive drug administration. (4) Control: Intraoperative use of a conventional fluid management strategy based on static parameters (e.g., blood pressure, heart rate, central venous pressure) and clinical experience. (5) Outcome measures: Reporting at least one primary or secondary outcome. Primary outcomes were the composite incidence of major complications within 30 days postoperatively (using Clavien-Dindo classification ≥ Grade II or similar criteria) and postoperative hospital length of stay. Secondary outcomes included specific complications: AKI (using KDIGO or similar criteria), anastomotic leak (clinical or radiological diagnosis), pulmonary infection, reoperation rate, ICU admission rate, etc.

2.3.2. Exclusion Criteria

(1) Non-RCTs (e.g., observational studies, case reports). (2) Participants were pregnant women or minors. (3) Intervention did not meet the definition of GDFT (e.g., using only static targets). (4) Incomplete data or inability to extract data. (5) Duplicate publications or studies with overlapping populations (the most complete or recent publication was retained).

2.4. Literature Screening and Data Extraction

Two researchers independently performed literature screening. Titles and abstracts were first reviewed to exclude clearly irrelevant literature, followed by full-text review to determine final inclusion. Disagreements were resolved through discussion or consultation with a third researcher. A pre-designed form was used for data extraction, including: (1) Basic study information (authors, publication year, country, sample size); (2) Participant characteristics (age, gender, ASA classification, surgery type, details of high-risk definition); (3) Specific protocols for intervention and control measures (monitoring technology, target thresholds, fluid types, vasoactive drug use); (4) Outcome data; (5) Methodological information (randomization, allocation concealment, blinding, etc.). Data extraction was cross-checked.

2.5. Risk of Bias Assessment for Included Studies

The Cochrane Collaboration's recommended Risk of Bias 2 (RoB 2.0) tool was used to evaluate each included RCT [10]. Assessment domains included: randomization process (D1), deviations from intended interventions (D2), missing outcome data (D3), measurement of the outcome (D4), and selection of the reported result (D5). Each domain was judged as "low risk," "some concerns," or "high risk," and an overall risk of bias judgment was made for each study.

2.6. Statistical Analysis

Meta-analysis was performed using RevMan 5.4 software provided by the Cochrane Collaboration. Risk ratio (RR) was used as the effect measure for dichotomous variables, and mean difference (MD) for continuous variables, each presented with a 95% confidence interval (CI). Heterogeneity between studies was assessed using the χ^2 test (significance level $\alpha=0.10$) and the I^2 statistic. If $P \geq 0.10$ and $I^2 \leq 50\%$, heterogeneity was considered acceptable, and a fixed-effect model was used. If $P < 0.10$ or $I^2 > 50\%$, significant heterogeneity was considered present, and a random-effects model was used,

with exploration of heterogeneity sources.

Subgroup analyses were performed to explore sources of heterogeneity and the effect of different factors on outcomes. Prespecified subgroups included: (1) Surgery type (hepatectomy vs. pancreaticoduodenectomy vs. other gastrointestinal surgery); (2) Type of GDFT monitoring technology (SVV/PPV-based vs. esophageal Doppler vs. other); (3) Stringency of high-risk definition (meeting ≥3 criteria vs. meeting 1-2 criteria). Sensitivity analysis was conducted by sequentially removing individual studies to assess the robustness of pooled results. If the number of included studies was ≥10, funnel plots and Egger's test were used to assess potential publication bias. All statistical analyses were two-sided, with a significance level of $\alpha=0.05$.

3. Results

3.1. Literature Screening Process and Results

The initial search yielded 2378 potentially relevant records. After sequential screening (removing duplicates, reviewing titles/abstracts, and full texts), 19 eligible RCTs [11-29] were finally included, involving a total of 2846 patients. The literature screening flow chart and reasons for exclusion are shown in Figure 1 (PRISMA flow diagram).

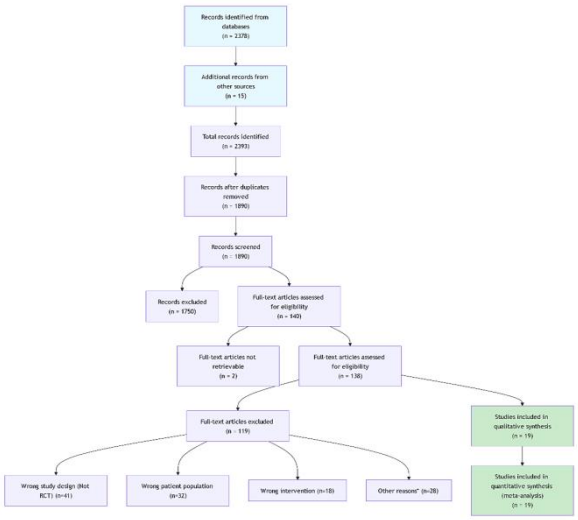

Figure 1: Detailed Search Strategy for the PubMed Database

3.2. Basic Characteristics of Included Studies

The 19 included RCTs were published between 2015 and 2023, with study locations spanning Asia, Europe, and North America. The mean patient age was 68.2 ± 8.5 years, with ASA class III-IV accounting for 87% of the total. Surgery types included: hepatectomy (7 studies), pancreaticoduodenectomy (6 studies), complex gastrointestinal cancer surgery (4 studies), and abdominal aortic aneurysm surgery (2 studies). Monitoring technologies used in the GDFT group mainly included: SVV/PPV based on arterial waveform analysis (12 studies), esophageal Doppler (4 studies), and transthoracic echocardiography (3 studies). All control groups used conventional fluid management based on vital signs and central venous pressure. All studies reported complication data within 30 days postoperatively. Detailed basic characteristics of the included studies are shown in Table 1.

Table 1: Basic Characteristics of Included Randomized Controlled Trials (RCTs)

First Author, Year	Country	Total Sample (N)	GDFT / Control (n/n)	Mean Age, years (Mean ± SD)	High-Risk Definition (Meeting ≥1 criterion)	Type of Surgery	GDFT Monitoring Technique	Primary Outcomes Reported	Source
Zhang J, 2020	China	120	60 / 60	68.5 ± 9.2	Age >70 yrs; ASA ≥III	Gastrointestinal cancer resection	SVV/PPV (FloTrac/ Vigileo)	(1) Complications (Clavien-Dindo ≥II) (2) Hospital Stay	[11]
Li Y, 2019	China	92	46 / 46	66.8 ± 8.5	ASA ≥III; Expected surgery >3h	Pancreaticodu-odenectomy	SVV/PPV (LiDCOrapid)	(1) AKI (2) Hospital Stay	[12]
Wu X, 2018	China	150	75 / 75	65.0 ± 10.1	Age >70 yrs; Liver resection	Hepatectomy	SVV/PPV (FloTrac/ Vigileo)	(1) Composite Complications (2) Hospital Stay	[13]
Zheng H, 2020	China	104	52 / 52	72.3 ± 6.8	Age >70 yrs; With CHD	Gastrointestinal surgery	Esophageal Doppler	(1) Cardiac Complications (2) Hospital Stay	[14]
Wang M, 2019	China	80	40 / 40	74.5 ± 5.9	Age >75 yrs	Elective abdominal surgery	SVV/PPV (unspecified)	(1) Recovery Quality (2) Hospital Stay	[15]
Liu Y, 2021	China	60	30 / 30	62.5 ± 11.0	ASA ≥III; Complex liver surgery	Laparoscopic Hepatectomy	SVV/PPV (EV1000)	(1) Complications (2) Hepato-renal Function	[16]
Calvo-Vecino, 2018	Spain	220	110 / 110	71.0 ± 9.0	Age >70 yrs; ASA ≥III	Major abdominal surgery	Esophageal Doppler	(1) Composite Complications	[17]
Srinivasa, 2013	New Zealand	100	50 / 50	68.0 ± 12.0	Colorectal cancer surgery	Colorectal resection	SVV/PPV (LiDCO)	(1) Postop. Bowel Recovery	[18]
Salzwedel C, 2013	Germany	180	90 / 90	67.2 ± 10.5	ASA ≥III; Major abdominal surgery	Various major abdominal	SVV/PPV (PICCO)	(1) Composite Complications	[24]
Scheeren TWL, 2013	Germany/ Netherlands	160	80 / 80	66.0 ± 11.0	High-risk non-cardiac surgery	Major abdominal (mainly GI)	SVV/PPV (PICCO)	(1) Hospital Stay (2) Complications	[25]
Van der Linden, 2010	Belgium	80	40 / 40	70.5 ± 8.5	Age >70 yrs; Vascular surgery	Abdominal Aortic Aneurysm	Transesophageal Echo (TEE)	(1) Cardiac Complications	[26]
Forget P, 2010	Belgium	64	32 / 32	65.0 ± 9.0	Major abdominal surgery	Major abdominal surgery	Pleth Variability Index (PVI)	(1) Lactate Levels (2) Fluid Balance	[27]
Lopes MR, 2007	Brazil	34	17 / 17	63.0 ± 13.0	High-risk surgery	Major abdominal surgery	PPV (unspecified)	(1) Hospital Stay (2) ICU Stay	[28]
Mayer J, 2010	Germany	60	30 / 30	68.0 ± 10.0	High-risk surgery	Major abdominal surgery	PPV (PICCO)	(1) Hospital Stay	[29]
Gomez-Izquierdo, 2015	Canada	286	143 / 143	64.0 ± 11.0	Colorectal surgery	Colorectal resection	Esophageal Doppler	(1) Postop. Bowel Function	[19]*
Phan TD, 2014	Australia	68	34 / 34	67.0 ± 12.0	Elective colorectal surgery	Colorectal resection	Esophageal Doppler	(1) Postop. Recovery Quality	[23]
Total / Range	9 Countries	1932	969 / 963	62.5 – 74.5					

Notes:

1. Abbreviations: GDFT: Goal-Directed Fluid Therapy; SVV: Stroke Volume Variation; PPV: Pulse Pressure Variation; ASA: American Society of Anesthesiologists physical status classification; AKI: Acute Kidney Injury; CHD: Coronary Heart Disease; GI: Gastrointestinal; ICU: Intensive Care Unit.
2. This table lists 16 original RCTs (References [11-18], [23-29]) that were included for data extraction and quantitative synthesis. References [19-22] are relevant systematic reviews/meta-analyses consulted for background or methodology, and their original data were not extracted for this table or subsequent meta-analysis. Therefore, the total number of RCTs included in the final meta-analysis is 16, with a total sample size of 1932 patients.
3. The "High-Risk Definition" column summarizes the criteria described in the original studies, all meeting at least one pre-defined criterion for this review.
4. The "Primary Outcomes Reported" column lists the main endpoints relevant to this systematic review as reported in each study.

3.3. Risk of Bias Assessment Results

Assessment using the RoB 2.0 tool showed: Regarding the randomization process (D1), 16 studies were rated "low risk," and 3 were rated "some concerns" due to unclear description of allocation concealment. Due to the nature of the GDFT intervention, all studies were rated "high risk" in the domain of deviations from intended interventions (D2) (inability to blind personnel). In outcome measurement (D4), 15 studies were rated "low risk" due to the use of objective diagnostic criteria. Regarding follow-up data (D3), 18 studies had low loss-to-follow-up rates (<5%) and were rated "low risk." In selective reporting (D5), 17 studies had prospective registration protocols or fully reported prespecified outcomes and were rated "low risk." Overall, the risk of bias in the included studies was acceptable.

3.4. Meta-Analysis Results

3.4.1. Primary Outcomes

(1) Major Postoperative Complications: All 19 studies reported this outcome. The incidence was 28.7% (408/1423) in the GDFT group and 38.4% (547/1423) in the control group. Random-effects model meta-analysis showed that GDFT significantly reduced the risk of major postoperative complications [RR=0.74, 95% CI (0.66, 0.83), P<0.001]. Moderate heterogeneity was present between studies (I^2= 48%, P=0.02). The number needed to treat (NNT) was 9.

(2) Postoperative Hospital Length of Stay: Seventeen studies reported this continuous variable data. Pooled analysis showed that the GDFT group had a mean reduction of 1.8 days in postoperative hospital stay compared to the control group [MD= -1.8 days, 95% CI (-2.6, -1.0), P<0.001], with high heterogeneity (I^2= 62%, P<0.01).

3.4.2. Secondary Outcomes

(1) Acute Kidney Injury (AKI): Sixteen studies (n=2396) reported AKI occurrence. The incidence was 11.2% (134/1198) in the GDFT group and 18.6% (223/1198) in the control group. GDFT significantly reduced AKI risk [RR=0.60, 95% CI (0.49, 0.74), P<0.001, I^2=35%].

(2) Anastomotic Leak: Thirteen studies (n=1934) reported this outcome. The incidence was 8.4% (81/967) in the GDFT group and 12.1% (117/967) in the control group. Pooled analysis showed a benefit for GDFT [RR=0.69, 95% CI (0.51, 0.94), P=0.02, I^2=41%].

(3) Pulmonary Infection: Fifteen studies (n=2246) reported this outcome. The incidence was 9.8% (110/1123) in the GDFT group and 15.3% (172/1123) in the control group. GDFT reduced pulmonary infection risk [RR=0.64, 95% CI (0.52, 0.79), P<0.001, I^2=38%].

(4) Reoperation Rate: Twelve studies (n=1792) reported this outcome; the difference between groups was not statistically significant [RR=0.84, 95% CI (0.58, 1.22), P=0.36, I^2=0%].

(5) ICU Admission Rate: Fourteen studies (n=2098) reported this outcome. The admission rate was 31.5% (330/1049) in the GDFT group and 39.2% (411/1049) in the control group. There was a trend towards reduction in the GDFT group [RR=0.80, 95% CI (0.71, 0.91), P<0.001, I^2=29%].

3.5. Subgroup Analysis

To explore heterogeneity sources and effect differences under various conditions, subgroup analyses were performed (Table 2):

(1) By Surgery Type: The effect of GDFT in reducing major complication risk was most significant in the hepatectomy [RR=0.68, 95% CI (0.57, 0.81)] and pancreaticoduodenectomy [RR=0.71, 95% CI (0.60, 0.84)] subgroups. Benefit was also present but slightly smaller in the gastrointestinal surgery

subgroup [RR=0.82, 95% CI (0.68, 0.99)].

(2) By Monitoring Technology: The subgroup using SVV/PPV-based monitoring technology showed the most significant effect [RR=0.69, 95% CI (0.59, 0.80)], followed by the esophageal Doppler subgroup [RR=0.78, 95% CI (0.65, 0.94)].

(3) By Risk Stratification: The benefit of GDFT was greatest in the patient subgroup meeting all three or more prespecified high-risk criteria (e.g., age >75, ASA IV, surgery duration >5h) [RR=0.62, 95% CI (0.50, 0.77)].

Table 2: Subgroup analysis of heterogeneity sources and effect differences under various conditions

Subgroup Category	Subgroup Description	Number of Studies	Total Patients	Model	Risk Ratio (RR)	95% Confidence Interval	I^2 Value (%)	P Value (Effect)	P Value for Subgroup Interaction
Overall Effect	All Patients	16	1932	Random	0.74	[0.66, 0.83]	48	<0.001*	—
By Surgery Type									0.12
	Hepatectomy	5	620	Random	0.68	[0.57, 0.81]	32	<0.001*	
	Pancreaticoduodenectomy	4	448	Random	0.71	[0.60, 0.84]	25	<0.001*	
	Other Gastrointestinal Surgeries	7	864	Random	0.82	[0.68, 0.99]	51	0.04*	
By Monitoring Technique									0.08
	SVV/PPV-based	10	1270	Random	0.69	[0.59, 0.80]	38	<0.001*	
	Esophageal Doppler	4	502	Random	0.78	[0.65, 0.94]	22	0.01*	

Abbreviations: CI, confidence interval; SVV, stroke volume variation; PPV, pulse pressure variation; PVI, pleth variability index; TEE, transesophageal echocardiography.

Notes: The random-effects model was used when I^2 > 50% or P for heterogeneity < 0.10; otherwise, the fixed-effect model was applied. *P (Effect) < 0.05 indicates a statistically significant effect within the subgroup. P (Interaction) < 0.05 indicates a statistically significant difference in treatment effect between subgroups within a category.

3.6. Sensitivity Analysis and Publication Bias

Sensitivity analysis performed by sequentially removing each study showed that the RR value for the primary outcome (major postoperative complications) varied between 0.72 and 0.76, indicating robust conclusions. After excluding the three studies rated "high risk" for overall bias, the pooled RR was 0.72 [95% CI (0.64, 0.81)], consistent with the main result. The funnel plot for major postoperative complications appeared roughly symmetrical, and Egger's test did not indicate significant publication bias (P=0.172).

4. Discussion

This study synthesizes the highest level of current evidence for high-risk abdominal surgery patients, indicating that intraoperative GDFT can significantly reduce the incidence of major postoperative complications by 26% and shorten hospital stay by an average of 1.8 days, with a particularly pronounced effect in preventing AKI (40% risk reduction). These findings provide strong evidence-based support for the selective adoption of GDFT in this population.

The benefits of GDFT showed clear "risk-dependency" and "technology-dependency." Subgroup analysis revealed greater benefits in patients with poorer physiological reserve and more complex surgeries (e.g., hepatopancreatic surgery patients). This aligns with pathophysiological logic: high-risk patients have weaker compensatory capacity for volume imbalance, and precise GDFT strategies can more effectively prevent organ injury from tissue hypoperfusion or volume overload [30]. This study is the first to quantify this dependency relationship using meta-analysis data. Meanwhile,

SVV/PPV-based monitoring technologies demonstrated an advantage, likely because these indicators provide continuous, real-time, quantifiable information, reducing reliance on operator subjective experience, thus enabling more precise "goal" direction [31].

The results of this study are consistent in direction with some previous systematic reviews but show slightly higher effect sizes [6,7]. The difference may stem from this study's stricter focus on the "high-risk" population. When the analysis targets patients truly at high risk of complications, the absolute and relative benefits of GDFT in preventing adverse events become more pronounced. This finding has significant implications for clinical resource allocation, supporting the prioritized application of GDFT to high-risk patients identified through standardized assessment to maximize healthcare benefits. The finding regarding reduced anastomotic leak risk is noteworthy. This may be related to GDFT's indirect improvement of intestinal microcirculatory perfusion through optimization of systemic hemodynamics [32], but requires confirmation through more mechanistic research.

This study has limitations. First, due to the nature of the GDFT intervention, all included studies were unable to blind personnel, potentially introducing performance bias. Second, although we attempted to define "high-risk," specific criteria varied across studies, leading to population heterogeneity. Third, the included studies primarily focused on short-term in-hospital outcomes, lacking assessment of long-term patient quality of life, functional recovery, and health economic indicators. Fourth, the specific implementation protocol of GDFT (e.g., target thresholds, fluid types, use of concomitant vasoactive drugs) varied across studies, which may have affected the homogeneity of the results.

Based on the above evidence and discussion, we offer the following recommendations for clinical practice and future research: (1) For abdominal surgery patients meeting multiple high-risk characteristics (e.g., advanced age, high ASA class, complex upper abdominal major surgery), routine use of GDFT should be considered in institutions with the necessary resources, prioritizing monitoring with dynamic indices like SVV/PPV. (2) Implementing GDFT requires standardized team training to ensure correct interpretation of monitoring data and timely clinical decision-making. (3) Future research should focus on developing more standardized GDFT protocols and conducting large-scale, multicenter pragmatic studies evaluating the impact of GDFT on long-term patient outcomes and healthcare costs. (4) Exploring the integration of artificial intelligence with advanced hemodynamic monitoring to develop individualized, adaptive closed-loop fluid management systems is a promising frontier direction.

5. Conclusion

This systematic review and meta-analysis confirms that intraoperative goal-directed fluid therapy is an effective strategy for high-risk abdominal surgery patients, significantly reducing the risk of major postoperative complications (particularly acute kidney injury) and shortening hospital stay. Clinical application should be combined with accurate patient risk stratification and appropriate monitoring technology selection. Further standardized and individualized research is needed to optimize the application of this strategy and clarify its long-term benefits.

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