World J Surg (2019) 43:2747–2755
https://doi.org/10.1007/s00268-019-05091-y

SCIENTIFIC REVIEW

Perioperative Fluid Restriction in Abdominal Surgery: A Systematic Review and Meta-analysis

Yanfei Shen[1] · Guolong Cai[1] · Shijin Gong[1] · Jing Yan[1]

Published online: 22 July 2019

Abstract

Background Perioperative fluid management is a critical component in patients undergoing abdominal surgery. However, the benefit of restricted fluid regimen remains inconclusive. This systematic review aimed to explore potential factors causing these inconsistent findings.

Methods The literature searches were performed in three databases including PubMed, Embase, and the Cochrane library until August 30, 2018. Only randomized, controlled trials comparing the effect of restricted versus liberal regimen in abdominal surgery were included. The primary outcome was total postoperative complications. Subgroup analysis was performed according to between-group weight increase difference ($\geq$ 2 kg and $<$ 2 kg) and fluid intake ratio ($\geq$ 1.8 and $<$ 1.8).

Results Sixteen studies were finally included in this meta-analysis. The benefit of the restricted regimen in reducing postoperative complication was only significant in the subgroup with high weight increase difference ($\geq$ 2 kg) (RR 0.67, 95% CI 0.57–0.79) and the subgroup with high fluid intake ratio ($\geq$ 1.8) (RR 0.72, 95% CI 0.62–0.82). In the subgroup with low weight increase difference ($<$ 2 kg) or low fluid intake ratio ($<$ 1.8), the effect of the restricted regimen was not significant (RR 0.88, 95% CI 0.51–1.50, and RR 1.18, 95% CI 0.91–1.53, respectively).

Conclusions The benefit of the restricted regimen was only significant in the subgroup with high weight increase difference ($\geq$ 2 kg) or high fluid intake ratio ($\geq$ 1.8).

Introduction

More than 310 million major surgical procedures are performed worldwide every year [1]. Despite significant advances in perioperative care over the past few decades, the incidence of complications after abdominal surgery remains high [2, 3]. Perioperative fluid strategy plays a critical role in perioperative care [4]. However, the conclusions remain conflicting. Early consensus suggested aggressive fluid administration [5] to increase tissue perfusion and oxygenation [6], as hypovolemia was common due to preoperative fasting, anesthesia-related vasodilation, and blood loss [7]. However, recent studies found that perioperative positive fluid accumulation was a major cause of postoperative complications [8, 9], and the Enhanced Recovery After Surgery (ERAS) program suggested maintaining a zero fluid balance [10] for a better prognosis.

For the past 20 years, the restricted perioperative fluid regimen has been considerably investigated in patients undergoing abdominal surgery. However, the findings were

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00268-019-05091-y) contains supplementary material, which is available to authorized users.

✉ Guolong Cai
caiguolongzhejiang@126.com

[1] Department of Intensive Care Unit, Zhejiang Hospital, No. 12, Linyin Road, Hangzhou 310000, Zhejiang, People's Republic of China

inconsistent. Several studies [11, 12] reported that the restricted regimen was associated with fewer postoperative complications, while Futier et al. [13] reported that fluid restriction may aggravate hypovolemia and was associated with more postoperative complications. Recently, a large multi-center study [14] reported that the incidence of acute kidney injury was significantly higher in patients receiving a restricted fluid regimen than in those receiving the standard fluid regimen. However, the possible reasons behind these contradictory conclusions remain unclear. We noticed that the benefits of fluid restriction were more frequently reported in studies with high postoperative weight increase [15–17] while they were less significant in those with low weight increase [14, 18]. Clinically, despite the application of similar fluid restriction, the fluid accumulation status would be quite different in different populations. Thus, we speculate that weight increase may play a critical role in these inconsistent findings. Furthermore, although the intervention was named "restricted fluid regimen" in most of these studies, the volumes of fluid intake were quite different. Thus, we performed this meta-analysis to investigate whether different weight increases and volumes of fluid intake have an interactive effect with fluid restriction in patients undergoing abdominal surgery.

Methods

Search strategy

The literature searches were conducted in PubMed, Embase, and the Cochrane library database by two authors, using the key words "Gastro* surgery" or "Pancre* surgery" or "major surgery" or "abdom* surgery" or "colon resect*" or "colorect*" and "standard fluid" or "crystall* fluid" or "colloid* fluid" or "fluid restrict*" or "volume replacement" or "liberal fluid" with no limitations applied to the publication year or language. All references listed in each identified article were also manually reviewed to identify all eligible studies and minimize potential bias. The detailed search protocol for the PubMed database is supplied in a Supplementary file (p. 1).

Inclusion and exclusion criteria

Eligible clinical trials were identified based on the following criteria:

1. Studies only including patients undergoing abdominal surgery. 2. Patients receiving a perioperative restricted or liberal/standard fluid regimen, including intraoperative and postoperative protocols. 3. The rate of postoperative complication was reported as a primary or secondary outcome. 4. Only randomized controlled trials were screened for inclusion. Studies were excluded if the volume of administered fluid was similar between the two groups on the day of operation [19, 20] or if they were performed in animals or in patients younger than 18 years.

Study selection

Two authors performed the study selection independently, in two phases. First, they excluded all duplicated, non-randomized, or irrelevant studies by screening titles and abstracts. Second, full texts of all eligible studies were carefully reviewed using the previously mentioned inclusion criteria. Any discrepancies were resolved by discussion in the presence of a third author.

Data extraction

All relevant data were extracted and recorded in a standard form by two independent investigators. This form contained details of the authors, publication year, number of centers, age, sex, body mass index, American Society of Anesthesiologists (ASA) class, surgery types, funding, outcome measures (duration of follow-up, total postoperative complications), and fluid data. For any missing data, the corresponding authors were contacted by e-mail to obtain the original data. Any differences in opinions were resolved by discussion in the presence of a third author.

Quality assessment

For the quality assessment of each included study, the Cochrane risk of bias tool was used. Each study was assessed using the following six items: (1) random sequence generation; (2) allocation concealment; (3) blinding of participants; (4) blinding of outcome assessors; (5) incomplete data; (6) selective reporting; Two independent investigators conducted quality assessments of study methodology, and any divergences were resolved through discussion.

Outcome measure

The primary outcome was total postoperative complications, defined as the number of patients who at least had one complication after abdominal surgery. However, in the study by Myles et al. [14], the number of patients with complications was not available and the total number of complications was used in this analysis. Other outcomes, such as time-to-first flatus and bowel movement, were not analyzed due to the significant non-normal distribution. Cardiopulmonary complications were also not reported as only the total number of these complications was available in most included studies.

Subgroup analysis

As the main purpose of this meta-analysis was to explore the possible reasons behind these inconsistent conclusions, subgroup analysis was performed according to two factors. Factor one: weight increase difference $\geq$ 2 kg or weight increase difference $<$ 2 kg between the liberal and restricted groups [4]. Weight increase difference was defined as the difference of weight increase on postoperative day 1 between the two groups. The threshold value of 2 kg was defined according to the recommendation of the ERAS [4] program. Only eight studies were included in this subgroup analysis due to lack of data. Factor two: fluid ratio $\geq$ 1.8 or fluid ratio $<$ 1.8. In all included studies; the volume of fluid intake on the operation day varies greatly, largely due to the different definitions of the duration, such as intraoperative duration, intraoperative + post-anesthesia care unit duration, postoperative day 1, and 24 h after operation. To minimize this bias, the fluid intake ratio was used for subgroups, which was defined as the fluid intake volume of the standard group/fluid intake volume of the restricted group. The mean value of fluid intake ratio (1.8) was used as the threshold point. All sixteen studies [12–18, 21–29] were included in this subgroup analysis.

Statistical analysis

Statistical analysis of the study was performed using STATA 14.0 (College Station, TX, USA). For dichotomous variables, a Mantel–Haenszel risk ratio with 95% confidence interval was calculated. The value of $I^2 > 50\%$ [30] was used to indicate a significance of heterogeneity. A random-effect model was applied in the presence of statistical heterogeneity. Meta-regression was also performed to explore potential factors causing heterogeneity, and publication bias was tested by funnel plot and Harbord method. Sensitivity analysis was performed to assess the impact of excluding studies based on methodological quality.

Results

Study description

We identified sixteen trials that met our inclusion criteria (2341 patients were treated with restricted regimen and 2337 patients receiving liberal regimen). A summary of the study selection process is shown in Fig. 1, and the details of excluded references are presented in the Supplementary

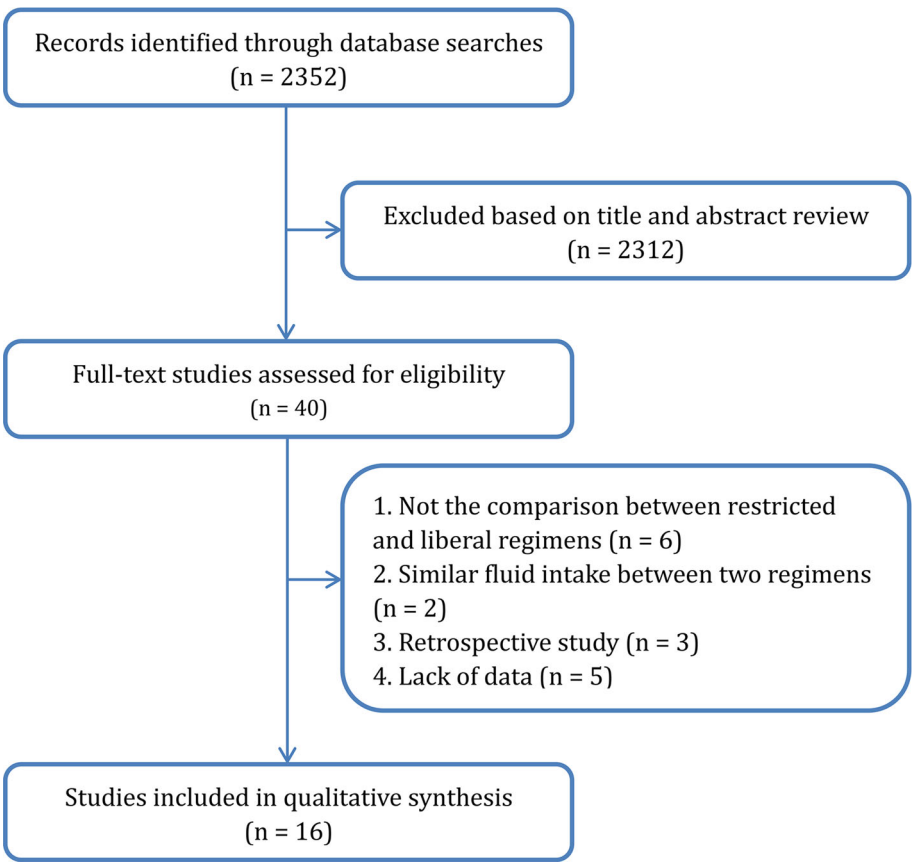

Fig. 1 Flow chart of study selection

file (pp. 1–2). It is noteworthy that the study by Holte et al. [31] was excluded in two previous systematic reviews [32, 33] due to the definitions of fluid regimen in their study, which were more likely standard and supplemental regimens although they were designated as "restricted regimen" and "liberal regimen." A meta-analysis including the study by Holte et al. [31] was also performed, and the results are shown in the Supplementary file (Figure S1, S2).

All sixteen studies compared the total complication rates between restricted and standard regimens in patients undergoing abdominal surgery. Postoperative weight increase was reported in eight studies [14–18, 22, 24, 26]. The volume of fluid intake was reported in all included studies. For surgical types, four trials included patients undergoing elective colorectal surgery [16–18, 25]. Two trials included patients undergoing pancreatic surgery [28, 29]. Two trials included patients undergoing elective abdominal aortic surgery [12, 23]. The remaining eight trials included patients with other major abdominal surgery. Details of all included studies are summarized in Table 1.

Quality assessment

Assessment of the bias risk is summarized in Fig. 2. The quality of all included trials was moderately high. However, blinding of patients was unclear in nine and negative in two of these trials. The blinding of outcome assessors was well reported in 14 of these trials. No studies were excluded for low quality or dubious decisions in sensitivity analysis.

Subgroups of weight increase difference

Eight trials were included in this subgroup comparison (Fig. 3). The overall total postoperative complication was decreased in the restricted group (RR 0.71, 95% CI 0.51–0.96), and the heterogeneity was obvious (I^2 = 87.3%, $p < 0.001$). In the subgroup with high postoperative weight increase difference ($\geq$ 2 kg), the postoperative complication rate was significantly lower in the restricted group (RR 0.67, 95% CI 0.57–0.79), and the heterogeneity was not significant (I^2 = 0%, p = 0.419). In the subgroup with low weight increase difference ($<$ 2 kg), the difference was not significant (RR 0.88, 95% CI 0.51–1.50).

Subgroups of different fluid intake ratio

Sixteen trials were included in the subgroup analysis of fluid intake ratio (Fig. 4). The overall total postoperative complication rate was not significant (Figure S3, RR 0.84, 95% CI 0.69–1.03), while the heterogeneity was significant (I^2 = 81.7%, $p < 0.001$). In the subgroup with high fluid intake ratio ($\geq$ 1.8), the postoperative complication rate was significantly lower in the restricted group (RR 0.72, 95% CI 0.62–0.82), and the heterogeneity was not significant (I^2 = 10.1%, p = 0.351). However, in the subgroup with low fluid intake ratio ($<$ 1.8), the difference was not significant (RR 1.18, 95% CI 0.91–1.53).

Meta-regression

Meta-regression was performed to test the contribution of these two stratification factors in heterogeneity. According to the result of univariate meta-regression (Supplementary file, Table S1), only fluid intake ratio (p = 0.002) was suggested as a potential cause of heterogeneity of these studies. However, this finding could be underpowered by the small number of included trials.

Publication bias

A regular funnel plot is shown in Supplementary file Figure S4. Visual asymmetry of the plot was observed, and the p value of the Harbord test was significant (p = 0.026), which suggested the presence of publication bias.

Discussion

The main finding of this meta-analysis was that postoperative weight increase is a critical factor in the effectiveness of the restricted fluid regimen, and that a weight increase difference of 2 kg may be a threshold to determine whether the restricted regimen is effective. In trials with fluid intake ratio $\geq$ 1.8, the effect of the restricted fluid regimen in reducing postoperative complications is significant, as the difference of weight increase between liberal and restricted fluid regimens may be greater.

Opinions regarding appropriate fluid strategy remain controversial. Although sufficient fluid administration is necessary to maintain adequate tissue perfusion, positive fluid accumulation has been reported as a major risk factor for postoperative complications [8]. In a cohort of critically ill patients undergoing acute surgery [9], Galinos found that achieving negative fluid balance during ICU admission was associated with a significant reduction in the risk for mortality, and a zero fluid balance was also recommended by ERAS program [10] for a better prognosis in these patients.

Aiming to alleviate the detrimental effect of fluid accumulation, restricted fluid management was evaluated and was reported to be associated with improved outcomes in cohorts of trauma and acute respiratory distress

Table 1 Characteristics of included studies

References	Duration	Fluid intake Res/Lib	Journal	Surgery	Study center	Proportion of ASA ≥ III	Age	M/F	BMI	Sample-size Res/Lib	Funding
Lobo [15]	Operation day	3236/5909	Lancet	Hemicolectomy	1	N/A.	60	14/6	25	10/10	Yes
Brandstrup [16]	Operation day	3734/6283 (Median)	Ann Surg	Elective colorectal resection	8	3/141	66	70/71	25	69/72	Yes
Nisanevich [22]	Operation time	1408/3878	Anesthesiology	Major abdominal surgery	1	39/152	61	78/74	25	77/75	No
Mackay [18]	Operation day	2000/2750	Br J Surg	Elective colorectal resection	1	20/80	73	37/43	26	39/41	No
Vermeulen [21]	Protocol	1500/2500	Trials	Major abdominal surgery	1	8/62	55	40/22	24	30/32	No
McArdle [12]	Operation day	4652/6472	Ann Surg	Abdominal aortic surgery	1	N/A.	74	18/3	26	11/10	No
Cohn [25]	Operation time	1861/3635	Ann Surg	Elective colorectal resection	2	17/27	52	14/13	24	18/9	Yes
Futier [13]	Operation time	3380/5588	Arch Surg	Major abdominal surgery	1	43/70	61	39/31	25	36/34	Yes
Nordling [17]	Operation day	3050/5775	Br J Surg	Elective colorectal resection	1	19/161	68	88/73	25	79/82	Yes
Gao [27]	Operation day	1555/3050	World J Surg	Major abdominal surgery	1	63/179	72	103/76	21	93/86	Yes
Peng [24]	Operation day	1560/3030	Hepatogastroenterology	Major abdominal surgery	1	62/174	62	94/80	N/A.	84/90	No
Wuethrich [26]	Operation time	1700/4300	Anesthesiology	Radical cystectomy	1	68/166	68	114/52	24	83/83	Yes
Grant [28]	Operation time + PACU	3618/6077 (Median)	Ann Surg	Pancreatic surgery	1	139/330	65	174/156	26	166/164	Yes
Piljic [23]	Operation day	4039/5017	Thorac Cardiovasc Surg	Abdominal aortic surgery	2	N/A.	69	48/12	25	30/30	No
Weinberg [29]	Operation time	2050/4088 (Median)	Plos One	Pancreatic surgery	4	38/52	65		27	26/26	No
Myles [14]	24 h after operation	3671/6146	NEJM	Major abdominal surgery	47	1806/2983	66	1554/1429	N/A.	1490/1493	Yes

Res/Lib restricted group/liberal group, *ASA* American Society of Anesthesiologist, *M/F* male/female, *BMI* body mass index

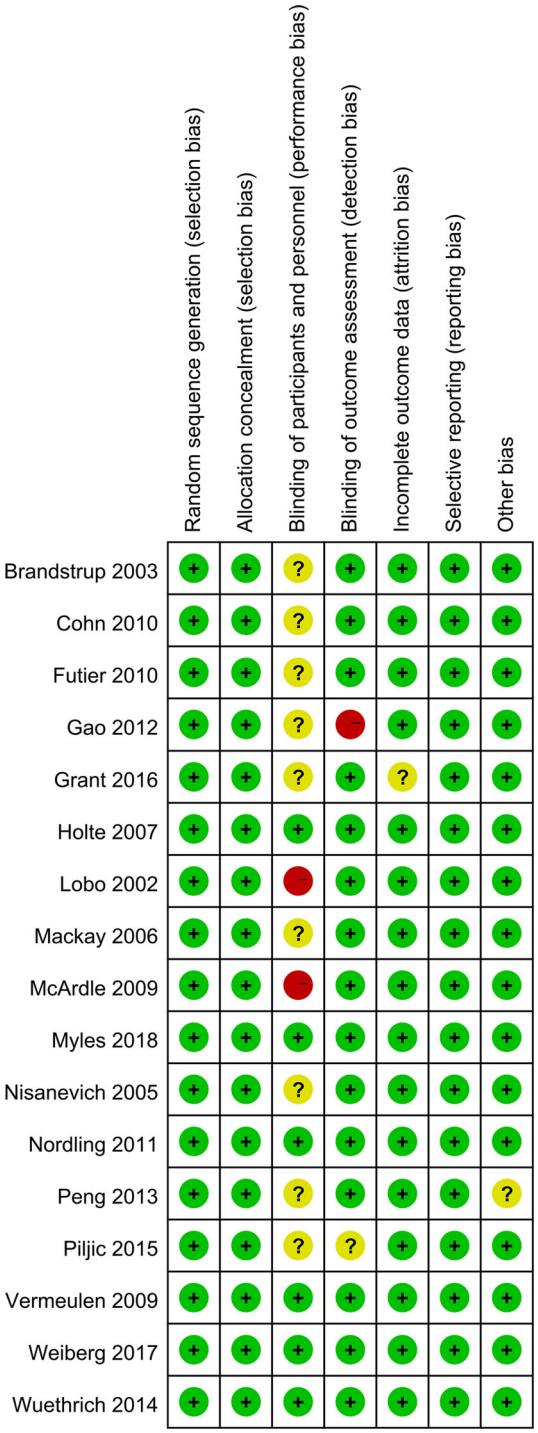

Fig. 2 Risk of bias summary. Green indicates a low risk of bias, red indicates a high risk of bias, and yellow indicates an unclear risk of bias

syndrome patients. However, in patients undergoing abdominal surgery, the effect of restricted fluid regimen remained inconsistent. In 2003, Brandstrup et al. [16] performed a multi-center randomized, observer-blinded clinical trial to evaluate the effects of the combined intraoperative and postoperative fluid restriction on postoperative complications in 172 patients undergoing elective colorectal surgery. They found that a restricted regimen aiming at unchanged body weight could significantly decrease both overall and cardiopulmonary complications; the weight increases on postoperative day 1 were 0.57 kg and 2.76 kg in the restricted and liberal groups, respectively. Similar findings were also found in two other single-center randomized trials wherein Lobo et al. [15] reported that compared to restricted regimen, liberal regimen sufficient to cause a 3 kg weight increase after surgery delayed the recovery of gastrointestinal function and prolonged hospital stay in patients undergoing elective colonic resection, and Nordling et al. [17] also found that restricted perioperative fluid regimen was associated with reduced rate of complications after elective colorectal resection, but did not reduce the length of hospital stay or readmission. One common characteristic of these studies was that the weight increase difference on postoperative day 1 between liberal and restricted regimen is relatively high ($\geq$ 2 kg), and in other studies with low weight increase difference, MacKay et al. reported that there were no differences in complications between the groups. Furthermore, a recent multi-center randomized study [14] including 2983 patients undergoing major abdominal surgery found that compared to the liberal fluid regimen, a restrictive fluid regimen was not associated with a higher rate of disability-free survival and was even associated with a higher rate of acute kidney injury.

However, in clinical practice, even under similar fluid restriction protocols, the fluid accumulation statuses could differ considerably. For instance, the volume of fluid intake was quite similar in studies by Myles et al. (3671 mL vs. 6146 mL) and Lobo et al. (3236 mL vs. 5909 mL), but the difference in weight increase was larger in the study by Lobo et al. (0.64 vs. 2.68 kg) than in the study by Myles et al. (0.3 vs. 1.6). However, whether the weight increase difference was a major factor behind these contradictory findings have remained unclear. In the current meta-analysis, this issue has been addressed. In the subgroup with a low weight increase difference, the pooled benefit of the restricted fluid regimen was not significant, while in the subgroup with a high weight increase difference, the effect of the restricted regimen was significant. Notably, the mechanism cannot be directly inferred from the current review. However, in clinical practice, differences in weight increase often represent differences in fluid accumulation status after surgery. As many studies have reported positive associations between positive fluid balance and poor outcomes, we speculate that, compared to the liberal fluid regimen, the benefit of the restricted fluid regimen only remained significant when it led to a low weight increase. To determine whether our hypothesis is correct, the

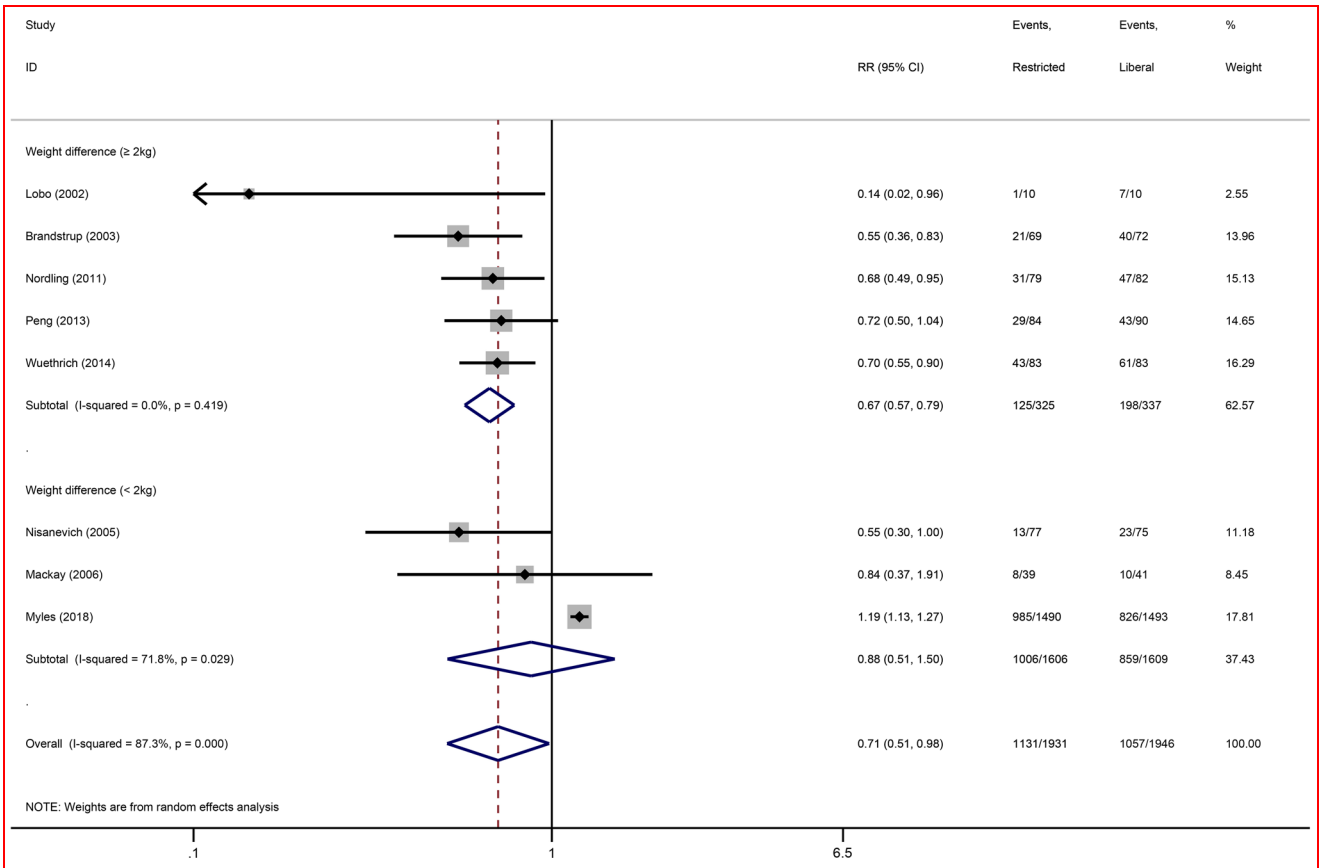

Fig. 3 Forest plot of subgroup comparison of weight increase difference: weight increase difference was defined as the difference of weight increase on postoperative day 1 between the restricted and liberal groups, using a threshold value of 2 kg

mediating effect of fluid accumulation/weight increase in trials investigating the benefit of fluid restriction should be re-evaluated in further controlled studies.

In addition, the impact of different fluid intake ratio was evaluated in this meta-analysis. The effect of restricted regimen was significant in studies with high fluid intake ratio, whereas it was not significant in trials with ratio < 1.8. In trials with high ratio, the liberal fluid regimen was more likely to lead to hypervolemia. It is noteworthy that all three studies with low weight increase differences were in the low fluid intake ratio subgroup, and four of five trials with high weight increase differences were in the high ratio subgroup. Thus, the high fluid ratio was more likely to be associated with increased weight difference; in this subgroup, the restricted fluid regimen was associated with fewer complications.

Several limitations should be addressed in the current study. First, heterogeneity is a significant issue in all included studies. In subgroup analysis, the heterogeneity was not significant in subgroups with weight difference ≥ 2 kg and fluid intake ratio ≥ 1.8. However, in subgroups with weight difference < 2 kg and fluid intake ratio < 1.8, the heterogeneity remains significant. A meta-regression approach was applied to evaluate the contribution of these two factors in heterogeneity; however, the conclusion was unstable due to the small number of included studies. Second, weight increase difference is reported as an important factor affecting the effectiveness of restricted regimen; however, this is only reported in eight trials. Selection bias should be considered when interpreting our findings. Third, as the volume of fluid intake varies greatly (from 1408/3878 to 4652/6472 mL) due to the different durations of intervention in all included studies, fluid intake ratio was adopted in the subgroup analysis. Fourth, the funnel plot and the result of Harbord method suggested a publication bias in all included studies. As the heterogeneity was significant in all analysis, we believed this may be an important factor of this bias. On the other hand, due to the small number of included studies in each subgroup, trim-and-fill method is not applied in this analysis [34, 35].

In conclusion, this meta-analysis showed that differences in weight increase played an important role in the effectiveness of restricted fluid regimens in patients undergoing abdominal surgery, as the benefit of fluid restriction may have only existed in subgroups with high weight increase. Further rigorously designed controlled trials are needed to confirm our findings.

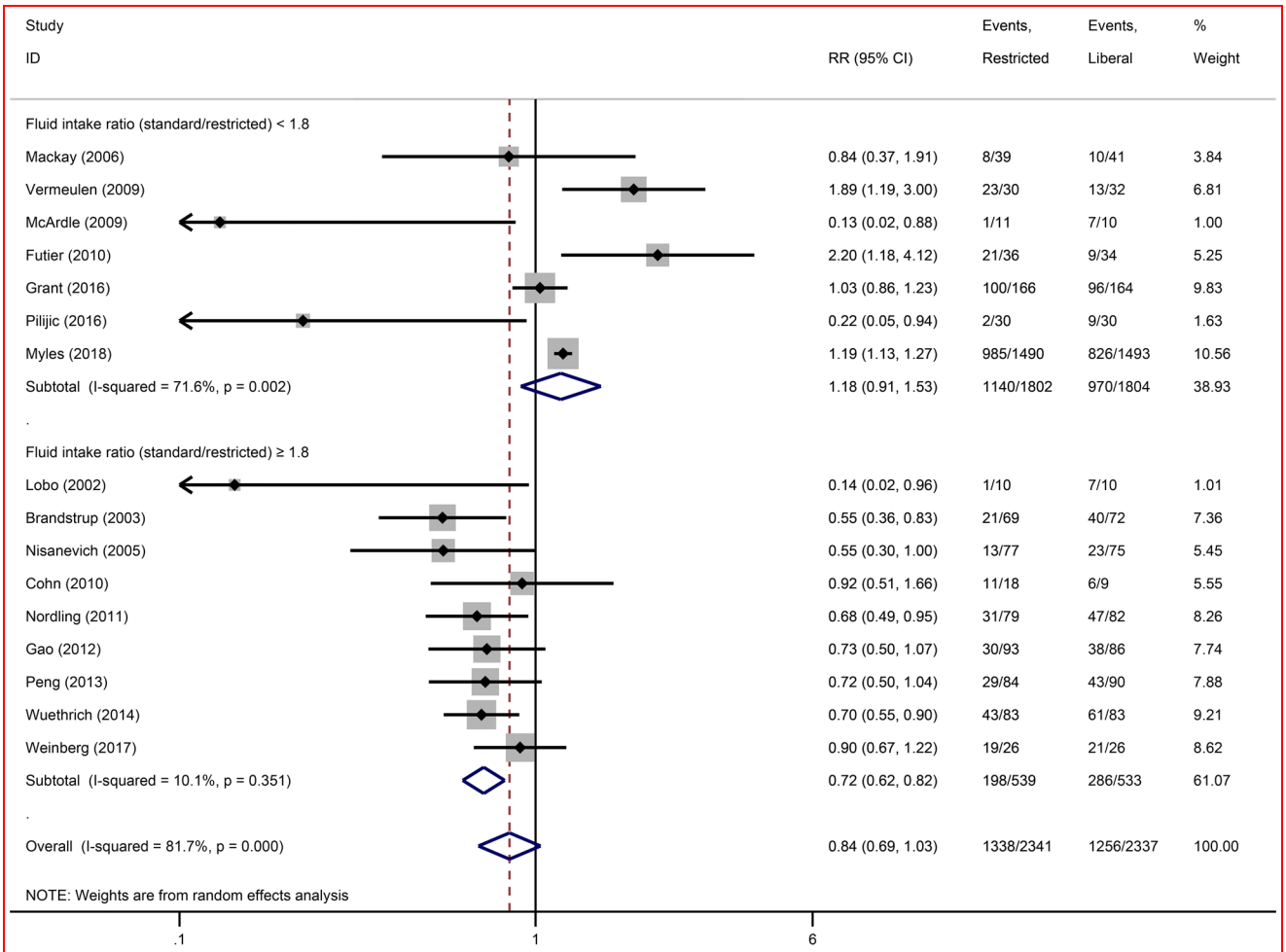

Fig. 4 Forest plot of subgroup comparison of fluid intake ratio: fluid intake ratio was defined as the fluid intake volume of the standard group/fluid intake volume of the restricted group, using a threshold value of 1.8

Funding This meta-analysis received funding from Zhejiang Province health high-level talents and Zhejiang Province sepsis innovation subject during the language polishing.

Compliance with ethical standards

Conflicts of interest The authors declare that they have no competing interests.

References

1. Weiser TG, Haynes AB, Molina G et al (2015) Estimate of the global volume of surgery in 2012: an assessment supporting improved health outcomes. Lancet 385(Suppl 2):S11
2. Pearse RM, Moreno RP, Bauer P et al (2012) Mortality after surgery in Europe: a 7 day cohort study. Lancet 380:1059–1065
3. Jhanji S, Thomas B, Ely A et al (2008) Mortality and utilisation of critical care resources amongst high-risk surgical patients in a large NHS trust. Anaesthesia 63:695–700
4. Ljungqvist O, Scott M, Fearon KC (2017) Enhanced recovery after surgery: a review. JAMA Surg 152:292–298
5. Tambyraja AL, Sengupta F, MacGregor AB et al (2004) Patterns and clinical outcomes associated with routine intravenous sodium and fluid administration after colorectal resection. World J Surg 28:1046–1051. https://doi.org/10.1007/s00268-004-7383-7 **discussion 1051–1042**
6. Arkilic CF, Taguchi A, Sharma N et al (2003) Supplemental perioperative fluid administration increases tissue oxygen pressure. Surgery 133:49–55
7. Shires T, Williams J, Brown F (1961) Acute change in extracellular fluids associated with major surgical procedures. Ann Surg 154:803–810
8. Bragg D, El-Sharkawy AM, Psaltis E et al (2015) Postoperative ileus: recent developments in pathophysiology and management. Clin Nutr 34:367–376
9. Barmparas G, Liou D, Lee D et al (2014) Impact of positive fluid balance on critically ill surgical patients: a prospective observational study. J Crit Care 29:936–941
10. Feldheiser A, Aziz O, Baldini G et al (2016) Enhanced Recovery After Surgery (ERAS) for gastrointestinal surgery, part 2:

consensus statement for anaesthesia practice. Acta Anaesthesiol Scand 60:289–334
11. Gonzalez-Fajardo JA, Mengibar L, Brizuela JA et al (2009) Effect of postoperative restrictive fluid therapy in the recovery of patients with abdominal vascular surgery. Eur J Vasc Endovasc Surg 37:538–543
12. McArdle GT, McAuley DF, McKinley A et al (2009) Preliminary results of a prospective randomized trial of restrictive versus standard fluid regime in elective open abdominal aortic aneurysm repair. Ann Surg 250:28–34
13. Futier E, Constantin JM, Petit A et al (2010) Conservative vs restrictive individualized goal-directed fluid replacement strategy in major abdominal surgery: a prospective randomized trial. Arch Surg 145:1193–1200
14. Myles PS, Bellomo R, Corcoran T et al (2018) Restrictive versus liberal fluid therapy for major abdominal surgery. N Engl J Med 378:2263–2274
15. Lobo DN, Bostock KA, Neal KR et al (2002) Effect of salt and water balance on recovery of gastrointestinal function after elective colonic resection: a randomised controlled trial. Lancet 359:1812–1818
16. Brandstrup B, Tonnesen H, Beier-Holgersen R et al (2003) Effects of intravenous fluid restriction on postoperative complications: comparison of two perioperative fluid regimens: a randomized assessor-blinded multicenter trial. Ann Surg 238:641–648
17. Abraham-Nordling M, Hjern F, Pollack J et al (2012) Randomized clinical trial of fluid restriction in colorectal surgery. Br J Surg 99:186–191
18. MacKay G, Fearon K, McConnachie A et al (2006) Randomized clinical trial of the effect of postoperative intravenous fluid restriction on recovery after elective colorectal surgery. Br J Surg 93:1469–1474
19. Zatlo Ukal J, Pradl R, Kletecka J et al (2017) Comparison of absolute fluid restriction versus relative volume redistribution strategy in low central venous pressure anesthesia in liver resection surgery: a randomized controlled trial. Minerva Anestesiol 83:1051–1060
20. Srinivasa S, Taylor MH, Singh PP et al (2013) Randomized clinical trial of goal-directed fluid therapy within an enhanced recovery protocol for elective colectomy. Br J Surg 100:66–74
21. Vermeulen H, Hofland J, Legemate DA et al (2009) Intravenous fluid restriction after major abdominal surgery: a randomized blinded clinical trial. Trials 10:50
22. Nisanevich V, Felsenstein I, Almogy G et al (2005) Effect of intraoperative fluid management on outcome after intraabdominal surgery. Anesthesiology 103:25–32
23. Piljic D, Petricevic M, Ksela J et al (2016) Restrictive versus standard fluid regimen in elective minilaparotomy abdominal aortic repair-prospective randomized controlled trial. Thorac Cardiovasc Surg 64:296–303
24. Peng NH, Gao T, Chen YY et al (2013) Restricted intravenous fluid regimen reduces fluid redistribution of patients operated for abdominal malignancy. Hepatogastroenterology 60:1653–1659
25. Cohn SM, Pearl RG, Acosta SM et al (2010) A prospective randomized pilot study of near-infrared spectroscopy-directed restricted fluid therapy versus standard fluid therapy in patients undergoing elective colorectal surgery. Am Surg 76:1384–1392
26. Wuethrich PY, Burkhard FC, Thalmann GN et al (2014) Restrictive deferred hydration combined with preemptive norepinephrine infusion during radical cystectomy reduces postoperative complications and hospitalization time: a randomized clinical trial. Anesthesiology 120:365–377
27. Gao T, Li N, Zhang JJ et al (2012) Restricted intravenous fluid regimen reduces the rate of postoperative complications and alters immunological activity of elderly patients operated for abdominal cancer: a randomized prospective clinical trail. World J Surg 36:993–1002. https://doi.org/10.1007/s00268-012-1516-1
28. Grant F, Brennan MF, Allen PJ et al (2016) Prospective randomized controlled trial of liberal vs restricted perioperative fluid management in patients undergoing pancreatectomy. Ann Surg 264:591–598
29. Weinberg L, Ianno D, Churilov L et al (2017) Restrictive intraoperative fluid optimisation algorithm improves outcomes in patients undergoing pancreaticoduodenectomy: a prospective multicentre randomized controlled trial. PLoS ONE 12:e0183313
30. Higgins JP, Thompson SG (2002) Quantifying heterogeneity in a meta-analysis. Stat Med 21:1539–1558
31. Holte K, Foss NB, Andersen J et al (2007) Liberal or restrictive fluid administration in fast-track colonic surgery: a randomized, double-blind study. Br J Anaesth 99:500–508
32. Boland MR, Noorani A, Varty K et al (2013) Perioperative fluid restriction in major abdominal surgery: systematic review and meta-analysis of randomized, clinical trials. World J Surg 37:1193–1202. https://doi.org/10.1007/s00268-013-1987-8
33. Rahbari NN, Zimmermann JB, Schmidt T et al (2009) Meta-analysis of standard, restrictive and supplemental fluid administration in colorectal surgery. Br J Surg 96:331–341
34. Mayo-Wilson E, Imdad A, Herzer K et al (2011) Vitamin A supplements for preventing mortality, illness, and blindness in children aged under 5: systematic review and meta-analysis. BMJ 343:d5094
35. Duval S, Tweedie R (2000) Trim and fill: a simple funnel-plot-based method of testing and adjusting for publication bias in meta-analysis. Biometrics 56:455–463