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REVIEW ARTICLE

Systematic review of the literature for the use of oesophageal Doppler monitor for fluid replacement in major abdominal surgery

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Summary

The use of intra-operative Doppler oesophageal probes provides continuous monitoring of cardiac output. This enables optimisation of intravascular volume and tissue perfusion in major abdominal surgery, which is thought to reduce postoperative complications and shorten hospital stay. Medline and EMBASE were searched using the standard methodology of the Cochrane collaboration for trials that compared oesophageal Doppler monitoring with conventional clinical parameters for fluid replacement in patients undergoing major elective abdominal surgery. Data from randomised controlled trials were entered and analysed in Meta-view in Rev-Man 4.2 (Nordic, Denmark). We included five studies that recruited 420 patients undergoing major abdominal surgery who were randomly allocated to receive either intravenous fluid treatment guided by monitoring ventricular filling using oesophageal Doppler monitor or fluid administration according to conventional parameters. Pooled analysis showed a reduced hospital stay in the intervention group. Overall, there were fewer complications and ICU admissions, and less requirement for inotropes in the intervention group. Return of normal gastro-intestinal function was also significantly faster in the intervention group. Oesophageal Doppler use for monitoring and optimisation of flow-related haemodynamic variables improves short-term outcome in patients undergoing major abdominal surgery.

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Background

Major abdominal surgery is often performed in elderly patients who suffer from multiple comorbidities [1, 2]. Such patients require careful peri-operative care including optimal fluid management. Occult hypovolaemia commonly occurs during major surgery and is thought to result in impaired tissue perfusion, decreased oxygen delivery and increased postoperative complications. This form of hypovolaemia is not detected by the usual monitoring of heart rate and blood pressure, which remain unchanged due to normal homeostatic mechanisms [3].

Frequently, large quantities of fluids are administered during major surgical procedures [4]. Peri-operative optimisation of patients admitted for elective major surgery by aggressive fluid resuscitation and increasing cardiac output using dopexamine infusion has shown significant reduction in morbidity and mortality by increasing tissue oxygen delivery [5]. Goal-directed fluid optimisation is thought to reduce mortality among septic patients by maintaining $SVO_2 > 70\%$ [6]. The underlying principle for such improvement is thought to be increased tissue oxygen delivery [5]. Traditional invasive measurement of cardiac output is associated with increased morbidity [7]. However, measurement of cardiac output using the low morbidity technique of oesophageal Doppler monitoring has been shown to correlate well with invasive methods such as thermodilution [8].

To optimise fluid therapy, further studies have investigated the role of goal-directed fluid replacement by utilising intra-operative Doppler oesophageal probes to provide continued monitoring of cardiac output to optimise tissue perfusion, reduce inflammatory responses, and fluid overload [9–12].

Intra-operative hypovolaemia is known to result in organ dysfunction, which is thought to result in increased complications, longer hospital stay and increased mortality. Goal-directed fluid therapy using continuous intra-operative Doppler monitoring provides immediate optimisation of tissue perfusion by maintaining intravascular volume and improving tissue oxygenation without invasive monitoring [10, 13]. Serial measurement of inflammatory markers such as C-reactive protein (CRP), interleukin (IL)-6 and tumour necrosis factor (TNF) has previously been performed in studies investigating the possibility of reducing the inflammatory response following surgery, which is associated with increased morbidity [1, 14, 15].

This review addresses the benefits of haemodynamic optimisation of patients undergoing major abdominal surgery using oesophageal Doppler monitoring of cardiac filling, which may also reduce the systemic inflammatory response by immune modulation. Recently, a systematic review for the role of oesophageal Doppler in surgery in general was published [16]. In this article we have included only studies that recruited patients for abdominal surgery, due to the unique nature of the physiological changes that accompany abdominal surgery.

Methods

Search strategy for identification of studies

Medline and EMBASE were searched using the standard methodology of the Cochrane collaboration for controlled randomised clinical trials that compared oesophageal Doppler monitoring with conventional clinical parameters for fluid replacement in patients undergoing major elective abdominal surgery. The following terms were used for the search; intravenous fluid replacement, oesophageal Doppler monitoring, major surgery, cardiac output and oxygen delivery; exploded medical subject headings and suitable combinations of those terms were used. Only randomised controlled trials were retrieved and those trials that dealt with orthopaedic and cardiac surgery were not included.

To identify primary studies from EMBASE, the search was limited using the terms above to randomised and clinical controlled trials by using: 'randomisation'/all subheadings, 'controlled-study'/all subheadings, 'clinical-trial'/all subheadings. Reference lists of included studies have been manually scrutinised. Relevant Conference Proceedings were searched. There were no language restrictions.

Eligibility criteria

The review included randomised controlled trials that compared the oesophageal Doppler monitor for intra-operative fluid management in patients undergoing major abdominal surgery compared with conventional clinical practice. Abstracts obtained from the search strategy were assessed and relevant articles were retrieved; studies were analysed according to their inclusion criteria.

Methods of the review

We included trials that studied patients who were admitted for elective major abdominal surgery and randomly allocated to receive either intravenous fluids as guided by the continuous measurement of cardiac filling and output using oesophageal Doppler monitoring; or intravenous fluid therapy according to conventional measures of central venous pressure, heart rate and arterial blood pressure.

The quality of each trial was assessed according to its methodology, randomisation method, and allocation concealment and blinding of the investigators. Only studies with acceptable quality were included. The reviewers have assessed the methodological quality of each clinical trial. The method of randomisation, nature of interventions, co-intervention and follow-up were critically appraised.

Data were collected by the reviewers and checked, including the following; patient demographics, pre-operative haemoglobin level; comorbidities according to physiological scores, type of surgery, total volume of fluids administered during the operation, cardiac output at the end of the operation, mean arterial blood pressure, total urine output, oxygen delivery, hospital stay, complications and mortality, use of inotropes and ICU admissions.

Statistical analysis

Data from randomised controlled trials were entered in Meta-view in Rev-Man 4.2 (Nordic, Denmark). Dichotomous variables were compared using the Mantel-Haenszel test and presented as odd ratios and 95% confidence intervals. For continuous variables the results are presented as weighted mean difference and 95% confidence intervals; the mean and standard deviation of the mean were analysed using fixed-effects model for calculation of the weighted mean difference.

Statistical heterogeneity in the results of the meta-analysis was assessed both by graphical presentations of the confidence intervals (CI) on Forest plot (if CI of two studies do not overlap, this suggests a significant statistical heterogeneity) and by calculating a test of heterogeneity (Chi-squared test using Rev Man; a p value < 0.1 was regarded as significant heterogeneity).

Sensitivity analysis was performed by including and excluding the poor quality studies; studies of doubtful eligibility and studies that may look like an outlier. When heterogeneity was found, random-effect models were used to assess the robustness of the results.

When data were not available or could not be appropriately pooled from more than one study, the results were described in the text.

Results

Description of included studies

We identified eight clinical trials that had studied the use of oesophageal Doppler monitoring for fluid replacement during major surgery. Two trials investigated patients who had orthopaedic operations and one examined cardiac patients, and these were excluded from the meta-analysis. We included five studies that recruited 420 patients who were randomly allocated to receive either intravenous fluid treatment guided by monitoring ventricular filing using oesophageal Doppler monitor or fluid administration according to conventional parameters including heart rate, blood pressure, central venous pressure and urine output (Table 1).

Noblett et al. [11] randomly assigned 103 patients admitted for elective colorectal resection to undergo Doppler optimised fluid management or conventional management. All patients had pre-operative assessment of their POSSUM score, which was comparable in both groups. The control group received fluids at the discretion of the anaesthetist depending on arterial blood pressure, central venous pressure (CVP) and urine output. The intervention group received additional colloid to maintain descending aortic corrected flow time (FTc) of > 350 ms; further boluses were administered to optimise the stroke volume. Postoperative fluid administration was the same in both groups and based on conventional parameters. In addition to analysis of the primary outcome measures they performed serial measurements of serum interlekin (IL)-6 and concluded that it rose significantly higher in the conventional group.

In the trial conducted by Wakeling et al. [12] in patients admitted for elective colorectal resection, the intervention group of patients had Doppler-guided intra-operative fluid management. All patients had pre-operative assessment of their POSSUM score, which was comparable in both groups. In the intervention group the velocity of blood flow in the descending thoracic aorta was measured and cardiac output and stroke volume deducted; crystalloids were administered to optimise cardiac output and stroke volume, additional colloid boluses were administered to obtain immediate results. Patients in the control group underwent central line monitoring of intravascular volume, fluids were given to maintain CVP between 12 and 15 mmHg. In addition to the main outcome measures they analysed tissue oxygen delivery.

Gan et al. [9] randomly allocated 100 patients undergoing major elective abdominal surgery with anticipated blood loss of > 500 ml to goal-directed fluid administration or conventional fluid administration. The preoperative physiological status of patients in both groups was assessed using the ASA grades and was comparable. The intervention group received additional amounts of colloid to maintain descending aortic corrected flow time (FTc) of > 350 ms; further boluses were given to optimise the stroke volume. Postoperative fluid administration was the same in both groups and based on conventional parameters. Intravenous fluids were given in the control group to maintain urine output $> 0.5\ ml.kg^{-1}h^{-1}$, heart rate < 110 beats.min^{-1} and systolic blood pressure > 90 mmHg.

Conway et al. [17] randomly assigned 57 patients admitted for elective colorectal resection to receive either Doppler guided fluid administration or fluids replacement using conventional parameters. All patients had pre-operative assessment of the Goldman Cardiac Risk Index and ASA status. The intervention group received additional amounts of colloid to maintain descending aortic FTc of > 350 ms; further boluses were given to optimise the stroke volume. The control group was managed according to the conventional parameters. Postoperative fluid administration was the same in both groups.

Szakmany et al. [15] randomly assigned 40 patients to receive Doppler-guided fluid administration or conventional fluid management in patients who underwent oesophageal, gastric and pancreatic surgery. The intervention group received fluids to maintain the Intrathoracic Blood Volume index between 850 and 950 ml.m^{-2}. The

Table 1 Methodological quality of the included studies.

Study	Randomisation	Allocation concealment	Blinding for intervention	Blinding of assessment	Intention to treat analysis	Comments
Noblett et al. [11]	Adequate	Adequate	Adequate	Yes	Yes	Colorectal resections
Szakmany et al. [15]	Adequate	Adequate	Not clear	Yes	Yes	Upper gastro-intestinal surgery
Wakeling et al. [12]	Adequate	Adequate	Adequate	Yes	Yes	Colorectal resections
Gan et al. [9]	Adequate	Adequate	Adequate	Yes	Yes	Major abdominal operations
Conway et al. [17]	Adequate	Adequate	Adequate	Yes	Yes	Colorectal resections

control group received fluid to maintain CVP between 8 and 12 mmHg. Serial measurement of inflammatory parameters were performed and included serum tumour necrosis factor (TNF)-α, CRP and procalcitonin; this showed no difference in the inflammatory response between the intervention and control group (Table 1).

Table 2 Physiological scores of the enrolled patients.

Study	Intervention	Control	Significance	Score
Szakmany et al. [15]	14	16	NS	POSSUM
Gan et al. [9]	3 (I), 36 (II), 11 (III)	8 (I), 32 (II), 10 (III)	NS	ASA
Conway et al. [17]	3	3	NS	Goldman
Wakeling et al. [12]	17	18	NS	POSSUM
Noblett et al. [11]	16	16	NS	POSSUM

Main results

Patients in the studies included were comparable for age, type of surgery, pre-operative haemoglobin levels and physiological scores measured using ASA, Goldman Cardiac Risk Index and POSSUM scores. There was no difference in these parameters between the Doppler and the control group (Table 2).

Main outcomes

Hospital stay was compared in four trials and meta-analysis revealed significantly reduced hospital stay in the intervention group (Fig. 1).

Complications. Meta-analysis of data reported from four trials showed significantly fewer complications in the intervention group. These included cardiovascular, renal, respiratory and gastro-intestinal complications (Fig. 2).

Admissions to ICU. Three trials reported the requirement for admission to the ICU. Meta-analysis of these three trials revealed that fewer admissions to the ICU in

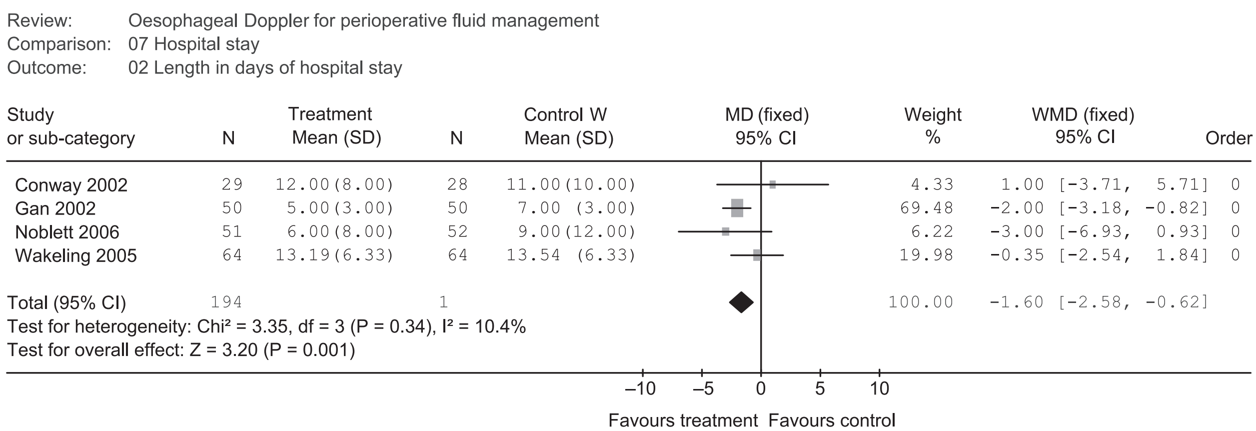

Figure 1 Hospital stay.

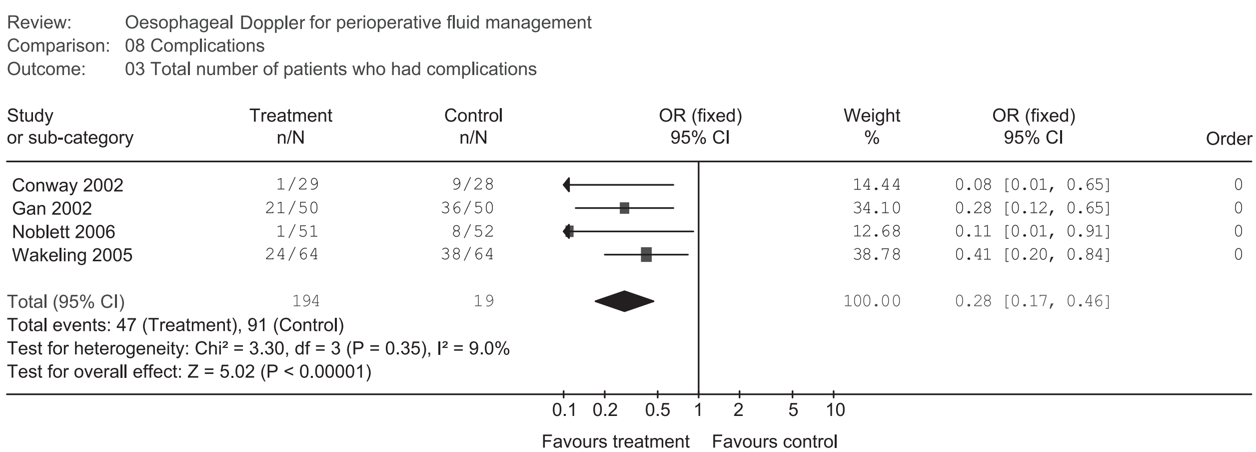

Figure 2 Overall rate of complications.

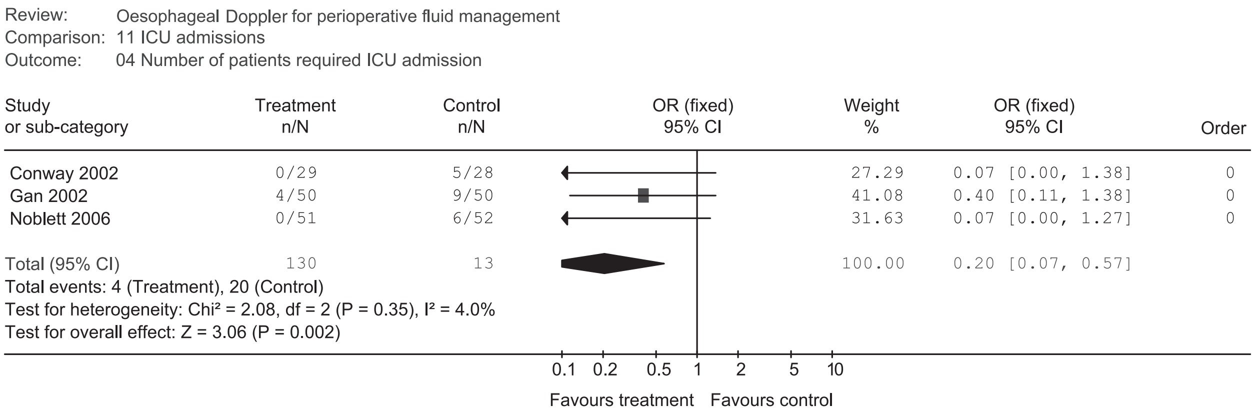

Figure 3 ICU admissions.

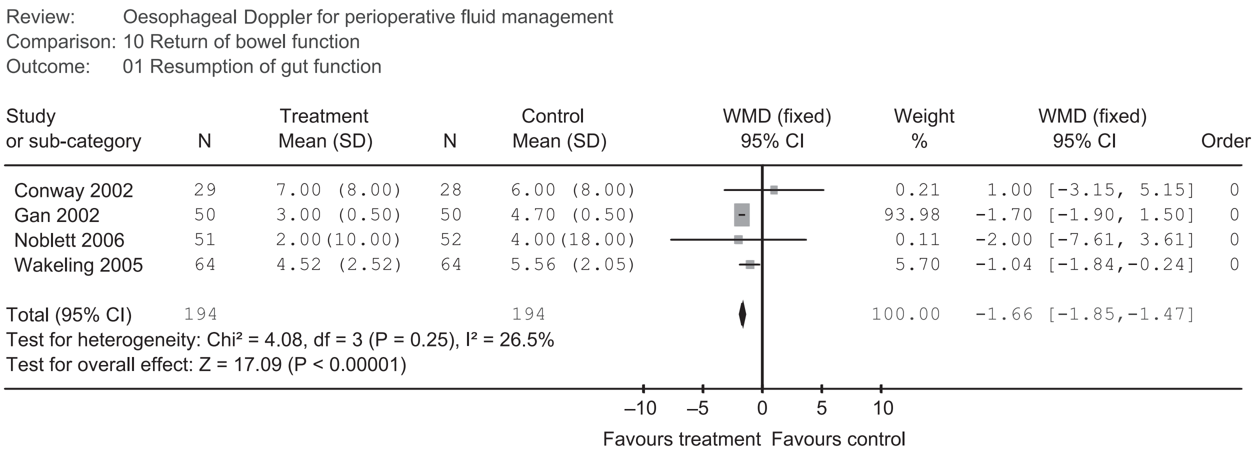

Figure 4 Return of bowel function.

patients managed using oesophageal Doppler monitoring to guide fluid administration (Fig. 3).

Return of gut function. Four trials reported the mean time required for return of gut function, which was defined as patients being able to tolerate solid food. Meta-analysis of the four trials revealed more rapid return of gut function in the intervention group (Fig. 4).

Use of inotropes. Two trials had reported the number of patients who required inotropes in each group. Meta-analysis was not appropriate due to significant heterogeneity of those two studies.

Mortality. Meta-analysis of all five trials showed no difference in mortality (Fig. 5).

Other outcomes

Crystalloid use. Similar volumes of crystalloid were used in both groups.

Colloid use. Significantly greater volumes of intravenous colloids were administered in the intervention group.

Urine output. Two trials reported total urine output during surgery; mean urine output was equal in both groups.

Cardiac output. All five trials reported significantly greater cardiac output in the intervention group (Fig. 6).

Mean arterial blood pressure. Three studies reported mean arterial pressure at the end of the operation. Meta-analysis of those studies revealed no difference in mean arterial blood pressure between the intervention and the control groups (Fig. 7).

Oxygen delivery. Wakeling et al. [12] reported significantly higher oxygen delivery in the Doppler-guided fluid group (median 535 vs 445 $ml.min^{-1}m^{-2}$); $p < 0.05$.

CVP. Central venous pressure reading was reported in two trials and meta-analysis of these trials showed no significant difference.

Corrected flow time in the descending aorta. The Doppler oesophageal monitor measures the corrected velocity of blood flow in the descending thoracic aorta; such readings

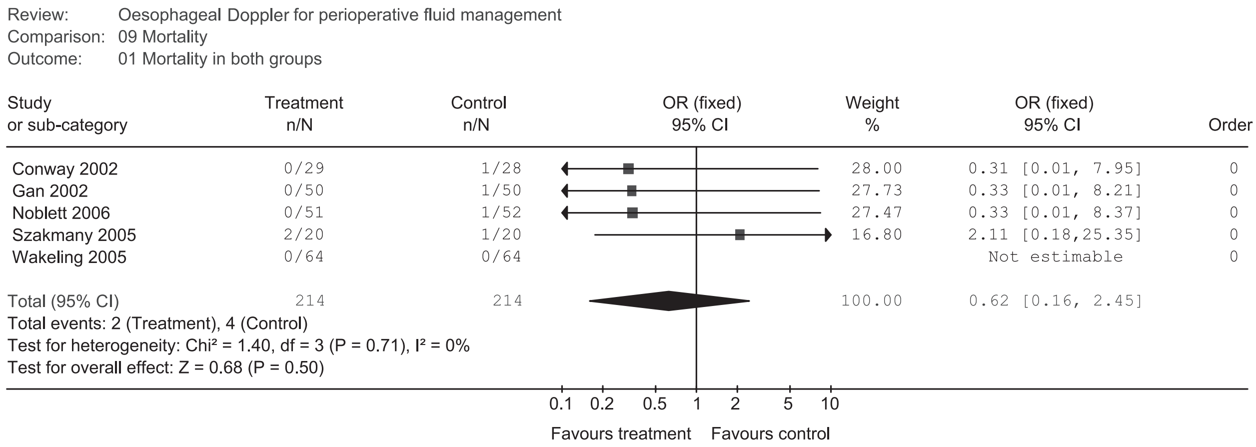

Figure 5 Mortality.

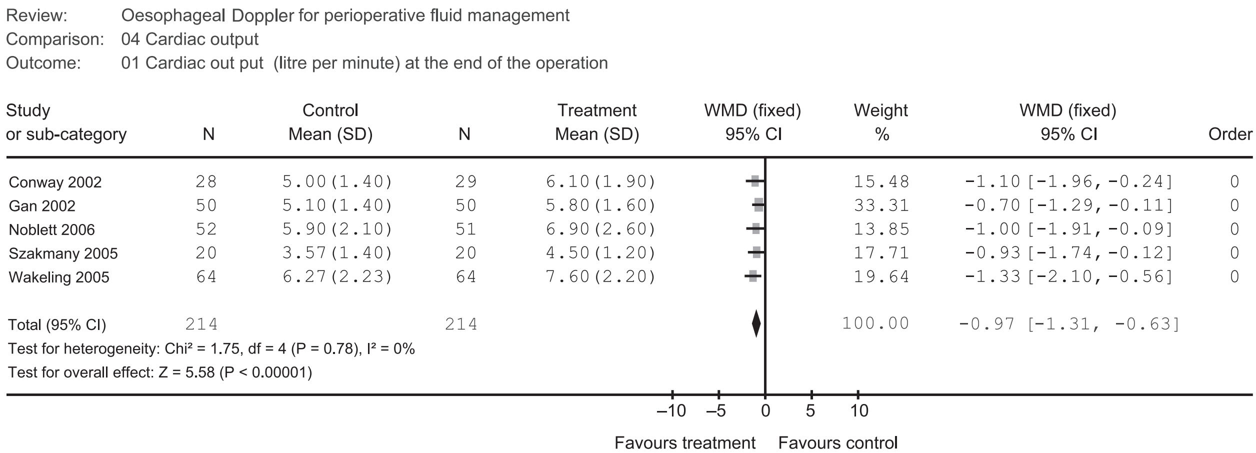

Figure 6 Cardiac output.

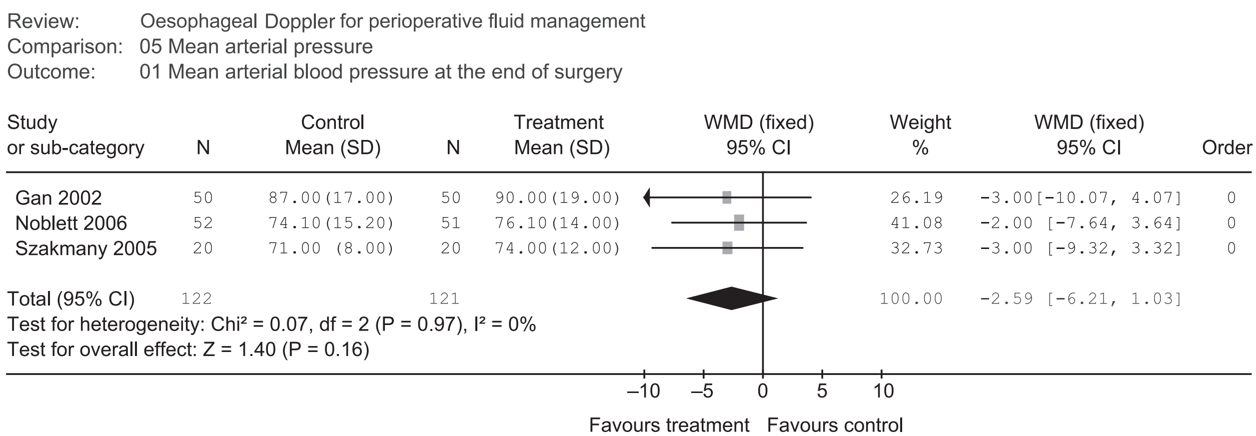

Figure 7 Mean arterial pressure.

were reported in three trials and these trials showed significantly higher corrected flow time in the intervention group.

Three studies analysed the *difference in the systemic response* to injury by serial measurement of serum IL-6, CRP and TNF [11, 12, 15]. Noblett et al. [11] reported significantly higher levels of IL-6 in the control group with the peak difference at 6 h after surgery. Wakeling et al. [12] reported no difference in the postoperative levels of IL-6 and CRP between the control and the intervention group. Szakmany et al. [15] described increased levels of TNF-α, IL-6 and procalcitonin after major surgery with no difference between the control and the intervention group.

Discussion

This study is a meta-analysis of randomly assigned controlled trials that have reported on the role of intra-operative oesophageal Doppler monitoring in fluid administration during major abdominal surgery. Five trials involving 420 patients were suitable for inclusion in this meta-analysis. We excluded trials that enrolled patients admitted for orthopaedic surgery or cardiac surgery due to the unique nature of abdominal surgery and to avoid heterogeneity. Clinical homogeneity among the trials was acceptable, with comparable mean ages, pre-operative haemoglobin levels, and type of surgery and associated comorbidities.

This systematic review shows improved haemodynamic control when oesophageal Doppler monitoring is used to guide fluid replacement instead of the conventional parameters of arterial blood pressure, central venous pressure, heart rate and urine output. Pooled analysis revealed shorter hospital stay in the intervention group. Overall, the number of complications, ICU admissions, and requirement for inotropes was also significantly reduced in the intervention group. Return of normal gastro-intestinal function, which was defined as tolerating solid diet, was significantly faster in the intervention group. There is not enough evidence to show a decreased inflammatory response with goal-directed fluid replacement.

Patients in the control and intervention groups received equal amounts of intravenous crystalloids; however, the intervention group received significantly greater volumes of colloids. Colloids were given to the intervention group as boluses to maintain corrected flow time in the descending aorta > 350 ms, and hence to maintain a higher cardiac output. Pooled analysis of the included trials that reported the relevant results showed no difference in the mean arterial blood pressure, central venous pressure and urine output between the control groups, which suggests significant hypovolaemia can occur without noticeable changes being seen in these parameters. The oesophageal Doppler monitor detects changes in intravascular volume and enables immediate goal-directed volume replacement to maintain optimum cardiac output. We speculate that the use of goal-directed fluid replacement improves tissue oxygen delivery by enhancing cardiac output. Unfortunately only one study [9] reported significantly greater oxygen delivery in the intervention group; the rest of the trials did not report tissue oxygen delivery.

Patients undergoing elective colorectal surgery are often elderly with multiple associated comorbidity; commonly, these patients receive oral bowel preparation including all patients included in this review. This results in dehydration and electrolyte disturbance, which contributes to postoperative complications. The utilisation of Doppler guided fluid management for intra-operative fluid administration may help to optimise the intravascular volume to maintain cardiac output and tissue oxygen delivery. Intra-operative hypovolaemia is commonly seen in surgery and may contribute to organ dysfunction and further complications [3, 18]. Conventional parameters such as reduced urine output, systolic blood pressure and central venous pressure remain the standard of care for assessment of fluid requirements in patients who undergo uncomplicated major surgery and have no comorbidities. These signs are often delayed for a significant period of time following the reduction of the intravascular volume compared with oesophageal Doppler, which can detect these changes more rapidly.

Heart rate and blood pressure may remain unchanged in early hypovolaemia, which results in splanchnic vasoconstriction. Cardiac output, however, falls and can be detected using the Doppler monitor [8]. Gut mucosal hypoperfusion may result in bacterial translocation and endotoxaemia with activation of the systemic inflammatory response [5]. In that meta-analysis the role of goal-directed fluid administration in decreasing inflammation is not conclusive.

The trials included in this review included patients who underwent major abdominal surgery; however, four studies did not include those who had gastric or oesophageal resections due to the unsuitability of the intervention for those patients. Gastric and oesophageal surgery is a major undertaking and the exclusion of these patients is regarded as a significant drawback of those trials. None of the studies conducted cost-benefit analysis.

Fluid administration in the postoperative period is often more critical than during surgery itself; however, none of the trials conducted Doppler-guided postoperative fluid management. Due to the cumbersome nature of the intervention, its use may be precluded in the postoperative period. None of the studies was conducted in an optimised peri-operative care programme. The added benefit of using oesophageal Doppler in such an environment, requires investigation.

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