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Comparison of esophageal Doppler monitoring and conventional targeted fluid therapy in major orthopedic surgery cases

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Ethics Committee Approval
The study was approved by the Ethics Committee of Harran University Faculty of Medicine, Şanlıurfa, Turkey on 06.05.2016, session number 04, and approval number 04.
All procedures in this study involving human participants were performed in accordance with the 1964 Helsinki Declaration and its later amendments.

Conflict of Interest
No conflict of interest was declared by the authors.

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Abstract

Background/Aim: Conventional physiological parameters such as heart rate and mean blood pressure may not adequately detect hypovolemia. Esophageal Doppler monitoring (EDM) is a device that continuously measures blood flow in the descending aorta using a transesophageal Doppler transducer. In this study, we aim to compare Esophageal Doppler Monitoring (EDM) with conventional targeted fluid treatment in major orthopedic surgery cases.

Methods: Forty patients, aged between 18–65 years and falling within the American Society of Anesthesiologists (ASA) classifications I-III, who were slated for major orthopedic surgery were included in the study. Patients were escorted to the operating room and standard monitoring along with arterial monitoring was applied. Baseline systolic arterial pressure (SAP) and heart rate were recorded. The patients were then divided into two groups of 20 each, using a sealed method. For induction, 2–3 mg/kg propofol and remifentanil 1 μg/kg were administered to both groups and muscle relaxation was achieved with 0.6 mg/kg rocuronium before intubation. The first group, labeled as Group D, was monitored by EDM and fluid management followed using EDM. The second group, labeled as Group K, had its fluid management guided by conventional methods (pulse, blood pressure, urine output). For maintenance of anesthesia, both groups were administered 2–3% sevoflurane along with a 50% O_2 + 50% air mixture. In both groups, we recorded hemodynamic parameters, urine output, serum lactate level, the total given fluid and blood volume, inotropic or vasopressor requirement, anesthesia and surgery times, postoperative recovery time, hospital stay, oral diet starting time, and potential complications associated with postoperative nausea and vomiting.

Results: No difference was observed between the two groups in terms of demographic data. SAP in the control group was found to be statistically and significantly lower at the 10th, 20th, 25thh, 30th, and 90th minutes, compared to the Doppler group. Diastolic blood pressure was also noticeably lower in the control group at the 20th and 30th minutes than in the Doppler group. When comparing the lactate levels of the Doppler and control groups, the lactate level of the Doppler group was significantly lower at the 90th minute. Tachycardia was significantly lower in the postoperative Doppler group.

Conclusion: In major orthopedic surgery cases, we concluded that better results are obtained in perioperative vital signs with targeted fluid therapy, especially when accompanied by EDM. Specifically, the lactate level, which is considered important in terms of mortality and morbidity, is lower.

Keywords: major orthopedic surgery, general anesthesia, esophageal Doppler, targeted fluid therapy

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Introduction

Appropriate fluid management in anesthesia applications effectively impacts mortality and morbidity rates by maintaining tissue perfusion. This is particularly crucial during major surgeries, where proper fluid management can prevent complications. Inadequate intraoperative fluid management can lead to a decrease in splenic perfusion and oxygenation of the liver, kidney, and intestines due to hypovolemia. This disruption in blood flow can cause gastrointestinal dysfunction and delay enteral nutrition. As a result, malnourished patients undergoing major surgery may experience prolonged hospitalization [1].

Several studies on intravenous (IV) fluid therapy have demonstrated that adequate fluid administration is necessary during the perioperative period, while excessive fluid can cause significantly adverse outcomes [2].

The life-threatening consequences of inadequate IV fluid therapy can include lactic acidosis, acute renal failure, and multiple organ failure. Similarly, excessive IV fluid therapy can lead to life-threatening consequences such as pulmonary edema and heart failure. Less severe, but still significant, outcomes of excessive IV fluid therapy may manifest as peripheral edema, periorbital edema, and impairments in intestinal function and wound healing [3].

Conventional physiological parameters such as heart and mean blood pressure may not be sufficient to reliably detect hypovolemia. Although methods such as central venous oxygen saturation and pulmonary artery catheterization are recognized as useful in demonstrating fluid balance, their invasive nature is considered a disadvantage. esophageal Doppler monitoring (EDM) is a device that monitors cardiac output or stroke volume by continuously measuring blood flow in the descending aorta using a transesophageal Doppler transducer. The EDM can compute the patient's cardiac output and stroke volume using a nomogram based on the patient's age, height, weight, and the velocity integral of descending thoracic aorta blood flow. The aortic cross-sectional area is estimated from the velocity-time waveform, which allows for the calculation of left ventricular stroke volume [4-5].

The goal of this study is to compare intraoperative EDM with the traditional method for IV fluid therapy in significant orthopedic surgery cases by analyzing the improvement of intravascular volume status and perioperative outcomes.

Materials and methods

Patient population (selection)

This prospective study received ethical board approval from the Ethics Committee of Harran University Faculty of Medicine, Şanlıurfa, Turkey on 06.05.2016, session number 04, and approval number 04. The study was conducted in compliance with the Declaration of Helsinki. Once verbal and written informed consent was secured during a preoperative visit one day before the operation, 40 patients between the ages of 18 and 65 who were slated for major orthopedic surgery and classified as ASA I-III according to the American Society of Anesthesiologists (ASA) classification were included in the study. The study was carried out at the Harran University Faculty of Medicine Research Hospital between 2016-2017. Exclusion criteria included obesity (BMI>30), cancer, liver and/or kidney failure, left ventricular ejection fraction <30%; esophageal pathology or recent upper gastrointestinal surgery; known hypersensitivity to hydroxyethyl starch; significant renal disease (creatinine >50%); significant liver disease (liver enzyme elevation >50%); patients classified as ASA IV-V, and those who declined to participate in the study.

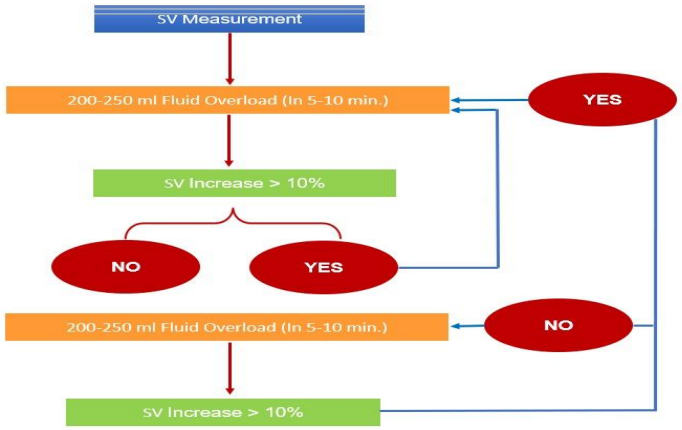
Anesthesia method

All patients read and signed the written consent form before the operation. Following this, they were transferred to the operating room for surgery. Venous access was established using 18 G and 16 G peripheral vein cannulas in the operation room, and both standard and arterial monitoring were conducted. Basal systolic arterial pressure (SAP), basal diastolic arterial pressure (DAP), and heart rate were recorded. Using the closed envelope method, patients were divided into two groups, each consisting of 20 individuals.

For induction, every group received 2–3 mg/kg propofol and 1 $\mu g.kg^{-1}$ remifentanil, followed by 0.6 $mg.kg^{-1}$ rocuronium for muscle relaxation and endotracheal intubation. Anesthesia was maintained with 2–3% sevoflurane combined with a mix of 50% O_2 and 50% air in both groups. Remifentanil infusion began at a rate of 0.1 µg/kg/min in both sets of patients. In instances of mean arterial pressure 20–30% above the basal value and heart rate exceeding 90/min, 0.05 µg/kg remifentanil was administered to both patient groups. Fluids were provided at 8 ml/kg/h for all patients.

Patients were then randomly assigned to either the EDM group or the control group using a sequentially sealed opaque envelope system. The first group, Group D, was monitored using EDM, and fluid management was conducted in the EDM's presence. Upon calculating and tracking stroke volume, 250 ml of colloid was administered for 15 min. If stroke volume increased more than 10% at the end of 15 min, the patient was deemed fluid-responsive, and this process was repeated. If the increase was less than 10%, the patient was considered fluid-unresponsive, and the procedure was repeated if the stroke volume decrease surpassed 10% compared to the last baseline value (Figure 1).

Figure 1: Esophageal Doppler monitoring group's fluid algorithm



SV: Stroke Volume

The other group, labeled as Group K, had fluid management conducted using conventional methods, including monitoring pulse, blood pressure, and urine output.

Data collection method

The heart rate, systolic arterial blood pressure, diastolic arterial blood pressure, and end-tidal CO_2 (basal, induction, 0.5, 10, 15, 20, 25, 30, 60, 90, 120, 150, 180, 210 min) were monitored.

The total amount of colloid used, the amount of crystalloid, the amount of bleeding, urine output, and lactate levels (0.60, 120 min) were also recorded in the control group of patients undergoing major orthopedic surgery under general anesthesia.

In patients from the EDM group who were set to undergo major orthopedic surgery under general anesthesia, the probe was orally inserted into the thoracic aorta level to measure the stroke volume. Once the stroke volume was calculated and monitored, a total of 250 ml of colloid was administered over 15 min. After 15 min, if the stroke volume increase surpassed 10%, the patient was classified as fluid-responsive, and the procedure was subsequently repeated. Conversely, if the increase was less than 10%, the patient was deemed fluid-unresponsive, and the procedure was repeated when the stroke volume decrease exceeded 10% compared to the last baseline value. Parameters such as heart rate, systolic arterial blood pressure, diastolic arterial blood pressure, end-tidal CO_2, stroke volume measured at various time intervals (baseline, induction, and at 0.5, 10, 15, 20, 25, 30, 60, 90, 120, 150, 180, 210 min), total colloid used, crystalloid volume, bleeding quantity, urine output, and lactate levels (at 0, 60, 120 min) were recorded.

The hemodynamic parameters, total urine output, serum lactate levels, total amounts of fluids and blood administered, the duration of anesthesia, postoperative recovery times, hospitalization and oral diet initiation durations, postoperative nausea and vomiting, mortality, morbidity, and potential complications were recorded in both groups.

Statistical analysis

The SPSS Statistics 22 program (Armonk, New York: IBM Corp.) was utilized for statistical analyses to assess the study's findings. The parameters' suitability for normal distribution was assessed using the Shapiro-Wilks test, indicating that the parameters were appropriate for normal distribution. Aside from descriptive statistical methods (Mean, Standard deviation, Frequency), Repeated Measures Analysis of Variance (ANOVA) was employed to compare quantitative data at baseline, following foot lifting and fluid loading. The Bonferroni test was utilized to identify the time causing the difference. The Student's t-test was employed for comparisons between two groups of independent parameters, while the Paired Sample t-test was used for comparisons of dependent parameters. Qualitative data were evaluated using Fisher's Exact test. Statistical significance was considered at a *P*-level <0.05. The sample size was computed based on Sinclair et al. studies, yielding a sample size of 4 with a 0.05 margin of error and 0.80 power. The power analysis was conducted using the G*Power 3.1 program [6].

Results

Forty patients who underwent orthopedic surgery at our University Faculty of Medicine Hospital were included (see Consort Diagram). Factors such as age, sex, ASA, BMI, operation type, comorbidity, previous operation, medication use, and anesthesia duration were evaluated for the study's participant groups. No statistically significant difference was found between the groups. Table 1 presents the demographic data of the patients included in the study.

Table 1: Demographic data of the patients included in the study

Variables	Group D	Group K	*P*-value
Age	56 (39.50)	49.5 (19.48)	0.628[1]
ASA	2 (2)	2 (1)	0.390[1]
BMI	21.47 (5.3)	15.53 (4.9)	0.843[1]
Sex(M/F)	12/8	17/3	0.77[2]
Operation type			0.615
• **Hip prosthesis**	2 (10%)	4 (20%)	
• **Femur fracture**	5 (25%)	6 (30%)	
• **Knee prosthesis**	6 (30%)	5 (25%)	
• **Tibia-fibula fracture**	7 (35%)	4 (20%)	
• **Foot fracture**	0 (0%0)	1 (5%)	
Previous operation	8 (40%)	13 (65%)	0.113[2]
Medication use	16 (80%)	17 (85%)	0.677[2]
Anesthesia duration (min)	140.9 (17.9)	137.2 (25.91)	0.602[1]

[1]Student Test [2]Fisher's Exact Test, ASA: American Society of Anesthesiologists, BMI: Body Mass Index

Comparison of SAP between the groups; showed that SAP in Group K was significantly lower than the other group at 10 minutes, 20 minutes, 25 minutes, 30 minutes and 90 minutes (*P*=0.032) (Figure 2). The comparison of DAP among the groups showed that DAP in Group K was statistically significantly lower than the other group at both 20 and 30 min (*P*=0.038) (Figure 3).

Figure 2: Comparison of systolic arterial pressures between groups

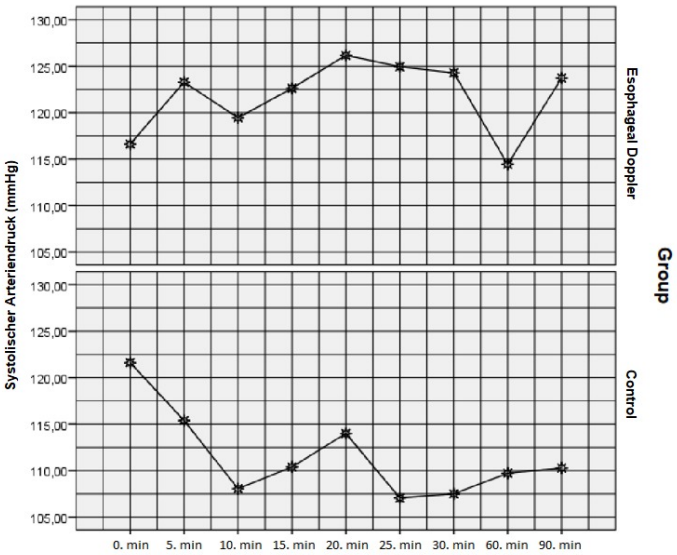
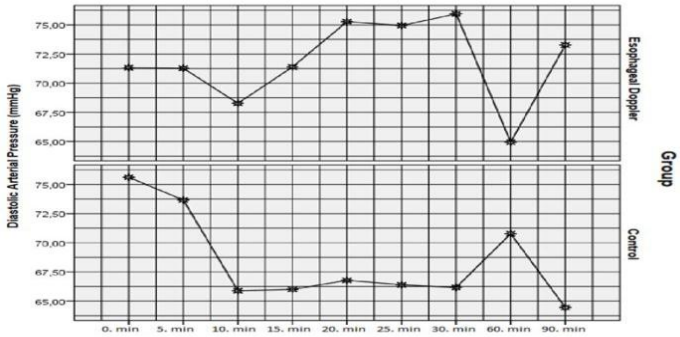


Figure 3: Comparison of diastolic arterial pressures between the groups



The comparison of lactate levels between groups was statistically significantly lower in Group D at 90 minutes of operation (*P*=0.045) (Table 2). When comparing the total amount of crystalloid, colloid, and urine used intraoperatively, the amount of crystalloid used in Group D was found to be significantly lower than in the other group (*P*<0.001). Conversely, the total amount of urine used in Group D was significantly higher than in the control group (*P*=0.031) (Table 3).

Table 2: Comparison of lactate levels between Doppler and control groups

Variables	Group D	Group K	*P*-value
0th min lactate levels	1.01 (0.416) mmol/L	1.33 (0.68) mmol/L	0.498
60th min lactate levels	1.14 (0.401) mmol/L	1.35 (0.654) mmol/L	0.212
90th min lactate levels	1.21 (0.377) mmol/L	1.67 (0.782) mmol/L	0.045

Table 3. Comparison of total crystalloid, colloid and urine amounts used intraoperatively between groups

Variables	Group D	Group K	*P*-value
Total amount of crystalloid used	1225 (600) ml	2500 (1000) ml	<0.001
Total colloid amount used	875 (500) ml	0	<0.001
Total urine amount	400 (362.5) ml	262 (175.5) ml	0.031

The postoperative follow-up comparison revealed no significant differences between the groups in terms of postoperative oral intake time, mobilization time, and discharge time (P=0.609, P=0.945, P=0.284, respectively) (Table 4). Postoperative complications such as bradycardia, tachycardia, nausea, vomiting, arrhythmia, hypertension, hypotension, delirium, and respiratory depression were noted and questioned. Tachycardia was found to be significantly lower in the Doppler group, a find denoted by a statistical significance (P=0.013) (Table 5).

Table 4: Comparison of postoperative follow-up between groups

Variables	Group D	Group K	*P*-value
Postoperative intake time	6 (1.5) h	6 (4.0) h	0.609
Postoperative mobilization time	3 (2.75) h	3 (2.85) h	0.945
Postoperative discharge time	8 (4)h	9 (3.5) h	0.284

Table 5: Comparison of complications between groups

Variables	Group D	Group K	*P*-value
Bradycardia	0 (0%)	1 (5%)	0.311
Tachycardia	2 (10%)	9 (45%)	0.013
Nausea and vomiting	0 (0%)	1 (5%)	0.341
Arrhythmia	0 (0%)	0 (0%)	0.648
Hypertension	2 (10%)	2 (10%)	0.984
Hypotension	0 (0%)	2 (10%)	0.147
Delirium	0 (0%)	0 (0%)	0.518
Respiratory depression	1 (5%)	1 (5%)	0.95

Discussion

Our study, which evaluated 40 cases of major orthopedic surgery conducted under general anesthesia, aimed to compare perioperative and postoperative hemodynamic parameters, total urine output, serum lactate levels, the total amount of fluid and blood administered, the duration of anesthesia, postoperative recovery times, hospitalization duration, the initiation time of an oral diet, postoperative nausea and vomiting, and possible morbidity-related complications between EDM and conventional targeted fluid therapy. Intraoperative systolic and diastolic pressure values were found to be significantly more stable and higher in the EDM group compared to the control group.

Moreover, the results demonstrated that perioperative urine output was significantly higher in this group compared to the other group. Upon analysis of postoperative complications, significant tachycardia was found in the control group, and the 90th-minute lactate level was lower in the esophageal Doppler group compared to the traditional method.

The anesthesiologist's assessment of the patient's fluid status and appropriate administration of individual treatment is crucial. Improving outcomes in the postoperative period hinges on the concept of "patient-directed fluid management" or "targeted fluid management". Utilization of Perioperative Targeted Fluid Therapy Technologies allows anesthesiologists to closely monitor patients and determine the delicate balance between benefits and risks.

Patients undergoing intermediate and high-risk surgical procedures carry a significant risk of morbidity and mortality. A significant proportion of these patients exhibit clinically significant dehydration preoperatively and lose varying amounts of fluid during the surgical procedure. If the body's fluid level is insufficient, the volume of blood pumped to the body by the heart decreases with each heartbeat. This results in inadequate blood supply to tissues and vital organs, depriving them of oxygen and nutrients. Without appropriate intervention, this can lead to the development of serious complications, prolonged hospitalization, and even death. When administering IV fluids, the benefits of maintaining optimal circulatory volume and organ perfusion should be weighed against the risks of fluid overload, which can lead to pulmonary edema and other complications. In a study by Bellamy et al [7], a well-established relationship between the volume of fluid administered to patients in the perioperative period and postoperative morbidity was identified.

In two studies by Marik et al. [8] and Le Manach et al. [9], it is asserted that standard fluid management is typically based on clinical assessments, vital signs, and/or central venous pressure (CVP) monitoring. Nonetheless, clinical studies indicate that CVP measurement does not suffice in predicting fluid responsiveness, and changes in blood pressure should not be utilized to monitor changes in stroke volume and cardiac output. In a study by Sivrikoz et al. [10], conventional physiological parameters such as heart rate and mean blood pressure are shown neither to be adequate nor subclinically detect hypovolemia. The studies suggest that methods including central venous oxygen saturation and pulmonary artery catheterization are effective in revealing fluid balance, yet their invasiveness as intravascular hemodynamic monitoring techniques is viewed as a disadvantage. Hemodynamics delineates the relationship between the heart's pumping mechanism and the blood's movement. Hemodynamic monitoring showcases real-time variables of the cardiovascular system in the perioperative period to maintain tissue perfusion and oxygen supply to anesthetized patients' tissue. When examining cardiovascular variables, the anesthesiologist evaluates the adequacy of cardiac output. The crucial and most challenging issue is optimizing the volume status. Thiele et al. [11] present new technologies utilized in hemodynamic monitoring, such as pulse contour analysis, Doppler, bioimpedance bioreactance measurements, and pulse wave delay time. In the appraisal of devices for targeted fluid therapy, the esophageal Doppler and arterial wave analysis methods were deemed the most desirable. According to a study by Roeck et al. [12], these methods are the most preferred choices among the devices used. In a study with 19 adult intensive care unit patients, EDM, and the thermodilution methods were compared to explore the changes in stroke volume due to fluid overload, with similar results shown in both groups. Waldron et al. [13] conducted a prospective study on non-invasive cardiac monitoring with EDM in targeted fluid therapy for colorectal surgeries on 100 patients. Postoperative pain, nausea and vomiting, improved bowel functions, renal and pulmonary complications, wound complications, infections, and length of hospitalization were compared in both methods. Both methods exhibited similar performance with no clinically significant difference detected. In EDM, fluid management is linked with left ventricular stroke volume, and maximization of intraoperative stroke volume substantially reduces intensive care unit admission and hospitalization, especially post-abdominal, orthopedic, and

cardiac surgeries. [14-18] Another randomized controlled meta-analysis study by Giglio et al. [19] revealed that patients undergoing EDM-guided targeted fluid therapy present more rapid improvement in gastrointestinal functions. In a meta-analysis of randomized trials of targeted fluid therapy utilizing the esophageal Doppler and arterial pulse pressure waveform (APPWA) method in adult patients undergoing high-risk abdominal surgery, Lengard et al. [20] found that EDM and APPWA are more effective and cost-efficient than the conventional approach when comparing clinical evaluation and cost-effectiveness. The advantages of EDM over other techniques include less training, less invasive monitoring needs like central venous catheters, and fewer complications compared to other invasive techniques.

Tissue hypoperfusion is common in trauma patients but cannot be identified and eliminated by conventional methods, such as blood pressure, heart rate, and urine output. The most commonly used marker for occult tissue hypoperfusion in trauma patients is blood lactate levels. In a randomized controlled trial involving 82 multi-trauma patients with blood loss exceeding 2000 ml in the intensive care unit, fluid resuscitation using EDM was compared with the conventional method. In the group where intravascular volume optimization was performed with EDM, it proved more effective in reducing blood lactate levels, decreasing infectious complications, and reducing the duration of both intensive care unit and hospital stays [21]. In that study, postoperative 12th and 24th-hour lactate levels were significantly lower in the EDM group compared to ours. In our study, the 90th-minute lactate level was lower in the esophageal Doppler group compared to the conventional method. We attribute this difference to the larger sample size of our study. We had 162 patients in total, while the referenced study had 40. Blood lactate level, one of the commonly used indicators for evaluating fluid and hemodynamic resuscitation, is an indicator of tissue perfusion disorder and is associated with mortality. High blood lactate levels in trauma patients are an indicator of severe injury, poor cardiac performance, and increased mortality. Both our study and the one mentioned above demonstrate these findings. Therefore, devices such as EDM that will be used in targeted fluid resuscitation will provide valuable assistance.

In plastic surgery procedures, intraoperative fluid management must be balanced for proper flap function. A randomized clinical study was conducted on 104 patients undergoing flap surgery, with two intraoperative fluid management methods being utilized. The first involved EDM, while the second used targeted fluid therapy, employing CVP and arterial catheter monitoring. In both methods, flap perfusion was evaluated by the intraoperative fluids given to patients, intraoperative bleeding, and urine output. The EDM group had less fluid deficit, shorter anesthetic duration, reduced hospitalization, and fewer flap complications [22]. Our study found that intraoperative systolic and diastolic pressure values were significantly more stable and higher in the EDM group compared to the other. Additionally, perioperative urine output was significantly higher in this group compared to the other, and significant tachycardia was detected in the control group as a postoperative complication.

Limitations

Our study has several limitations. First, the study was relatively small and conducted in a single center. While the number of patients is statistically sufficient, a larger patient group might yield more robust results. Second, the traditional postoperative processes managed by the surgical team - such as patient mobilization, oral intake, and discharge - represent additional limitations. Lastly, the type of surgery also limits the study. The amount of fluid to be administered can vary depending on the surgical procedure. We focused on just one type of surgery, so it is crucial to validate these findings with other surgical procedures.

The conclusion drawn was that targeted fluid therapy with EDM, in major orthopedic surgery cases, yielded better outcomes in perioperative vital signs – particularly lower lactate levels, which have significant implications for mortality and morbidity rates. Although it was noted that there was no impact on the postoperative duration of hospital stay, oral intake, or mobilization, more substantial findings might emerge with additional research.

Conclusion

In major orthopedic surgery cases, utilizing targeted fluid therapy with EDM provides improved results in perioperative vital signs. Additionally, it is been concluded that lactate levels, which are considered significant indicators of mortality and morbidity, are lower with this method. We hypothesize that procedures guiding fluid therapy, like EDM, will become standard in trauma surgery cases. This study is anticipated to catalyze the acceptance of EDM's effectiveness in major surgical operations outside of trauma surgery. A more expansive, multicenter study should be pursued to further corroborate our results.

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