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CASE SERIES

# Intraoperative fluid management in adult spinal deformity surgery: variation analysis and association with outcomes

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## Abstract

**Purpose** To evaluate the variability in intraoperative fluid management during adult spinal deformity (ASD) surgery, and analyze the association with complications, intensive care unit (ICU) requirement, and length of hospital stay (LOS).

**Methods** *Multicenter comparative cohort study*. Patients ≥ 18 years old and with ASD were included. Intraoperative intravenous (IV) fluid data were collected including: crystalloids, colloids, crystalloid/colloid ratio (C/C), total IV fluid (tIVF, ml), normalized total IV fluid (nIVF, ml/kg/h), input/output ratio (IOR), input–output difference (IOD), and normalized input–output difference (nIOD, ml/kg/h). Data from different centers were compared for variability analysis, and fluid parameters were analyzed for possible associations with the outcomes.

**Results** Seven hundred ninety-eight patients with a median age of 65.2 were included. Among different surgical centers, tIVF, nIVF, and C/C showed significant variation ($p < 0.001$ for each) with differences of 4.8-fold, 3.7-fold, and 4.9-fold, respectively. Two hundred ninety-two (36.6%) patients experienced at least one in-hospital complication, and ninety-two (11.5%) were IV fluid related. Univariate analysis showed significant relations for: LOS and tIVF ($\rho = 0.221$, $p < 0.001$), IOD ($\rho = 0.115$, $p = 0.001$) and IOR ($\rho = -0.138$, $p < 0.001$); IV fluid-related complications and tIVF ($p = 0.049$); ICU stay and tIVF, nIVF, IOD and nIOD ($p < 0.001$ each); extended ICU stay and tIVF ($p < 0.001$), nIVF ($p = 0.010$) and IOD ($p < 0.001$). Multivariate analysis controlling for confounders showed significant relations for: LOS and tIVF ($p < 0.001$) and nIVF ($p = 0.003$); ICU stay and IOR ($p = 0.002$), extended ICU stay and tIVF ($p = 0.004$).

**Conclusion** Significant variability and lack of standardization in intraoperative IV fluid management exists between different surgical centers. Excessive fluid administration was found to be correlated with negative outcomes.

*Level of evidence*: III.

**Keywords** Adult spinal deformity · Intraoperative fluid · IV fluid · Fluid management

## Introduction

Number of adults with spinal deformity increases as a result of the aging population. Despite the advances in the surgical management of adult spinal deformity (ASD), these complex procedures continue to carry a high burden of complications, with rates reaching up to 70% [1]. There are many different factors that are patient, procedure or surgeon related which contribute to these high rates, and the current trend in the literature is toward identifying these factors as a first step of complication mitigation.

Appropriate intraoperative intravenous (IV) fluid management is critical in maintaining organ perfusion and optimizing the patient's hemodynamic balance. Proper IV fluid management should avoid both under- and over-resuscitation, as both can be damaging [2]. Over the past two decades,

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anesthesiologists and surgeons from different specialties studied this extensively to find strategies for fluid management that will improve patient outcomes; however, there are still significant variations in practice [2–4].

Surgical procedures for ASD are extensive and challenging for hemodynamic management, considering the prolonged surgical time, significant blood loss, and prone positioning [5, 6]. Efforts to bring standardized "Enhanced Recovery After Surgery (ERAS)" protocols into spine surgery led to an increased number of investigations performed on both the quantity (liberal vs. restrictive or goal-directed) and quality (crystalloid vs. colloid) of intravenous resuscitation fluids [7–10]. These efforts, however, have not been sufficient to establish a consensus [11].

This multi-center study aims to (1) evaluate the variability in intraoperative IV fluid management during ASD surgery, and (2) analyze the association with complications, intensive care unit (ICU) requirement, and length of hospital stay (LOS). We primarily hypothesize that significant variability exists between different centers. As a secondary hypothesis, sub-optimal resuscitation (which can be either under- or over-resuscitation) is linked with inferior results.

## Materials and methods

### Patient selection

This study is designed as a multi-center comparative cohort study, utilizing a prospectively collected database on ASD from 21 different centers. Enrollment period was 10/2008–02/2020. Institutional review board approval was obtained from all contributing centers, and patient enrollment included informed consent. This database includes patients $\geq 18$ years old who were operatively treated for adult degenerative/idiopathic spinal deformity, and with at least one of the following criteria: coronal Cobb angle $\geq 20°$, sagittal vertical axis (SVA) $\geq 5$ cm, pelvic tilt (PT) $\geq 25°$, or thoracic kyphosis (TK) $\geq 60°$. Patients with spinal deformity secondary to traumatic, neuromuscular, congenital, infectious, and paralytic causes were not included in this database. For this study, patients with $\geq 6$ weeks of follow-up were included. Patients in the database who did not have a complete intraoperative fluid data that includes the five main variables (colloid and crystalloid amounts, urine output, estimated blood loss and volume of cell-saver blood products) were excluded from the analyses.

### Data collection

In addition to patient demographics (age, gender, frailty index [12], BMI…), surgical data (primary/revision, levels of fusion, surgical time, invasiveness…) and intraoperative fluid data were collected for each patient. Invasiveness was documented as a single score incorporating multiple surgical factors, as previously defined in the literature [13]. Amounts of crystalloid (ml) and colloid (ml) were documented, and crystalloid/colloid ratio (C/C) was calculated. Total IV fluid (tIVF, ml) was calculated by crystalloid (ml) + colloid (ml), and this data was later normalized to patient weight (kg) and surgical time (h): nIVF (ml/kg/h). Other collected variables were total urine output (ml), estimated blood loss (EBL, ml), cell-saver and non-cell-saver (packed red blood cells, platelets, fresh frozen plasma, and cryoprecipitate) blood products (ml) received, input/output ratio [IOR:(crystalloid + colloid + cell saver)/(EBL + urine output)], input–output difference (IOD: tIVF + cell saver − EBL − urine output), and normalized input–output difference (nIOD, ml/kg/h).

### Dependent variables—outcome measures

Dependent variables in this study were length of hospital stay (LOS, days), intensive care unit (ICU) stay (days), and complications. Both medical (cardiopulmonary, gastrointestinal, renal, coagulopathy and neurologic) and surgical (implant related, wound problems and infections) complications are included. Three time points were used for the reporting of complications: intraoperative (either during surgery and postoperative day 0), before discharge (postoperative day 1 until discharge), and in-hospital (during the entire stay, including both intraoperative and before-discharge events).

For the univariate and multivariate analyses, only the complications that were expected to be affected by IV fluid management were included (IVF-related complications: cardiac, pulmonary, renal, gastrointestinal, coagulopathic, wound related and infectious). The types of complication that were excluded from these analyses (implant related, mechanical and neurologic) were considered to be more closely related with surgical factors rather than IV fluid management. Independent variables were tIVF, nIVF, IOR, IOD, and nIOD, while the dependent variables were LOS, ICU stay, extended ICU stay (>48 h), and in-hospital complications. Non-cell-saver blood products were excluded from these analyses, because their management is different from other IV fluids and their allogeneic nature may be a significant confounder for the analysis of complications.

Data were collected separately from each center, and the study enrollment timeframe (from 10/2008 to 02/2020) was divided into four periods (based on the number of patients) to assess for trends.

### Statistical analysis

Descriptive statistics include means-standard deviations (SD) and medians-inter-quartile ranges (IQR) for continuous

variables, and percentages for categorical variables. Variability analysis included only centers with ≥50 patients, and mean/median values were compared using the Kruskal–Wallis test followed by post hoc analyses with the appropriate corrections. Possible correlations with dependent variables were assessed by univariate (Pearson correlations) and multivariate (multiple regression models) analyses controlling for patient (age, frailty index, previous spine surgery) and surgical (invasiveness, fusion length, osteotomies, interbody fusions) factors. Positive regression coefficients and odds ratios indicate that as the independent variable increases, the dependent variable also tends to increase. Due to the very small scale of some variables (e.g., tIVF), coefficients of the analyses regarding these variables were not reported. All analyses were performed using the software package SPSS v23 (IBM Corp, 2015. Armonk, NY).

## Results

Review of the database revealed 1,185 patients eligible for this study. After the exclusion of patients who did not have a complete IV fluid data, 798 (67%) were included in the study. Demographic and basic surgical parameters are summarized on Table 1.

The variability analysis utilized data from eight sites, representing 85% (674/798) of the included patients. Descriptive data on different IV fluids can be seen on Table 2. The number of patients who received packed red blood cells was 531 (66%). Median tIVF, nIVF, and C/C all showed significant variation ($p < 0.001$ for each) with differences of 4.8-fold (range: 1560–7412 ml), 3.7-fold (range: 3.4–12.5 ml/kg/h), and 4.9-fold (range: 2.1–10.2), respectively (Fig. 1).

Assessment of trends in IV fluid management throughout the study timeframe (Table 3) showed no significant changes for tIVF or nIVF. C/C increased from 4.6 to 7.0 in the 2016–2017 time interval ($p = 0.018$, Fig. 2) and IOR showed significant variation ($p < 0.001$).

**Table 1** Demographic and surgical parameters of the study population

| Variable | Study population ($n = 798$) |
|---|---|
| Age (years, median-IQR) | 65.2 (55.7–71) |
| Gender (male/female) | 238 (31%)/551 (69%) |
| BMI (kg/m$^2$, mean ± SD) | 28.4 (±6.1) |
| Frailty index (mean ± SD) | 3.5 (±1.5) |
| Invasiveness (mean ± SD) | 84.4 (±33.4) |
| Surgical time (min, median-IQR) | 382 (303–477) |
| Number of levels fused (median-IQR) | 9 (8–13) |
| Three-column osteotomies (*n*, %) | 143 (18%) |
| Interbody fusions (*n*, %) | 469 (59%) |

*IQR* inter-quartile range, *BMI* body mass index, *SD* standard deviation

**Table 2** Descriptive statistics of the IV fluids used

| Variable[a] | Total (ml) | Normalized (ml/kg/h) |
|---|---|---|
| IVF | 4000 (2900–5675) | 8.6 (6.1–11.9) |
| Total crystalloid | 3000 (2000–4800) | 6.8 (4.6–9.6) |
| Total colloid | 750 (75–1000) | 1.4 (0–2.6) |
| Total urine output | 640 (400–1000) | 1.3 (0.9–2.1) |
| EBL | 1200 (600–2000) | 2.5 (1.3–4.3) |
| Total cell saver | 348 (111–675) | 0.7 (0.2–1.4) |
| Non-cell saver blood products | 980 (0–16000) | 2 (0–26.8) |
| Input/output difference | 2300 (1354–3405) | 5.2 (2.8–7.7) |
| Input/output ratio | 2.2 (1.6–3.1) | |
| Crystalloid/colloid ratio | 4 (2.2–6.9) | |

*IVF* intravenous fluid, *EBL* estimated blood loss, *IQR* inter-quartile range

[a]All descriptives are presented as medians and IQRs

A total of 292 (36.6%) patients experienced at least one in-hospital complication. Intraoperative complications were seen in 183 (22%) patients, while before-discharge complications were seen in 156 (19%) patients. IVF-related complications were seen in 92 patients (11.5%). Table 4 shows the rates of in-hospital IVF-related complications. Two hundred and seventy one (34%) patients did not require an ICU stay after surgery, while one hundred twenty-one (15%) had an extended ICU stay (>48 h). Median LOS was 6 days (IQR 5–8 days).

In the univariate analysis, LOS was found to be significantly correlated with tIVF ($\rho = 0.221$, $p < 0.001$), IOD ($\rho = 0.115$, $p = 0.001$) and IOR ($\rho = -0.138$, $p < 0.001$), while nIVF ($p = 0.913$) and nIOD ($p = 0.156$) were not significant. Multivariate regression analysis controlling for patient (age, Frailty index, previous spine surgery) and surgery-related (Invasiveness, fusion length, osteotomies, interbody fusions) factors and including all fluid data revealed that tIVF ($p < 0.001$) and nIVF ($p = 0.003$) were significant independent predictors. Multivariate analyses yielded positive regression coefficients.

Univariate analyses for ICU stay and extended ICU stay are on Table 5. In the multivariate analysis for ICU stay, IOR (adjusted odds ratio = 1.4, 95% confidence interval = 1.1–1.7, $p = 0.002$) was the only significant predictor, and for extended ICU stay, tIVF ($p = 0.004$ with a positive adjusted odds ratio) was the only significant predictor.

Univariate analysis of in-hospital IV fluid-related complications revealed that only tIVF ($p = 0.049$) was a significant predictor, while nIVF ($p = 0.968$), IOD ($p = 0.954$), nIOD ($p = 0.456$), and IOR ($p = 0.080$) were not. Multivariate analysis was not performed.

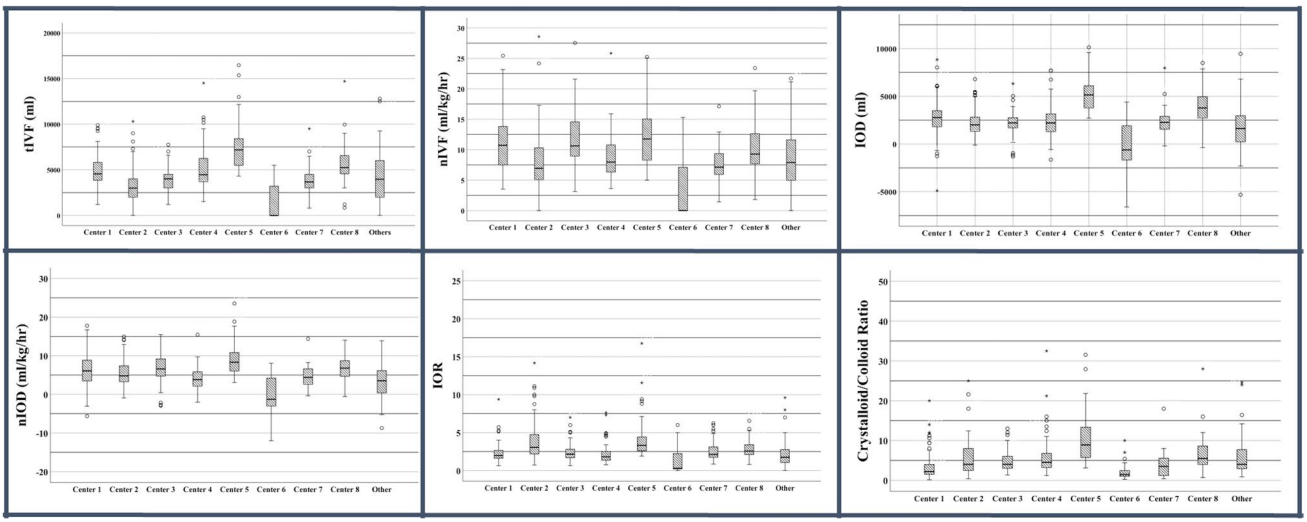


**Fig. 1** Graphs showing different IV fluid parameters of the centers participating in the study. The graphs show eight centers which provide 85% of the study population, and the remaining centers are represented together as "Other". Median tIVF, nIVF, and C/C all showed significant variation ($p < 0.001$ for each) with differences of 4.8-fold, 3.7-fold, and 4.9-fold, respectively

**Table 3** IV fluid trends across different time intervals

| | Time interval | | | | |
|---|---|---|---|---|---|
| | 2008–2013 ($n = 199$) | 2013–2016 ($n = 200$) | 2016–2017 ($n = 200$) | 2017–2020 ($n = 199$) | $p$ value |
| tIVF (ml, mean ± SD) | 4325 (±2565) | 4384 (±2154) | 4546 (±2697) | 4083 (±2366) | =0.142 |
| nIVF (ml/kg/h, mean ± SD) | 9.3 (±5.6) | 9.1 (±5.6) | 9.1 (±4.8) | 9.1 (±4.7) | =0.911 |
| Crystalloid/colloid ratio (mean ± SD) | 4.6 (±4.3) | 5.4 (±6.9) | 7.0 (±8.5) | 4.9 (±4.5) | **=0.012*** |
| IOR (mean ± SD) | 2.3 (±2.8) | 2.5 (±1.7) | 3.2 (±3.6) | 2.8 (±1.8) | **<0.001**** |
| IOD (mean ± SD) | 2142 (±2394) | 2477 (±1893) | 2761 (±2124) | 2308 (±1869) | =0.181 |
| nIOD (mean ± SD) | 4.7 (±5) | 5.3 (±4) | 5.5 (±4.2) | 5.3 (±3.9) | =0.763 |

Bold $p$ values indicate statistically significant findings

*tIVF* total intravenous fluid, *nIVF* normalized total intravenous fluid, *IOR* input/output ratio, *IOD* input–output difference, *nIOD* normalized input–output difference

* In pairwise comparisons, significant difference was found in 2008–2013 vs. 2016–2017 ($p = 0.018$)

** In pairwise comparisons, significant differences were found in: 2008–2013 vs. 2017–2020 ($p = 0.002$) and 2008–2013 vs. 2016–2017 ($p < 0.001$)

## Discussion

Based on a prospectively collected large multi-centric database, this study clearly demonstrates the significant variability and lack of standardization in intraoperative fluid management between different surgical centers. Excessive fluid administration was also found to be correlated with negative outcomes (LOS, ICU stays and complications), which again underlines the importance of fluid management and supports the current trend in the literature toward goal-directed fluid therapy (GDFT).

During these extensive surgeries, appropriate IV fluid management is of utmost importance since both inadequate and excessive amounts of fluids have been linked with adverse outcomes [14]. Traditionally, intraoperative resuscitation of patients during major surgical procedures included very high volumes of IV fluids for several reasons: excessive blood loss, preoperative dehydration, and third-space sequestration of body fluids [15]. Most of these assumptions were not evidence based, and this liberal fluid management approach is slowly being abandoned. Despite these advancements, optimal fluid management is

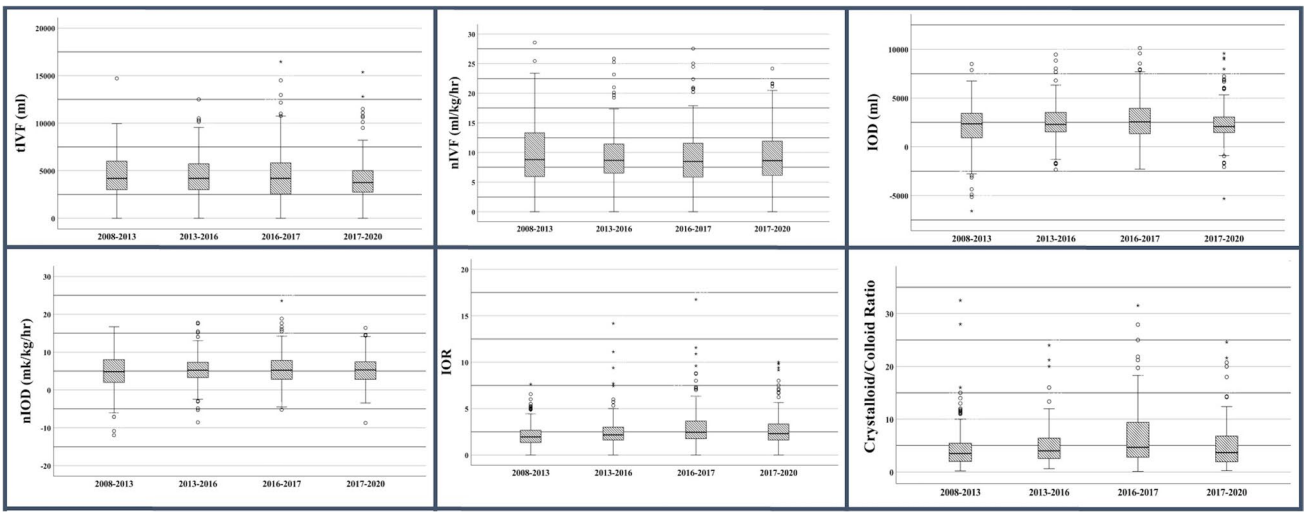


**Fig. 2** Graphs showing the trends in IV fluid management throughout the study timeframe. C/C ($p = 0.018$) and IOR showed significant variation ($p < 0.001$)

**Table 4** IVF-related in-hospital complications

| In-hospital complication | Number of patients (%) |
|---|---|
| Cardiac | 12 (1.5%) |
| Pulmonary | 20 (2.5%) |
| Renal | 7 (0.9%) |
| Gastrointestinal | 40 (5%) |
| Coagulopathic | 12 (1.5%) |
| Surgical site infection | 2 (0.3%) |
| Infectious (other than surgical site) | 17 (2.1%) |
| Wound-related | 6 (0.8%) |

still complicated by many patient- and surgery-related factors, and significant variations exist. In their study on intra-abdominal procedures, Lilot et al. showed that in addition to significant institutional variations, the strongest predictor of the intraoperative IV fluid amount was the anesthesiologist: the average normalized amount ranged between 2.3 and 14 ml/kg/h, which represents a striking sixfold difference [4]. Similar variations can also be seen in non-abdominal procedures [16]. This study verifies a similar variability for patients undergoing surgery for ASD with 4.8- and 3.7-fold differences in tIVF and nIVF, respectively, among eight different centers. There are many possible underlying factors

**Table 5** Univariate analysis for ICU stay and extended ICU stay

| Variable[a] | Study population ($n = 798$) | | | | | |
|---|---|---|---|---|---|---|
| | ICU stay | | | Extended ICU stay | | |
| | Yes ($n = 519$) | No ($n = 271$) | $p$ value | Yes ($n = 121$) | No ($n = 664$) | $p$ value |
| tIVF (ml) | 4500 (3500–6370) | 3000 (1700–4100) | **<0.001** | 5400 (4000–7400) | 4000 (2500–5200) | **<0.001** |
| nIVF (ml/kg/h) | 9.4 (7.1–12.6) | 6.9 (4.3–10.4) | **<0.001** | 9.8 (7.2–12.2) | 8.5 (5.9–11.9) | **=0.010** |
| IOD (ml) | 2710 (1665–3878) | 1800 (775–2720) | **<0.001** | 2950 (1857–4500) | 2230 (1306–3240) | **<0.001** |
| nIOD (ml/kg/h) | 5.6 (3.4–7.9) | 4.3 (2.1–7.5) | **<0.001** | 5.6 (3.2–7.4) | 5.1 (2.7–7.8) | =0.398 |
| IOR | 2.2 (1.6–3) | 2.3 (1.5–3.8) | =0.142 | 2.1 (1.5–2.8) | 2.2 (1.6–3.3) | =0.344 |
| Crystalloid/colloid ratio | 4 (2.3–7) | 3.9 (2–6.5) | =0.509 | 4.3 (2.2–8) | 4 (2.2–6.2) | =0.222 |

Bold $p$ values indicate statistically significant findings

*ICU* intensive care unit, *tIVF* total intravenous fluid, *nIVF* normalized total intravenous fluid, *IOD* input–output difference, *nIOD* normalized input–output difference, *IOR* input/output ratio, *IQR* inter-quartile range

[a]All variables are presented as medians-IQRs

contributing to the variability in fluid administration (e.g., surgeon, anesthesiologist, patient specific factors), which must be analyzed with further studies and are out of the focus of the current study. Although a patient's requirements may change depending on many factors, such variability is hardly plausible. Multidisciplinary action is necessary to improve standardization and, in turn, surgical outcomes.

Liberal and fixed-volume fluid approaches have been abandoned, because they frequently resulted in volume overload, tissue edema, and adverse outcomes. The relation between the amount and type of intraoperative fluids on postoperative complications has not been studied extensively in spine surgery literature. In a retrospective analysis of 135 patients undergoing thoracic and lumbar spine surgery, the subgroup that required delayed extubation had received higher total crystalloids (6018 ml vs. 4186 ml, $p < 0.05$), total colloids (787 ml vs. 442 ml, $p < 0.05$), and blood transfusions (3.6 units vs. 0.7 units, $p < 0.05$) [17]. These reports are susceptible to many confounding factors, and in an effort to resolve this issue, Ramchandran et al. performed a propensity-score matched analysis and reported that the subgroup with delayed extubation had a higher crystalloid/colloid ratio (8.5 vs. 6.8, $p = 0.03$) but received similar total IV fluids (9100 vs. 8500, $p = 0.14$) [9]. Other postoperative events that have been linked with excess fluid administration were urinary retention and delirium [18, 19]. Our study supports the correlation between excess fluids and postoperative complications, but it must be noted that we analyzed only for the IV fluid-related complications.

Length of stay has become an important perioperative metric and proxy for quality of care and value. Implementation of ERAS protocols has emphasized this importance in all aspects of spine surgery, especially ASD. After reducing bias by controlling for confounding factors, we found that the LOS was significantly affected by tIVF and nIVF. Studies from different surgical disciplines strongly support this relation [20]; however, spine surgery literature is inconclusive [7, 21]. Most of these studies were not designed to detect differences in LOS, and further studies are required to investigate this relation in more detail.

In light of recent evidence, there is a growing preference for goal-directed or restrictive approaches in major surgeries. In GDFT, the anesthesia team decides on one or more hemodynamic measures to follow perioperatively, and adjust the amount of fluid accordingly [22]. Restrictive fluid therapy (RFT) aims to achieve a zero-balance during surgery, and the presumed third-space loss is usually not covered [23]. These strategies include much less fluid administration when compared to the traditional approach. Bacchin et al. retrospectively analyzed the effects of stroke-volume variation-based GDFT on patients undergoing posterior spinal fusion, and reported less transfusions (2 vs. 4 units, $p = 0.001$), non-invasive ventilation support (0% vs. 22%, $p = 0.049$), and ICU stays (44 h vs. 50 h, $p = 0.040$) when compared to the liberal group [7]. Yokoi et al. reported the results of a pulse-pressure variation-based GDFT on patients undergoing major spine surgery: in addition to less transfusions and fluid overload, extubation within the OR also increased by 13.3% ($p = 0.005$) [24].

The benefits of a standardized and goal-directed approach to intraoperative fluid management during spinal surgery are becoming more and more clear with accumulating evidence. Excessive fluid administration seems to be the main factor behind adverse outcomes, but the benefit of GDFT is not only in restricting fluids but also in focused timely resuscitation. In a multi-center randomized controlled trial on patients undergoing major abdominal, urological, gynecological, or orthopedic surgery, it was reported that the GDFT group had significantly less complications (8.6% vs. 16.6%, $p = 0.018$) and shorter hospital stays (5 vs. 7 days, $p = 0.001$) without any reduction in intraoperative fluids [25]. A similar observation was reported by Che et al. on 300 patients undergoing posterior spinal fusion: individualized intraoperative fluid management resulted in a lower rate of complications (32 vs. 48%, $p < 0.01$), despite the same amount of crystalloids and colloids administered [26]. In addition to correct timing, GDFT regulates the use of vasopressors as well, which may be one of the reasons behind these intriguing findings.

In an effort of standardizing patient care in spinal surgery, GDFT has been implemented into the ERAS protocol: the consensus report strongly recommends that GDFT must be considered if significant comorbidities exist [11]. The recommendation does not extend to short segment fusions, and with the current evidence, it is unclear where to set the limit. However, as this study highlights, variation between different surgical centers is massive, and consensus protocols may lead to much-needed standardization. Thus far, the integration of GDFT into spinal surgery practice appears to be progressing slowly. Despite the rising interest in ERAS protocols and GDFT, our data indicate that the majority of IV fluid parameters have remained unchanged throughout the study period (especially nIVF). To effectively implement ERAS protocols in routine clinical practice, new strategies are needed, beginning with heightened awareness and sustained adherence.

This study has certain limitations. Even though the database is prospectively collected, the study was carried out in a retrospective manner which makes it susceptible to certain types of bias such as selection and information bias. And as for any multi-center study, heterogeneity among clinical practice may be a confounder. Fluid data were missing for a significant number of patients, which was not only because of uncollected data, but also the methods and formats of data collection adopted by certain surgical centers that were not possible to combine and analyze. A centralized

system, or a shared platform used by different centers to record intraoperative data may be needed to overcome this problem. The allogeneic blood products are also a significant part of intraoperative resuscitation, and they should be analyzed separately, which is out of the focus of this study. In addition, as shown on Table 2, the amount of allogeneic non-cell-saver blood products is considerably smaller than the other IV fluids. Other possibly relevant variables that were not included in the analyses were the anesthesiologist and surgeon. The multi-centric nature of the study brings significant heterogeneity for both patient characteristics and routine fluid management protocols. As there is no widely accepted ideal method, some centers may have already adapted to goal-directed approaches, while others are still following traditional practices. Our database includes a wide variety of surgical procedures, and we did not perform any stratifications. Further analyses on certain subgroups (e.g., more invasive procedures) may reveal valuable results. The available literature is limited in providing a true causal link between IV fluids and certain types of complications; therefore, the definition of "IV fluid related complications" that was used in this study can be debated. The excluded complications may also be related with different aspects of IV fluid management (e.g., neurologic complications may be caused by hypotension and hypoperfusion; however, they are more likely to be caused by surgical factors and fluid management may affect recovery), and further studies are required to evaluate these relations. Another further consideration is the lack of a standardized and validated classification system for complications in this patient population.

## Conclusion

In conclusion, this study represented the striking difference in the amount of IV fluids administered during surgery for ASD. In addition, the significant relations between excessive intraoperative IV fluids and adverse outcomes (higher rate of complications, higher LOS and ICU stay) have also been demonstrated. The need for standardization in these extensive ASD surgeries, particularly in the context of intraoperative fluid management, is evident. We recommend that further studies should investigate standardization and goal-directed approaches in spine surgery, and analyze their effects on the outcomes.

**Author contributions** Riza M. Cetik: writing and original draft preparation, finalizing the manuscript and approval of the final version of the manuscript. Jeffrey L. Gum: conceptualization, project supervision, approval of the final manuscript, data collection. Renaud Lafage: data analysis and interpretation, approval of the final version of the manuscript. Justin S. Smith: data collection, approval of the final version of the manuscript. Shay Bess: data collection, interpretation of the data, approval of the final version of the manuscript. Jeffrey P. Mullin: data collection, approval of the final version of the manuscript. Michael P. Kelly: conceptualization, data collection, data interpretation, approval of the final version of the manuscript. Bassel Diebo: data collection, approval of the final version of the manuscript. Thomas J. Buell: data collection, data analysis, approval of the final version of the manuscript. Justin K. Scheer: data collection, conceptualization, writing the original draft of the manuscript, approval of the final version of the manuscript. Breton G. Line: data collection, data interpretation, approval of the final version of the manuscript. Virginie Lafage: data analysis and interpretation, approval of the final version of the manuscript. Eric O. Klineberg: data collection and analysis, approval of the final version of the manuscript. Han Jo Kim: conceptualization, data collection, approval of the final version of the manuscript. Peter G. Passias: drafting the original manuscript, approval of the final version of the manuscript. Khaled M. Kebaish: project supervision, data collection, approval of the final version of the manuscript. Robert K. Eastlack: data collection and analysis, approval of the final version of the manuscript. Alan H. Daniels: data collection, analysis, approval of the final version of the manuscript. Alex Soroceanu: drafting the original manuscript, approval of the final version of the manuscript. Gregory M. Mundis: data collection and analysis, approval of the final version of the manuscript. Richard A. Hostin: drafting the original manuscript, revising the manuscript, approval of the final version of the manuscript. Themistocles S. Protopsaltis: data collection and interpretation, approval of the final version of the manuscript. D. Kojo Hamilton: data interpretation, approval of the final version of the manuscript. Robert A. Hart: data collection, approval of the final version of the manuscript. Munish C. Gupta: data collection, data analysis, approval of the final version of the manuscript. Stephen J. Lewis: conceptualization, approval of the final version of the manuscript. Frank J. Schwab: project supervision, data interpretation, approval of the final version of the manuscript. Lawrence G. Lenke: project supervision, data collection, approval of the final version of the manuscript. Christopher I. Shaffrey: conceptualization, approval of the final version of the manuscript. Christopher P. Ames: data collection, approval of the final version of the manuscript. Douglas C. Burton: data collection, data interpretation, approval of the final version of the manuscript.

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## Declarations

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