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Postoperative Serum Albumin Levels and Their Association with Clinical Outcomes Following Major Abdominal Surgery: A Prospective Observational Study

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ABSTRACT

Background & objectives Postoperative complications following major abdominal surgery remain a significant cause of morbidity, prolonged hospitalisation, and increased healthcare costs. Serum albumin, a negative acute-phase reactant, decreases rapidly following surgical trauma and may reflect the magnitude of systemic inflammatory response. The present study was undertaken to evaluate the relationship between postoperative serum albumin levels and clinical outcomes following elective major abdominal surgery and to assess its utility as an early predictor of postoperative morbidity.

Methods This prospective cohort study was conducted in the Department of Surgery of a tertiary care Armed Forces hospital between January 2020 and October 2021. A total of 120 adult patients undergoing elective major abdominal surgery were enrolled. Serum albumin levels were measured preoperatively (POD−1) and serially on postoperative day (POD) 0, POD1, POD2 and POD3. Clinical outcomes, including postoperative complications, duration of surgery, estimated blood loss, surgical approach and length of hospital stay were recorded. Statistical analysis was performed using SPSS version 20.0, and a P value <0.05 was considered significant.

Results The mean age of the study population was 50.73 ± 16.52 yr, and 65 (54.2%) patients were male. Postoperative complications occurred in 48 (40%) patients, while 72 (60%) had an uncomplicated postoperative course. Patients who developed complications had significantly lower postoperative serum albumin levels on POD1 ($P=0.017$), POD2 ($P=0.008$) and POD3 ($P=0.023$) compared with those without complications. Patients with hospital stay >10 days exhibited significantly lower serum albumin levels from the preoperative period through POD3 ($P<0.05$). Greater postoperative albumin decline was observed in patients undergoing open surgery, procedures lasting ≥150 min and those with blood loss >300 ml; however, these associations were not consistently statistically significant.

Interpretation & conclusions Lower postoperative serum albumin levels were significantly associated with postoperative complications and prolonged hospital stay following major abdominal surgery. Serial postoperative serum albumin measurement may serve as a simple, inexpensive and readily available biomarker for early identification of patients at increased risk of adverse postoperative outcomes. Further multicentric studies are required to validate its role in perioperative risk stratification.

Keywords: *Albumin; abdominal surgery; postoperative complications; hypoalbuminaemia; length of hospital stay; surgical outcomes; biomarker.*

INTRODUCTION

Major abdominal surgery induces a complex systemic response involving neuroendocrine activation, inflammation, alterations in intermediary metabolism, changes in vascular permeability and redistribution of body proteins.[1-4] The magnitude of this response varies according to the extent and type of surgical procedure, duration of surgery, operative approach, blood loss, underlying disease, nutritional status and pre-existing comorbidities.[1,2] An exaggerated or prolonged postoperative stress response is associated with delayed recovery, postoperative complications and prolonged hospital stay.[3-5] Consequently, identification of simple and readily available biomarkers capable of identifying patients at increased risk of postoperative morbidity remains clinically important.

Serum albumin is the most abundant plasma protein and is synthesized exclusively by the liver. It contributes substantially to plasma colloid osmotic pressure and also has important transport, antioxidant and ligand-binding functions.[6-8] Traditionally, serum albumin has been regarded as an indicator of nutritional status and has been extensively investigated as a predictor of postoperative morbidity and mortality.[9-12] However, serum albumin concentration is not determined solely by nutritional intake. It is influenced by hepatic synthesis, degradation, intravascular and extravascular distribution, vascular permeability, hydration status and systemic inflammation.[6,13]

Surgical trauma produces a characteristic acute-phase response. Tissue injury stimulates the release of cytokines, particularly interleukin-1, interleukin-6 and tumour necrosis factor-α, resulting in increased hepatic production of positive acute-phase proteins and relative reduction in the synthesis of negative acute-phase proteins such as albumin.[14,15] In addition, surgical trauma increases endothelial permeability and transcapillary protein movement, resulting in redistribution of albumin from the intravascular to the extravascular compartment.[16] Fleck et al. demonstrated that transcapillary albumin escape increases markedly following major surgery and may increase further in severe inflammatory states.[16] Therefore, the early postoperative reduction in serum albumin may reflect the systemic physiological response to surgical trauma rather than nutritional deficiency alone.

Preoperative hypoalbuminaemia has been consistently associated with adverse surgical outcomes. In the National Veterans Affairs Surgical Risk Study involving more than 54,000 patients, Gibbs et al. demonstrated a strong inverse relationship between preoperative serum albumin and postoperative morbidity and mortality.[9] Kudsk et al. similarly reported that preoperative albumin was associated with major postoperative complications in patients undergoing elective gastrointestinal surgery, with the effect varying according to the operative site.[10] A large meta-analysis by Vincent et al. further demonstrated that hypoalbuminaemia was associated with increased mortality, morbidity and length of hospital stay.[11]

Large contemporary surgical databases have also confirmed the prognostic importance of hypoalbuminaemia. Gibson et al., using data from major surgical procedures, demonstrated that hypoalbuminaemia was associated with increased postoperative morbidity and mortality, although the magnitude of the association differed between procedures.[12] Similar relationships have been reported in gastrointestinal, oesophageal, hepatobiliary, gynaecological and other surgical populations.[17-20] These findings establish albumin as an important marker of perioperative risk; however, a single preoperative measurement may not adequately reflect the physiological stress imposed by the surgical procedure.
Increasing attention has therefore been directed towards dynamic changes in postoperative serum albumin. Hübner et al. conducted a prospective pilot study of 70 patients undergoing abdominal procedures of varying magnitude and demonstrated an immediate postoperative decrease in serum albumin, from 42.2±4.5 g/L preoperatively to 33.8±5.3 g/L on postoperative day (POD) 1.[21] The maximal albumin decrease correlated with operative duration, estimated blood loss and maximum C-reactive protein concentration. Furthermore, patients who developed complications had a greater albumin decrease, and albumin decrease was associated with longer hospital stay.[21] These observations suggested that postoperative albumin kinetics may provide an early measure of surgical stress.

Labgaa et al. subsequently conducted a prospective cohort study involving 138 patients undergoing major abdominal surgery, with serum albumin measured preoperatively and on POD0, POD1, POD2 and POD3.[22] They demonstrated that postoperative albumin decreased rapidly and that the magnitude of decrease correlated with operative duration, blood loss and postoperative complications. A decrease of ≥10 g/L on POD1 was independently associated with an increased risk of postoperative complications.[22] These findings are particularly relevant to the present study because our study used a similar prospective design and serial measurements during the immediate postoperative period.

Other studies have investigated postoperative albumin kinetics in specific gastrointestinal procedures. Ge et al., in a retrospective cohort of 626 patients undergoing colorectal resection, reported that a postoperative albumin reduction of ≥15% was independently associated with postoperative complications and was also associated with major complications, higher Comprehensive Complication Index (CCI), prolonged postoperative stay and surgical-site infection.[23] Liu et al. reported that postoperative albumin decrease was associated with short-term complications following gastric cancer resection.[24] Ai et al. subsequently demonstrated that changes in postoperative albumin could predict short-term complications even among patients with normal preoperative albumin concentrations.[25]

The prognostic value of postoperative albumin has also been demonstrated after oesophagectomy. Ryan et al. reported that patients with serum albumin <20 g/L on POD1 had a substantially higher incidence of postoperative complications, respiratory complications and mortality than those with albumin >20 g/L.[26] Importantly, POD1 albumin remained independently associated with postoperative complications following multivariable analysis.[26] These findings suggest that the absolute postoperative albumin concentration may have prognostic significance independent of the preoperative nutritional state.

The relationship between postoperative albumin and surgical stress is also supported by studies examining the association with operative characteristics. Postoperative albumin decrease has been associated with operative duration and blood loss, both of which are surrogate markers of surgical trauma.[21,22] The decrease may be caused by several mechanisms, including vascular leakage, haemodilution, redistribution into the interstitial compartment, blood loss and altered hepatic protein synthesis.[13,16,27]

A systematic review by Joliat et al. identified 16 studies evaluating postoperative albumin decrease as an early predictor of complications following gastrointestinal surgery.[28] The review reported sensitivity ranging from 63–84% and specificity from 61–86%, while reported discriminatory thresholds for albumin decrease ranged from approximately 5–11 g/L.[28] The authors concluded that postoperative albumin decrease appeared promising as an early marker of postoperative complications but emphasised heterogeneity among studies.[28]

Despite these observations, several important questions remain. It is uncertain whether absolute postoperative albumin concentration, absolute decrease from baseline, or percentage decrease is the most clinically useful parameter. Furthermore, previous studies have frequently focused on a single surgical specialty, particularly colorectal or oesophageal surgery. Evidence from heterogeneous populations undergoing major abdominal surgery remains comparatively limited, particularly from Indian tertiary-care surgical centres.

Therefore, the present prospective cohort study was undertaken to evaluate the relationship between serial postoperative serum albumin levels and clinical outcomes following major elective abdominal surgery. The study specifically assessed the association of postoperative albumin levels and albumin decrease with postoperative complications, length of hospital stay, duration of surgery, estimated blood loss and operative approach (open versus laparoscopic).

MATERIALS AND METHODS

Study design and setting

This prospective observational study was conducted in the Department of Surgery of a tertiary care hospital from January 2020 to October 2021. Approval was obtained from the Institutional Ethics Committee before commencement of the study, and informed written consent was obtained from all participants.

Study population

A total of 120 consecutive patients undergoing elective major abdominal surgery were enrolled in the study.

Inclusion criteria

- Patients aged >18 years.
- Patients undergoing elective major abdominal surgery with an expected operative duration of ≥2 hours.

Exclusion criteria

- Emergency abdominal surgeries and re-explorations.
- Pregnant women.
- Patients receiving immunosuppressive therapy or antibiotic treatment immediately preceding surgery.
- Patients who received perioperative albumin infusion.

Data collection

Baseline demographic characteristics, comorbidities and operative details were prospectively recorded. Serum albumin and haematocrit levels were measured on the day before surgery (preoperative day 1), within 4–6 h after completion of surgery (postoperative day 0), and subsequently on postoperative days 1, 2 and 3.
The following variables were recorded:

- Surgical approach (open or laparoscopic).

- Duration of surgery (minutes).
- Estimated intraoperative blood loss (mL).
- Postoperative complications graded using the Comprehensive Complication Index (CCI).
- Length of postoperative hospital stay (days).

Outcome measures

The primary outcome was the association between postoperative decline in serum albumin levels and postoperative complications.

Secondary outcomes included:

- Length of hospital stay.
- Operative duration.
- Estimated blood loss.
- Type of surgical approach (open versus laparoscopic).

Statistical analysis

Data were analysed using Statistical Package for the Social Sciences (SPSS) software version 20.0 (IBM Corp., Armonk, NY, USA).

Continuous variables were expressed as mean ± standard deviation (SD) or median (interquartile range) depending on data distribution. Categorical variables were presented as frequencies and percentages.

Normality of continuous variables was assessed using the Shapiro–Wilk test. Comparisons between two groups were performed using the independent Student's t-test for normally distributed variables and the Mann–Whitney U test for non-normally distributed variables. Repeated measurements of serum albumin levels were analysed using repeated-measures analysis of variance (ANOVA) or the Friedman test, as appropriate.

Correlations between postoperative albumin decline and clinical outcomes (CCI score, length of hospital stay, operative duration and blood loss) were assessed using Pearson's or Spearman's correlation coefficient. Multivariable linear or logistic regression analysis was performed to identify independent predictors of postoperative complications where appropriate.

A two-tailed P value <0.05 was considered statistically significant.

RESULTS

A total of 120 patients were included in the study. The mean age was 50.73 ± 16.52 years. The mean serum albumin concentration was 3.05 ± 0.60 g/dL on POD −1 and declined progressively to 2.45 ± 0.52 g/dL by POD 3. The mean duration of surgery was 147.22 ± 35.29 minutes, mean length of hospital stay was 8.35 ± 4.82 days, and mean blood loss was 339.58 ± 176.88 mL.

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mong the study participants, 65 (54.2%) were male, and 55 (45.8%) were female. Patients aged 51–60 years and 61–70 years constituted the largest age categories, with 35 patients (29.2%) in each group. Open surgery was performed in 98 (81.7%) patients and laparoscopic surgery in 22 (18.3%). Complications were documented in 48 (40.0%) patients, whereas 72 (60.0%) had no complications. Eighty-nine patients (74.2%) had a hospital stay of ≤10 days and 31 (25.8%) stayed >10 days. Blood loss was ≤300 mL in 65 (54.2%) patients and >300 mL in 55 (45.8%) (Table 1).

Table 1. Descriptive characteristics of the study population (n=120)

Variable	n	%
Male	65	54.2
Female	55	45.8
Age <20 years	11	9.2
Age 21–30 years	8	6.7
Age 31–40 years	6	5.0
Age 41–50 years	20	16.7
Age 51–60 years	35	29.2
Age 61–70 years	35	29.2
Age 71–80 years	5	4.2
Laparoscopic surgery	22	18.3
Open surgery	98	81.7
No complications	72	60.0
Complications	48	40.0
Hospital stay ≤10 days	89	74.2

Hospital stay >10 days	31	25.8
Blood loss ≤300 mL	65	54.2
Blood loss >300 mL	55	45.8

Serum albumin declined progressively over the postoperative period in the overall study population, from 3.05 ± 0.60 g/dL on POD −1 to 2.45 ± 0.52 g/dL on POD 3. The mean decreases from POD −1 were 0.19 ± 0.17 g/dL on POD 0, 0.36 ± 0.29 g/dL on POD 1, 0.54 ± 0.35 g/dL on POD 2, and 0.60 ± 0.42 g/dL on POD 3(Table 2).

Table 2. Overall postoperative serum albumin profile

Parameter	Mean ± SD	Median	Minimum	Maximum
POD −1	3.05 ± 0.60	3.10	1.20	4.00
POD 0	2.86 ± 0.57	2.90	1.00	3.80
POD 1	2.69 ± 0.50	2.70	1.80	3.70
POD 2	2.50 ± 0.52	2.40	1.60	3.70
POD 3	2.45 ± 0.52	2.40	1.70	3.60
Difference POD 0–POD −1	0.19 ± 0.17	0.20	−0.40	0.60
Difference POD 1–POD −1	0.36 ± 0.29	0.40	−0.90	0.80
Difference POD 2–POD −1	0.54 ± 0.35	0.60	−0.90	1.30
Difference POD 3–POD −1	0.60 ± 0.42	0.60	−1.20	1.30

Patients without complications had higher mean serum albumin levels than patients with complications at every assessed postoperative time point. The between-group difference was not statistically significant on POD −1 (p=0.133) or POD 0 (p=0.296), but was significant on POD 1 (p=0.017), POD 2 (p=0.008), and POD 3 (p=0.023)(Table 3).

Table 3. Postoperative serum albumin according to complication status

Postoperative day	No complications, Mean ± SD	Complications, Mean ± SD	t	p
POD −1	3.11 ± 0.64	2.95 ± 0.53	1.512	0.133
POD 0	2.90 ± 0.62	2.79 ± 0.49	1.050	0.296
POD 1	2.78 ± 0.55	2.56 ± 0.40	2.423	0.017
POD 2	2.60 ± 0.58	2.36 ± 0.38	2.689	0.008
POD 3	2.53 ± 0.59	2.33 ± 0.37	2.303	0.023

Serum albumin was also higher among patients with a hospital stay of ≤10 days than among those with a stay of >10 days at each postoperative assessment. These differences were statistically significant from POD −1 through POD 3, with p values ranging from 0.002 to 0.011. In contrast, the differences in the magnitude of albumin decline from POD −1 were not statistically significant (Table 4).

Table 4. Postoperative serum albumin according to length of hospital stay

Postoperative day	≤10 days, Mean ± SD	>10 days, Mean ± SD	t	p
POD −1	3.14 ± 0.55	2.78 ± 0.67	2.921	0.004
POD 0	2.94 ± 0.53	2.62 ± 0.62	2.795	0.006
POD 1	2.75 ± 0.54	2.51 ± 0.32	3.016	0.003
POD 2	2.56 ± 0.57	2.34 ± 0.32	2.596	0.011
POD 3	2.51 ± 0.57	2.26 ± 0.25	3.226	0.002

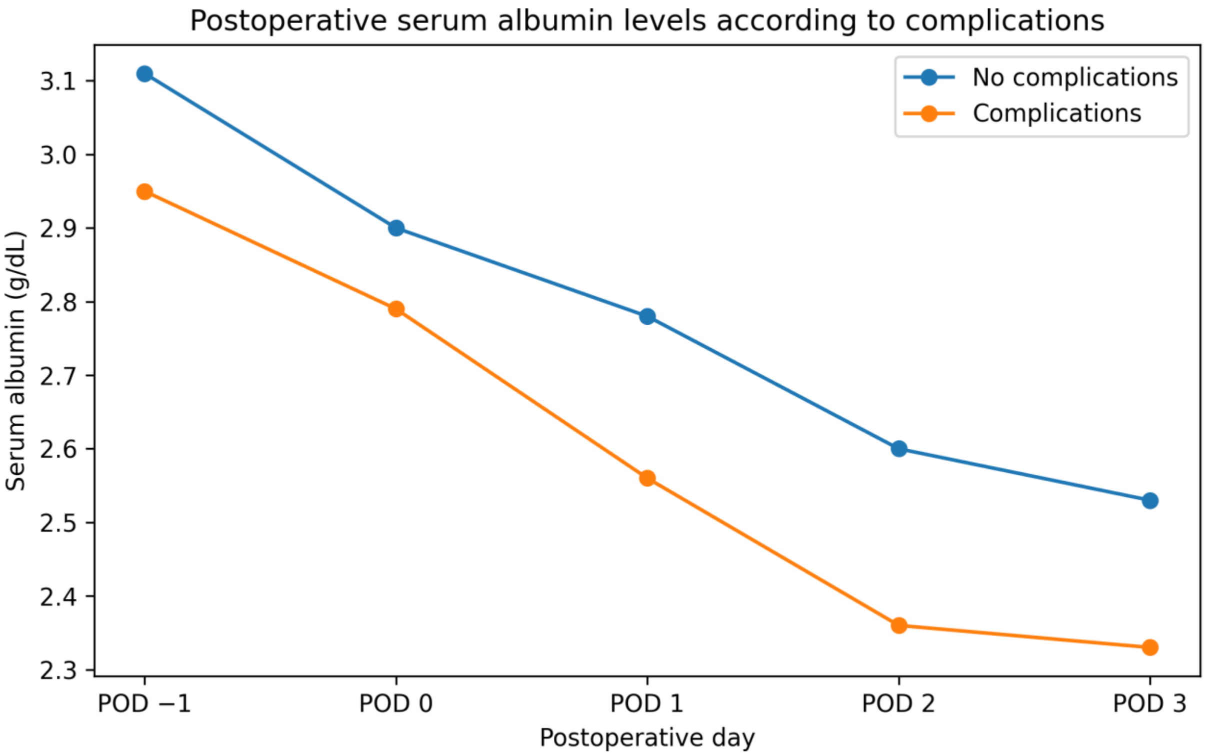
Patients with blood loss >300 mL had lower mean albumin values at all postoperative assessments, although none of the differences in absolute albumin concentration was statistically significant. The difference in albumin decline from POD −1 to POD 1 was statistically significant (p=0.030). Mean length of hospital stay was significantly longer in the >300-mL blood-loss group (9.44 ± 4.51 vs. 7.43 ± 4.91 days; p=0.022), and mean blood loss differed markedly between the groups (490.00 ± 144.95 vs. 212.31 ± 67.48 mL; p<0.001)(Table 5).

Table 5. Postoperative albumin and perioperative outcomes according to blood loss

Variable	≤300 mL (n=65)	>300 mL (n=55)	t	p
POD −1 albumin	3.13 ± 0.54	2.95 ± 0.66	1.714	0.089
POD 0 albumin	2.92 ± 0.52	2.78 ± 0.61	1.362	0.176
POD 1 albumin	2.72 ± 0.55	2.65 ± 0.45	0.723	0.471
POD 2 albumin	2.55 ± 0.56	2.44 ± 0.47	1.160	0.249
POD 3 albumin	2.48 ± 0.55	2.41 ± 0.49	0.674	0.502
Difference POD 1–POD −1	0.41 ± 0.18	0.29 ± 0.36	2.218	0.030
Length of hospital stay (days)	7.43 ± 4.91	9.44 ± 4.51	−2.313	0.022
Blood loss (mL)	212.31 ± 67.48	490.00 ± 144.95	−13.061	<0.001

Comparison according to duration of surgery showed no statistically significant differences in serum albumin levels between patients undergoing surgery for <150 minutes and those undergoing surgery for ≥150 minutes at any postoperative time point (all p>0.05). Similarly, no statistically significant differences were observed between laparoscopic and open surgery groups for postoperative albumin, length of hospital stay, or blood loss (all p>0.05)(Figure 1).

Figure 1. Postoperative serum albumin levels according to complication status



Values are mean serum albumin concentrations (g/dL). POD, postoperative day.

DISCUSSION

The present prospective cohort study evaluated serial serum albumin levels in 120 patients undergoing major elective abdominal surgery and examined their relationship with postoperative clinical outcomes. Forty-eight patients (40%) developed postoperative complications, whereas 72 patients (60%) had no complications. The principal finding was that patients who developed complications had significantly lower postoperative serum albumin concentrations on POD1, POD2 and POD3. In contrast, the difference in the magnitude of albumin fall between the complication and non-complication groups did not reach statistical significance. Lower albumin levels were also significantly associated with prolonged hospital stay. Albumin decrease was greater among patients undergoing longer operations and open surgery, although these differences were not statistically significant. Blood loss showed a significant association with the change in albumin between POD1 and the preoperative value.

Postoperative albumin and postoperative complications

In the present study, the incidence of postoperative complications was 40% (48/120). Complications included postoperative blood transfusion, sepsis, requirement for total parenteral nutrition, surgical-site infection, ventilatory support, single-organ dysfunction, multiple-organ dysfunction and death. Patients who developed complications had significantly lower serum albumin levels on POD1 (P=0.017), POD2 (P=0.008) and POD3 (P=0.023).

This finding is consistent with the concept that postoperative hypoalbuminaemia reflects the physiological response to major surgical trauma. Hübner et al. reported an immediate fall in albumin following abdominal surgery and found that patients who developed complications had a significantly greater maximal albumin decrease than those without complications (10.0±5.4 versus 6.1±5.2 g/L; P=0.005).[21] Their study therefore supports the use of postoperative albumin kinetics as an early marker of adverse outcome.

Similarly, Labgaa et al., in a prospective cohort of 138 patients undergoing major abdominal surgery, found that postoperative albumin decrease was associated with postoperative complications and that a POD1 decrease ≥10 g/L independently predicted complications.[22] Their findings are highly relevant to the present study because both investigations used serial albumin measurements from the preoperative period through POD3.

However, an important difference exists between our results and those of Hübner et al. and Labgaa et al. In our study, absolute postoperative albumin concentrations were significantly lower in patients with complications, whereas the difference in albumin fall between the two groups was not statistically significant. This suggests that the absolute postoperative albumin value and the change from baseline should not necessarily be considered interchangeable variables. Several factors may explain this discrepancy. First, the present study included a heterogeneous group of abdominal operations, whereas some previous studies had more uniform surgical populations. Second, baseline albumin concentrations, perioperative fluid administration, blood loss, operative procedure and inflammatory response may influence the magnitude of ΔAlb. Third, our sample size of 120 patients was smaller than the 626-patient colorectal cohort reported by Ge et al.[23] Therefore, the present study may have had insufficient statistical power to demonstrate a significant difference in ΔAlb despite observing a clinically meaningful difference in absolute postoperative albumin.

Ge et al. studied 626 patients undergoing colorectal resection and reported that a ≥15% postoperative albumin decrease was an independent risk factor for overall complications.[23] Patients with ΔAlb ≥15% also had more major complications, higher CCI, longer postoperative stay and more surgical-site infections.[23] The difference between this study and our findings may be related to the different study population and the use of a percentage rather than absolute change in albumin. Liu et al. similarly demonstrated an association between postoperative albumin decrease and short-term complications following gastric cancer surgery.[24] Ai et al. extended this observation by showing that postoperative albumin changes could predict complications even in patients with normal preoperative albumin.[25] These findings reinforce the importance of postoperative albumin kinetics rather than relying exclusively on preoperative albumin.

Absolute postoperative albumin versus albumin decrease

An important observation from the present study is that the absolute postoperative albumin concentration showed stronger statistical associations with complications than the calculated fall in albumin. This finding is supported by the study of Ryan et al., who evaluated 200 patients undergoing oesophagectomy and found that patients with POD1 albumin <20 g/L had significantly more postoperative complications than those with albumin >20 g/L (54% versus 28%; P<0.011).[26] POD1 albumin was also independently associated with postoperative complications on multivariable analysis.[26]

Thus, our findings are consistent with the concept that the postoperative albumin concentration itself may provide clinically relevant prognostic information. However, because the present study did not establish an independent predictive threshold through ROC analysis or multivariable regression, a specific postoperative albumin cut-off should not be recommended on the basis of our results alone.

The systematic review by Joliat et al. provides important context.[28] Sixteen studies were included, and the reported thresholds for postoperative albumin decrease varied considerably. Sensitivity ranged from 63–84% and specificity from 61–86%.[28] This heterogeneity suggests that there is currently no universally accepted ΔAlb threshold applicable to all types of gastrointestinal or abdominal surgery.

Biological basis for postoperative hypoalbuminaemia

The postoperative decrease in albumin is biologically plausible. Albumin is a negative acute-phase protein, and inflammatory cytokines released after tissue injury alter hepatic protein synthesis.[14,15] At the same time, increased endothelial permeability promotes movement of albumin into the extravascular compartment.[16] Fleck et al. demonstrated a marked increase in transcapillary albumin escape following major surgery and an even greater increase in septic shock.[16]

Therefore, the early postoperative reduction in serum albumin probably represents a combination of inflammatory response, capillary leak, redistribution, haemodilution and blood loss rather than simply inadequate protein intake. This distinction is important because albumin should not be interpreted as an isolated nutritional marker in the immediate postoperative period.

Soeters et al. emphasized that hypoalbuminaemia is closely related to inflammation and disease severity and should not be regarded simply as a surrogate for malnutrition.[13] Nicholson et al. similarly described the multiple physiological roles of albumin and the mechanisms responsible for its reduction during critical illness.[6]

Duration of surgery

In our study, patients undergoing operations lasting ≥150 min demonstrated a greater postoperative decrease in serum albumin than those undergoing shorter procedures. However, this difference was not statistically significant; the greatest difference was observed between POD1 and the preoperative value, with $P=0.08$.

Our findings are directionally similar to those of Hübner et al., who reported a significant correlation between maximal albumin decrease and operation duration (Pearson $\rho=0.470$; $P<0.001$).[21] Labgaa et al. also demonstrated a significant association between albumin decrease and operative duration.[22]

The absence of statistical significance in our study may be explained by the choice of a 150-min cut-off and by heterogeneity in the types of abdominal procedures. Operative duration is an imperfect surrogate for surgical stress; two operations of similar duration may differ substantially in tissue injury, blood loss and inflammatory response.
Furthermore, the number of patients in the two duration categories was 73 for <150 min and 47 for ≥150 min, which may have limited statistical power. The study by Labgaa et al. assessed operative duration as a continuous variable rather than simply dividing patients according to a threshold.[22] Future analysis of our dataset using continuous correlation or multivariable regression may therefore provide additional information.

Blood loss

In the present study, 65 patients (54.2%) had estimated blood loss ≤300 ml and 55 (45.8%) had blood loss >300 ml. A significant association was observed between blood loss and albumin change between POD1 and the preoperative measurement ($P=0.03$). In addition, patients with blood loss >300 ml had a significantly longer hospital stay ($P=0.022$).
These findings are consistent with the observations of Hübner et al., who found a strong correlation between albumin decrease and estimated blood loss ($\rho=0.605$; $P<0.001$).[21] Labgaa et al. also reported a significant association between postoperative albumin decrease and blood loss.[22]

Blood loss can reduce circulating albumin directly and may also be accompanied by replacement with crystalloid or colloid solutions, resulting in haemodilution. In addition, procedures associated with greater blood loss are often technically more extensive and may produce a greater inflammatory response. Thus, the association between blood loss and albumin decrease probably reflects several simultaneous mechanisms.

Our finding that greater blood loss was also associated with prolonged hospital stay further supports the clinical importance of operative blood loss. Nevertheless, because albumin was not measured immediately before and after every transfusion or fluid intervention, the independent contribution of blood loss to albumin kinetics cannot be established conclusively.

Surgical approach: open versus laparoscopic surgery

In our cohort, 98 patients (81.7%) underwent open surgery and 22 (18.3%) underwent laparoscopic surgery. A greater reduction in albumin was observed in the open surgery group from POD0 through POD3, although this difference was not statistically significant.

The direction of this finding is biologically plausible because laparoscopic surgery is generally associated with less tissue trauma and a lower systemic inflammatory response than conventional open surgery. However, our study cannot establish an independent effect of operative approach.

The small number of laparoscopic procedures is an important limitation. Only 22 patients underwent laparoscopic surgery compared with 98 undergoing open surgery. Furthermore, operative approach is strongly influenced by the type and complexity of the underlying procedure. Therefore, the observed difference may be confounded by procedure type and operative magnitude.

Previous studies of postoperative albumin have similarly emphasized the importance of considering surgical magnitude rather than surgical approach alone.[21,22] Thus, a larger multicentre study with adequate numbers of both laparoscopic and open procedures would be required to determine whether postoperative albumin kinetics independently differ according to operative approach.

Length of hospital stay

A particularly consistent finding in the present study was the association between albumin concentration and prolonged hospital stay. Patients with hospital stay >10 days had significantly lower serum albumin from the preoperative period through POD3:

- POD−1: $P=0.004$
- POD0: $P=0.006$
- POD1: $P=0.003$
- POD2: $P=0.011$
- POD3: $P=0.002$.

This finding is consistent with Hübner et al., who reported a significant correlation between maximal albumin decrease and length of hospital stay (Pearson $\rho=0.285$; $P<0.020$).[21] Labgaa et al. also demonstrated a relationship between postoperative albumin decrease and postoperative recovery.[22]

Ge et al. found that patients with a ≥15% postoperative albumin decrease had a longer postoperative stay following colorectal surgery.[23] The systematic review by Joliat et al. also identified prolonged length of stay among the outcomes associated with postoperative albumin decrease in several studies.[28]

The present study adds to these observations because the association was demonstrated across a heterogeneous group of major abdominal procedures rather than within a single surgical specialty.

The association should nevertheless be interpreted as prognostic rather than causal. Patients with complications naturally remain hospitalized longer, and the complications themselves may contribute to continuing hypoalbuminaemia. Therefore, low albumin may be both a marker of increased postoperative stress and a consequence of complicated recovery.

Preoperative albumin and postoperative outcome

The present findings also need to be interpreted in relation to the extensive literature on preoperative albumin. Gibbs et al. demonstrated that preoperative serum albumin was a strong predictor of operative mortality and morbidity in the National VA Surgical Risk Study.[9] Kudsk et al. similarly found that low preoperative albumin was associated with major postoperative complications, particularly in high-risk gastrointestinal operations.[10]

Vincent et al., in a meta-analysis, reported that hypoalbuminaemia was associated with increased mortality, morbidity and length of hospital stay.[11] These studies support the prognostic significance of albumin but predominantly examine the preoperative value.

In contrast, the present study focused on serial postoperative albumin levels. This distinction is important because postoperative albumin incorporates information about the patient's baseline state as well as the physiological consequences of surgery, including inflammation, vascular permeability, fluid shifts and blood loss.
Thus, our study complements rather than contradicts the established literature on preoperative albumin.

Comparison with oesophageal and other gastrointestinal studies

Ryan et al. demonstrated that POD1 albumin <20 g/L was associated with increased complications, respiratory failure and mortality after oesophagectomy.[26] Their findings are particularly relevant because they demonstrate the prognostic value of an absolute postoperative albumin level, rather than only the percentage decrease.
Our results are broadly consistent with this observation because the complication group had significantly lower POD1, POD2 and POD3 albumin values. However, our study included different types of abdominal surgery and did not identify a specific absolute albumin threshold.

Ge et al. reported a 15% ΔAlb threshold after colorectal surgery.[23] Wierdak et al. similarly found that postoperative albumin decrease was associated with infectious complications following colorectal surgery.[28] Wang et al. reported that ΔAlb was an independent predictor of major complications after laparoscopic colorectal cancer surgery.[28]
These studies collectively suggest that postoperative albumin has potential prognostic utility across several gastrointestinal procedures, although the optimal parameter and threshold may vary according to the surgical population.

Comprehensive Complication Index

The present study used the Comprehensive Complication Index to quantify postoperative morbidity. The CCI was developed by Slankamenac et al. to provide a continuous measure of overall postoperative morbidity rather than considering only the most severe complication.[29] It is based on the Clavien-Dindo classification and incorporates all postoperative complications occurring in a patient.

Dindo et al. originally proposed the Clavien-Dindo classification to standardize reporting of surgical complications.[30] The use of a standardized complication system strengthens the comparability of postoperative outcome studies.
However, in the current analysis, the available results primarily compare patients with and without complications. Therefore, the relationship between postoperative albumin and individual CCI scores or CCI severity categories should only be reported if the underlying numerical CCI data are available. It would be inappropriate to infer a significant relationship between albumin and CCI grade solely from the binary complication analysis.

Clinical implications

The findings of this study have potential clinical relevance because serum albumin is inexpensive, routinely available and can be measured within the early postoperative period. In contrast to biomarkers such as CRP, which generally rise more gradually following surgical trauma, albumin may demonstrate an early postoperative change.[21]
A persistently low albumin concentration during POD1–3 may therefore alert clinicians to patients who warrant closer surveillance for postoperative complications and delayed recovery. However, the present study does not establish that albumin-guided intervention improves outcome.

In particular, these results should not be interpreted as evidence that routine albumin infusion should be administered solely because postoperative albumin is low. Hypoalbuminaemia may be a marker of inflammatory and physiological stress rather than a correctable nutritional deficiency.[13]

Strengths and limitations

The principal strengths of the present study are its prospective cohort design, serial assessment of albumin from the preoperative period through POD3, inclusion of different major abdominal procedures and simultaneous assessment of complications, hospital stay, operative duration, blood loss and operative approach.

Several limitations should be acknowledged. First, this was a single-centre study with a relatively small sample size. Second, the study population comprised heterogeneous abdominal procedures, which may have introduced variation in surgical stress. Third, the laparoscopic subgroup was considerably smaller than the open-surgery subgroup. Fourth, perioperative fluid administration and transfusion may have influenced albumin concentration. Fifth, the present analysis does not demonstrate whether postoperative albumin is an independent predictor after adjustment for age, baseline albumin, comorbidities, procedure type, duration, blood loss and other confounders. Finally, the lack of a statistically significant difference in ΔAlb between complication groups means that the manuscript should avoid claiming that postoperative albumin fall independently predicts complications unless multivariable analysis supports this assertion.

CONCLUSION

Early postoperative serum albumin levels were significantly associated with clinically important outcomes following major abdominal surgery. Patients who developed postoperative complications had significantly lower albumin levels on POD1, POD2 and POD3, while patients with hospital stay >10 days had significantly lower albumin levels throughout the perioperative observation period.

Although albumin decline was greater in patients undergoing longer and open procedures and in those with greater blood loss, these relationships were not consistently statistically significant.

Serial postoperative serum albumin measurement may therefore represent a simple, inexpensive and readily available marker for early postoperative risk stratification. Further prospective multicentre studies are required to establish standardised albumin-change thresholds and determine whether incorporation of postoperative albumin into clinical prediction models improves prediction of surgical morbidity.

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Conflict of Interest

The authors declare no conflicts of interest regarding the publication of this article.

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