Original Article

JHSMR Journal of Health Science and Medical Research

A Prospective Observational Study on the Evaluation of Early Postoperative Lactate Levels in Predicting the Surgical Outcome in Major Abdominal Surgeries

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Received 8 May 2025 • Revised 24 June 2025 • Accepted 9 July 2025 • Published online 24 November 2025

Abstract:

Objective: Early postoperative lactate levels are emerging as key predictors of surgical outcomes. This study aimed to evaluate their predictive value in patients undergoing major abdominal surgeries.

Material and Methods: A prospective observational study was conducted from October 2023 to February 2025 of 238 patients. Lactate levels were measured at 0, 6, 12, and 24 hours postoperatively. Complications and 30-day mortality were recorded. ROC curve analysis and logistic regression were used to assess predictive accuracy using SPSS software.

Results: Postoperative complications occurred in 43.5% and mortality in 9.2% of patients. The 24-hour lactate (L24) had the highest predictive value (AUC=0.82 for complications, 0.91 for mortality). Cut-offs of 1.4 mmol/L and 3.0 mmol/L were optimal for predicting complications and mortality, respectively. SOFA score (AUC=0.97) showed stronger mortality prediction.

Conclusion: L24 lactate is a reliable biomarker for the early detection of postoperative morbidity and mortality. Integration into routine care can guide early interventions and improve outcomes.

Keywords: lactate, logistic regression, mortality prediction, postoperative morbidity, reliable biomarker

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J Health Sci Med Res
doi: 10.31584/jhsmr.20251288
www.jhsmr.org

Introduction

Major abdominal surgeries are frequently associated with significant postoperative morbidity and mortality, despite the ongoing advancements in perioperative care and surgical techniques. Postoperative complications not only delay recovery but are also strong predictors of long-term functional decline, prolonged hospitalization, and increased healthcare costs[1]. Timely identification of patients at risk of deterioration remains a cornerstone in improving surgical outcomes.

Among the various biomarkers explored for early detection of adverse outcomes, serum lactate has gained substantial clinical relevance. Lactate is a by-product of anaerobic metabolism, often elevated in conditions involving hypoperfusion, systemic inflammatory response, or sepsis[2]. Studies in critical care and emergency settings have consistently demonstrated that both elevated lactate levels and delayed lactate clearance are associated with poor clinical outcomes[3]. However, its routine use in postoperative monitoring,particularly in elective major abdominal surgeries,remains underutilized.

The utility of lactate as a predictive marker is rooted in its ability to reflect both the severity of underlying tissue hypoxia and the effectiveness of perfusion restoration efforts. Recent evidence suggests that serial lactate measurements, rather than isolated values, offer greater predictive accuracy for postoperative complications and mortality[4]. Suetrong and Walley emphasized that persistent hyperlactatemia may reflect not just anaerobic metabolism but also impaired lactate clearance due to mitochondrial dysfunction, which can herald a worse prognosis[5].

In high-risk surgical patients, especially those undergoing gastrointestinal or oncologic procedures, the first 24 hours post-surgery are critical. Lactate levels during this window have shown promise in stratifying patients into risk categories for organ dysfunction, sepsis, and death[6,7]. Moreover, combining lactate trends with clinical scoring systems such as the Sequential Organ Failure Assessment (SOFA) score may provide a more comprehensive assessment of patient trajectory[8].

Therefore, the present study aimed to evaluate the predictive value of early postoperative lactate levels,specifically at 0, 6, 12, and 24 hours—in relation to postoperative complications and 30-day mortality among patients undergoing major abdominal surgeries, and comparing it with the SOFA score, which is an established score for predicting risks in critically ill patients. By identifying the reliable cut-off values of lactates at different time intervals in the early postoperative period, this study sought to propose an evidence-based approach for integrating lactate monitoring into routine postoperative surveillance, thereby improving patient outcomes.

Material and Methods

This prospective observational study was conducted in the Department of General Surgery at the Institute of Medical Sciences and SUM Hospital, Bhubaneswar, from October 2023 to February 2025. The study received ethical approval from the Institutional Ethics Committee vide letter no. Ref. no./IEC/ims.sh/soa/2024/876 dated 5th October, 2024, and written informed consent was obtained from all participants prior to enrollment. Eligibility was confirmed using the defined inclusion and exclusion criteria. No patients were excluded after enrollment, and there were no losses to follow-up during the 30-day observation period. This approach ensured the minimization of selection and exclusion bias (Figure 1).

A total of 238 patients aged 18 years and above undergoing elective major abdominal surgeries were recruited consecutively (Supplementary Table 1). Major abdominal surgery was defined as any laparoscopic or open abdominal procedure with an operative duration exceeding

2 hours[9,10]. Exclusion criteria included patients below 18 years of age, those undergoing minor abdominal procedures (lasting <2 hours), those with pre-existing decompensated cardiac failure (to avoid lactate metabolism confounders), and individuals who did not provide informed consent[11]. Postoperative lactate levels were assessed at 4 standardized time points: immediately post-surgery (L0), and at 6 hours (L6), 12 hours (L12), and 24 hours (L24) postoperatively. Arterial blood samples were collected and analyzed using an automated Arterial Blood Gas (ABG) analyzer for serum lactate measurement[12]. Additionally, SOFA scores were recorded at admission to the ICU postoperatively and used to assess multi-organ dysfunction and its correlation with lactate trends[13].

The primary endpoints of the study were the incidence of postoperative complications and 30-day mortality. Complications were defined as any postoperative event requiring medical or surgical intervention, such as sepsis, prolonged ventilation, wound infection, or hemodynamic instability[14]. Mortality was defined as all-cause death occurring within 30 days of surgery[15]. Secondary outcomes included the duration of ICU stay, hospital length of stay, and the requirement for vasopressor support or reoperations[16].

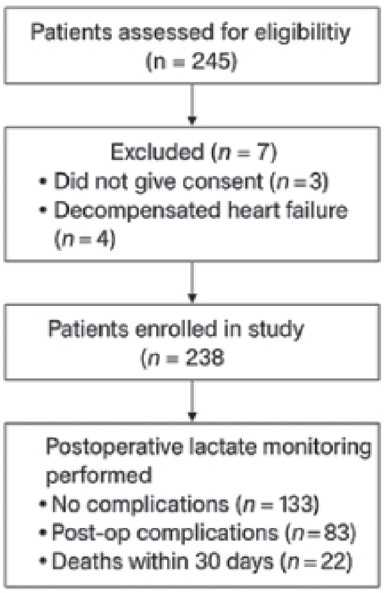


Figure 1 Patient enrollment and follow-up are summarized in the CONSORT flow diagram

Statistical analysis

Statistical analysis was performed using SPSS Version 27.0. Continuous variables (e.g., lactate levels) were expressed as Mean±Standard Deviation (S.D.) and compared using the independent t-test. Categorical variables were analyzed using the Chi-square test or Fisher's exact test as appropriate. Receiver Operating Characteristic (ROC) curve analysis was performed to assess the predictive ability of lactate levels for complications and mortality. Area Under the Curve (AUC) values were calculated for each time point, and optimal cut-off values were derived using Youden's Index. To determine independent predictors of complications and mortality, binary logistic regression analysis was conducted, with results reported as odds ratios (ORs) and 95.0% confidence intervals (CIs). A p-value<0.05 was considered statistically significant for all analyses.Patient data were anonymized to maintain confidentiality throughout the research process, and all procedures adhered to standard ethical and scientific reporting guidelines.

Results

Patient demographics

A total of 238 patients who underwent major abdominal surgeries were included in this study. The mean age of the study population was 50.68 years (range: 18–77). The gender distribution consisted of 150 males (63.0%) and 88 females (37.0%) (Table 1).

Table 1 Baseline characteristics of study participants

Variables	Mean/frequency	S.D./percentages
Age in years	50.1	
Gender		
Male	150	63.0
Female	88	37.0
Comorbidities		
Diabetes Mellitus (DM)	20	8.3
Hypertension (HTN)	4	1.7
Both DM and HTN	8	3.3
Chronic Resp Disease	23	9.6
Others	37	15.5
None	146	60.8
Surgical Procedures		
Whipples Procedure	24	10.1
D2 Gastrectomy	12	5.0
Open D2 Subtotal Gastrectomy,R-E-Y GjWith Fj With Cholecystectomy	8	3.4
D2 Distal Radical Gastrectomy +R-E-Y Gj+Nj Tube Insertion	8	3.4
Hemocolectomy With Ileocolic End To End Anastamoses	8	3.4
Others	178	75.8

All values are presented as Mean±Standard Deviation (S.D.) for continuous variables. The total number of study participants is N=238

Frequency of postoperative complications and mortality

Postoperative complications occurred in 94 patients (43.5%). The most frequently observed complications included prolonged ventilatory support (11.8%), wound-related complications (11.3%), and sepsis with ARDS (4.6%). Septic shock with acute kidney injury (AKI) occurred in 6.3%, while persistent delirium and prolonged vasopressin support were less frequent (1.7% and 2.5%, respectively). A total of 22 patients (9.2%) died within 30 days of surgery, while 216 (90.7%) survived (Table 2 and Supplementary Tables 2 and 3).The most common causes of death observed were septic shock, multi-organ failure, and sepsis-related complications. Five deaths occurred following colorectal surgeries (e.g., hemicolectomy, APR), commonly due to anastomotic leaks and fecal peritonitis; 4 deaths occurred after pancreaticoduodenectomy (Whipple's), primarily due to postoperative pancreatic fistula with sepsis, and 3 deaths occurred after gastrectomy for stomach carcinoma, complicated by ARDS and nosocomial pneumonia. Other causes included mesenteric ischemia, acute myocardial infarction, and ARDS secondary to sepsis in high-risk emergency surgeries. The majority of these patients had elevated 24-hour lactate levels (L24 ≥3.0 mmol/L) and developed signs of organ dysfunction within 48 hours of surgery (Supplementary Table 4).

Predictive value of lactate levels for complications

Lactate levels were serially measured at 0 (L0), 6 (L6), 12 (L12), and 24 (L24) hours postoperatively. ROC analysis demonstrated that lactate measured at 24 hours provided the best predictive value for postoperative complications, with an AUC of 0.82 (95.0% CI: 0.71–0.92, p-value<0.001). In comparison, L0 had an AUC of 0.60 (p-value=0.106), L6 had an AUC of 0.71 (p-value=0.002), and L12 had an AUC of 0.72 (p-value=0.001). The optimal

L24 cut-off identified via Youden's Index was 1.4 mmol/L, which yielded a sensitivity of 92.4%, specificity of 59.4%, and a positive predictive value of 64.2% (Table 3).The ROC curve for lactate at different time points for complications is shown in Figure 2A.

Table 2 Complications of surgery

Complication	Number	Percentages
None	133	55.9%
Persistent delirium	4	1.7%
Prolonged vasopressin support	6	2.5%
Prolonged ventilation/septic shock/septic encephalopathy	4	1.7%
Prolonged ventilatory support	28	11.8%
Sepis+wound related	6	2.5%
Sepsis-ARDS	11	4.6%
Septic shock with AKI	15	6.3%
Wound related	27	11.3%
Presence of any complication		
Status	Number	Percentages
Yes	94	43.5%
No	122	56.5%
Death		
Status	Number	Percentages
Yes	22	9.2%
No	216	90.7%

ARDS=acute respiratory distress syndrome, AKI=acute kidney injury, The total number of study participants for this analysis is N=238. Values are presented as Frequency in Number and Percentage. "Presence of Any Complication" and "Death" are summarized categories indicating the overall occurrence of complications and mortality, respectively

Predictive value of lactate levels for mortality

Lactate at 24 hours was also the strongest predictor of mortality, with an AUC of 0.91 (95.0% CI: 0.82–1.00, p-value<0.001). At earlier time points, predictive values were lower: L0 (AUC=0.61, p-value=0.220), L6 (AUC=0.83, p-value=0.004), and L12 (AUC=0.72, p-value=0.041). The optimized cut-off for L24 in predicting mortality was 3.0 mmol/L, with sensitivity and specificity values of 100.0% and 79.6%, respectively. The positive predictive value at this threshold was 33.3% (Table 4). The ROC curve for lactate at different time points for mortality is shown in Figure 2B.

SOFA score and lactate in outcome prediction

When comparing lactate and SOFA scores in ROC analysis, lactate at 24 hours (AUC=0.82) demonstrated slightly better performance than the SOFA score (AUC=0.74) in predicting complications. However, for mortality prediction, the SOFA score significantly outperformed lactate, with an AUC of 0.97 compared to 0.91. These results indicate that while lactate levels are reliable indicators of overall risk, the SOFA score provides superior prognostic accuracy for mortality due to its inclusion of multiple organ dysfunction parameters (Figure 3).

A progressive increase in optimal lactate cut-off values was observed for both complications and mortality over time. For complications, the approximate thresholds were 2.1 mmol/L at L0, 2.3 mmol/L at L6, 2.5 mmol/L at

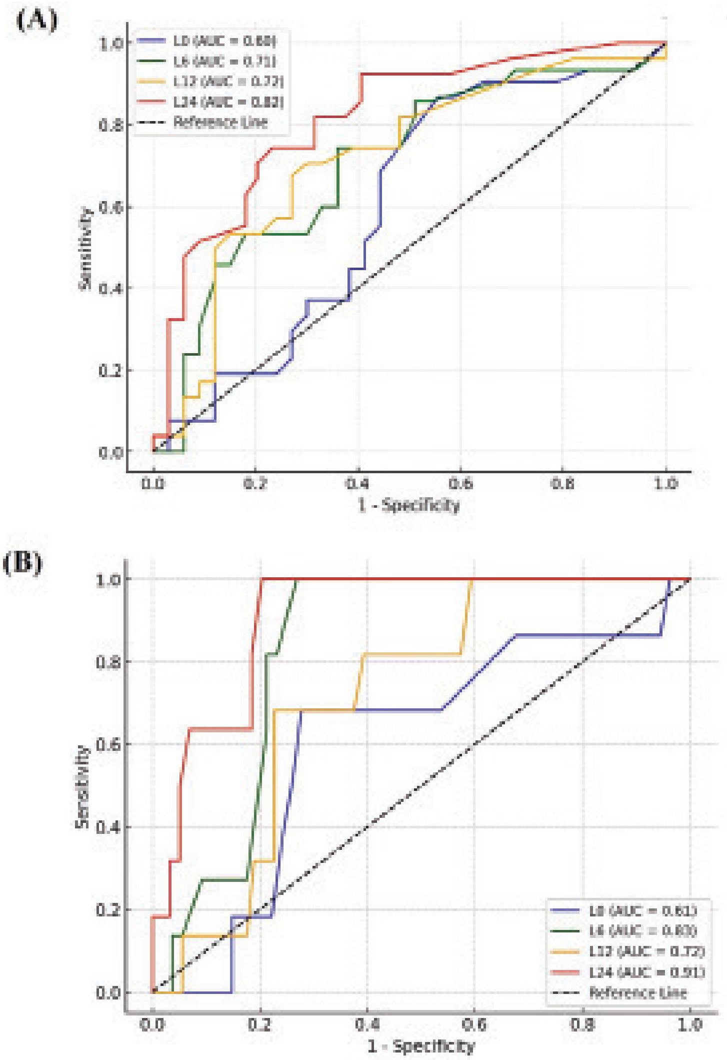
Table 3 Predictive accuracy of lactate for complications

Lactate time point	AUC value	95% confidence interval (CI)	p-value
L0	0.60	(0.45–0.74)	0.106
L6	0.71	(0.58–0.83)	0.002
L12	0.72	(0.59–0.84)	0.001
L24	0.82	(0.71–0.92)	<0.001

This table presents the predictive accuracy of lactate levels at different time points (L0, L6, L12, L24) for the occurrence of complications. A 95% confidence interval (CI) is provided for each AUC value, and a p-value indicates the statistical significance of the AUC being greater than 0.5

L12, and 1.4 mmol/L at L24. For mortality, the corresponding cut-offs were 2.5, 2.9, 3.2, and 3.0 mmol/L, respectively. The L24 values were the most clinically significant, indicating that sustained elevation of lactate beyond the immediate postoperative phase is a critical warning sign (Table 5).

Mean SOFA scores were significantly higher among patients with complications (6.0) compared to those without (3.46), with p-value<0.001. Likewise, lactate levels at L6, L12, and L24 were all significantly elevated in the complication group (p-value=0.002, 0.001, and <0.001, respectively). At L0, there was no statistically significant difference (3.25 vs. 2.98 mmol/L; p-value=0.203). At 24 hours, the mean lactate level in the complication group was 3.50 mmol/L compared to 1.73 mmol/L in the non-complication group (Supplementary Table 5).



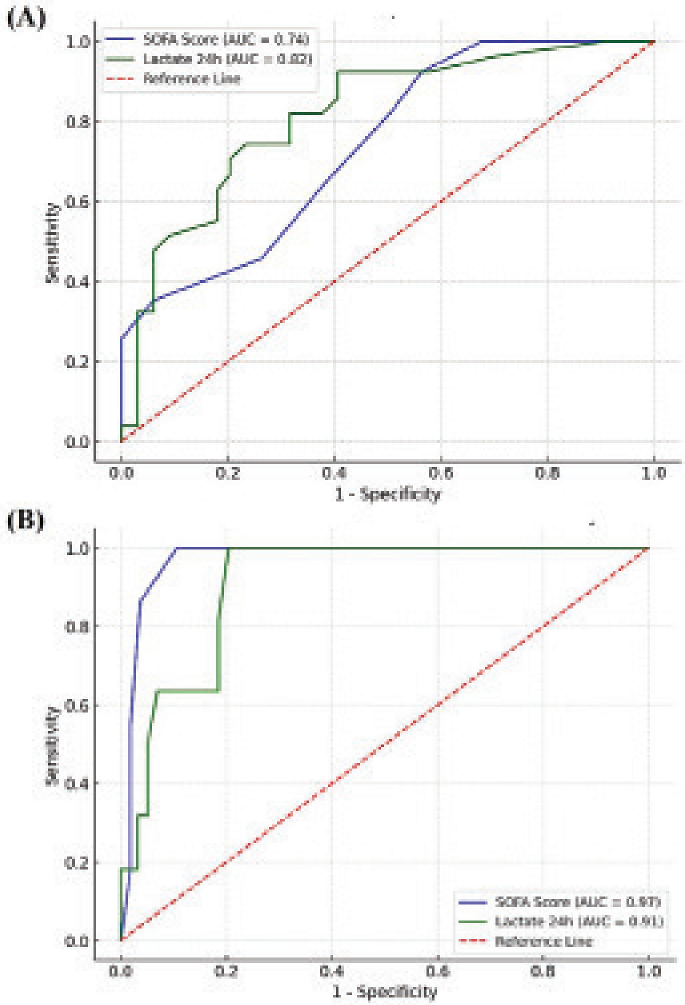
ROC=receiver operation characteristic

Figure 2 (A) ROC curve analysis of lactate levels for predicting complications (B) ROC curve for lactate at different time points in Predicting mortality

Table 4 ROC curve analysis of Lactate levels for predicting mortality

Lactate time point	AUC value	95.0% confidence interval (CI)	p-value
L0	0.61	(0.40–0.82)	0.220
L6	0.83	(0.66–0.99)	0.004
L12	0.72	(0.50–0.93)	0.041
L24	0.91	(0.82–1.00)	<0.001

The predictive accuracy of lactate levels at different time points (L0, L6, L12, L24) for predicting patient mortality. The 95% confidence interval (CI) provides the range within which the true AUC likely falls, and the p-value indicates the statistical significance of the AUC being greater than 0.5



ROC=receiver operating characteristic, SOFA=sequential organ failure assessment

Figure 3 (A) ROC curve comparing SOFA score and lactate at 24 hours (L24) for predicting complications (B) ROC curve comparing SOFA score and lactate at 24 hours (L24) for mortality prediction

Table 5 Optimal cut-off values for L0, L6, L12, and L24 for both complications and mortality

Lactate time point	Optimal cut-off for complications (mmol/L)	Optimal cut-off for mortality (mmol/L)
L0	~ 2.1 mmol/L	~ 2.5 mmol/L
L6	~ 2.3 mmol/L	~ 2.9 mmol/L
L12	~ 2.5 mmol/L	~ 3.2 mmol/L
L24	~ 1.4 mmol/L	~ 3.0 mmol/L

The optimal cut-off values for lactate levels at various time points (L0, L6, L12, L24) to predict post-operative complications and mortality. All lactate values are in millimoles per liter (mmol/L)

Discussion

This prospective observational study evaluated the prognostic value of early postoperative lactate levels in predicting complications and 30-day mortality following major abdominal surgeries. Among all the time points measured, the 24-hour postoperative lactate (L24) level demonstrated the highest predictive accuracy for both complications and mortality. Of the 22 deaths that occurred, the most common contributors were sepsis-related complications, followedby gastrointestinal surgery, particularly after colorectal and pancreatic resections. This aligns with the existing literature identifying these procedures as high-risk for leak-related mortality and early organ failure.

These findings support the growing consensus that lactate is a robust, dynamic biomarker that reflects underlying tissue hypoxia, systemic inflammation, and impaired metabolic recovery in the immediate postoperative period.

In the present study, the L24 lactate threshold of 1.4 mmol/L was identified as the optimal cut-off for predicting complications, with excellent sensitivity and moderate specificity. For mortality prediction, the optimal L24 threshold was 3.0 mmol/L, which offered high discriminatory power (AUC=0.91), with perfect sensitivity and strong specificity. These findings are consistent with earlier studies that have demonstrated the utility of serial lactate measurements over single-point values in critically ill and surgical patients. Zhang et al. reported that lactate levels exceeding 2.5 mmol/L within the first 24 hours postoperatively were associated with adverse outcomes in gastrointestinal surgeries[4]. Similarly, Suetrong and Walley emphasized that persistent hyperlactatemia reflects both circulatory and mitochondrial dysfunction, often preceding clinical deterioration[5].

Our study further established that while lactate was more predictive of complications, the SOFA score was more accurate in forecasting mortality, with an AUC of 0.97 compared to 0.91 for L24. This suggests that while lactate is a valuable early warning marker, multi-organ scoring systems like SOFA offer a more comprehensive picture of physiologic decline when evaluating fatal outcomes. However, both parameters performed significantly above the baseline, affirming their clinical relevance.

Importantly, our findings highlight a progressive increase in lactate cut-off values over time for both complications and mortality. This temporal trend may indicate worsening metabolic stress and cumulative hypoperfusion in high-risk patients, further supporting the role of serial lactate monitoring rather than isolated values. The strengths of this study include its prospective design, use of objective biochemical markers, and ROC-based statistical analysis. However, certain limitations exist, including the single-center setting and a relatively limited sample size for mortality analysis. Moreover, external factors, such as fluid management protocols and sepsis control, could have influenced lactate kinetics and were not uniformly controlled.

Conclusion

This study highlights the critical prognostic value of early postoperative lactate trends, especially at 24 hours, in predicting complications and mortality following major abdominal surgery. The 24-hour lactate level proved to be the most clinically practical marker, with optimal thresholds of 1.4 mmol/L for complications and 3.0 mmol/L for mortality. Although SOFA scores demonstrated higher accuracy in mortality prediction, serial lactate monitoring offers a simple, rapid, and cost-effective approach that can be readily incorporated into postoperative care protocols. Combining lactate surveillance with established clinical scoring systems may enhance risk stratification, enabling earlier intervention and improved patient outcomes.

Acknowledgement

We are grateful to the Dean, IMS, and SUM Hospital Bhubaneswar for the extended use of the research facility at the Medical Research Laboratory. The authors also acknowledge Dr. Debasmita Dubey, MRL Lab, IMS, and SUM Hospital Siksha 'O' Anusandhan University for providing the necessary facilities and support.

Funding sources

None

Conflict of interest

None

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Supplementary Table 1 Distribution of procedure

Procedure	Frequency	Percentage
Whipples procedure	24	10.0
D2 gastrectomy	12	5.04
Open D2 subtotal gastrectomy,rouxen y GJ with FJ with cholecystectomy	8	3.36
D2 distal radical gastrectomy +rounen y GJ+NJ tube insertion	8	3.36
Hemocolectomy with ileocolic end to end anastamoses	8	3.36
Open cholecystectomy with modified grahams patch repair	8	3.36
Right hemicolectomy	7	2.94
Ileal resection with ileostomy	4	1.68
Open chole+cbd exploration +s to s choledochoduodenostomy	4	1.68
Open cbdexploration+rouen y choledochojejunostomy side to side +jejunojenuostomy with primary anatomical repair of hernia	4	1.68
Exploratory laparotomy with drainage of pus from a cavity , removal of foreign body, loop ileostomy	4	1.68
Open anterior resection with colorectal stapled circular anastamosis	4	1.68
Open AR+limited rt hemicolectomy+segmental mid jejunal resection+end to end colorectal anastamosis+side to side la anastamosis+diverse loop ileostomy	4	1.68
Lar with diversion ileostomy	4	1.68
Midline laparotomy with resection of around 20cm of gangrenous ileal patch with appendicectomy	4	1.68
Exploratory lap + modifioed grahams patch repair	4	1.68
Exp lap+ primary ileal perforation closure	4	1.68
Laparotomy with transvers loop colostomy with right salpingo oophorectomy	4	1.68
End ileostomy with end colostomy of descending colon	4	1.68
Resection of distal ielum+caecum+proximal part of ascending colon+end ileostomy	4	1.68
Emergency laparotomy for acute small bowel obstruction & loop ileostomy under ga	4	1.68
Hartmaann procedure	4	1.68
Exp lap +appendicectomy+toileting	4	1.68
Exp lap+rt hemicolectomy with ileo colic anastamosis	4	1.68
Exploratory laparotomy with resection of jejunal,ileal loop and sigmoid colon with appendicectomy	4	1.68
Extended left hemicolectomy with omentectomy with diversion loop ileostomy	4	1.68
Radical cholecystectomy	4	1.68
Lap assisted lar with left extended hemicolectomy f/b transverse colondistal rectum end to end staple anastomosis and diversion loop ileostomy	4	1.68
Exp lap +lavage+ primary closure of rectal perforation +diversion ileostomy	4	1.68
Lpj	4	1.68

Supplementary Table 1 Continued

Procedure	Frequency	Percentage
Cytoreductive surgery	4	1.68
Emergency laparotomy with ileal perforation closure	4	1.68
Proximal jeunal resection and duodenojejunostomy	4	1.68
Gastrojejunostomy with feeding jejunostomy	4	1.68
Oesophagectomy and gastric pull up	4	1.68
Laparotomy, ra, stoma	4	1.68
Lap converted open rt.radical nephrectomy + ivs thrombectomy	4	1.68
Exploratory laparotomy with rt. Hemicolectomy +rt.nephrectomy+cholecystectomy+ileotransverseanastamosis	4	1.68
Excision of retroperitoneal liposarcoma	4	1.68
Exp lap + primary repair of rectal portion of proximal sigmoid loop colostomy	4	1.68
Distal pancreactomy	3	1.26
Laparotomy with resection of intussusception involving sigmoid colon into rectum and colorectal anastomosis	3	1.26
Open splenectomy	3	1.26
Open appendicectomy with peritoneal toileting done	3	1.26
Truncal vagotomy with retrocolic posterior isoperistaltic gastrojejunostomy using stapler	3	1.26
Primary closure of ileal perforation	3	1.26
Exp lap+distalgastectomy+left lateral sectionectomy + cholecystectomy+cbd exploration with t tube +appendectomy	3	1.26
Total gastectomy+rny+Gj+fj	3	1.26
Staging laparotomy +thoraco abdominal partial esophagogastrectomy+d2 lymphadenectomy+fj	3	1.26

Supplementary Table 2 Postoperative complications by severity (N=238)

Severity category	Complication type	n
No complications	–	133
Minor	Wound discharge	11
	Wound dehiscence	16
	Cholangitis (resolved)	4
	Persistent delirium (non-ICU)	4
Major Non-fatal	Prolonged ventilatory support with/without sepsis	24
	Septic shock with AKI	11
	Sepsis + AKI	4
	ARDS with sepsis	4
	Septic shock + vasopressor support	6
	Sepsis + fecal peritonitis	3
	Sepsis + encephalopathy	4
	MI + ventilatory support	4
Fatal	Deaths (from any cause within 30 days)	22

ICU=intensive care unit, AKI=acute kidney injury, ARDS=acute respiratory distress syndrome

Supplementary Table 3 Complication count summary

Category	n	% of total (N=238)
No complications	133	55.9
Minor complications	35	14.7
Major non-fatal complications	64	26.9
Fatal (30-day mortality)	22	9.2
Total with ≥1 complication	105	44.1

Supplementary Table 4 Procedure-wise mortality summary

Surgical procedure	No. of deaths (n=22)	Primary cause
Left/right hemicolectomy, APR	5	Anastomotic leak, fecal peritonitis, sepsis
Whipple's procedure	4	Pancreatic fistula, intra-abdominal sepsis
Gastrectomy (D2)	3	Pneumonia, ARDS
Emergency laparotomy (adhesiolysis, perforation closure)	5	Septic shock, mesenteric ischemia
Hepatobiliary surgery (e.g., CBD exploration)	2	Biloma, cholangitis
Miscellaneous (MI, stroke post-op)	3	Acute cardiac events, multiorgan failure

APR=abdomino perineal resection, ARDS=acute respiratory distress syndrome, CBD=common bile duct

Supplementary Table 5 SOFA score and lactate levels for complication and mortality prediction

Parameter	Mean (complications)	Mean (no complications)	p-value
SOFA Score	6.0	3.46	<0.001
L0	3.25	2.98	0.203
L6	4.00	2.91	0.002
L12	3.73	2.38	0.001
L24	3.50	1.73	<0.001

SOFA=sequential organ failure assessment, The p-value indicates the statistical significance of the difference in means between the two groups. A p-value less than 0.05 indicates a statistically significant difference