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Journal of Comprehensive Surgery

Original Article

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A rare cause of mechanical intestinal obstruction: biliary obstruction due to gallstones: our clinical experience with 12 cases and review of the current literature

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ABSTRACT

Aims: Biliary ileus is a rare clinical condition in which gallstones cause mechanical obstruction in the gastrointestinal tract as a result of biliary enteric fistula formation. The aim of this study is to present the clinical characteristics, diagnostic processes and surgical outcomes of cases undergoing surgical treatment due to biliary ileus.

Methods: Twelve patients who underwent surgical treatment for gallstone ileus between February 2019 and June 2025 were retrospectively evaluated. Demographic characteristics, presenting symptoms, laboratory values, type of biliary-enteric fistula, obstruction location, surgical methods used, length of hospital stay and mortality data were analyzed.

Results: The mean age of the patients was 77.4±10.3 years, and 66% were female. All patients presented with symptoms of intestinal obstruction. Contrast-enhanced computed tomography confirmed intestinal obstruction in all cases and enabled preoperative diagnosis in 11 patients. Cholecystoduodenal fistula was the most common fistula type (91.7%). The obstruction was most frequently located in the ileum (41.7%). Enterotomy/enterolithotomy was the most commonly performed surgical procedure (66.6%). The mean hospital stay was 12.1±6.2 days, and one patient (8.3%) died due to postoperative sepsis.

Conclusion: Gallstone ileus is a rare cause of intestinal obstruction, frequently seen in the elderly and requiring surgical treatment. The findings of our study demonstrate that early diagnosis with contrast-enhanced CT and a surgical approach to relieve the obstruction constitute an effective treatment strategy.

Keywords: Gallstone ileus, intestinal obstruction, enterotomy, cholecystoenteric fistula

INTRODUCTION

The most common cause of ileus is small bowel adhesions secondary to previous surgery,[1] while another frequent cause is obstruction due to intraluminal pathologies. Only a small proportion of patients presenting to the emergency department with intestinal obstruction have gallstones. Gallstone ileus accounts for only 1-4% of all intestinal obstructions.[2] Gallstone ileus is a rare but serious complication of cholelithiasis. Overall, gallstone ileus develops in approximately 0.3-0.5% of all cholelithiasis cases.[3] It occurs when gallstones pass into the intestinal lumen and cause mechanical obstruction as a result of a biliary-enteric fistula forming between the gallbladder or bile ducts and a segment of the gastrointestinal tract (most commonly the duodenum, stomach, or colon).[2,4] Intestinal obstruction usually occurs when the gallstone exceeds 2.5 cm in diameter.[5] The obstruction most commonly occurs in the terminal ileum, but it can also be seen in the proximal ileum, jejunum, colon or duodenum.[4] Significantly, approximately 80% of gallstones that pass into the intestinal system via biliary-enteric fistula are spontaneously expelled without causing any symptoms.[4] However, other cases that cannot be expelled spontaneously are extracted via enterotomy. The most common fistula locations are cholecystoduodenal and cholecystocolic.[4]

Gallstone ileus is seen more frequently in elderly patients and women because gallstone disease is more common in this population.[6,7] Advanced age, comorbidities, and delays in diagnosis contribute to higher morbidity and mortality, with reported mortality rates of approximately 15%.[5]

In this study, we present the demographic characteristics, clinical findings, diagnostic methods, surgical management, and outcomes of 12 patients who underwent surgical treatment for gallstone ileus. This case series was prepared in accordance with the PROCESS 2025 guidelines.

METHODS

Patients who underwent surgical treatment for gallstone ileus between February 2019 and June 2025 in a single tertiary care center were retrospectively reviewed. Ethical committee approval was obtained prior to the start of the study Ankara

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Bilkent City Hospital Medical Researches Ethics Committee (Date: 12.11.2025, Decision No: TABED 2-25-1627). All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki.

Inclusion criteria for the study were defined as being 18 years of age or older, having a confirmed diagnosis of gallstone ileus based on clinical, radiological [computed tomography (CT), ultrasonography (USG)] and/or intraoperative findings, having undergone surgical treatment and having complete medical records available. Patients who did not receive a diagnosis of biliary obstruction or who were followed up with conservative treatment, cases under 18 years of age, those with a different intraoperative obstruction etiology and patients with incomplete clinical or surgical records were excluded from the study. The diagnostic process was formally evaluated according to national surgical protocols and all consecutive patients meeting the criteria within the specified time frame were included in the analysis. Study data were collected by researchers from the hospital information system and patient files.

Twelve patients were included in the study. The patients' demographic data (age, gender), presenting symptoms (abdominal pain, vomiting, distension, absence of gas or stool passage, etc.), comorbidities, laboratory findings [white blood cell (WBC), C-reactive protein (CRP), liver function tests, electrolytes], imaging findings (CT, USG, direct radiography), location of obstruction (duodenum, jejunum, ileum, colon), fistula type (cholecystoduodenal, cholecystocolic, cholecystogastric, etc.), surgical method used (enterolithotomy, enterolithotomy+cholecystectomy+fistula repair, two-stage approach, etc.) and length of hospital stay and mortality rate were noted.

Surgical procedures were performed under general anesthesia. Patients were placed on the operating table in the supine position and standard sterilization procedures were applied. Laparotomy was performed via a midline incision. Depending on the location of the gallstone, the small bowel segment was carefully evaluated through exploration. Absorbable 3-0 suture material was used for the enterotomy procedure and the intestinal wall was primarily closed in a single or double layer. In cases where cholecystectomy and fistula repair were performed, gallbladder dissection was performed using the classic open technique and the fistula tract was closed with primary sutures. A standardized surgical instrument set was used for surgical procedures; additionally, a monopolar cautery was used as an energy device. The application of a nasogastric tube and drain at the end of the surgery was evaluated according to clinical indication for all patients. In the postoperative period, patients were followed up in the intensive care unit or ward according to the standard protocol.

Postoperative complications were graded according to the internationally accepted Clavien-Dindo classification system. Complications developing in each patient were categorized and recorded according to this system, ranging from class I to class V.

No Artificial Intelligence-based tools, software or language models were used in the preparation of this article during the stages of hypothesis development, data analysis, statistical interpretation or text generation. All content was prepared manually by researchers and evaluated in accordance with scientific accuracy and ethical principles.

Statistical Analysis

Descriptive statistical analyses were used. Continuous variables were expressed as mean±standard deviation, and categorical variables were presented as numbers and percentages. Statistical analyses were performed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA). Since this was primarily a descriptive study, no comparative statistical tests were applied.

RESULTS

All patients presented with complaints of abdominal pain, nausea, vomiting and inability to pass gas or stool. Different combinations of Rigler's triad [intestinal obstruction, pneumobilia (Figure 1) and ectopic gallstone (Figure 2)] were detected in patients diagnosed by CT. Preoperative gallstone ileus was diagnosed in 11 patients, while 1 patient underwent surgery for acute abdomen and ileus and the diagnosis was confirmed.

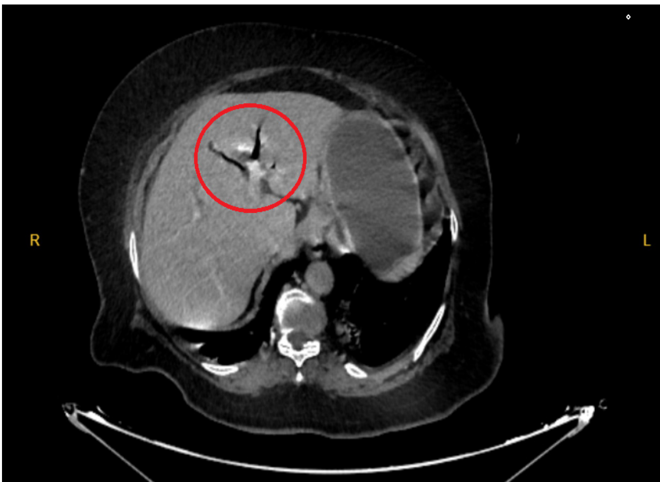

Figure 1. Pneumobilia (enclosed in an ellipse)

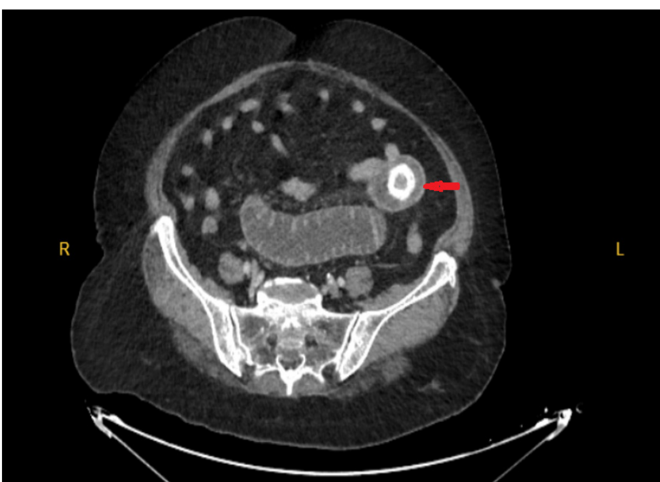

Figure 2. Ectopic gallstone, Double Sign Image (indicated by the arrow)

The demographic, clinical, surgical and laboratory findings of the 12 patients included in the study are presented in Table 1 and Table 2. The mean age of the patients was 77.42±10.30, and 8 (66%) were female. All cases were elderly and had multiple comorbidities. Concomitant diseases included hypertension (n=7, 58.3%), diabetes mellitus (n=4, 33.3%), cardiac disease (n=4, 33.3%) and congestive heart failure or cerebrovascular disease (n=3, 25%). A history of abdominal surgery was present in 4 patients (33.3%).

Table 1. Demographic, clinical, and surgical characteristics of patients

Patient no	Age (years), gender	Comorbidity	CCI, 10 year expected survival[9]	The story of the abdominal surgery	The story of biliyer	Biliary-enteric fistula site	Gallstone obstruction area	The operation performed	Hospitalization period (days)	Mortality
1	82, M	CAD, CVO	6, 2%	Absent	Absent	Choledochoduodenal	Jejunum	Enterotomy	12	Survivor
2	56, F	Absent	1, 96%	Absent	Present	Choledochoduodenal	Ileum	Subtotal cholecystectomy + primary fistula repair + enterotomy	11	Survivor
3	87, F	COPD, HT, CHF, CAD	6, 2%	Present	Present	Choledochoduodenal	Ileum	Enterotomy	10	Survivor
4	70, F	Absent	3, 77%	Absent	Absent	Cholestaticgastritis	Jejunum/ proximal ileum	Subtotal cholecystectomy + primary fistula repair + enterotomy	8	Survivor
5	77, F	DM, HT, CHF, Hypothyroidism	5, 21%	Absent	Present	Choledochoduodenal	Jejunum	Enterotomy	10	Survivor
6	73. F	HT, DM	4, 53%	Present	Present	Choledochoduodenal	Ileum	Enterotomy	14	Survivor
7	93, F	CAD, DM, PE, CVO, HT, Alzheimer's disease, Lung cancer	11, 0%	Absent	Absent	Choledochoduodenal	Jejunum	Enterotomy	6	Deceased
8	74, F	COPD, Dementia	5, 21%	Present	Present	Choledochoduodenal	Jejunum/ proximal ileum	Enterotomy	7	Survivor
9	88, M	CAD, HT, Alzheimer's disease	7, 0%	Absent	Present	Choledochoduodenal	Ileum	Small intestine resection + anastomosis	18	Survivor
10	69, F	Absent	2, 90%	Absent	Absent	Choledochoduodenal	Jejunum/ proximal ileum	Enterotomy	6	Survivor
11	74, M	HT	3, 77%	Present	Absent	Choledochoduodenal	Duodenum and Jejunum	Cholecystectomy +primary fistula repair+ enterotomy+ gastroenterostomy + nutritional jejunostomy	28	Survivor
12	86, M	HT, DM, CVO, CHF	7, 0%	Absent	Present	Choledochoduodenal	Jejunum	Enterotomy	15	Survivor

*M: Male, F: Female, CAD: Coronary artery disease, CVO: Cerebrovascular event, HT: Hypertexxnsion, COPD: Chronic obstructive pulmonary disease, CHF: Congestive heart failure, DM: Diabetes mellitus, PE: Pulmonary thromboembolism, CCI: Charlson Comorbidity Index

Table 2. Laboratory findings of patients

Patient no	Glucose (mg/dl)	Creatinine (mg/dl)	Albumin (g/L)	GGT (U/L)	LDH (U/L)	Total bilirubin (mg/dl)	WBC (x109/L)	Hemoglobin (g/dl)	CRP (mg/L)
1	135	3.19	37	22	300	1.3	19.3	18.7	96
2	175	0.99	52	33	439	1.12	7.6	14.7	10
3	125	1.37	42	35	193	1.34	16.5	12.5	90
4	141	1.28	50	18	347	1.66	14.1	14	40
5	188	1.7	43	38	231	1.66	12.1	13.4	56
6	262	1.21	39	24	192	0.73	12.1	13.9	51
7	224	1.2	34	46	313	1.09	22.8	10	200
8	81	0.66	34	229	258	0.37	15.9	10.8	104
9	144	1.19	42	21	215	1.2	14.7	14.8	109
10	138	0.78	34	30	374	0.28	14.4	13.7	42
11	163	3.52	38	28	248	0.53	23.2	14.8	16
12	138	1.83	30	96	536	0.48	30.2	14.4	252

*GGT: Gamma-glutamyl transferase, LDH: Lactate dehydrogenase, WBC: White blood cell, CRP: C-reactive protein

Seven patients (58.3%) had a previous diagnosis of cholelithiasis or a history of attacks, while five patients (41.7%) did not. The bile-enteric fistula type was predominantly cholecystoduodenal (Figure 3) (11 patients; 91.7%); only 1 patient (8.3%) had a cholecystogastric fistula.

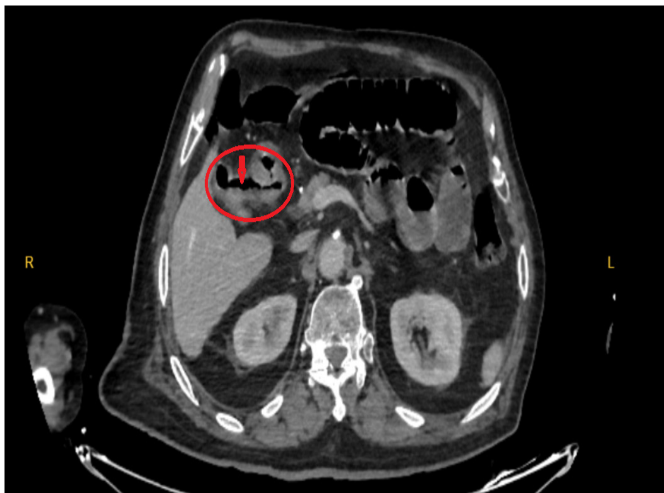

Figure 3. Cholecystoduodenal fistula (red ellipse) and fistula tract (red arrow)

The most common site of gallstone obstruction was the ileum (5 patients, 41.7%). This was followed by the jejunum (4 patients, 33.3%) and the jejunum/proximal ileum (3 patients, 25%). One patient had obstruction in both the duodenum and the jejunum.

Laboratory data showed that the mean glucose level of patients at admission was 159.5±47.85 mg/dl, the mean creatinine level was 1.57±0.89 mg/dl, the mean albumin level was 39.58±6.61 g/L, the mean gamma glutamyl transferase (GGT) was 51.67±59.54 U/L, lactate dehydrogenase (LDH) was 303.83±105.42 U/L, total bilirubin was 0.98±0.48 mg/dl, WBC mean 16.9±6.1 x10^9/L, hemoglobin mean 13.8±2.18 g/dl, CRP mean 88.83±72.78 mg/L. A marked increase in creatinine levels was detected in four patients, and they presented with acute renal failure due to ileus.

When evaluating the surgical methods applied, the most frequently preferred approach was enterotomy/enterolithotomy (Figure 4, 5), which was performed in 8 cases (66.6%). In two patients (16.6%), subtotal cholecystectomy and fistula repair were performed in addition to enterotomy during the same session. In one case (8.3%), complex surgical procedures were performed, including cholecystectomy, fistula repair, gastroenterostomy, and jejunostomy in addition to enterotomy. Furthermore, in one patient (8.3%), small bowel resection and end-to-end anastomosis were performed due to advanced damage detected in the intestinal segment.

The average length of hospital stay for patients was calculated as 12.08±6.23 days. Close monitoring and supportive treatments were administered to all patients during the postoperative period. Postoperative complications were evaluated according to the Clavien-Dindo classification (8); grade V mortality was observed in one patient [case No. 7, 93-year-old female, Charlson Comorbidity Index (CCI) 11, 10-year survival expectation 0% (9)], while Clavien-Dindo grade I-II complications were observed in the other cases. Overall, mortality was low (1/12; 8.3%) with early diagnosis and appropriate surgical approach.

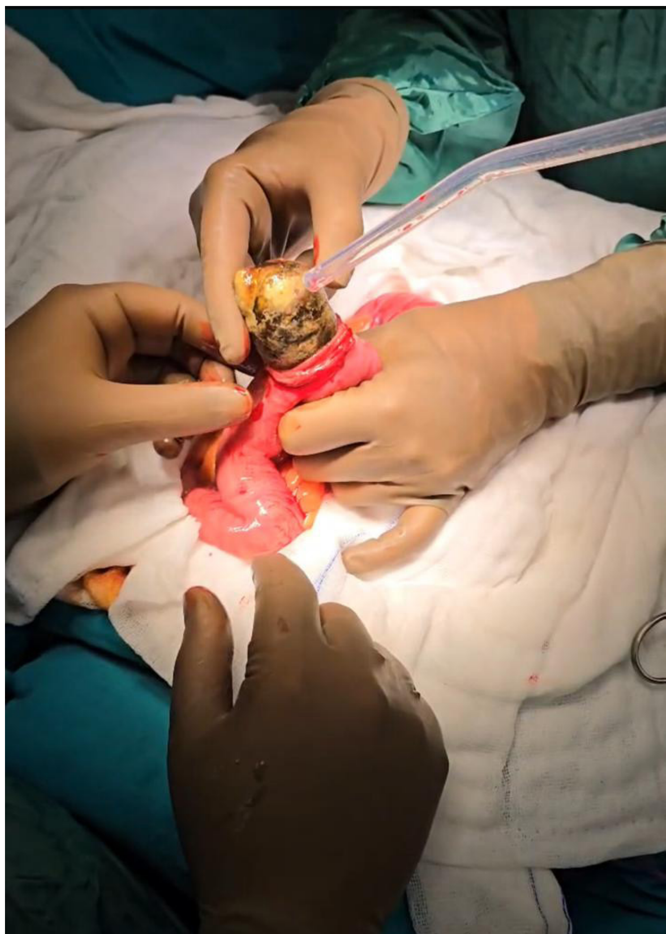

Figure 4. Enterotomy

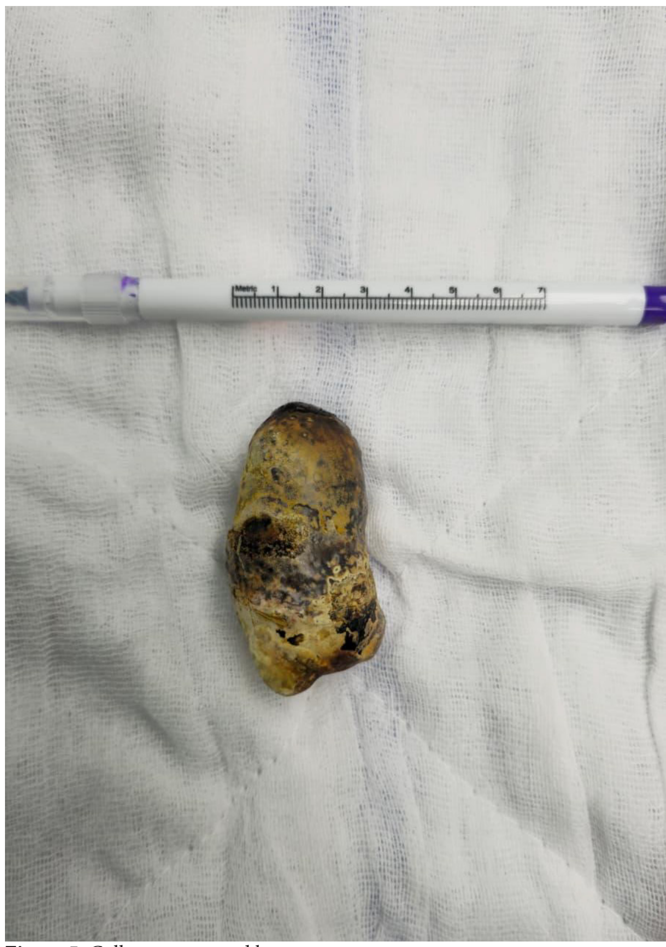

Figure 5. Gallstone removed by enterotomy

DISCUSSION

Gallstone ileus is a rare cause of intestinal obstruction in elderly and female patients.[10,11] It tends to occur in this patient group in elderly patients with concomitant cardiovascular, pulmonary or metabolic comorbidities. This increases the surgical risk profile and mortality rates. The reported mortality rates of 12-27% in the literature for cases of gallstone ileus indicate that these patients belong to a high-risk group.[10,12] In our case series, the average age of the patients was advanced (most >70 years) and a significant proportion had one or more comorbidities. When the CCI was evaluated, it was determined that the majority of our patients had a high CCI score (5±2.69) and consequently, low estimated 10-year survival rates; this shows that the actual surgical risk level of the patients in our series was quite high, consistent with the literature.

The diagnosis of gallstone ileus is often delayed due to nonspecific clinical symptoms and the fact that radiological findings such as Rigler's triad are not always fully apparent.[11] Patients may generally present with subacute, intermittent obstruction symptoms (e.g., intermittent abdominal pain, nausea-vomiting, temporary improvements), which can lead to misdiagnosis in the early stages. The literature reports that the rate of correct preoperative diagnosis varies between 30% and 70%, which is relatively low.[12] Consequently, in many cases, a definitive diagnosis can only be made during laparotomy.[3] This delay in diagnosis increases the risk of prolonged obstruction, dehydration, electrolyte imbalance and sepsis in patients, making postoperative complications more likely. Indeed, delayed diagnosis and treatment significantly increase mortality; some series have reported mortality rates reaching 30% in cases where a diagnosis could not be made.[12] Therefore, cholelithiasis ileus should be considered in cases of unexplained intestinal obstruction, especially in elderly patients.

Contrast-enhanced CT examination performed in the early period enables the definitive diagnosis of gallstone ileus, allowing surgery to be planned at the appropriate time and thereby significantly reducing morbidity and mortality rates.[13-15] The patients in our study were diagnosed with contrast-enhanced CT and early treatment strategies were planned based on these imaging findings. CT examination enabled detailed determination of the gallstone size, the anatomical region where fistula formation occurred, the stone's location, and the level of ileus; thus, surgical intervention could be performed without delay and in a targeted manner.

In the literature, obstruction with gallstones most commonly occurs in the ileum (particularly the terminal ileum and ileocecal valve region).[16] According to different sources, approximately 60-70% of cases are obstructed by stone impaction in the terminal ileum region.[17] The jejunum is the second most commonly affected segment of the small intestine, but its rate is lower in the literature (usually around 10-15%).[18] In our study, the terminal ileum was frequently observed as the location of gallstone ileus (41.7%). This was followed by the jejunum (33.3%) and the jejunum/proximal ileum (25%).

In the literature, cholecystoduodenal fistulas are the most common type, with rates reported between 60% and 85%.[10,19] Cholecystocolic fistulas are generally the second most common type, accounting for approximately 10-20% of cases.[3] Choledochogastric fistulas are rarer and have been reported in most series at a rate of 5-8%.[3] In addition, other types of fistulas, such as choledochojejunal and choledochoduodenal, have been described but constitute a very small proportion of total cases.[3] Our series is consistent with this distribution: in 11 of 12 patients (91.7%), the fistula causing the passage of gallstones into the intestine was cholecystoduodenal (gallbladder-duodenum), while only 1 patient (8.3%) had a cholecystogastric (gallbladder-stomach) fistula; no cases of cholecystocolic or cholecystojejunal fistula were observed.

In the literature, a significant proportion of patients who develop gallstone ileus may not have a previously diagnosed gallstone disease. Sources indicate that only approximately 50% of cases have a history of gallbladder stones or related clinical history.[6,12] In other words, approximately half of patients with gallstone ileus present with intestinal obstruction for the first time and have no history of a significant gallstone-related attack in the past. In our study, 58.3% of patients had a known history of cholelithiasis (gallstones) or a history of biliary colic/acute cholecystitis attacks prior to gallstone ileus. The 58.3% rate in our series is similar to the approximately 50% rate reported in the literature. Consistent with the literature data, biliary obstruction can occur in a significant number of patients without a history of gallstones. Therefore, biliary obstruction should be considered in the differential diagnosis of elderly patients presenting with ileus, even if they have no history of biliary disease.

The primary goal in treating gallstone ileus is to rapidly relieve intestinal obstruction. Surgical removal of the stone (enterotomy or enterolithotomy) is the first step in all cases; however, there are different approaches regarding subsequent procedures.[12,20] Some surgeons prefer to perform cholecystectomy and biliary-enteric fistula repair in the same session (single-stage surgery), while others recommend only stone removal in the first stage and elective cholecystectomy and fistula closure in the second stage (following the patient's recovery), especially in high-risk patients.[12] The literature emphasizes that in most cases, enterotomy to relieve obstruction is sufficient and is associated with lower morbidity compared to other more extensive procedures.[10,12,21] In our series, the surgical techniques used were tailored to the patient's clinical condition. In the majority of patients, stones were primarily removed via enterotomy. In a limited number of patients who were hemodynamically stable and had an acceptable surgical risk, simultaneous subtotal cholecystectomy and fistula repair were performed. In one case, segmental small bowel resection and anastomosis were required due to intestinal damage caused by the stone. The literature reports that resection may be performed in cases where bowel ischemia or perforation develops due to ileus duration.[12] The absence of significant complications in the cases where we performed single-stage surgery demonstrates that this approach can be safely applied when appropriate patients are selected. Overall, the results in our series suggest that the choice of surgical technique is not decisive for short-term outcomes. Some studies have also shown that the preferred surgical method (enterotomy alone vs. single-stage) does not significantly affect mortality rates.[11] The key is to determine the most appropriate strategy based on the patient's overall condition and risk profile. Compared to the mortality rates of 7-30% reported in the literature,[10] the fact that mortality in our series remained at a lower rate of 8% may be due to prompt diagnosis and treatment, as well

as a multidisciplinary approach supported by intensive care. In our postoperative follow-ups, no recurrence of biliary ileus was observed in any patient who underwent enterotomy alone. The literature also indicates that in most cases following enterotomy, the biliary-enteric fistula closes spontaneously and these patients can be followed without experiencing recurrent biliary symptoms.[22] However, classical knowledge indicates that gallstone ileus may recur in 5-17% of cases where the gallbladder and fistula are left in place.[3,20] Therefore, especially in younger patients with a long life expectancy, elective cholecystectomy and fistula repair should be planned for the future if the gallbladder is left in place.

This study is significant in that it presents the clinical and surgical characteristics of patients who underwent surgical treatment for gallstone ileus based on real-life data. All cases were evaluated consecutively, and the diagnostic process was confirmed by contrast-enhanced computed tomography. Critical parameters affecting the surgical decision, such as the obstruction site and fistula type, were reported in detail. This allows the study to provide a robust clinical dataset that contributes to the literature.

Limitations

The retrospective design of this study, the limited sample size and the fact that it was conducted at a single center constitute significant limitations. Due to the limited long-term follow-up data, recurrence and late complications could not be evaluated. As it does not include randomized and prospective comparisons, definitive conclusions cannot be drawn regarding the effectiveness of different surgical approaches.

There are cost differences between surgical methods and it is consistent with the literature that single-stage enterolithotomy may offer advantages with lower resource utilization. This study does not include a direct economic analysis.

Since gallstone ileus is a rare clinical condition, studies with larger sample sizes, multicenter designs and prospective designs are required. Advanced research comparing the long-term outcomes of surgical approaches, recurrence rates and cost-effectiveness analyses will contribute to establishing treatment standards in clinical practice.

CONCLUSION

Biliary obstruction is a rare but serious condition commonly seen in elderly patients with comorbidities. Early diagnosis and prompt surgical intervention are critical in reducing mortality in these cases. As a clinical recommendation, gallstone ileus should be considered in elderly patients presenting with symptoms of intestinal obstruction and a history of gallstones and contrast-enhanced CT should be performed for diagnosis. In treatment, rather than a one-size-fits-all approach, a strategy tailored to the patient's general condition should be followed. In most cases, enterotomy to relieve the obstruction, which has a low mortality rate, should be preferred as the first-line treatment. Additional surgical procedures should be planned according to individualized treatment principles, taking into account the patient's clinical condition and comorbidity burden. This selective approach will minimize complications in the acute period and improve patient outcomes by preventing problems that may arise in the long term.

ETHICAL DECLARATIONS

Ethics Committee Approval

This study was approved by the Ankara Bilkent City Hospital Medical Researches Ethics Committee (Date: 12.11.2025, Decision No: TABED 2-25-1627).

Informed Consent

This retrospective study used pre-existing anonymized patient data. No additional intervention was performed, and there was no direct patient contact. The study was approved by the Ethics Committee, and the requirement for written informed consent was waived by the ethics committee.

Peer Review Process

This manuscript was subject to external peer review.

Conflict of Interest

The authors declare no conflicts of interest related to this study.

Financial Disclosure

The authors received no financial support for the conduct or publication of this research.

Author Contributions

Concept: AY, EŞ, EY, HPÖ, SE; Design: AY, EŞ, EY, HPÖ, SE; Control: AY, EŞ, EY, HPÖ, SE; Resources: AY, EŞ, EY, HPÖ, SE; Materials: AY, EŞ, EY, HPÖ, SE; Data Collection and/or Processing: AY, EŞ, EY, HPÖ, SE; Analysis and/or Interpretation: AY, EŞ, EY, HPÖ, SE; Literature Review: AY, EŞ, EY, HPÖ, SE; Writing the Article: AY, EŞ, EY, HPÖ, SE; Critical Review: AY, EŞ, EY, HPÖ, SE.

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The effect of the prone position on intra-abdominal pressure and renal function

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ABSTRACT

Aims: Various surgical procedures are performed on patients in the prone position. Intra-abdominal pressure (IAP) refers to the pressure within the abdominal cavity between the internal organs and the abdominal wall. This study investigated the effect of the prone position-via increased IAP-on renal function.

Methods: This prospective observational study included patients aged 18-75 years with an American Society of Anesthesiologists (ASA) classification of I-III. 38 patients undergoing spinal surgery in the prone position and 37 patients undergoing colorectal surgery in the supine position were evaluated. Demographic characteristics, IAP, perioperative renal parameters, intraoperative blood loss, and postoperative course were assessed. IAP was measured by intravesical pressure monitoring.

Results: In patients undergoing lumbar surgery, IAP was significantly higher in the prone position (14 mmHg) compared with the supine position (11 mmHg; $p<0.05$). The incidence of class I intra-abdominal hypertension (IAH) was significantly higher in the prone position than in the supine position ($p<0.001$). A positive and significant correlation was found between body-mass index and IAP in both patients undergoing lumbar and colorectal surgery ($p<0.001$). Postoperative urea levels at 1, 24, and 48 hours were significantly higher in patients who underwent lumbar surgery ($p<0.05$). Among those undergoing colorectal surgery, patients with class I IAH had significantly higher intraoperative blood loss than those with normal IAP ($p<0.05$).

Conclusion: To prevent renal complications during surgery, patient positioning and fluid management should be monitored carefully. In addition, it should be noted that increased IAP can lead to greater intraoperative blood loss.

Keywords: Prone position, intra-abdominal hypertension, kidney function test

INTRODUCTION

Patient positioning for surgery is the joint responsibility of the anesthesiologist, surgeon, and nurses.[1] The optimal position should provide the best surgical access while being the most appropriate for the patient's tolerance.[1] In this context, the prone position is frequently preferred, particularly in procedures, such as spinal surgery.[1] Depending on the selected surgical position, especially in the prone position, an increase in intra-abdominal pressure (IAP) and associated complications can occur.[1,2]

IAP refers to the steady pressure within the abdominal cavity resulting from the interaction between the abdominal wall and internal organs.[2] While values up to 5 mmHg are considered physiologically normal in adults, IAP can rise to 10 mmHg or higher because of conditions, such as obesity.[2] Intra-abdominal hypertension (IAH) is defined as a sustained pathological elevation of IAP greater than 12 mmHg in three consecutive measurements.[3] In cases where IAP is consistently 20 mmHg or higher, abdominal compartment syndrome (ACS) that can present with organ dysfunction, might be observed.[3]

Based on this information, the hypothesis of our study was that lumbar disc surgery performed in the prone position will significantly increase IAP compared with colorectal surgery in the supine position, and this will have negative effects on renal function parameters (eg, urea, creatinine, and estimated glomerular filtration rate) (eGFR) in the perioperative period. The primary endpoint of the study was the IAP value; the secondary endpoints were the relationship between body-mass index (BMI) and IAP, renal function parameters, and the amount of intraoperative bleeding.

METHODS

This prospective, observational clinical study was conducted in accordance with the principles of the Declaration of Helsinki with approval from the Ankara Bilkent City Hospital Medical Researches Ethics Committee (Date: 20.03.2024, Decision No: TABED 2-24-21) and with informed consent from the participants.

Subject Selection, Inclusion and Exclusion Criteria

The study included patients aged 18-75 years with an American Society of Anesthesiologists (ASA) classification of I-III, who were undergoing spinal surgery or colorectal surgery with

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identical anesthesia and fluid management at Ankara Bilkent City Hospital.

The exclusion criteria were obesity (BMI >35 kg/m²), a history of dementia, psychiatric disorders, severe heart disease, central nervous system diseases, renal or liver dysfunction, bleeding diathesis, active infection, pregnancy, chronic inflammatory disease, oral corticosteroid use, a history of allergy and conditions preventing cooperation in the postoperative period (eg, mental retardation, communication barriers, etc).

Intervention

Within the scope of the study, all patients fasted according to the standard protocol. In the preoperative period, patients' demographic characteristics and laboratory test values were recorded in the ward. The patient group for colorectal surgeries to be performed in the supine position was labelled as group S, and the patient group for spinal surgeries to be performed in the prone position was group P.

Intraoperatively, duration of surgery, heart rate, mean arterial pressure, intravesical pressure, bleeding and the amount of intravenous fluid administered were recorded. In the postoperative period, urea, creatinine, eGFR, 24-hour urine output, and length of stay in the ward and intensive care unit were recorded. IAP in patients was evaluated via intravesical pressure. The Modified Kron technique was used as the intravesical pressure measurement method.[4]

Anesthesia Management

Routine preoperative preparations were performed for patients taken to the operating room and standard monitoring was undertaken with peripheral oxygen saturation (SpO_2) level, electrocardiography (ECG), non-invasive blood pressure (NIBP) and bispectral index (BIS, A 2000 Bispectral Index, Aspect Medical Systems). After induction with 1 mg/kg lidocaine, 2 mg/kg propofol, 1 mcg/kg fentanyl, and 0.5 mg/kg rocuronium, the patients were intubated with an appropriate endotracheal tube. A urinary catheter was placed for urine monitoring and IAP also monitored. Anesthesia was maintained with continued sevoflurane and remifentanil in a 50% oxygen and 50% air mixture.

Patients undergoing lumbar stabilization were placed in the prone position. During positioning, lateral pillows were used to facilitate diaphragm movements, soft silicone pads used to prevent nerve compression and pillows placed under the tibia to prevent foot malposition. Additionally, the head was supported in a neutral position with silicone pillows and adjusted to avoid pressure to the eyes, nose and ears. Patients were administered 100 mg tramadol and 1 g paracetamol as analgesics. Body temperature was checked regularly and maintained at approximately 36°C. Post-operation, 2 mg/kg sugammadex was given to the patients. When respiratory function was restored after surgery (tidal volume >6 ml/kg and end tidal CO_2<50 mmHg), patients were extubated and transferred to the post-anesthesia care unit. Patients with an Aldrete score greater than 9 during follow-up were taken to the ward. Postoperative fluid management was standardized for both groups and administered according to the institutional postoperative fluid therapy protocol. For postoperative analgesia, all patients received both 100 mg tramadol and 1 g paracetamol three times a day intravenously.

Measurements and Outcome Parameters

Patient demographic characteristics and intraoperative data were recorded. Urea, creatinine and eGFR values were evaluated 24 hours preoperatively and at 1, 24, and 48 hours postoperatively. Intraoperative IAP measurements in both groups were performed using the Modified Kron method.[4] After administering a urinary catheter to each patient, 25 ml of sterile saline was injected into the catheter. The measurement was taken after the pressure transducer was aligned with the mid-axillary line and calibrated. Preoperative measurements were performed in the ward; intraoperative measurements were performed after anesthesia induction and intubation but during the stable period before the surgical incision. Postoperative measurements were recorded at 1, 24 and 48 hours in the ward.

IAH grading was defined according to current recommendations as class I 12-15 mmHg, class II 16-20 mmHg, class III 21-25 mmHg, and class IV >25 mmHg. Additionally, patients' 24-hour urine outputs and lengths of stay in the ward and intensive care unit in the postoperative period were evaluated within the scope of the study.

Statistical Analysis

G*power 3.1.9.7 (Franz Faul, Universitat Kiel, Germany) software was used to calculate the sample size. For 90% power, an effect size of d=0.79 and α=0.05, a minimum of 70 (n1=35, n2=35) patients was sufficient. SPSS 22.0 software was used for statistical analysis. The normality of the data was examined using histogram curves and the Kolmogorov-Smirnov or Shapiro-Wilk tests. Frequency, Chi-squared, mean±standard deviation, and median (minimum-maximum) values were primarily used, while Mann-Whitney U, Wilcoxon's, independent samples T test, and ANOVA tests were performed with these values. The statistical significance level was accepted as $p<0.05$, and all p-values lower than 0.001 were indicated as $p<0.001$.

RESULTS

In this study, 80 patients were evaluated, including 40 patients in the prone position for spinal surgeries (group P) and 40 patients in the supine position for colorectal surgeries (group S). 75 patients met the specified criteria and 38 were assigned to group P and 37 to group S. No significant difference was observed between the groups in terms of age, ASA score, 24-hour urine output (ml), amount of intraoperative fluid received (ml) and lengths of stay in the ward and intensive care unit ($p>0.05$; Table 1). Significant differences were found between the groups in terms of sex, BMI, duration of surgery and amount of intraoperative bleeding ($p<0.05$; Table 1).

When the groups were split according to BMI (≤30 kg/m² and >30 kg/m²), no significant difference was found between the groups regarding the mean preoperative and postoperative urea, creatinine, and eGFR levels ($p>0.05$; Table 2). However, a moderate positive and significant correlation was observed between BMI and IAP values in patients undergoing lumbar and colorectal surgery ($p<0.001$, r=0.53 and $p<0.001$, r=0.61, respectively; Table 3).

The median IAP of patients undergoing lumbar surgery was 11 mmHg (range 7-12 mmHg) in the supine position and 14 mmHg (range 11-15 mmHg) in the prone position, and a significant difference was found between the positions ($p<0.05$;

Table 1. Demographic data and clinical characteristics

		Lumbar (n=38)	Colon (n=37)	p-value
Sex (n, %)	Female	29 (76.3%)	15 (40.5%)	**0.002***
	Male	9 (23.7%)	22 (59.5%)	
Age (years)		59.50±9.59	57.27±17.00	0.48**
BMI (kg/m²)		28.37±4.00	25.37±5.34	**0.008****
ASA score (n, %)				0.942*
I		8 (21.1%)	7 (18.9%)	
II		15 (39.5%)	14 (37.8%)	
III		15 (39.5%)	16 (43.2)	
24-hour urine output (ml, n=53)		2311.76±628.62	2128.61±623.11	0.32**
Intraoperative bleeding (ml, n=47)		600 (50-3800)	150 (50-700)	**<0.001*****
Intraoperative fluid intake (ml)		2300 (1200-5800)	2500 (500-5600)	0.70***
Ward stay (days, n=73)		6 (2-13)	6 (3-89)	0.55***
ICU stay (days, n=37)		1 (1-10)	1 (1-11)	0.58***
Surgery duration (min, n=75)		270 (150-600)	180 (120-420)	**<0.001*****

Data are presented as mean±SD, number (%), (n), or median (min-max). Statistically significant p-values are in bold font. *Chi-squared test, **Independent samples T test, ***Mann-Whitney U test. BMI: Body-mass index, ASA: American Society of Anesthesiologists, ICU: Intensive care unit, SD: Standard deviation, Min: Minimum, Max: Maximum

Figure 1). The increased intra-abdominal pressure observed in the prone position likely contributed to the observed differences between positions. Conversely, the median IAPs of patients undergoing lumbar and colorectal surgery in the supine position were 11 mmHg (range 7-12 mmHg) and 10 mmHg (range 7-13 mmHg), respectively, with no significant difference observed between the groups (p>0.05; Figure 1).

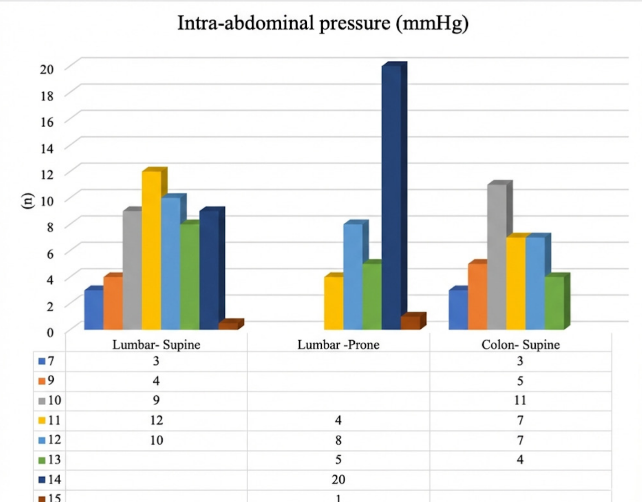

Figure 1. Intra-abdominal pressure values of the cases

Data are presented as number (n)

In patients undergoing lumbar surgery, although 28 cases were evaluated as normal according to IAH pressure grading in the supine position, class I IAH was detected in 24 patients in the prone position. The incidence of class I IAH in the prone position was significantly higher compared with the supine position (p<0.001; Figure 2). No cases were class II, class III, or class IV according to IAH grading.

Table 2. Comparison of urea, creatinine, and eGFR values according to BMI

		BMI ≤30 kg/m²	BMI >30 kg/m²	p-value*
Urea (mg/dl)	Preoperative	33.30±13.39	35.13±9.75	0.55
	Postoperative (1 hour)	30.23±13.45	30.80±8.05	0.83
	Postoperative (24 hours)	28.15±15.84	29.07±8.48	0.83
	Postoperative (48 hours)	26.05±15.53	31.13±10.73	0.14
Creatinine (mg/dl)	Preoperative	0.79±0.28	0.76±0.14	0.69
	Postoperative (1 hour)	0.72±0.27	0.69±0.11	0.65
	Postoperative (24 hours)	0.72±0.28	0.68±0.15	0.58
	Postoperative (48 hours)	0.69±0.25	0.70±0.12	0.95
eGFR (ml/dak/1.73m²)	Preoperative	91.46±24.71	89.06±16.33	0.65
	Postoperative (1 hour)	98.13±26.31	93.86±13.04	0.37
	Postoperative (24 hours)	97.03±24.62	96.00±15.12	0.83
	Postoperative (48 hours)	99.10±26.29	94.13±14.01	0.32

Data are presented as mean±SD. *Independent samples T test. eGFR: Estimated glomerular filtration rate, BMI: Body-mass index, SD: Standard deviation

Table 3. Evaluation of IAH grading according to BMI

BMI (kg/m²)	Lumbar (supine)			Lumbar (prone)			Colon (supine)		
	IAH		p*	IAH		p*	IAH		p*
	Normal (n, %)	Class I (n, %)		Normal (n, %)	Class I (n, %)		Normal (n, %)	Class I (n, %)	
Underweight	-	-		-	-		5 (19.2%)	-	
Normal weight	6 (21.4%)	1 (10%)	0.13	4 (100%)	3 (8.8%)	<0.001	9 (34.6%)	2 (18.2%)	0.17
Overweight	16 (57.1%)	3 (30%)		-	19 (55.9%)		11 (42.3%)	7 (63.6%)	
Obesity	6 (21.4%)	6 (60%)		-	12 (35.3%)		1 (3.84%)	2 (18.2%)	
Total	28 (100%)	10 (100%)		4 (100%)	34 (100%)		26 (100%)	11 (100%)	

Underweight: BMI <18.5; normal weight: BMI 18.5-24.9; overweight: BMI 25-29.9; and obesity: BMI 30-34.9. Data are presented as number (n, %). *Pearson's Chi-squared test. IAH: Intra-abdominal hypertension, BMI: Body-mass index

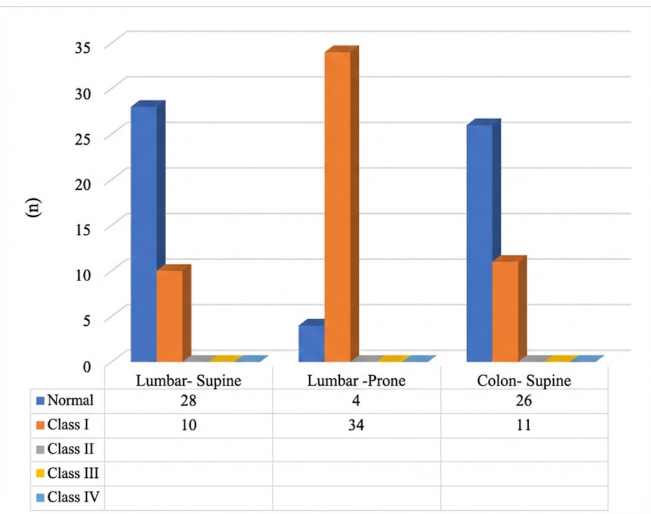

Figure 2. Distribution of cases according to IAH grading

Data are presented as number (n). IAH: Intra-abdominal hypertension

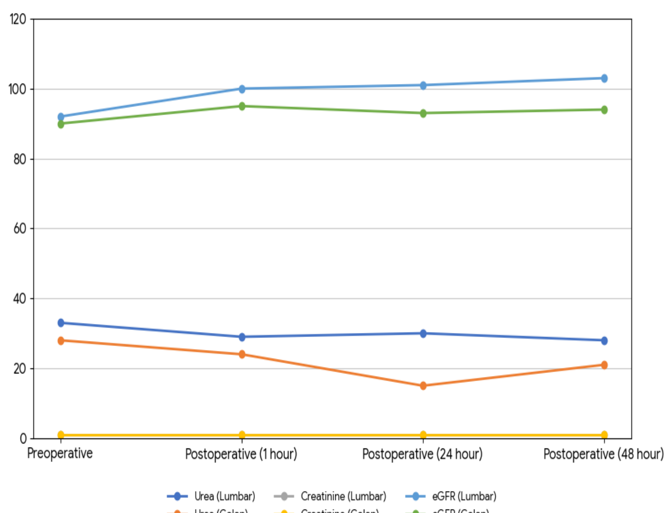

Figure 3. Urea, creatinine, and eGFR values

eGFR: Estimated glomerular filtration rate

In patients undergoing lumbar surgery, no significant difference was observed between the preoperative and postoperative 1, 24, and 48-hour eGFR values of patients with prone position IAP values of 11, 12 and 13 mmHg versus those with 14 mmHg and higher (p>0.05; Table 4). Comparison between the groups revealed no significant difference between them in terms of creatinine and eGFR values according to sampling time (p>0.05; Table 5, Figure 3). However, significant differences were observed between the groups in urea values at the postoperative 1-, 24-and 48-hour timepoints, and the values of patients undergoing lumbar surgery were higher in all of these instances (p<0.05; Table 5, Figure 3).

Table 4. Comparison of eGFR values in patients undergoing lumbar surgery according to prone position IAP

	IAP values in the prone position		
eGFR (ml/dak/1.73m2)	**<14 mmHg (n=17)**	**≥14 mmHg (n=21)**	**p***
Preoperative	85.94±19.74	92.52±16.19	0.27
Postoperative (1 hour)	95.17±20.02	94.61±16.53	0.92
Postoperative (24 hours)	90.00±20.51	95.47±17.03	0.38
Postoperative (48 hours)	90.41±19.38	96.00±14.95	0.33

eGFR (ml/min/1.73 m^2) values are presented as mean±SD. *Independent samples T test. eGFR: Estimated glomerular filtration rate, IAP: Intra-abdominal pressure, SD: Standard deviation

In patients undergoing colorectal surgery, the amount of bleeding during the operation in 11 patients with class I IAH was higher compared with 26 patients with normal IAP (p<0.05; Table 6).

Table 6. The effect of intraoperative hypertension on bleeding amount in colorectal surgery

	Colon (n=37)		
	Normal IAP (n=26)	**Class I IAH (n=11)**	**p***
Intraoperative bleeding, (ml, n=37)	225 (100-500)	100 (50-700)	0.02

Values are presented as median (min-max). Statistically significant p-values are in bold font. *Mann-Whitney U test. IAP: Intra-abdominal pressure. IAH: Intra-abdominal hypertension

DISCUSSION

Our study showed that IAP increases in the prone position in patients undergoing lumbar surgery and that the incidence of class I IAH was higher compared with the supine position. Additionally, there was a significant relationship between BMI and IAP. Postoperative urea levels at 1, 24 and 48 hours were higher in lumbar surgeries performed in the prone position. In patients undergoing colorectal surgery, the amount of intraoperative bleeding in those with class I IAH was higher compared with those without IAH.

Table 5. Comparison of urea, creatinine, and eGFR values in the preoperative and postoperative periods

		Lumbar (n=38)	Colon (n=37)	p-value
Urea (mg/dl)	Preoperative	33 (17-62)	28 (5-71)	0.10*
	Postoperative (1 hour)	29 (17-66)	24 (4-69)	0.03*
	Postoperative (24 hour)	30 (13-68)	15 (6-58)	<0.001*
	Postoperative (48 hour)	28 (13-77)	21 (4-68)	<0.001*
Creatinine (mg/dl)	Preoperative	0.71 (0.41-1.49)	0.83 (0.19-1.42)	0.36*
	Postoperative (1 hour)	0.66 (0.40-1.34)	0.72 (0.21-1.48)	0.41*
	Postoperative (24 hour)	0.65 (0.43-1.30)	0.71 (0.13-1.48)	0.75*
	Postoperative (48 hour)	0.66 (0.43-1.24)	0.68 (0.25-1.42)	0.64*
eGFR (ml/dak/1.73m^2)	Preoperative	92.43±27.79	89.57±17.94	0.60**
	Postoperative (1 hour)	99.75±29.40	94.86±17.92	0.39**
	Postoperative (24 hour)	100.72±26.38	93.02±18.61	0.15**
	Postoperative (48 hour)	102.83±29.54	93.50±17.06	0.10**

eGFR (ml/min/1.73 m^2) values are presented as mean±SD. Statistically significant p-values are in bold font. Urea (mg/dl) and creatinine (mg/dl) values are presented as median (min-max). *Mann-Whitney U test, **Independent samples T-test. eGFR: Estimated glomerular filtration rate, SD: Standard deviation, Min: Minimum, Max: Maximum

IAP is a crucial parameter affecting the perfusion of abdominal organs and general hemodynamic status.[6] It is reported that high IAP can impair the functions of abdominal organs and lead to renal damage.[6] In this context, the monitoring and management of IAP hold an important place in patients undergoing surgery. In a meta-analysis by Kwee et al.,[6] 53 studies evaluating complications associated with the prone position were examined of which two studies focused on increased IAP and its associated complications.[6-8] Akıncı et al.[7] compared the prone position and jackknife position in patients undergoing spinal surgery and observed a reduction in IAP and intraoperative bleeding amounts in patients in the jackknife position. The reason for more bleeding in the prone position was explained by the increased intra-abdominal and intrathoracic pressure that reduced venous return and raised venous pressure in the surgical area.[7]

In our study, IAP values measured in the prone position were higher than in the supine position, which aligns with the literature. Additionally, a significant difference between IAP and intraoperative bleeding amount in the colorectal surgery group was observed, also in accordance with the literature. The difference in intraoperative bleeding amounts in lumbar and colorectal surgeries can be explained by various reasons, such as the variability of surgeries, durations, and teams; however, the effect of increased IAP due to the prone position was also evaluated in this context.

Studies have stated that there is a strong correlation between BMI and IAP in individuals placed in the prone position.[9,10] Han et al.[9] examined three groups (normal, overweight, and obese) of surgery patients according to BMI, and reported that the increase in IAP was greater in the group with high BMI and in the prone position. Wilson et al.[10] emphasized that the IAPs of individuals with morbid obesity were higher than those with normal BMI, but this elevation was not sufficient for IAH. In our study, the IAP increase in the prone position in those with BMI higher than normal increased more significantly, consistent with the literature.

When cases were accepted with a threshold value of 30 kg/m^2 according to BMI, no significant difference was found in terms of urea, creatinine, and eGFR values. A reason for this finding could be the narrow range of the study group in terms of BMI (excluding patients with BMI >35 kg/m^2), surgical durations not being long enough to affect renal functions, and the role of effective fluid management.

In the review by Mobley et al.,[11] controversial results were reported regarding the relationship between prone position and renal functions. While Bradley et al.[12] stated that IAP values of 15 mmHg and higher negatively affected renal perfusion, Hering et al.[13] emphasized that IAP increase did not affect renal perfusion. In our study, IAP values of 14 mmHg and higher did not affect renal functions and these differences could be related to the variability of patient groups and surgery types.

Furthermore, in our study, both urea and creatinine concentrations decreased as the postoperative sampling time was extended; this decrease was significant in urea concentration, especially in the colorectal surgery group. These results were evaluated because of long preoperative fasting duration and effective hydration in the intraoperative period. Long-term preoperative fasting can lead to fluid loss and hypovolemia, reducing renal perfusion.[14] This circumstance increases the activation of the renin-angiotensin-aldosterone system and antidiuretic hormone.[15] If the process is not managed properly, renal dysfunction can become permanent.[14] With correct and controlled fluid replacement, intravascular volume is rebalanced, renal perfusion increases, and glomerular filtration is restored.[16] In this way, ischemia and tubular damage in the kidneys can regress, toxic metabolites can be excreted, and kidney capacity can be preserved.[15] Therefore, detailed planning of fluid management before, during, and after surgery is a crucial step for preventing hypovolemia and renal damage.[14,16] The study results indicate that fluid therapy administered to patients in the intraoperative and postoperative periods was adequate and effective.

Limitations

There are limitations to our study. The surgical team in our clinic restricts oral intake (solid and liquid) for 8 hours in the preoperative period, which might explain the decrease in urea and creatinine values after fluid therapy. Most of the participants in the lumbar surgery group were female and male in the colorectal surgery group, while BMI was higher in the lumbar surgery group and surgical duration and intraoperative bleeding amount was higher in the lumbar surgery group, which are some limitations of the study. Additionally, since the discharge times of the study population varied between 48-72 hours, only the blood results in the first 48 hours were evaluated to standardize. Regarding the effect of patient position on IAP, the possibility that the surgical intervention performed in the abdomen in the colorectal surgery group could affect the measurements in the postoperative period-although it was performed after the IAP measurement in the intraoperative period-is another limitation in the study. Furthermore, the non-evaluation of preoperative hemoglobin levels, amounts of blood and blood products given perioperatively, postoperative fluid and blood product replacements, and postoperative hemoglobin levels, which could affect renal functions other than IAP due to supine and prone positions, is another limitation of the study.

CONCLUSION

The prone position can lead to unwanted complications by causing increases in IAP. Increased IAP in the prone position may contribute to alterations in renal function parameters and increased intra-operative blood loss. If this surgical position is preferred, it is necessary to provide adequate and effective fluid therapy and carefully monitor renal function values, such as urea, creatinine, and eGFR.

ETHICAL DECLARATIONS

Ethics Committee Approval

This study was approved by the Ankara Bilkent City Hospital Medical Researches Ethics Committee (Date: 20.03.2024, Decision No: TABED 2-24-21).

Informed Consent

Written informed consent was obtained from all individual participants prior to their inclusion in the study. Participants were fully informed about the study's aims, procedures, potential risks and benefits, and their rights-including the right to withdraw at any time without consequence. All participants voluntarily signed a written informed consent form.

Peer Review Process

This manuscript was subject to external peer review.

Conflict of Interest

The authors declare no conflicts of interest related to this study.

Financial Disclosure

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Author Contributions

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Prior COVID-19 infection is associated with statistically lower but clinically minimal blood loss after total knee and hip arthroplasty

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ABSTRACT

Aims: The influence of previous COVID-19 infection on perioperative blood loss in total joint arthroplasty remains uncertain. Although COVID-19-related inflammatory and vascular alterations have been described, their impact on early postoperative hemoglobin and hematocrit changes after total knee arthroplasty (TKA) and total hip arthroplasty (THA) has not been well established.

Methods: This retrospective comparative study included patients who underwent primary TKA or THA between April 2022 and April 2025. Demographic characteristics, comorbidities, vaccination status, and perioperative laboratory values were recorded. Patients were categorized based on prior COVID-19 infection history. Changes in hemoglobin and hematocrit from the preoperative period to postoperative day 1 were calculated. Intergroup comparisons were performed, and multivariable linear regression analysis was used to identify independent predictors of postoperative hemoglobin decline.

Results: A total of 381 patients were included (244 TKA, 137 THA; mean age 63.4±10.1 years). Overall mean decreases were -2.53±1.32 g/dl for hemoglobin and -7.85±5.34% for hematocrit. Patients with a history of COVID-19 infection demonstrated smaller reductions in hemoglobin (-2.22±1.37 vs -2.65±1.25 g/dl, p=0.003) and hematocrit (-7.02±4.33 vs -8.18±5.76%, p=0.031) compared with COVID-negative patients. Multivariable analysis identified prior COVID-19 infection, BNT162b2 vaccination, and undergoing TKA (vs THA) as independent factors associated with reduced postoperative hemoglobin decline. Despite statistical significance, the absolute differences were small.

Conclusion: Prior COVID-19 infection and vaccination status were associated with statistically lower early postoperative hemoglobin and hematocrit decreases following TKA and THA; however, these differences were not clinically meaningful. A history of COVID-19 does not appear to significantly alter perioperative bleeding profiles in arthroplasty patients.

Keywords: COVID-19, total knee arthroplasty, total hip arthroplasty, blood loss, hemoglobin, hematocrit

INTRODUCTION

The COVID-19 pandemic markedly disrupted healthcare delivery worldwide. Elective orthopedic procedures were widely restricted, and many scheduled operations were postponed or cancelled. Previous studies have reported a substantial decline in arthroplasty volume during peak pandemic periods.[1] In addition, COVID-19 has been associated with increased perioperative morbidity and mortality in several orthopedic procedures.[2-4] Furthermore, the hypercoagulable state related to COVID-19 has been linked to an increased risk of thromboembolic complications in arthroplasty patient.[5]

The demand for hip and knee arthroplasty continues to rise due to population ageing, increased life expectancy, and higher functional expectations.[6] Total joint arthroplasty is a major procedure that may be associated with considerable intraoperative and postoperative blood loss.[7] Published data suggest that mean blood loss ranges from 1,000 to 1,400 ml after total knee arthroplasty (TKA) and from 1,200 to 1,600 ml after total hip arthroplasty (THA).[7,8] Excessive perioperative blood loss may increase the need for allogeneic transfusion and may adversely affect length of stay, periprosthetic joint infection risk, and overall postoperative morbidity.[9,10]

Although the effect of COVID-19 on orthopedic surgery has been widely investigated, its influence on perioperative bleeding in arthroplasty patients remains insufficiently studied. Accordingly, we aimed to compare perioperative blood loss parameters in arthroplasty patients with and without a prior history of COVID-19 infection. We hypothesized that arthroplasty-related blood loss would be lower in patients with prior COVID-19 infection because of persistent prothrombotic and vascular changes associated with the disease. To our knowledge, limited data exist regarding the effect of prior COVID-19 infection on perioperative blood

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loss in arthroplasty patients, and the clinical relevance of this relationship remains unclear.

METHODS

This was a retrospective comparative study. Data collection was initiated after approval had been obtained from our institutional clinical research Ankara Bilkent City Hospital Medical Researches Ethics Committee (Date: 18.03.2026, Decision No: TABED 2-26-1873). All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki. Patients who underwent primary arthroplasty for gonarthrosis or coxarthrosis between April 2022 and April 2025 were eligible for inclusion. Patients with advanced varus deformity, valgus knee deformity, previous knee or hip surgery, dysplastic hip anatomy, intraoperative periprosthetic fracture, chronic renal failure, bleeding disorders, prior malignancy treatment, or incomplete clinical or laboratory data were excluded. The patient selection process is illustrated in **Figure 1**.

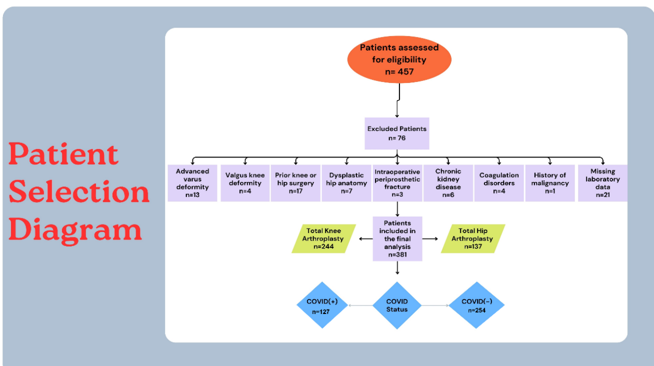

Figure 1. Study flowchart

Flow diagram demonstrating application of inclusion/exclusion criteria and final allocation of patients into COVID-positive (n=127) and COVID-negative (n=254) arthroplasty cohorts

Prior COVID-19 infection status was determined using the health registry system, and patients were categorized as COVID-positive or COVID-negative. Vaccination status, including vaccine type and cumulative dose, was also retrieved from the health registry for each patient.

Patient demographics including age, sex, comorbidities, and operated side were recorded. Laboratory parameters including hemoglobin, hematocrit, and transfusion data were recorded preoperatively and on postoperative days 0 and 1. Changes between preoperative and postoperative values were calculated.

All procedures were performed by experienced arthroplasty surgeons. Patients were admitted one day prior to surgery. Prophylactic cefazolin was administered 30 minutes before incision. Tranexamic acid (10 mg/kg) was given preoperatively to reduce blood loss. Thromboprophylaxis with low-molecular-weight heparin was initiated 8 hours after surgery.

Total Knee Arthroplasty

TKA procedures were performed under spinal or epidural anesthesia using a standard medial parapatellar approach following tourniquet inflation. The patella was everted, osteophytes were removed, and lateral facetectomy with denervation was performed. Femoral and tibial bone resections were performed in alignment with the mechanical axis. After cement fixation and adequate hemostasis, a closed-suction drain was inserted and the wound was closed in layers. After the effect of post-operative spinal/epidural anesthesia wore off, passive quadriceps exercises were started. A compressive dressing was applied after wound closure. The drain and dressing were removed on postoperative day 1. Patients were mobilized with full weight bearing and allowed unrestricted range of motion.

Total Hip Arthroplasty

All patients underwent spinal/epidural anesthesia. THA procedures were performed via a posterolateral approach. Following release of the short external rotators and capsule, the femoral head was dislocated. After trialing, the definitive acetabular component was implanted at the planned inclination and anteversion. Depending on the surgeon's preference, a ceramic or polyethylene liner was implanted. After proper access to the femoral canal, trial femoral components were used to determine appropriate stem size and offset. Hip stability, limb length, and range of motion were assessed during trial reduction. The definitive femoral stem and head were then implanted. Following bleeding control, the capsule and external rotators were repaired. All patients were started passive muscle exercises after the effect of spinal/epidural anesthesia wore off. All patients were mobilized with full weight bearing on postoperative day 1.

Statistical Analysis

Continuous variables are presented as mean±standard deviation, whereas categorical variables are expressed as frequencies and percentages. Normality of data distribution was assessed using histogram evaluation, Q-Q plots, and the Kolmogorov-Smirnov test because of the relatively large sample size. For comparisons between two groups, the independent-samples T test was used for normally distributed continuous variables, and the Mann-Whitney U test was applied when normality assumptions were not met. Comparisons among three or more groups were performed using one-way analysis of variance (ANOVA), with appropriate post hoc analyses when indicated. Categorical variables were compared using the chi-square test or Fisher's exact test, as appropriate. Multivariable linear regression analysis was performed to identify factors associated with postoperative hemoglobin change. Variables entered into the regression model included age, sex, comorbidities, type of arthroplasty (total knee arthroplasty vs total hip arthroplasty), prior COVID-19 infection status, and vaccination status. Regression coefficients were reported with corresponding p values.

$p<0.05$ was considered statistically significant. All statistical analyses were performed using SPSS software (version 26.0; IBM Corp., Armonk, NY, USA).

RESULTS

Following application of eligibility criteria, a total of 381 patients' data were included in the study. 244 (64%) of these patients underwent TKA and 137 (36%) underwent THA. The mean age of the patients in the study was 63.4±10.1 years. 64.8% of the patients had no history of COVID infection, while 33.3% had a history of COVID infection. Of the patients with a history of COVID infection, 15 (4.1%) had a history of hospitalization due to COVID infection. The mean age of patients without a history of COVID infection was 63.2±10.5 years, while the mean age of patients with a history of infection was 63.9±9.3 years. No significant difference in age was

observed between the two groups (p=0.47). The distribution of comorbid diseases of patients in both groups is shown in Figure 2.

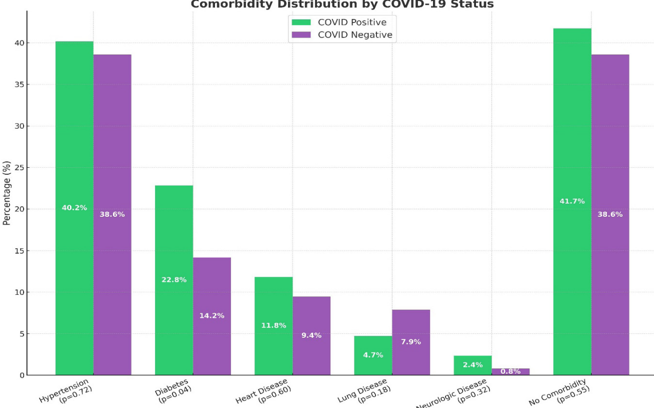

Figure 2. Comorbidity distribution between cohorts

Bar chart comparing the prevalence of major comorbidities in COVID-positive and COVID-negative patients undergoing arthroplasty, with percentage values displayed and p-values indicating between-group differences

The Charlson Comorbidity Index was 2.24±1.23 in patients without a history of COVID infection and 2.28±1.17 in patients with a history of infection. No significant difference was observed between the groups (p=0.715).

Among patients without a history of COVID-19 infection, 98 underwent THA and 156 underwent TKA, whereas among patients with prior infection, 39 underwent THA and 88 underwent TKA. No significant difference was observed between the groups in terms of arthroplasty distribution (p=0.162).

While 140 of the patients without a history of COVID infection were women, 75 of the patients with a history of infection were women. There was no significant difference was observed between the groups in terms of sex distribution (p=0.43).

The data on the mean blood values of the patients in the study on preoperative and post-operative day 1 are presented in Table 1.

Table 1. Mean hemoglobin. hematocrit values of the patients in the study on pre-operative and post-operative day 1 and the changes between the two values

Parameter	Preop mean±SD	Postop day 1 mean±SD	Change (postop-preop), mean±SD
Hemoglobin change	13.27±1.35	10.73±1.37	-2.53±1.32
Hematocrit change	40.81±4.48	32.95±4.52	-7.85±5.34

Postop: Postoperative, Preop: Preoperative, SD: Standard deviation

Data on the changes in pre-operative and post-operative laboratory values of the groups (patients with and without a history of COVID infection) and their comparison are presented in Table 2.

Table 2. Data on the mean changes in pre-operative and post-operative laboratory values of patients with and without COVID infection history and the evaluation of both patient groups in terms of change

Parameter	Group	Mean change (postop-preop)±SD	n	p-value
Hemoglobin	COVID (-)	-2.65±1.25	254	-
Hemoglobin	COVID (+)	-2.22±1.37	127	0.003
Hematocrit	COVID (-)	-8.18±5.76	254	-
Hematocrit	COVID (+)	-7.02±4.33	127	0.031

Postop: Postoperative, Preop: Preoperative, SD: Standard deviation

No significant difference was observed was found between the hemogram and hematocrit change values of patients hospitalized due to COVID infection and patients with a history of COVID infection but without hospitalization (p=0.282) (p=0.305).

When the changes in hemoglobin and hematocrit values were compared with vaccination status, the mean change in Hgb was -2.14±1.25 g/dl in the group vaccinated only with Sinovac and -2.86±1.45 g/dl in the group vaccinated only with BioNTech (p=0.0002). Htc change was -6.57±3.73 in the group vaccinated only with Sinovac and -8.59±6.70 in the group vaccinated only with BioNTech (p=0.0087). When the relationship between the total vaccine dose (0, 1-2, or ≥3 doses) and the changes in the parameters was examined, no significant difference was found between the changes in Hgb and Htc values and vaccine dose (p>0.05).

To evaluate the independent factors affecting postoperative hemoglobin change, age, history of COVID-19 infection, hospitalization due to COVID-19 infection, type of arthroplasty (knee/hip), Sinovac and BioNTech vaccination doses, and Charlson Comorbidity Index were included in a multiple linear regression model, and the backward elimination method was applied. The analysis revealed that a history of COVID-19 infection, receipt of the BioNTech vaccine, and undergoing total knee arthroplasty (TKA) were significant independent factors associated with postoperative hemoglobin change. Patients with a history of COVID-19 infection demonstrated a 0.36 g/dl lower mean hemoglobin decrease. In addition, receipt of the BioNTech vaccine and undergoing TKA were negatively associated with hemoglobin decline. Hemoglobin change in patients who underwent TKA was 1.2 g/dl lower compared to those who underwent total hip arthroplasty (THA) (Table 3).

Table 3. Multiple linear regression analysis of independent factors affecting postoperative hemoglobin change

Variable	Coefficient (β)	SE	t-value	95% CI (lower-upper)	p-value
Constant	-3.09	0.19	-16.58	(-3.45)-(-2.72)	<0.001
COVID-19 history (1 vs 0)	+0.36	0.12	2.86	0.11-0.60	0.004
BioNTech dose (per increase)	-0.15	0.07	-2.27	(-0.29)-(-0.02)	0.024
Knee arthroplasty (vs hip)	+1.18	0.12	9.51	0.93-1.42	<0.001

SE: Standard error, CI: Confidence interval

DISCUSSION

The most important finding of this study was that although COVID infection and vaccination history were statistically different in early blood loss after arthroplasty surgery, these changes did not have a clinically significant effect.

Although normalization in daily life and health has been achieved after the COVID-19 pandemic, which is a serious process for the whole world, the effects of the pandemic on patients have become a very interesting topic in the literature. In the literature, it has been shown that complications related to cardiopulmonary, thromboembolic and kidney damage may occur more frequently in patients with a history of COVID infection after total joint arthroplasty.[11,12] The increased risk of post-operative complications and mortality has also been

demonstrated in other studies.[13] Lung et al.[14] compared patients with and without a history of COVID infection and reported that blood loss was significantly higher in patients with a history of COVID infection, but there was no difference in other complications such as venous thromboembolism and pneumonia. Weinberg et al.[15] also evaluated the effect of COVID infection by comparing patients with and without a history of infection and showed that patients with a history of COVID infection had lower ferritin and hemoglobin values before arthroplasty surgery compared to the control group, but surgery-related blood loss and transfusion requirement were similar to the control group. Since there are different results in the literature regarding the effect of COVID infection history on blood loss in arthroplasty operations, a study was designed on this subject. In the present study, we found statistically lower hemoglobin and hematocrit in patients with COVID infection in both TKA and THA, but this difference was clinically quite small. The authors hypothesized that the amount of bleeding due to hypercoagulability may be less because it is known to cause hypercoagulability due to the inflammatory state caused by COVID infection.[5] Although statistically significant differences in postoperative hemoglobin and hematocrit decreases were observed between patients with and without prior COVID-19 infection, the absolute magnitude of these differences was small (approximately 0.4 g/dl for hemoglobin). Therefore, these findings are unlikely to be clinically meaningful or to influence perioperative management, transfusion requirements, or postoperative recovery. This distinction between statistical significance and clinical relevance is important, particularly in large retrospective cohorts where small numerical differences may achieve statistical significance without reflecting a meaningful impact on patient outcomes.

Limitations

First of all, the fact that it is a retrospective and single-center study is an inherent limitation. The fact that the surgeries were not performed by a single surgeon limits the generalizability of the results. Another limitation is that blood loss assessment is based on hemoglobin/hematocrit change instead of direct intra-operative bleeding, drainage amount or occult blood loss calculation.

CONCLUSION

The hemoglobin and hematocrit decreases in TKA and THA patients with a history of COVID-19 infection were statistically significantly lower than in the control group. However, even though there is a numerical difference, the difference between both groups is not at a level that can make a clinical difference and affect the need for transfusion. Multicenter studies with larger participation are needed to evaluate the effects of COVID-19 infection on the bleeding profile of arthroplasty patients.

ETHICAL DECLARATIONS

Ethics Committee Approval

This study was approved by the Ankara Bilkent City Hospital Medical Researches Ethics Committee (Date: 18.03.2026, Decision No: TABED 2-26-1873).

Informed Consent

This retrospective study used pre-existing anonymized patient data. No additional intervention was performed, and there was no direct patient contact. The study was approved by the Ethics Committee, and the requirement for written informed consent was waived by the ethics committee.

Peer Review Process

This manuscript was subject to external peer review.

Conflict of Interest

The authors declare no conflicts of interest related to this study.

Financial Disclosure

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Author Contributions

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Review

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Pioneering green surgery: exploring current positions, advances, challenges, and pragmatic solutions for resource-inadequate settings-a scoping review

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ABSTRACT

Aims: Surgery is a major contributor to greenhouse gas emissions, especially through anesthetic gases, energy use from machines, and disposable materials. In low- and middle-income countries (LMICs) like Nigeria with limited access to surgery, its environmental impact further challenges already strained systems. This scoping review aims to map the current evidence on the feasibility, strategies, and future directions for implementing environmentally sustainable (green) surgical practices in resource-constrained settings. It also examines its potential role in promoting equity, reducing costs, and supporting ecological conservation.

Methods: We conducted a scoping review following methodological guidance for this study type. A structured search of peer-reviewed articles, global health reports, and case studies was performed using PubMed, Google Scholar, and Scopus. Key concepts and evidence were charted and synthesized thematically. Tools such as the PIPES instrument and Green Surgery Checklist were analyzed for their applicability in LMICs.

Results: Green surgical practices, which include reuse models, solar-powered theatres, digital health, and waste segregation, have been shown to reduce costs, improve outcomes, and cut emissions by up to 97%. The green channel model demonstrated reduced postoperative complications without compromising care. Tools like the PIPES assessment and 5Rs-based checklists support implementation. Climate-resilient infrastructure, ethical frameworks, and global collaborations, including WHO's three-bin waste system, further strengthen sustainability in surgical care.

Conclusion: Green surgery is both feasible and beneficial in LMICs. It aligns environmental goals with surgical equity, cost-effectiveness, and quality care. Embedding sustainable practices into health systems through innovation, policy, and global cooperation is essential for building climate-resilient surgical services and mitigating healthcare's environmental footprint.

Keywords: Green surgery, surgical applications, environmental health, environmental sustainability, health systems, surgery

INTRODUCTION

Conceptual Framework

Green surgery is a concept that aims to ensure surgical practices done in healthcare settings are safe for the environment, thereby minimizing or nullifying the negative, eco-inflammatory impact of surgery on climate.[1] As healthcare systems globally confront the urgent challenge of climate change, green surgery emerges as a model for responsible clinical care that aligns with environmental stewardship. It consists of strategies aimed at waste reductions, energy conservations, and utilization of resources responsibly. The ultimate goal is to decarbonize surgical pathways without compromising quality, safety, or equity, thereby making a positive impact on climate.

Environmental Burden

Surgical care contributes significantly to the environmental impact of healthcare systems. It is interesting to note that studies have estimated that the healthcare sector is responsible for 4.4% of global net emissions,[2] which include carbon

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dioxide, methane, and ozone, among others; and that if the healthcare sector were a country, it would be the fifth largest emitter. The National Health Service (NHS) in England generates an estimated 25 million tons of carbon dioxide per year,[3] responsible for around 4% of national greenhouse gas emissions.[4] Operating rooms (ORs), in particular, are among the most energy-intensive areas in hospitals, consuming three to six times more energy per square foot than other hospital areas.[5] Healthcare is expected to increasingly contribute to exacerbating climate change and its negative impacts, with increasing demand for care worldwide, unless actions are rapidly put in place.

Equity Imperative

A glaring paradox exists in the global distribution of surgical care and its environmental impacts. Low- and middle-income countries (LMICs) represent approximately 70% of the world's population, yet 93% of individuals living in these regions lack access to safe, timely, and affordable surgical care.[6] This contrasts sharply with high-income countries (HICs), where surgical care is more readily available. For example, surgical procedures in HICs often generate 10 to 20 times more waste per case than those performed in LMICs, primarily due to the use of single-use instruments, high rates of over-packaging, and more energy-intensive infrastructure.[7] This disparity highlights a crucial double burden: LMICs face a severe lack of access, while HICs contribute disproportionately to environmental damage from surgical waste.[8]

Review Scope and Objectives

This review sets out to evaluate recent innovations and adaptations in green surgery, with a particular focus on resource-constrained settings. It critically examines systemic barriers to implementation-such as financing, infrastructure, and workforce limitations-and proposes context-specific, pragmatic solutions. The review also explores future directions, including the integration of sustainability metrics into surgical system strengthening. The overarching goal is to inform strategies that expand surgical capacity in LMICs in a manner that is climate-resilient and equitable. The article also aims to critically examine the barriers to implementation. These may include limited financial investment, regulatory restrictions, lack of awareness among healthcare professionals, and cultural preferences for single-use items. The main goal is to ensure that as global surgical capacity expands, it does so in a disposition that aligns with climate resilience and global health equity.

PRINCIPLES AND CURRENT STATE

Core Principles: the 5R Framework

The pursuit of sustainable surgery is anchored in the 5R framework; reduce, reuse, recycle, rethink, and research.

This framework was originally adapted from waste reduction models and the principles have become instrumental in identifying actionable strategies to mitigate the environmental burden of surgical care without compromising safety or access.[9]

Reduce strategies focus on minimizing unnecessary consumption of energy, materials, and pharmaceuticals. Operating theatres consume 3-6 times more energy per square meter than other hospital environments.[4] Transitioning to low-flow anaesthesia, avoiding high-global warming potential agents like desflurane, and optimizing surgical tray content can significantly reduce carbon output.[10]

Reuse involves substituting single-use consumables with validated reusable alternatives, such as autoclavable laparoscopic instruments, surgical drapes, and gowns. When adequately sterilized, these can reduce waste generation by over 50% and lower costs over time.[11,12]

Recycle initiatives require structured segregation of theatre waste streams such as metals, plastics, and paper, supported by staff education and administrative commitment. Although recycling uptake varies globally, targeted interventions in surgical suites have shown recovery of up to 30% of perioperative waste.[13]

Rethink compels re-evaluation of standard protocols. Substituting general anaesthesia with spinal or local techniques, where clinically appropriate, can lower emissions and reduce resource intensity. Similarly, increased use of day-case surgery and enhanced recovery programs may lessen hospital stays and environmental footprint.

Research remains essential to scale sustainable practices. Although robust data exists from HICs, evidence from LMICs is limited. Investment in implementation science and carbon accounting is needed to inform policy and innovation in diverse contexts.[14]

Global Initiatives

Momentum toward green surgery has been propelled by coordinated global initiatives and institutional commitments. In 2020, NHS England became the world's first national health system to commit to net-zero emissions, with a 2040 target for direct care and 2045 for the entire supply chain.[4] Within this framework, the Green Surgery Challenge 2021 catalyzed hospital-led innovations, including eliminating desflurane, optimizing reusable theatre kits, and reducing single-use plastics. Collectively, the five finalist projects projected savings of over 130 tonnes of CO_2 equivalent yearly.[15]

In LMICs, sustainability is gaining traction through the platform of National surgical, obstetric, and anaesthesia plans (NSOAPs). These national blueprints, adopted in more than a dozen countries, emphasize infrastructure resilience and systems strengthening. Zambia has piloted solar-powered sterilization in district theatres, while Tanzania has explored modular, energy-efficient facility design.[16] Global alliances like the global green and healthy hospitals (GGHH) network support cross-border collaboration. Examples include reusable medical kits in India and hospital waste minimization in the Philippines, demonstrating that green solutions can be locally led and globally informed.[17]

HICs vs. LMICs: Contrasting Priorities and Implementation Landscapes

Disparities between HICs and LMICs shape the green surgery frontier. HICs benefit from established infrastructure, enabling sustainability efforts to focus on emission tracking, green procurement, and policy mandates. For instance, several UK and European centres have integrated carbon tracking tools into operating room audits, and are also trialing "carbon budgets" for procedures.[18] In contrast, many LMICs operate with foundational deficits: limited electricity,

water scarcity, supply chain fragility, and under-resourced workforces. Here, the immediate imperative is often access, not emissions. Nevertheless, green practices have emerged organically. Examples such as reprocessed mosquito nets used as hernia mesh in Uganda, or gasless laparoscopy systems deployed in rural India, exemplify low-waste, high-ingenuity interventions.[16,17]

A critical challenge remains the misalignment of incentives. Reusables often carry higher upfront costs, which are not reimbursed in fee-for-service models. Furthermore, global funding mechanisms rarely prioritize sustainability metrics in surgical investments. To bridge this divide, financing strategies, capacity building, and context-adapted innovation pipelines are vital (Table).

TECHNOLOGICAL ADVANCES

Energy-Efficient Technologies

Improving access to safe and affordable surgical care in LMICs is associated with notable health and economic benefits across a range of patient groups.[14] Several established methods exist to facilitate these improvements. As sustainability initiatives progress in LMICs and other resource-limited settings, policymakers should focus on adopting technological and energy-efficient approaches within surgical care to enhance outcomes.

For example, the LigaSure™ energy haemostatic device has been shown to reduce operative times, minimise blood loss, and improve results compared to traditional diathermy in low-resource environments.[20] Lighting contributes significantly to direct energy consumption in operating rooms; thus, introducing LED lighting in LMICs' operating theatres may both improve provider comfort and lower overall energy expenditure.[21] Additionally, energy-efficient technologies can contribute to the development of minimally invasive surgery in resource-constrained contexts. A randomised trial determined that gasless laparoscopy was not inferior to conventional laparoscopy, suggesting its suitability in these settings.[22] The TARGET study addressed issues related to sustainability and skills transfer in LMICs, concluding that structured training programmes in complex procedures increase knowledge and surgical skill acquisition in rural areas.[19]

Waste Reduction Innovations

Recent studies indicate that reusable instrument systems have certain benefits compared to single-use alternatives, such as reduced costs and more environmentally sustainable outcomes.[23,24] By adopting these models, LMICs may achieve economic efficiencies by utilising reusable equipment, which is estimated to cost between 47-83% of comparable single-use options.[23] It is important to note that disposing of reusable equipment before the end of its recommended lifespan can lead to increased overall costs.[25]

The use of biodegradable polymers in LMICs could help limit surgical waste and promote sustainable healthcare practices. Their biocompatibility supports tissue regeneration, and both synthetic and natural variants allow for specific adaptation in terms of mechanical properties, degradation rates, and antimicrobial profiles.[26] Unlike metal implants, biodegradable polymers do not require removal procedures, potentially reducing patient burden.[26] Thereby, offering better medical, financial, and psychological sustainable advantages when compared to conventional solid materials.

Resource-Optimizing Diagnostic Tools

Available data indicate that patients living in rural areas of HICs are offered fewer surgical options for certain treatable cancers compared to those in urban locations.[27] A similar disparity is observed as a significant concern in LMICs as well.[28] Addressing this challenge involves improving diagnostic tools to better allocate resources and potentially improve surgical outcomes in LMICs, especially where resources are limited. Techniques such as fluorescence-guided surgery have been proposed as possible strategies. Evidence suggests their usefulness across multiple surgical specialties, with growing support for their role in enhancing patient safety and surgical efficiency.[29,30] A recent study investigated the practicality of introducing new point-of-care imaging devices in LMICs. The research described the advantages of both basic technologies, such as point-of-care ultrasound, and advanced equipment, including portable ultra-low field MRI, for strengthening diagnostic capacity in these settings.[31] Considerations such as energy consumption, maintenance, and training-needs should be regularly evaluated over time to determine long-term viability as a model for sustainability for LMICs.

Digital Solutions

LMICs continue to encounter significant healthcare challenges, including workforce shortages and inadequate infrastructure. Telemedicine and Artificial Intelligence (AI) offer potential solutions for remote consultations, recordkeeping, diagnostics, and treatment monitoring; however, their implementation necessitates the development of robust ethical and data privacy frameworks.[32] In the

Table. A comparison of implementation policies and priorities between HICs and LMICs[4]

Domain	HICs	LMICs
Infrastructure	Reliable electricity, sterilization, and waste management systems	Unreliable electricity and water supply; limited sterilization and waste disposal capacity
Sustainability focus	Emission tracking, procurement reform, and surgical carbon budgeting[4]	Expanding access, minimizing waste, and maximizing equipment reuse
Examples of innovations	Carbon footprint calculators integrated into OR audits[4]	Mosquito nets used as low-cost hernia mesh in Uganda; gasless laparoscopy in rural India[19]
Economic barriers	Upfront costs of sustainable tools often supported by reimbursement or central funding	High capital costs for reusables rarely reimbursed; local systems lack fiscal incentives
Policy environment	Sustainability embedded in national strategy (e.g., NHS Net Zero)[4]	NSOAPs rarely incorporate environmental sustainability metrics
Innovation model	Top-down, institutionally funded green R&D pipelines	Grassroots, frugal innovations tailored to local limitations

HICs: High-income countries, LMICs: Low- and middle-income countries, OR: Operating room, NSOAPs: National surgical, obstetric, and anaesthesia plans, NHS: National health service

aftermath of the COVID-19 pandemic, telemedicine has been increasingly adopted to improve healthcare access, sustain continuity of services, and mitigate disparities in resource-limited environments.[33] Additionally, these technologies have improved access to specialist care, resulting in reduced travel costs and shorter wait times, particularly in the context of postoperative management.[34] Nonetheless, there remain unmet needs that could be addressed through broader adoption of these innovations across LMICs.

Furthermore, telemedicine has proven effective for skills transfer in low-resource settings, facilitating complex procedures as well as evaluation and peer mentoring during skill acquisition, even when trainers are located remotely from trainees.[19]

LMIC-Specific Adaptations

One example is the use of sterilized mosquito net mesh (MNM) as an alternative to the more costly commercial synthetic mesh (CSM). A systematic review study reported no statistically significant difference in overall post-operative complication rates between the two methods.[35] Furthermore, MNM has demonstrated patient-friendliness, clinical effectiveness, and cost efficiency, making it a promising option for adoption in resource-limited settings across LMICs.[36] Another adaptation that could benefit LMICs is the use of medicinal maggots in surgical care, as several studies have shown their superior benefits for treating complex surgical wounds.[36,37] Though these innovations enhance efficiency and are sustainable, challenges like ethico-cultural acceptance, training gaps, and uneven regulation must be addressed for broader use.

IMPLEMENTATION CHALLENGES IN RESOURCE-CONSTRAINED SETTINGS FOR GREEN SURGERY

Systemic Barriers

Implementing green surgery in resource-constrained settings, particularly in LMICs, faces significant systemic barriers that hinder sustainable surgical practices. A 2016 study highlighted that 31% of hospitals in low-income countries lack consistent electricity, severely limiting the feasibility of energy-efficient technologies like solar-powered systems for green surgery, while water scarcity and inadequate sterilization facilities, often reliant on outdated autoclaves, increase infection risks and force dependence on single-use items that elevate waste and carbon footprints.[38] The dependency on imported surgical supplies in LMICs creates vulnerabilities in green surgery implementation. Stockouts of essential materials, such as reusable surgical instruments, are common due to disrupted supply chains, leading to delays in care and reliance on less sustainable alternatives.[14] Stockpiles of broken or outdated donated medical devices are a well-documented issue in Sub-Saharan Africa, with 70% of donated equipment non-functional due to lack of maintenance or compatibility with local infrastructure.[39] These supply chain inefficiencies hinder the adoption of reusable, eco-friendly surgical tools. Furthermore, Limited budgets in LMICs make it hard to invest in sustainable infrastructure, such as energy-efficient operating rooms or reusable instruments. Fee-for-service payment models, widespread in Sub-Saharan Africa, favor cheaper disposable supplies over pricier reusable ones, as the high upfront costs of solutions like solar-powered sterilizers are out of reach without external funding.[40]

Workforce Limitations

The shortage of trained surgeons is another major hurdle. LMICs, especially in Sub-Saharan Africa, have fewer than one surgeon per 100,000 people, compared to 29 in high-income countries, leaving little capacity to train staff in sustainable practices like maintaining reusable equipment.[41] Task-shifting, where non-physician clinicians (NPCs) perform surgical procedures, is a common strategy in Sub-Saharan countries to address workforce shortages. However, its sustainability is compromised without adequate supervision and training. A 2020 review found that NPCs in 25 sub-Saharan countries face barriers like insufficient training and lack of regulatory support, which hinder their ability to adopt green surgery practices effectively.[42]

Four Delays Framework Application

The four delays framework, originally developed to address barriers in maternal healthcare,[43] provides a lens to analyze obstacles to implementing green surgery in resource-constrained settings. Lack of awareness about surgical needs and cultural stigmas in rural sub-Saharan Africa often deter patients from seeking care, leading to delayed interventions that increase the environmental burden due to advanced diseases requiring resource-intensive procedures.[44] Geographic inaccessibility and transportation challenges further exacerbate delays, with poor road infrastructure and reliance on carbon-intensive diesel-powered ambulances increasing emissions, countering green surgery goals; a 2018 study estimated that 92.5% of sub-Saharan Africa's population lives within two hours of a surgical facility, but this assumes functional transport, which is often unavailable in rural areas.[45] Inadequate equipment and frequent power outages disrupt surgical procedures, as evidenced by a 2023 study in Malawi, Tanzania, and Zambia, which found that only 60% of district hospitals had reliable surgical tools, with power outages forcing reliance on diesel generators that undermine sustainability efforts by increasing carbon emissions.[46] Post-operative care is compromised by poor sanitation and infection control, with 22% of sub-Saharan African hospitals lacking running water, increasing infection risks and necessitating additional resource-intensive interventions that further strain environmental sustainability.[38]

Data and Metrics Gaps

Data gaps make things worse. Unlike high-income countries, LMICs lack standard ways to measure surgical carbon emissions, with less than 5% of global surgical sustainability studies focusing on LMICs, leaving little evidence to shape policy.[41]

Data on waste generation, energy use, and supply chain emissions are rarely collected, hindering the ability to design targeted interventions. For example, the carbon footprint of single-use versus reusable instruments in Sub-Saharan hospitals remains unquantified, making it difficult to advocate for sustainable alternatives.

Case Studies: Surgical Capacity in Sub-Saharan Africa District Hospitals

The PIPES (Personnel, Infrastructure, Procedures, Equipment, Supplies) Index is a standardized tool used to assess surgical capacity in healthcare facilities, particularly in low-resource settings, by evaluating five key components: personnel (availability of trained surgical staff), infrastructure (access

to reliable electricity, water, and facilities), procedures (types of surgeries performed), equipment (availability of functional surgical tools), and supplies (access to consumables like sutures and anesthetics).[47] The PediPIPES Index is a specialized adaptation of the PIPES tool, specifically designed to assess pediatric surgical capacity, focusing on the unique needs of children, such as age-appropriate equipment and specialized procedures. A 2023 study across 67 district hospitals in Malawi, Tanzania, and Zambia reported low PediPIPES scores, highlighting critical shortages, including no specialist surgeons or anesthesiologists, inconsistent electricity and water supply, and poor availability of pediatric surgical equipment and supplies, with Malawi showing the most severe deficits and Tanzania slightly better capacity.[47] In Sudan, Djibouti, and the Central African Republic, an efficiency-productivity paradox is evident: despite high surgical demand, limited resources result in low surgical output, with only 295 surgeries performed per 100,000 population annually compared to 11,110 in high-income countries, exacerbating environmental impacts due to reliance on disposable supplies and carbon-intensive diesel generators.[48]

FEASIBILITY AND SUSTAINABILITY STRATEGIES

The concept of green surgery might sound outlandish, especially in the context of low-income countries still grappling with basic health problems like brain drain, poor infrastructure and healthcare access. However, sustainable strategies exist to make it feasible, taking advantage of preexisting systems and simple innovations to enable efficient, effective change in process and practices.

Context-Adapted Models

- **SURG-Africa's specialist supervision:** SURG-Africa, Scaling up Safe Surgery for District and Rural Populations in Africa is a tested intervention that has trained and supervised non-physician clinicians to deliver essential and emergency surgery using remote training and in person visits to support delivery of surgical services.[49] Green surgery initiatives, now a routine practice in HICs can be included in these programs, enabling effective inclusion using preexisting processes.
- **Surgathons:** The Surgathon model focuses on local medical students and healthcare provider communities, building teams to troubleshoot and solve local health challenges with support and mentorship,[50] enabling local problems to be solved with local solutions and also creating a local innovation system focused on peculiar challenges. This model can be particularly useful in finding solutions specific to an environment to tackle challenges in establishing green initiatives.

5R Framework in LMICs

Reduce: Blood test rationalization involves the development and implementation of quality improvement interventions to reduce the unnecessary abuse of laboratory testing. This has been shown to significantly reduce the cost laboratory procedures and consumption of laboratory resources.[52] Streamlining surgical trays to exclude infrequently used or excess instruments, with preference cards for suture requirements and estimated suture use has also been found to improve operating efficiency, save time, reduce sterilization costs and reduce wastage across board.[53]

Reuse: Reusable surgical linens and instruments are considered to be environmentally friendly. Preferring reusable materials will lead to less waste generation and reduce landfill and incineration costs.[54] Using reusable gowns in operating theaters could lead to a 70% final waste reduction. Currently, reusable gowns are preferred by surgeons and operating theatre technicians, but disposable ones are still broadly used.[55] Establishing reusable surgical linen systems in LMICs, using supply nodes, dissemination, tracking and return is both economical and environmentally friendly.

Recycle: Recycling in the health-care setting presents several challenges, however concerns like contamination and infection control can be mitigated with education on waste handling and clear protocols. Materials like paper, cardboard and metal products can be easily collected for recycling in the operating room. A cohort study that evaluated the waste generated by 237 operations concluded that recycling is not associated with additional costs and has several advantages if the practice is expanded.[56] Establishing formalized regional waste segregation programs makes this more feasible and effective.

Rethink: Rethinking involves selecting the most sustainable choice of intervention and equipment to treat patients without causing any harm. While patient outcomes remain the main focus, sustainability should become a part of practice. Choices like anesthesia type, with the American Society of Anesthesiologists Task Force on the Environment recommending using regional and total intravenous anesthesia as the most sustainable option compared to inhalational agents[57] with an 80% atmospheric loss and global warming potential 2000 times that of carbon dioxide,[58] or an increase in the creation and use of reusable medical devices compared to more expensive but profitable single use devices. Telementoring and Telemedicine, new and emerging solutions, can help reduce pressure on saturated health systems, reduce patient travel and vehicle emissions and also enable international networking in surgical training through virtual conferences, eliminating unnecessary travel.[57]

Research: Environmentally protective choices are typically economical, and promoting more sustainable surgical practice would help improve environmental protection and financial saving. This is especially important in LMICs with struggling economies. There remains a wide gap in sustainable healthcare research, and an even wider gap in sustainable healthcare research specific to developing countries. Research partnerships are necessary to bridge this gap, leveraging preexisting mutually beneficial relationships in vaccine research and tropical disease eradication to drive collaborative efforts. Although the motivation of practitioners and researchers is crucial, the support of national and international entities is needed to address this issue adequately (**Figure**).[57]

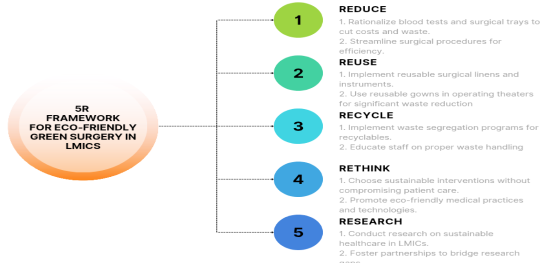

Figure. A process flow chart of the 5R eco-friendly framework for green surgery in LMICs like Subsaharan Africa

5R: Reduce, reuse, recycle, rethink, and research, LMICs: Low- and middle-income countries

Workforce Development

Implementing these changes requires a mental shift, with increasing priority being given to sustainable surgical care at the educational level to retrain and remodel actions and thought processes using mentorship pyramids and curriculum changes.

Surgical mentorship pyramids: This framework is a hierarchical structure where senior surgeons guide junior surgeons and they in turn guide medical officers and students below them, creating a repeating model of improving skills, academic, professional, and technical development. Incorporating sustainable health models, where innovative ideas at the level of surgathons are moved up the pyramid and tested by the seniors, while rethinking choices, new protocols and research focus are subsequently mentored down the pyramid will be an important part of redeveloping the healthcare workforce with a focus on sustainable health.

Green surgery curriculum integration: Also, the integration of environmentally sustainable practices into surgical training, clinical settings and medical school curriculum will stimulate the continued interest in sustainable health research and practices as found in the Green Surgery report.[16]

Policy and Financing

In countries with poor access to surgical care, the approach to sustainable surgical practice is twofold, first to identify and eliminate delays in accessing surgical care like the South Africa's Four Delays prioritization framework,[59] and then establishing National work plans like NSOAPs to implement identified changes on a bedrock of sustainable health practices in a progressively scalable manner.

Integrating green principles into NSOAPs: NSOAPs are strategic efforts embedded in a countries' national health plan to scale up surgical obstetric and anesthesia care. They provide country specific blueprints for building surgical systems that are contextually adapted to the local healthcare system and policies. Meeting the projected need for an additional 143 million surgeries in LMICs and fulfilling the goal of a NSOAP would mean that total emissions could reach 858.0 million to 116.4 billion kg of emitted CO2.[60] Of the eight NSOAPs launched in 2023, only two reported consideration for environmental sustainability and no guidelines regarding indicators for assessing or improving environmentally sustainable surgical capacity building exist. Sustainable health practices and policies must be designed to mitigate the effects of climate change and optimize resource preservation,[61] and NSOAPs created with sustainable surgical care in consideration, provide the most effective pathway to implementation of green surgery in LMICs.

Results-based financing for sustainable practices: By linking financial rewards to the achievement of predetermined sustainable practice targets, results-based financing helps to improve efficiency, accountability and effectiveness of efforts in sustainable health development.

Business Models

Moving towards green surgery is economically beneficial, and embracing the principles of resource optimization, reuse and cost efficiency helps reduce the financial burden of healthcare on low-income populations. Business models exist to take advantage of this, leveraging green initiatives to deliver increasingly affordable surgical goods and services.

Circular economy approaches for device reprocessing: In an era of electronics-driven healthcare, the disposability of many medical devices raises environmental concerns. Transitioning these devices towards a circular economy, extending their lifecycle, involving practices like reuse, remanufacturing, and recycling, holds promise.[62] These approaches involve collecting, cleaning, decontaminating, and potentially repairing or replacing parts of used devices to make them safe and functional for further use (reuse, refurbishment, remanufacturing, recycling, redesign, repair, recover).

Another model to consider is Cross-subsidization, which is a situation where profits from one type of surgical service are used to offset the losses incurred from another, often less profitable, surgical service. This can be a crucial mechanism to ensure continued access to essential but less profitable services for low-income populations. Reducing wastage in high income services helps improve profit margins, providing crucial funds for running low-income essential services.

METRICS AND EVALUATION

Several metrics and evaluation tools can be used to standardize and improve the guidelines for green surgery transformation, especially for low-resource settings. They include environmental impact assessment, clinical outcome measures, equity metrics, and other standardized tools.

Environmental Impact Assessment

Carbon footprint quantification and life-cycle analysis (LCA) are important metrics for this assessment. A study documented the carbon footprints of surgical procedures performed in hospitals around the globe, pointing out carbon hotspots related to surgery and identifying discrepancies in reported carbon footprints.[63] The carbon dioxide equivalents (CO2e) of the estimated carbon footprint varied from 28.49 kg to 505.1 kg CO2e. Emissions from medical equipment and consumables were the highest, with the majority of this carbon hotspot coming from material production and manufacturing. This suggests that sustainability initiatives should be targeted at medical devices and consumables.

Furthermore, according to life cycle studies, the bulk (74%) of total emissions from medical plastic manufacture are caused by items like surgical piping or Polypropylene Random Pipe (PP-R), which have a significant negative impact on the environment.[64] Therefore, the key to reducing the carbon emissions of PP-R pipe by an estimated 50% is the use of more recovered materials and novel technologies for PP-R raw material production.[64]

Clinical Outcome Measures

Emerging novel techniques for anastomotic leak reduction through perfusion assessment, like indocyanine green fluorescence angiography (ICG-FA) for increasing surgical perfusion accuracy, are seen as tech-enabled green methods to stop leaks and cut reoperation rates, hence reducing resource consumption and carbon footprint.[65] Additionally, while considering the rate of surgical site infections between reusable and disposable items, Tevlin et al.[66] in their study, found that a high-volume tertiary referral hand surgery division implemented a three-stage "green case" strategy over one year

to proactively minimize waste and expense associated with routine ambulatory hand treatments. The findings showed that following greening, waste and expenses decreased by 64% and 75%, respectively. Following the use of greening, no rise in surgical site infections or problems was noted.[66] Surgeons can effectively use green measures to cut expenses and waste while maintaining asepsis of surgical sites.

Equity Metrics

Green surgery at low-resource institutions significantly expanded access and decreased delays in surgery without sacrificing results. According to Wang et al.,[67] Green channel surgery's short-term effectiveness in treating hip fractures in older individuals was investigated in their study, comparing the green with the non-green group, and there was no significant difference between the two groups. Additionally, surgical complications were drastically reduced in the green group.[67] The frequency of postoperative problems can be considerably decreased by establishing green channel surgery and collaborating with multidisciplinary teams.

Furthermore, the adoption of green surgery practices is resource-efficient; that is involving the use of less equipment and reuse models, which reduces the overall cost of surgery, which usually contributes to catastrophic expenditure.[68]

Standardized Tools

A verified and trustworthy metric for evaluating surgical capability in environments with limited resources is the PIPES tool (personnel, infrastructure, procedures, equipment, supplies). To evaluate the inter-rater reliability of the PIPES tool, the tool evaluated the infrastructure and processes, equipment, and supply sections. The PIPES instrument is a useful indicator of surgical capability, according to the results.[69]

Another standardized tool used as a metric is the Green Surgery Checklist, which was developed by the 3 UK surgical colleges and distributed among their members. It includes 16 primary suggestions for addressing recognized carbon hotspots in surgery that are focused on the "5 Rs" (reduce, reuse, recycle, rethink, research).[70] Action on the climate catastrophe must be taken immediately. The NHS will be able to meet its NetZero goal by using the Green Theatre checklist to encourage frontline surgical teams to adopt more sustainable practices.[70] The Green Surgery Checklist can, following a conditioning, be adapted and modified for use in low-resource settings.

PROSPECTS

Priority Research Areas

According to a study, they reported that the surgical system in low- and middle-income countries (LMICs) consist of the public and private sectors.[14] The private sector consists of all sorts of qualified doctors, quacks and traditional medical professionals. In some countries under LMICs, the private surgical system controls about ninety percent (90%) of surgical practices.[71] Most patients in LMICs patronize the private sector especially the quacks and traditional medical professionals due to the easy accessibility and affordability.[72]

Additionally, in order to reduce the threats to the surgical system and to promote safe surgical practice, it is important to have climate resilient surgical infrastructure. An example of the climate resilient surgical technique used in some countries is the digestive endoscopic system.[57] This system promotes the 'reduce, reuse, renew and recycle' techniques which help to improve the deleterious effect of surgical processes like anesthetic gases such as desflurane on climate change.[73]

Technological Opportunities

In LMICs, there is an important course to maintain a carbon-free surgical system because of its negative impact on climate change such as harsh weather conditions and emergency of various health conditions.[74]

Therefore, approaches such as use of solar powered surgical suites have been employed in some LMICs such as Rwanda in Butaro District Hospital thereby reducing the use of carbon emitting materials such as generators.[75]

Additionally, the application of the digital technique can also help to promote better green surgical practices in LMICs. For example, in Rwanda, mobile health is now used to practice primary health care services.[76]

Ethical Frameworks

The implementation of ethical guidelines for sustainable green surgical practices requires a robust multidisciplinary team consisting of healthcare providers, researchers and policy makers in order to provide a functional policy change.[77]

Global Collaboration

In the Global North, most of the equipment in the surgical systems are usually used once, while in the Global South, reuse is still very common. This helps to reduce financial and environmental impact of surgical practices, thereby creating a gap for South North learning.[78]

Globally, in order to mitigate the risk associated with surgical practices, the WHO advocates for the introduction of a three-bin system. This system entails separating waste into non-infectious, general and infectious or sharp waste bins. The waste should be collected regularly and rightly labelled.[79]

THE ROLE OF GREEN SURGERY IN ECO-CONSERVATION; A FOCUSED UPDATE

Climate change is the greatest threat to human health in the 21st century. Healthcare provision contributes to 4.4% of total global greenhouse gas emission.[80] This has various effects of extreme weather conditions such as heatwaves, flooding, droughts and storms. Hospital worldwide are responsible for considerable amount of hazardous emission and toxic waste product into base climate.[80]

Healthcare systems, particularly operating theatres are among the foremost causes of environmental pollution due to high energy procedures, anaesthetic gas, and single use surgical instruments. Green surgery practice highlights the need to minimize the use of disposable instruments and promote recycling. This has a significant role in conserving the eco-system by; reducing emissions, conserving energy, and reducing waste. The potential reduction in carbon emission from adoption of sustainable practices in operating theatre is substantial. In the United Kingdom this has been effective in reducing carbon footprints of surgery by about 50-97%.[81] Also, the endoscopic project in Würzburg reduced carbon emission by 20.1%.[81] The health sector consumes a significant amount of fossil fuels, and contributes to considerable greenhouse

gas emission. Placing solar panels in operating theatres and hospitals reduced fossil fuels consumption and power vital appliances and equipment.[82] The use of biodegradable plastic materials and diversion of uncontaminated plastic waste from recycling help minimize the waste sent to the land fills.[81]

Limitations

This review has several inherent methodological constraints. As a scoping review, its synthesis is descriptive and did not include a formal quality assessment of the included literature. While this allowed for broad mapping of a nascent field, it means the findings represent a spectrum of evidence that varies in robustness. The highly heterogeneous nature of the evidence also prevented quantitative synthesis or direct comparison of outcomes. Finally, despite a comprehensive search, the broad scope may have introduced selection bias, with potential underrepresentation of local grey literature from LMICs.

CONCLUSION

This scoping review affirms that green surgery is not a luxury but a necessary and feasible evolution of surgical care in LMICs. It is underpinned by pragmatic frameworks like the 5Rs, enabled by context-adapted technologies and frugal innovations, and measurable through evolving metrics. The path forward requires integrated action:

- **Embed sustainability in foundational plans:** Environmental considerations must be explicitly integrated into national surgical plans (NSOAPs) and health infrastructure projects.
- **Invest in context-specific evidence:** Funding must support research partnerships that generate LMIC-focused data on the environmental and economic impacts of surgical practices.
- **Empower the workforce:** Sustainability must be core to surgical education and training, fostering leadership from within clinical teams.
- **Foster equitable collaboration:** Global partnerships must value and integrate knowledge from LMICs, moving beyond a donor-recipient model to shared innovation. By championing green surgery, the global health community can simultaneously advance two urgent agendas: ensuring universal access to safe, timely surgical care and protecting the planetary systems upon which human health depends.

ETHICAL DECLARATIONS

Peer Review Process

This review was externally peer-reviewed.

Conflict of Interest

The authors declare no conflicts of interest.

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Letter to the Editor

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Beyond analgesia: a perioperative continuum for diaphragm protection

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Dear Editor,

Postoperative pulmonary complications remain a leading cause of morbidity after abdominal surgery. The recent study by Gültop and Şensöz Çelik[1] offers an important contribution: combined block and intravenous (BIV) analgesia effectively preserves postoperative diaphragm contractility compared with single-modality techniques. This finding is significant because it goes beyond pain management and highlights a functional outcome-the preservation of diaphragmatic function, which plays a central role in postoperative recovery.

Protecting diaphragm function, however, requires a perspective that extends beyond the choice of analgesic technique. It should be viewed as part of a continuous perioperative strategy that begins even before the patient enters the operating room. Postoperative diaphragmatic dysfunction (PDD) frequently occurs after abdominal surgery, often resulting from surgical trauma, reflex inhibition, and opioid use. This risk can be reduced through prehabilitation. Preoperative conditioning, particularly inspiratory muscle training (IMT), strengthens diaphragmatic reserve and has been shown to significantly reduce postoperative pulmonary complications.[2]

Intraoperatively, applying lung-protective ventilation (LPV) principles is essential to maintain alveolar stability and minimize ventilator-induced diaphragmatic stress.[3] Using low tidal volumes and moderate levels of PEEP helps prevent a "second hit" on the diaphragm before emergence from anesthesia. Regional techniques such as thoracic epidural analgesia can further reduce opioid consumption and support postoperative respiratory mechanics.

In the recovery phase, the concept of functional analgesia highlighted by Gültop and Şensöz Çelik emerges as a crucial link in this continuum. It reinforces an important clinical reality: being pain-free does not always mean breathing effectively. By reducing opioid use and pain-related reflex inhibition, multimodal analgesia-such as BIV or thoracic epidural techniques-helps preserve diaphragmatic motion. This approach is best guided by objective monitoring, including diaphragm ultrasonography as employed in their study, and refined through understanding how different analgesics modulate neural respiratory drive at the central level.[4] Diaphragm ultrasound, in particular, provides a practical bedside tool to assess dynamic respiratory muscle function and guide individualized optimization.[5]

Integrating IMT, LPV, and multimodal analgesia offers a practical and evidence-based approach to preserving diaphragm function after abdominal surgery. These perioperative measures align with the principles of enhanced recovery after surgery and provide a focused approach that integrates diaphragm protection into respiratory recovery. The anesthesiologist's role extends beyond the operating room, as effective postoperative analgesic management plays a critical part in maintaining diaphragmatic function and supporting respiratory recovery.

ETHICAL DECLARATIONS

Informed Consent

Written informed consent was obtained from the patient for the publication of this correspondence and any related clinical details.

Peer Review Process

This letter was externally peer-reviewed.

Conflict of Interest

The authors declare no conflicts of interest.

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Author Contributions

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Response to the Letter to the Editor: "Beyond analgesia: a perioperative continuum for diaphragm protection"

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Dear Editor,

We sincerely thank the author for their thoughtful comments on our article, "The effects of analgesia methods on postoperative diaphragm muscle contraction in patients undergoing laparotomy." We appreciate their contribution to the discussion of postoperative diaphragmatic function.

We agree that preserving diaphragm function after major abdominal surgery requires a multifactorial perioperative approach, including prehabilitation (inspiratory muscle training), lung-protective ventilation, and early postoperative respiratory optimization. These strategies align with ERAS recommendations and complement our findings.

Our study focused specifically on the early postoperative effects of different analgesia modalities on diaphragm thickening fractions measured by ultrasound. We aimed to determine whether single-modality versus combined analgesia influenced immediate postoperative diaphragmatic contractility, which may affect early respiratory recovery. In this context, combined block plus intravenous analgesia (BIV) preserved diaphragm thickening fractions, whereas IV or block alone showed reductions. We also acknowledge the limitation that epidural analgesia patients were too few for analysis, and future studies including epidural or other multimodal techniques would provide further insight.

Finally, we appreciate the emphasis on diaphragm ultrasonography as a bedside tool for individualized perioperative respiratory management. Integration of objective monitoring can indeed enhance clinical decision-making.

In conclusion, the letter rightly broadens the discussion to include additional perioperative strategies. While these were beyond the scope of our study, our findings highlight the early functional benefits of multimodal analgesia and contribute to the larger framework of diaphragm-protective peroperative care.

Kind regards,
Fethi Gültop, MD
On behalf of the authors