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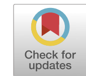

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ABSTRACT

Background: Historically, urgent surgery was advocated in patients with suspected appendicitis because of the risk of perforation and possible complications. Although recent studies have shown that it is safe to delay surgery under certain circumstances, many studies do not report adjusted data and exclude patients based on risk factors. Furthermore, it is unclear whether an ultrasound-based diagnostic workup is sufficient to safely delay surgery. This large retrospective study aimed to analyze the risk-adjusted association between delayed appendectomy and perforation and complication rates.

Methods: Data from consecutive patients who underwent appendectomy for suspected appendicitis at a single institution were reviewed and analyzed. The investigated outcomes were perforation and complication rates. Propensity score (PS) matching was used to create equal groups regarding confounding factors, and multivariate analysis was performed to control for risk factors and to calculate adjusted odds ratios (ORs) for in-hospital delay.

Results: Between January 2008 and June 2023, 4900 patients underwent appendectomy for suspected appendicitis. Ultrasound imaging was performed in 4754 patients. Multivariate analysis of PS-matched data showed no association between a waiting time of > 12 h and perforation rate (OR, 0.93; 95% CI, 0.67–1.31; *P* =.69) or complication rate (OR, 0.90; 95% CI, 0.62–1.30; *P* =.56). Similar results were obtained for a waiting time of 18 h and perforation rate (OR, 0.96; 95% CI, 0.48–1.56; *P* =.88) or complication rate (adjusted OR, 0.97; 95% CI, 0.57–1.68; *P* =.93).

Conclusion: This large PS-matched analysis showed that it is safe to delay surgery by 12 and 18 h, even when the diagnostic workup is based on ultrasound. In patients with risk factors for complications, postponement of the procedure can be considered if it can improve overall conditions or allow the procedure to be performed with a higher level of expertise.

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Introduction

Acute appendicitis is one of the most common causes of lower abdominal pain worldwide. With a lifetime risk of 2% in Africa and 8% to 9% in Europe and Northern America, appendicitis is one of the most common surgical conditions [1,2].

The rate of perforation ranges from 16% to 40% in the literature. Traditionally, it was assumed that an untreated appendicitis would progress to a perforated appendicitis over time [2,3]. The fear of progression to perforation or gangrene has traditionally led to the recommendation that patients with acute appendicitis should undergo appendectomy as early as possible. The origin of this assumption dates more than 100 years back to a time when perforated appendicitis had high mortality rates [4]. Currently, an increasing number of studies suggests that not all patients with acute appendicitis will progress to perforation and that resolution without surgical treatment is possible, which has been shown by several trials comparing surgical and antibiotic treatment of acute

The corresponding author attests that all listed authors meet the authorship criteria and that no other authors meeting the criteria have been omitted.

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appendicitis [3,5,6]. However, even today, gangrenous appendicitis and perforation are associated with higher morbidity. Several studies have shown that it is safe to delay surgery for uncomplicated appendicitis for 12 to 24 h. Guidelines recommend minimizing the delay but state that a delay of 12 to 24 h for presumed uncomplicated appendicitis is acceptable. There is still an ongoing debate about whether it is safe to delay surgery in the elderly population or if comorbidities are present. Of note, 2 randomized controlled trials have demonstrated noninferiority for a delayed surgical approach in imaging-confirmed uncomplicated appendicitis. However, in both trials, more than two-thirds of patients underwent preoperative computed tomography (CT) imaging [7,8]. In a recent meta-analysis, many of the included studies with an adult patient population either did not report imaging modalities or preferably performed CT imaging [9–12].

Ultrasound for appendicitis shows good sensitivity (49%–92%) and specificity (81%–96%), and the positive likelihood ratio (LR+, 8.65) and negative LR (LR−, 0.55) of ultrasound suggest that it is better suited to confirm the presence of appendicitis but less reliable to exclude appendicitis. Abdominal CT for suspected appendicitis is regarded as superior given its higher sensitivity (94%–96%) and specificity (94%–95%) rates, with an LR+ of 12.600 and LR− of 0.017 [13–18]. Although there are health systems that rely heavily on CT imaging for the diagnostic workup of suspected appendicitis, CT imaging is not a standard procedure for the workup of appendicitis in many healthcare systems in both developed and developing countries because of its higher cost, radiation exposure in mostly young patients, and lower availability in rural areas compared with ultrasound [17]. Therefore, the results of these studies may not be fully transferable to all healthcare systems as they do not allow conclusions to be drawn as to whether the exclusion of complicated or perforated appendicitis based on a CT scan is necessary to delay surgery safely. In addition, identifying patients who require early appendectomy to avoid complications is of paramount importance to ensure the safe use of delayed surgery for appendicitis.

We investigated whether in-hospital delay of surgery increases the risk of perforation and the risk of complications in a setting in which ultrasound rather than CT is the primary imaging modality for a diagnostic workup to guide decision-making processes. Many retrospective studies assessing the outcome of in-hospital delay in appendicitis suffer from selection bias as patients with more symptoms, severe leukocytosis, or elevation of C-reactive protein (CRP) levels or those with suspected complicated appendicitis undergo surgery urgently and usually have short waiting times. Therefore, we performed propensity score (PS) matching and adjustment for risk factors to minimize this source of bias.

This was a PS-matched analysis of 4900 consecutive patients who underwent surgery for suspected appendicitis investigating whether an in-hospital delay leads to higher complication rates or higher perforation rates when ultrasound is used as the main imaging modality in the diagnostic workup.

Methods

This study was conducted at the Department of General Surgery, Visceral, and Transplant Surgery at the University Hospital Augsburg, Augsburg, Germany as a single-center retrospective study. This study was approved by the ethics committee of the Ludwig Maximilians University, Munich, Germany (reference number: 23–0500) and was conducted in accordance with the Declaration of Helsinki.

Study population and definitions

We identified all patients aged ≥16 years who underwent emergency surgery for suspected appendicitis at our institution between January 2008 and June 2023 from the institutional electronic database. Electronic health records were reviewed, and perioperative data were extracted. Complications, comorbidities, operative data, and patient characteristics were collected from the database, including age, American Society of Anesthesiologists (ASA) status, body mass index (BMI), preoperative symptoms, preoperative CRP, white blood cell (WBC) count, radiologic findings, intraoperative findings, operating time, percentage of laparoscopic procedures, histopathology results, complication rate, and length of hospital stay. A suspected perforation on imaging was documented if a perforation was described in the written imaging report. Perforation as an endpoint was defined as histopathologically proven perforation or gangrene in the appendiceal specimen. Complication rate was defined as the percentage of patients experiencing a perioperative complication. Histopathologic, imaging, and surgical reports from all 4900 patients were reviewed. Patients who were initially managed conservatively with antibiotics and/or interventional drainage were not included in the analysis.

Surgical intervention

Laparoscopic appendectomy was performed using a 3-trocar technique (one 10-mm trocar for the camera, one 5-mm trocar, and one 12-mm trocar). Open appendectomy was performed using an oblique McBurney incision and a muscle-splitting technique. Depending on the surgeon's preference and intraoperative findings, conversion from laparoscopic surgery to open surgery was performed either via a midline incision or via an oblique incision in the right lower quadrant. In laparoscopic procedures, the appendix was transected using a laparoscopic stapler. In open procedures, either a ligation of the base with subsequent transection and inversion of the appendix stump was performed or a stapler was used to transect the base of the appendix.

Statistical analysis

Continuous data are presented as mean ± SD or median with an IQR, depending on the distribution. Categorical data are presented as numbers with percentages. Continuous variables were compared using the independent *t* test and the Mann-Whitney *U* test, depending on the distribution. Categorical data were compared using the $\chi 2$ test. The Fisher exact test was used for categorical data when the requirements for the $\chi 2$ test were not met. A 2-sided *P* value of < .05 was considered significant. Logistic regression was used to adjust for ASA score, age, diabetes mellitus, intake of anticoagulants, previous abdominal surgery, BMI, WBC count, CRP level, presence of guarding on physical examination, duration of symptoms, and suspected perforation on imaging. Odds ratio (OR) with a 95% CI was reported for each risk factor. Statistical analyses were undertaken using SPSS for macOS (version 29; IBM) and R (version 4.3.1; R Foundation for Statistical Computing).

PS matching

Factors, such as clinical presentation, laboratory values, abdominal examination, and radiologic findings, have a potential influence on the decision to operate on a patient early. Hence, we performed a PS-matched analysis to account for differences between patients with a shorter time from diagnosis to surgery and those with a longer time from diagnosis to surgery. The PS was estimated using a logistic regression model with variables recorded during admission: age, WBC count, CRP level, duration of symptoms, gender (male / female), presence of abdominal guarding on physical examination, ASA score, BMI, suspected perforation on imaging, diabetes mellitus, previous abdominal surgery, and intake of anticoagulants. Patients with missing data for the variables used for PS matching were not included in the analysis.

Patients with a longer time from diagnosis to surgery and those with a shorter time from diagnosis to surgery were matched 1:1 on

Table 1
Baseline characteristics.

Characteristic	N = 4900
Type of surgery	
Laparoscopic	4522 (92.3)
Open	170 (3.5)
Conversion from laparoscopic to open	208 (4.2)
ASA score	
1	2816 (57.5)
2	1693 (34.6)
3	372 (7.6)
4/5	19 (0.4)
Age, y	37.8 ± 18.0
Sex	
Female	2456 (50.1)
Male	2444 (49.9)
BMI, kg/m^2	25.6 ± 5.1
Diabetes mellitus	132 (2.7)
Anticoagulation	342 (7.0)
Previous abdominal surgery	567 (11.6)
Abdominal guarding	2124 (43.3)
Duration of symptoms > 48 h	1276 (27.4)
Preoperative WBC count (per nl)	
Mean ± SD	13.2 ± 4.5
≤10	1233 (25.2)
> 10 to ≤15	2071 (42.4)
> 15 to ≤20	1270 (26.0)
> 20	314 (6.4)
Unknown	12
Preoperative CRP level (mg/L)	
Mean ± SD	5.2 ± 7.1
≤50	3309 (67.8)
> 50 to ≤100	734 (15.0)
> 100 to ≤150	360 (7.4)
> 150	480 (9.8)
Unknown	17
Suspected perforation on imaging	414 (8.6)
Diagnosis to surgery (h)	
Mean ± SD	7.36 ± 7.40
≤12	4109 (83.9)
> 12	791 (16.1)
Operating time, min	58 (45–75)
Perforation on histopathologic examination	883 (18.0)
Complication rate	453 (9.2)
Complications (Clavien-Dindo classification)	
Grade 1 or 2	343 (7.0)
Grade 3a	45 (0.92)
Grade 3b	49 (1.0)
Grade 4a	10 (0.2)
Grade 4b	2 (0.04)
Grade 5	4 (0.08)
Comprehensive Complication Index	2.01 ± 7.40
Negative appendectomy	504 (10.3)
Mortality	4 (0.08)
Length of postoperative stay, d	2.4 (1.8–3.5)

ASA, American Society of Anesthesiologists; BMI, body mass index; CRP, C-reactive protein; WBC, white blood cell.
Data are presented as number (percentage), mean ± SD, or median (IQR).

the logit-transformed PS by a greedy nearest-neighbor algorithm, with a caliper of 0.2 of the SD of the logit of the PS. The balance between both groups was judged by SDs, in which a satisfying matching is obtained when the mean SD is < 0.1 for all variables.

We reported the rates of perforation and complication in each group and used an $\chi 2$ test to compare the results. Furthermore, we performed a logistic regression in the matched sample to adjust for the remaining differences between the matched groups and the calculated OR with a 95% CI for each endpoint.

Results

Between January 2008 and June 2023, a total of 4900 patients underwent appendectomy for suspected appendicitis. Patients who were initially managed conservatively with antibiotics and or interventional drainage were excluded from the analysis.

The demographic characteristics and perioperative findings of the study population are shown in Table 1.

For 4663 of 4900 patients (95.2%), data regarding the onset of symptoms were available. Of note, 1276 patients (27.4%) presented more than 48 h after the onset of symptoms.

An ultrasound examination was performed in 4754 patients, a CT scan was performed in 504 patients, and a magnetic resonance imaging (MRI) was performed in 8 patients. Ultrasound and CT were performed in 465 patients. CT or MRI without previous ultrasound was performed in 40 patients. No preoperative imaging data were available for 106 patients.

The mean time from diagnosis to the start of surgery was 442 min (7.4 h). The waiting time from diagnosis to surgery was > 6 h in 1902 patients (38.8%), > 12 h in 791 patients (16.1%), and > 24 h in 256 patients (5.2%). None of the patients developed an abscess due to the delay in surgery, which required interventional drainage. Laparoscopic appendectomy was performed in 4522 patients (92.3%), and open appendectomy or conversion to open appendectomy was performed in 378 patients (7.7%). The rate of negative appendectomies, defined as appendectomy specimens without pathologic findings, was 10.3% (n = 504). Perforation or gangrene on histopathologic examination was present in 883 patients (18.0%). Perioperative complications occurred in 453 patients (9.2%). The complication rates were 8.5% in patients who underwent laparoscopic appendectomy and 30.6% in patients who underwent open appendectomy. The mortality rate was 0.08% (n = 4).

Logistic regression analysis

A logistic regression analysis was performed for the endpoints "perforation" and "perioperative complication." The results for the endpoint "perforation" are shown in Table 2, and the results for the endpoint "perioperative complication" are shown in Table 3.

Higher ASA scores (P =.043), higher BMI (P < .001), symptom onset > 48 h before presentation (P =.02), age > 65 years (P < .001), suspected perforation on imaging (P < .001), leukocytosis (P < .001), and CRP levels of > 50 mg/L (P < .001) were risk factors for perforation in the multivariate analysis (Table 2). The risk factors for a

Table 2
Risk factors for perforation: multivariate analysis.

Risk factor	OR	95% CI	*P* value (multivariate)
ASA score	1.18	1.004–1.383	.043
Age > 65 y	1.93	1.46–2.55	< .001
Male sex	1.11	0.93–1.33	.25
BMI, kg/m^2	1.03	1.01–1.05	.001
Anticoagulants	1.33	0.95–1.86	.094
Diabetes mellitus	0.97	0.61–1.53	.90
Previous abdominal surgery	1.24	0.96–1.61	.098
Symptom onset > 48 h	1.27	1.04–1.55	.019
Abdominal guarding	1.14	0.95–1.35	.155
Suspected perforation on imaging	3.02	2.35–3.88	< .001
WBC count (per nl)			
≤10	–	–	–
> 10 to ≤15	1.70	1.32–2.21	< .001
> 15 to ≤20	2.77	2.12–3.64	< .001
> 20	2.67	1.82–3.89	< .001
CRP level (mg/L)			
≤50	–	–	–
> 50 to ≤100	2.99	2.38–3.74	< .001
> 100 to ≤150	4.80	3.64–6.33	< .001
> 150	6.02	4.64–7.81	< .001
In-hospital delay > 12 h	0.93	0.71–1.20	.56

ASA, American Society of Anesthesiologists; BMI, body mass index; CRP, C-reactive protein; OR, odds ratio; WBC, white blood cell.

Table 3
Risk factors for complication: multivariate analysis.

Risk factor	OR	95% CI	P value (multivariate)
ASA score	1.55	1.28–1.88	< .001
Age > 65 y	1.38	1.001–1.894	.047
Male sex	1.33	1.07–1.67	.012
BMI, kg/m^2	0.99	0.97–1.01	.24
Anticoagulation	1.37	0.94–1.98	.094
Diabetes mellitus	1.26	0.76–2.04	.36
Previous abdominal surgery	1.56	1.16–2.09	.003
Symptom onset > 48 h	1.26	0.99–1.61	.061
Abdominal guarding	0.99	0.80–1.24	.96
Suspected perforation on imaging	1.96	1.47–2.61	< .001
WBC count (per nl)			
≤10	–	–	–
> 10 to ≤15	1.18	0.88–1.60	.27
> 15 to ≤20	1.19	0.86–1.66	.30
> 20	1.77	1.14–2.72	.010
CRP level (mg/L)			
≤50	–	–	–
> 50 to ≤100	1.80	1.32–2.44	< .001
> 100 to ≤150	3.10	2.18–4.37	< .001
> 150	4.58	3.34–6.25	< .001
In-hospital delay > 12 h	1.22	0.90–1.64	.19

ASA, American Society of Anesthesiologists; BMI, body mass index; CRP, C-reactive protein; OR, odds ratio; WBC, white blood cell.

perioperative complication were higher ASA scores (*P* < .001), age > 65 years (*P* =.047), male sex (*P* =.012), CRP levels of > 50 mg/L (*P* < .001), suspected perforation on imaging (*P* < .001), and previous abdominal surgery (*P* =.003).

Waiting of > 12 h until surgery was neither a risk factor for perforation (adjusted OR [aOR], 0.93; 95% CI, 0.71–1.20; *P* =.56) nor a risk factor for the occurrence of a perioperative complication (aOR, 1.22; 95% CI, 0.90–1.64; *P* =.19) after adjustment for the aforementioned variables.

The signs of perforation on preoperative imaging were present in 414 patients. In this subgroup, an in-hospital delay of > 12 h compared with that of < 12 h was not associated with a higher complication rate after adjustment for risk factors (aOR, 1.38; 95% CI, 0.67–2.88; *P* =.39).

Propensity score–matched analysis

PS matching resulted in 2 matched groups of 737 patients each. The baseline characteristics before and after the matching are shown in Supplementary Tables 1 and 2. As indicated by the standard mean difference (SMD) values for the included variables, a successful matching was achieved in the study population. In the matched dataset, the perforation rates were 15.3% (113/737) in patients who waited < 12 h from diagnosis to surgery and 14% (103/737) in patients who waited > 12 h from diagnosis to surgery (*P* =.46). The complication rates within the matched sample were 10.6% (78/737) in patients who waited < 12 h until surgery and 9.2% (68/737) in patients who waited > 12 h until surgery (*P* =.38). In the matched data, a logistic regression was repeated with the endpoints “perforation rate” and “complication rate” to compare the group of patients who had to wait > 12 h for the procedure with the group of patients who had to wait < 12 h for the procedure, with an additional adjustment for the variables of the matching.

The logistic regression analysis in the matched dataset showed no evidence of a correlation between a waiting time of > 12 h and perforation rate (OR, 0.93; 95% CI, 0.67–1.31; *P* =.69) or complication rate (OR, 0.90; 95% CI, 0.62–1.30; *P* =.56).

A second PS-matched analysis was performed to evaluate the effect of a longer delay of 18 h using the same parameters. PS matching resulted in 2 matched groups of 406 patients each. The baseline characteristics before and after the matching are shown in Supplementary Tables 3 and 4. The SMD values before and after the matching indicate a successful matching in the study population. Logistic regression analysis did not show an association between a waiting time of > 18 h and perforation rate (OR, 0.96; 95% CI, 0.58–1.58; *P* =.88) or complication rate (OR, 0.97; 95% CI, 0.57–1.68; *P* =.93) in the matched dataset.

Discussion

This large retrospective study investigated the association between in-hospital delay and perforation or the occurrence of a perioperative complication in patients with suspected appendicitis undergoing appendectomy. A PS-matched analysis showed no association between a delay of > 12 h or 18 h and an increased complication rate or a higher perforation rate. To the best of our knowledge, this is the largest retrospective study from a single institution on the effect of in-hospital delay in patients undergoing appendectomy for suspected appendicitis.

Our findings are in line with the results from a 2018 meta-analysis of 45 observational cohort studies that did not reveal a higher risk of complicated appendicitis when appendectomy was delayed for 7 to 12 h or 13 to 24 h. The authors concluded that delaying appendectomy for up to 24 h for patients with no preoperative signs of complicated appendicitis does not increase complication rates and morbidity [12]. Unfortunately, many of the included study results were unadjusted for confounders, and among those that were adjusted, only very few were adjusted for the duration of symptoms at the time of presentation, which has been shown to be associated with complicated appendicitis and morbidity [19].

Patients who present with signs of advanced or complicated disease, such as guarding, high WBC counts, or CRP value, or signs of complicated appendicitis are more likely to undergo surgery with minimal delay, thereby introducing a severe selection bias in retrospective studies.

We addressed these issues in our analysis and introduced several statistical efforts to minimize selection bias. First, selection bias was reduced by performing a logistic regression analysis with adjustment for variables that potentially prompt an early operation and included the duration of symptoms as a variable. To further reduce selection bias, a logistic regression analysis with prior PS matching was performed. Of note, 1 group consisted of patients with an in-hospital delay of < 12 h, and the other group consisted of patients with an in-hospital delay of > 12 h. Both groups were matched according to WBC count, CRP level, age, BMI, duration of symptoms and suspected perforation on imaging, diabetes mellitus, anticoagulants, and previous abdominal surgery. This doubly robust analysis did not reveal an association between in-hospital delay of > 12 h and perforation rate or complication rate. The same was true for an in-hospital delay of 18 h in the PS-matched analysis.

Although measures were undertaken to reduce bias, this study has limitations. Apart from documentation bias that most retrospective studies are prone to, it should be noted that the varying levels of training and the absence of standardized definitions for suspected perforation on imaging represent a weakness of the study. Although signs of appendiceal perforation have been defined in the literature, no universally valid definition of perforation on imaging was used throughout the study, and it was solely at the discretion of the radiologist or physician performing the ultrasound examination to report a perforation in his written report based on his findings [20]. Guarding was routinely assessed. However, with any physical examination, there was a potential for slight differences in the interpretations of the results. Furthermore, this study did not incorporate conservative treatment strategies that have been shown to be safe and effective in certain circumstances, and one might argue for all studies investigating in-hospital delay in appendicitis that

some of the patients that are being treated with a delayed surgery might resolve with antibiotic treatment alone. All patients were given intravenous antibiotics before incision, but the administration of antibiotics while waiting for surgery was not standardized.

Of note, two recent randomized prospective trials investigated the role of in-hospital delay. They rely on preoperative CT imaging, which is not common practice in the diagnostic workup of appendicitis in certain healthcare systems. In the PERFECT trial by Jalava et al. [8] and the DELAY trial by Patel et al. [7], 68% and 73% of patients, respectively, underwent CT imaging during the workup. In contrast, only 512 of 4900 patients (10.4%) in our study underwent CT imaging or MRI, and most patients underwent ultrasound examination as the only imaging modality. One of the strengths of this study compared with prospective trials is that no patient was excluded on the basis of clinical, laboratory, or imaging findings or because the surgeon felt it was unsafe to delay surgery. These variables were mentioned as exclusion criteria in the DELAY and PERFECT trials [8,21].

Another strength of our study compared with prospective trials is the collection and analysis of real-world data. This study reflects a situation that is common in many hospitals worldwide. We not only included patients with high CRP levels and those with suspected perforation on preoperative imaging but also presented data representing a time span of 15 years. Diagnostic workup and surgical procedures were performed by physicians and surgeons with varying levels of training and experience.

Despite the results from our study suggesting that it is safe to delay surgery if ultrasound is being used as the primary imaging modality in the diagnostic workup, CT can be helpful if the diagnosis is uncertain. In addition, it has been suggested that CT scans can help reduce negative appendectomy rates [22].

In our retrospective study, patients with high CRP levels and those with suspected perforation on preoperative imaging were included. Interestingly, even in the subgroup of patients with suspected perforation on imaging, a delay of > 12 h did not lead to a higher complication rate. However, it should be noted that the number of patients with suspected perforation who waited > 12 h until surgery was relatively small compared with the total study population. Therefore, although we found no association between an in-hospital delay of > 12 h and an adverse outcome in patients with suspected complicated appendicitis, one should not conclude that it is safe to delay surgery in these patients. Alternatively, the decision to delay surgery for suspected complicated appendicitis may be reasonable in select cases, but the decision should be made carefully considering the patient's overall presentation, including vital signs, comorbidities, and available resources.

Of note, one possible explanation why a delay in surgery is not associated with higher perforation or complication rates in many studies is that perforated and nonperforated appendicitis might represent 2 distinct entities. Based on epidemiologic data, time series analysis, and immunologic studies, it has been postulated that perforated and nonperforated have a different underlying pathophysiology [3, 12, 23, 24]. This study adds to the growing body of evidence by showing the safety of in-hospital delay in acute appendicitis when ultrasound is the primary imaging modality of diagnostic workup. However, it should always be kept in mind that early treatment reduces the time of discomfort for patients when delaying surgery.

Conclusion

In this large retrospective trial, a PS-matched analysis demonstrated that it is safe to delay surgery for 12 h and 18 h, even if the diagnostic workup is based on ultrasound imaging. In patients with risk factors for complications, postponement of the procedure can be considered if it can improve overall conditions or allow the procedure to be performed with a higher level of expertise, as a delay in surgery does not increase complication rates.

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Author contributions

MCS developed the study concept. LA and MCS designed the study protocol. MCS, SS, GM, and AM developed the evaluation plan and performed the statistical analysis. MCS and AM contributed to the collection of data. AM and MCS drafted the initial manuscript. MA, LA, SS, GM, and MH critically revised the manuscript for important intellectual content. Final approval of the version to be published was given by all authors. MCS and AM take responsibility for the work and have control of the decision to publish.

Declaration of competing interest

The authors declare no competing interests.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gassur.2025.102003.

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