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Seasonal and cyclical variations in short-term postoperative outcomes of colorectal cancer: a time series analysis

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To identify a cyclical pattern in short-term postoperative outcomes after colorectal cancer (CRC) surgery across the year. Observational study including all consecutive patients diagnosed with CRC who underwent oncological surgery between January 2012 and December 2023. A time series study was performed to identify a possible cyclic pattern of postoperative complications. Non-supervised learning techniques were used to identify months of surgery with similar outcome variables in the time series. Multivariable analysis with logistic binary regression was conducted to identify independent risk factors for postoperative complications. A total of 1576 patients met the inclusion criteria. The postoperative morbidity and mortality rates were 41.1% and 3.7%, respectively. A cyclical pattern was identified, suggesting that postoperative complications were periodically higher in some months across the year. Three different clusters were identified. *Group 1*: January, April, July, and August; *Group 2*: February, May, September, November, and December; and *Group 3*: March, June, and October. No differences in baseline characteristics were found between clusters. Group 3 presented the highest rate of anastomotic leak ($p \leq 0.001$; OR = 1.61, 95% CI 1.30–2.00), unnoticed perforation $p = 0.027$; OR = 1.86, 95% CI 1.18–2.93), diffuse postoperative peritonitis ($p = 0.018$; OR = 1.50, 95% CI 1.10–2.04) and needed more postoperative reoperations ($p = 0.013$; OR = 1.33, 95% CI 1.07–1.65). Multivariate analysis revealed male sex ($p = 0.002$), duration of operation ($p = 0.017$) and month grouping ($p \leq 0.001$) as independent risk factors for anastomotic leak. Postoperative complications after CRC surgery follow a cyclical pattern, but without seasonal distribution. Three well-defined clusters with different postoperative outcomes have been identified. Month cluster was one of the independent risk factors for anastomotic leak.

Keywords Colorectal cancer, Postoperative outcomes, Cyclical pattern, Time series

Complications in colorectal cancer (CRC) surgery have been reported in up to 50% of patients during the postoperative period and postoperative mortality rate can reach 16%[1,2]. Identifying the factors that play a role in surgical complications is important given their association with lower health-related quality of life, worse survival and increased healthcare costs. The inherent risk factors for postoperative complications, including comorbidities, male sex, emergent surgery, duration of surgery, open approach and blood transfusions have previously been analysed[3,4].

Several studies comprising surgeries of different specialities have shown that postoperative complications exhibit seasonal patterns[5–8]. Emerging evidence suggests that the risk of surgical site infections (SSIs) following a wide range of procedures is significantly higher during the summer months, probably due to variations in meteorological conditions[9–11].

Nonetheless, other periodic factors may influence surgical outcomes, such as peaks in the incidence of medical pathologies putting pressure on healthcare systems during winter months. Holiday periods, staff turnover and

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months when interns are incorporated into hospitals at the beginning of the academic year are other cyclic phenomena potentially affecting postoperative outcomes[6,12,13].

To date, there is little evidence about cyclical variation and surgical outcomes. Research includes heterogeneous studies with different pathologies from diverse geographic locations. A Danish nationwide study by Iversen et al., the only one to focus on CRC surgery, concluded that 30-day mortality after surgery for CRC did not exhibit the seasonal variation observed for comorbid conditions such as cardio-respiratory diseases[14].

The main objective of this study was to analyse whether a cyclical pattern exists in short-term postoperative outcomes after CRC surgery across the year.

Material and methods

Study design, setting and patients

This observational study included a cohort of all consecutive adult patients diagnosed with CRC who underwent elective oncological surgery with curative intent from January 2012 to December 2023. All surgeries were performed by highly qualified colorectal surgeons at the colorectal unit of a tertiary university institution (University Clinic Hospital of Valencia, Spain). Patients presenting with tumours of histology other than adenocarcinoma (melanoma, neuroendocrine, lymphoma) were excluded from the study. Emergent surgery was not included in the study to avoid variability in the cohort. Cases with substantial missing, uncollectable data were also excluded. The study was carried out according to STROBE standards (Supplementary Information 1).

Study endpoints and outcome variables

The aim of this study was to identify a cyclical pattern in postoperative morbidity and mortality after CCR surgery. Outcome variables were 30-day postoperative complications, anastomotic leak, SSIs, postoperative ileus, postoperative reoperation, medical complications, 30-day postoperative mortality, in-hospital mortality, and the need of postoperative blood transfusion. Any deviation from the normal postoperative course was considered a postoperative complication, and these complications were stratified by Clavien-Dindo classification. Anastomotic leak was defined as an intestinal wall defect at the anastomotic site leading to communication between the intra- and extraluminal compartments, or as an abscess adjacent to the anastomosis, in accordance with the International Study Group of Rectal Cancer[15]. Anastomotic leaks were grouped into two pools depending on the management needed. Minor anastomotic leaks included small defects not requiring any treatment (grade A) and leaks with non-surgical treatment, such as antibiotherapy or percutaneous drainage (grade B), while major anastomotic leaks were those needing surgical management (grade C). SSIs were defined according to Centers of Disease Control and Prevention guidelines and classified into superficial or deep.

Data source and study variables

Patient data were collected in an institutional standardised database from hospital and primary care clinical records. The patient variables were age, sex, American Society of Anaesthesiologists (ASA) score and Charlson Comorbidity Index. Tumour variables were tumour location (right colon, transverse colon, splenic flexure of the colon, descending colon, sigmoid colon, or rectum) and tumour stage according to the 8th edition of the American Joint Committee on Cancer (2018). Surgery-related variables were month of surgery, surgical approach (laparoscopic or open surgery), duration of operation, and surgical procedure (right colectomy, segmental splenic flexure resection, left colectomy, sigmoid colectomy, subtotal colectomy, total colectomy, low anterior resection, abdominoperineal resection, or Hartmann's procedure). The need of preoperative transfusion was also recorded.

Ethics approval and consent to participate

The study was performed in accordance with the Declaration of Helsinki and was approved by the Research Ethics Committee of the Hospital Clínico Universitario de Valencia (Spain). Informed consent was waived because of the observational nature of the study and the analysis used anonymous clinical data.

Statistical analysis

Descriptive analysis was carried out of each variable of the sample. Normality of quantitative variables was determined through Kolmogorov–Smirnov test. Quantitative variables were expressed as median and range, and qualitative variables as absolute frequency and percentage. ASA score and Clavien-Dindo classification were dichotomized for the analysis. To analyse the time series, a data table was created relating the month of surgery and number of cases of each outcome variable. The time series were decomposed into trend, seasonal and random (or noise) components. The Dickey-Fuller test was used to study cyclical variation in postoperative complications. The time series was considered cyclical when p-value was ≤ 0.05.

Dendrogram and non-supervised learning techniques (K-medoids) were used to identify groups of surgery months with similar outcome variables in the time series: anastomotic leak, postoperative reoperation, severe complications (Clavien-Dindo > 2), 30-day postoperative mortality and in-hospital mortality. Next, we conducted a descriptive analysis of the month clusters and studied possible between-group differences. Fisher's exact test or χ^2 tests were used to find possible differences between qualitative variables, while the Kruskall-Wallis test was used for quantitative variables. Odds ratio with 95% confidence interval was calculated when significant differences were found. Multivariable analysis with logistic binary regression was conducted to identify independent risk factors for postoperative complications. To avoid possible confusion factors and to reduce the risk of multicollinearity the variance inflation factor was determined for every variable included in the model, and those with values greater than 4 were excluded. p value < 0.05 was considered statistically significant. Statistical analysis was performed using R Core Team, 2022 (R Foundation for Statistical Computing, Vienna, Austria).

Results

Descriptive analysis

A total of 1576 patients underwent surgery for CCR during the study period and met the inclusion criteria. Patient, tumour, and surgery characteristics were outlined in Table 1. Median patient age was 72 years (range = 71), and 601 patients were female (38.1%). Regarding anaesthetic risk, 767 patients were classified as ASA III (48.7%) and the mean Charlson index was 6 (range = 14). Tumours were located mainly in the colon (66.8%). Most patients included in the study presented tumour stage II (32.7%). Concerning surgical features, laparoscopic surgery was performed in 1189 (75.4%) of cases. The most frequent surgical procedures were right colectomy (33.6%) and low anterior resection (25.9%).

Surgery outcomes

A total of 648 (41.1%) patients presented postoperative complications during the 30 postoperative days. Surgery outcomes are detailed in Table 2. The most frequent postoperative surgical complication was postoperative ileus, occurring in 240 (15.2%) patients. The anastomotic leak rate was 7.7% and the SSI rate was 10.7%. During the postoperative period, 168 (10.7%) patients underwent reoperation. According to Clavien-Dindo classification, 254 (16.1%) patients presented severe complications (> II). The 30-day postoperative mortality rate was 3.7% across the whole series, while the in-hospital postoperative mortality rate was 4.1%.

Variable	n = 1576
Age (years)	72 (71)
Sex (female)	601 (38.1)
ASA	
I	48 (3.0)
II	743 (47.1)
III	767 (48.7)
IV	18 (1.1)
Charlson Comorbidity index	6 (14)
Tumour location	
Right colon	499 (31.7)
Transverse colon	84 (5.3)
Splenic flexure of the colon	75 (4.8)
Descending colon	55 (3.5)
Sigmoid colon	340 (21.6)
Upper third of the rectum	184 (11.7)
Middle third of the rectum	166 (10.5)
Lower third of the rectum	173 (11.0)
Tumour stage (AJCC, 2018)	
Unknown	25 (1.6)
0	84 (5.3)
I	361 (22.9)
II	516 (32.7)
III	438 (27.8)
IV	152 (9.6)
Surgical approach (laparoscopy)	1189 (75.4)
Duration of operation (minutes)	150 (487)
Surgical procedure	
Right colectomy	529 (33.6)
Segmental splenic flexure resection	52 (3.3)
Left colectomy	69 (4.4)
Sigmoid colectomy	281 (17.8)
Subtotal colectomy	39 (2.5)
Total colectomy	36 (2.3)
Low anterior resection	408 (25.9)
Abdominoperineal resection	83 (5.3)
Hartmann's procedure	76 (4.8)
Preoperative Transfusion	115 (7.3)

Table 1. Patient, tumour, and surgery characteristics of study patients. ASA, American Society of Anaesthesiologists. AJCC, American Joint Committee on Cancer, 8th edition (2018). Statistics presented as median (range) or n (%).

Variable	n = 1576
Any postoperative complication	648 (41.1)
Postoperative ileus	240 (15.2)
Surgical site infection	169 (10.7)
Superficial wound infection	123 (7.8)
Deep space infection	68 (4.3)
Anastomotic leak	122 (7.7)
Minor (A + B)	28 (1.8)
Major (C)	94 (5.9)
Diffuse peritonitis	59 (3.7)
Postoperative reoperation	168 (10.7)
Postoperative transfusion	180 (11.4)
Medical complications	248 (15.7)
Clavien-Dindo classification	
0	928 (58.9)
I	105 (6.7)
II	289 (18.3)
IIIa	35 (2.2)
IIIb	110 (7.0)
IVa	18 (1.1)
IVb	27 (1.7)
V	64 (4.1)
Postoperative mortality (30 days)	59 (3.7)

Table 2. Surgical outcomes during 30 postoperative days. Statistics presented as n (%).

Time series analysis

The Dickey-Fuller test revealed a cyclical pattern in some postoperative outcomes: severe complications ($p \leq 0.001$), anastomotic leak ($p \leq 0.05$), postoperative reoperation ($p \leq 0.001$), and postoperative mortality ($p \leq 0.001$). Likewise, Fig. 1 illustrates temporal behaviour in the incidence of these variables that was cyclically replicated throughout the study period, suggesting that postoperative complications were periodically higher in some months across the year. Non-supervised learning techniques (K-medoids) and a dendrogram were used to pool months with similar outcome variables in the time series, and three different clusters were clearly identified: *Group 1* = January, April, July, and August; *Group 2* = February, May, September, November, and December; and *Group 3* = March, June, and October (Figs. 2 and 3).

Cluster analysis

Patient, tumour, and surgery characteristics after clustering were outlined in Table 3. No significant differences in study variables were found between the three groups. Regarding surgical outcomes, Group 3 more frequently presented anastomotic leak ($p \leq 0.001$) and thereafter more postoperative diffuse peritonitis ($p = 0.029$) and reoperations ($p = 0.047$) than the other groups, whereas patients in Group 1 showed a higher rate of postoperative mortality ($p = 0.019$). No differences were found in postoperative ileus, SSIs, postoperative transfusion, or medical complications (Table 4).

Between-group analysis revealed that Group 3 presented the highest rate of anastomotic leak ($p \leq 0.001$; OR = 1.61, 95% CI 1.30–2.00), unnoticed perforation ($p = 0.027$; OR = 1.86, 95% CI 1.18–2.93), diffuse postoperative peritonitis ($p = 0.018$; OR = 1.50, 95% CI 1.10–2.04) and needed more postoperative reoperations ($p = 0.013$; OR = 1.33, 95% CI 1.07–1.65). Additionally, the patients included in Group 2 showed the lowest postoperative mortality rate ($p = 0.006$; OR = 0.575, 95% CI 0.37–0.89).

Multivariable analysis

A multivariable analysis was driven and those variables with variance inflation factor greater than 4 were excluded from the model. Logistic binary regression revealed male sex ($p = 0.002$), duration of operation ($p = 0.017$) and month grouping ($p \leq 0.001$) as independent risk factors for anastomotic leak.

Discussion

This study demonstrates the existence of a cyclical pattern in short-term outcomes of CRC surgery, identifying three well-defined month clusters with varying postoperative outcomes. Month clustering also emerged as an independent risk factor for anastomotic leak. These findings introduce new perspectives on CRC surgery outcomes, with potential practical and organizational implications for surgical practice, hospital resource planning, and healthcare policies.

The cyclical nature of medical conditions, particularly cardiopulmonary pathologies, is well-documented, with winter months frequently associated with worse outcomes due to exacerbation of pre-existing

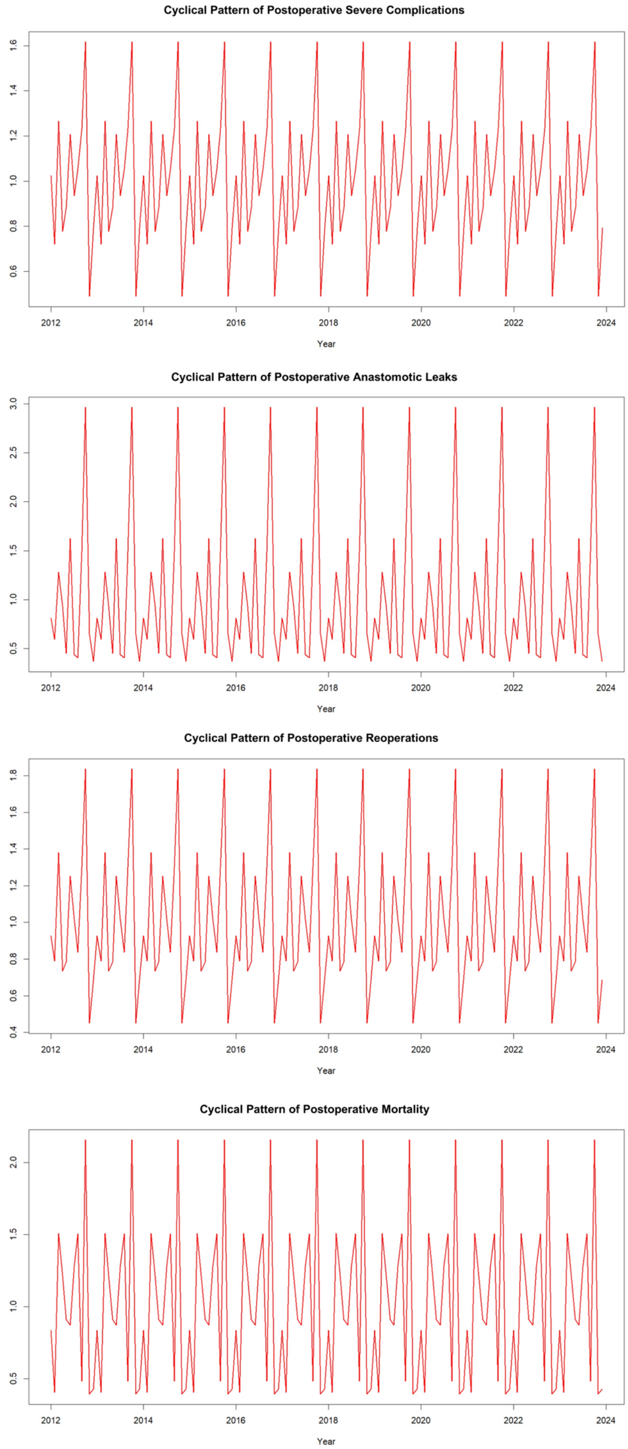

Fig. 1. Time series analysis showing cyclical patterns in postoperative complications. The graph indicates that the waveform is consistent across years, supporting the robustness of the identified cyclicality.

comorbidities[16–18]. In surgical fields, seasonality has been observed in acute abdominal conditions, emergency surgeries, and postoperative complications in bariatric and pancreatic surgery[19–24]. However, studies reporting similar patterns in CRC surgery are limited. The present study, by leveraging unsupervised machine learning (k-medoids clustering), provides novel evidence of cyclical variability, emphasizing the need for a broader understanding of the underlying factors influencing these patterns.

One of the main causes of postoperative complications are aggravations of coexisting cardiac or respiratory comorbidities and cyclical variations have been shown in the incidence of cardiopulmonary pathologies, mainly during the winter months. Likewise, a cyclical pattern has been suggested for short-term outcomes of surgery[23–25]. It has been reported that postoperative complications in pancreatic or bariatric surgery may

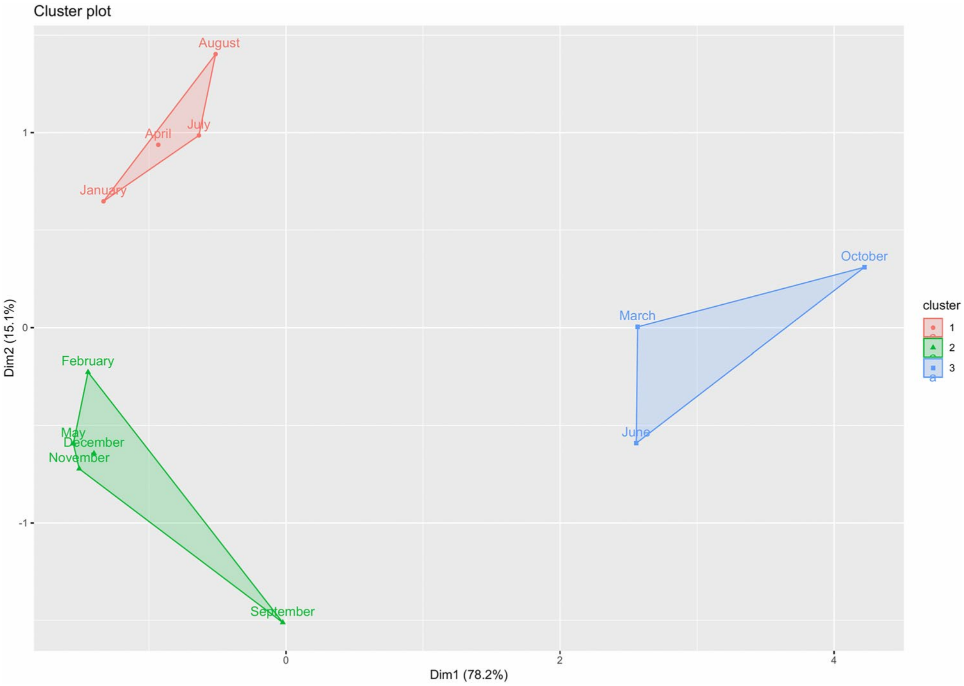

Fig. 2. Cluster plot of months of surgery according to postoperative outcomes.

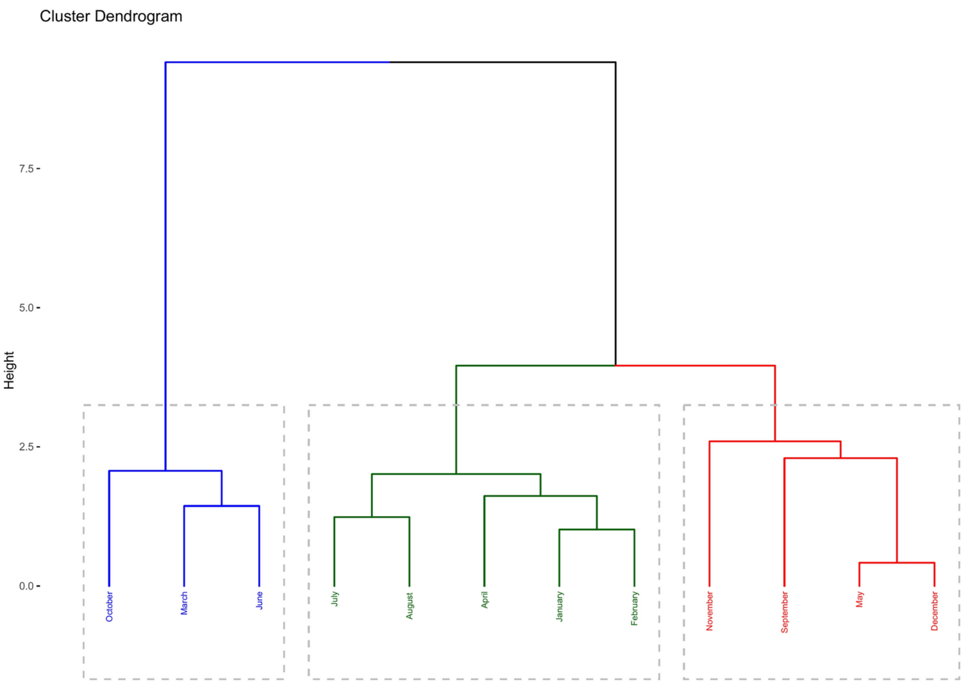

Fig. 3. Dendrogram of months of surgery according to postoperative outcomes.

present variable incidence, with peak periods of worse outcomes that could show a monthly cyclical pattern[26,27]. However, these findings have not been reported for CRC surgery[14]. The present study utilizes an innovative approach to identify a cyclical pattern of CRC postoperative outcomes using time series techniques. The k-medoids statistical classification grouped certain months from different seasons with similar patient, tumour and surgery characteristics that presented different short-term outcomes. However, the reason for this finding remains unclear.

The identification of month clustering as an independent risk factor for anastomotic leak highlights the multifactorial nature of surgical outcomes. While previous studies have associated this complication with patient

	Group 1 n = 492 (31.2)	Group 2 n = 631 (40.0)	Group 3 n = 453 (28.7)	*p*-value
Age (years)	71 (70)	73 (62)	72 (58)	0.393
Sex (female)	196 (39.8)	233 (36.9)	172 (38.0)	0.606
ASA				0.648
I	16 (3.3)	15 (2.4)	17 (3.8)	
II	229 (46.5)	291 (46.1)	223 (49.2)	
III	243 (49.4)	317 (50.2)	207 (45.7)	
IV	4 (0.8)	8 (1.3)	6 (1.3)	
Charlson Comorbidity Index	5 (13)	6 (14)	6 (10)	0.552
Tumour location				0.131
Right colon	162 (32.9)	207 (32.8)	130 (28.7)	
Transverse colon	26 (5.3)	34 (5.4)	24 (5.3)	
Splenic flexure of the colon	19 (3.9)	24 (3.8)	32 (7.1)	
Descending colon	14 (2.8)	27 (4.3)	14 (3.1)	
Sigmoid colon	104 (21.1)	138 (21.9)	98 (21.6)	
Upper third of the rectum	47 (9.6)	79 (12.5)	58 (12.8)	
Middle third of the rectum	64 (13.0)	52 (8.2)	50 (11.0)	
Lower third of the rectum	56 (3.6)	70 (11.1)	47 (10.4)	
Tumour stage (AJCC, 2018)				0.358
Unknown	7 (1.4)	13 (2.1)	5 (1.1)	
0	35 (7.1)	26 (4.1)	23 (5.1)	
I	109 (22.2)	157 (24.9)	95 (21.0)	
II	167 (33.9)	194 (30.7)	155 (34.2)	
III	131 (26.6)	175 (27.7)	132 (29.1)	
IV	43 (8.7)	66 (10.5)	43 (9.5)	
Surgical approach (laparoscopy)	354 (72.0)	486 (77.0)	349 (77.0)	0.095
Duration of operation (minutes)	150 (487)	150 (403)	163 (375)	0.578
Surgical procedure				0.630
Right colectomy	170 (34.6)	220 (34.9)	139 (30.7)	
Segmental splenic flexure resection	13 (2.6)	16 (2.5)	23 (5.1)	
Left colectomy	19 (3.9)	32 (5.1)	18 (4.0)	
Sigmoid colectomy	90 (18.3)	110 (17.4)	81 (17.9)	
Subtotal colectomy	8 (1.6)	20 (3.2)	11 (2.4)	
Total colectomy	9 (1.8)	16 (2.5)	11 (2.4)	
Low anterior resection	130 (26.4)	154 (24.4)	124 (27.4)	
Abdominoperineal resection	27 (5.5)	32 (5.1)	24 (5.3)	
Hartmann's procedure	24 (4.9)	30 (4.8)	22 (4.9)	
Preoperative Transfusion	40 (8.1)	42 (6.7)	33 (7.3)	0.641

Table 3. Patient, tumour and surgery characteristics after clustering. *Group 1*: January, April, July, and August. *Group 2*: February, May, September, November, and December. *Group 3*: March, June, and October. ASA: American Society of Anaesthesiologists; AJCC: American Joint Committee on Cancer, 8th edition (2018). Statistics presented as median (range) or n (%).

factors, surgical technique, and hospital characteristics, the present findings suggest that temporal factors may also play a role. This observation warrants further investigation into the interaction between cyclical patterns, comorbidity exacerbation, and healthcare system pressures.

The influence of operative season on patient outcomes has recent attracted research interest. Several studies have demonstrated that patients undergoing surgery during the winter have increased morbidity and mortality[5,6,8,26]. It has been hypothesized that weather conditions could follow a seasonal pattern influenced by temperature, sun exposure or viral infections; however, we found no seasonal pattern in CRC surgery outcomes, as the clusters of months followed a non-consecutive distribution. Several reports suggest no association between surgery season and postoperative outcomes. In a Danish population study including 33,556 CRC patients, 30-day mortality after surgery for CRC did not exhibit seasonal variation[14]. Similarly, in a cohort study conducted in Germany including 247,474 mixed surgeries, no seasonal variation in mortality was found[28]. Analogously, a retrospective study on 586 patients with gastric cancer reported no association between the season of gastrectomy and short-term outcomes[29].

There is evidence suggesting that SSIs following common surgical procedures, including both gram-positive cocci and gram-negative *bacilli* infections, are more frequent in summer months. Further, some studies reported

	Group 1 n = 492 (31.2)	Group 2 n = 631 (40.0)	Group 3 n = 453 (28.7)	*p*-value
Postoperative complications	205 (41.7)	249 (39.5)	189 (41.7)	0.677
Postoperative ileus	72 (14.6)	94 (14.9)	74 (16.3)	0.734
Surgical site infection	53 (10.8)	61 (9.7)	55 (12.1)	0.430
Superficial wound infection	36 (7.3)	45 (7.1)	42 (9.3)	0.384
Deep space infection	25 (5.1)	25 (4.0)	18 (4.0)	0.601
Anastomotic leak	28 (5.7)	40 (6.3)	54 (11.9)	**≤ 0.001**
Minor (A + B)	10 (35.7)	4 (10.0)	14 (25.9)	**0.036**
Major (C)	18 (64.3)	36 (90.0)	40 (74.1)	
Diffuse peritonitis	11 (2.2)	23 (3.6)	25 (5.5)	**0.029**
Postoperative reoperation	46 (9.3)	60 (9.5)	62 (13.7)	**0.047**
Postoperative transfusion	58 (11.8)	69 (10.9)	53 (11.7)	0.883
Medical complications	75 (15.2)	96 (15.2)	77 (17.0)	0.683
Pneumonia	9 (1.8)	16 (2.5)	16 (3.5)	0.257
Cardiac failure	13 (2.6)	13 (2.1)	18 (4.0)	0.164
Renal failure	10 (2.0)	18 (2.9)	8 (1.8)	0.450
Clavien-Dindo classification				0.103
0	287 (58.3)	381 (60.4)	260 (57.4)	
I	32 (6.5)	47 (7.4)	26 (5.7)	
II	97 (19.7)	112 (17.7)	80 (17.7)	
IIIa	11 (2.2)	12 (1.9)	12 (2.6)	
IIIb	26 (5.3)	42 (6.7)	42 (9.3)	
Iva	6 (1.2)	6 (1.0)	6 (1.3)	
IVb	6 (1.2)	16 (2.5)	5 (1.1)	
V	27 (5.5)	15 (2.4)	22 (4.9)	
Severe complications	76 (15.4)	91 (14.4)	87 (19.2)	0.177
Postoperative mortality (30 days)	27 (5.5)	14 (2.2)	18 (4.0)	**0.019**

Table 4. Surgical outcomes during 30 postoperative days after clustering. *Group 1*: January, April, July, and August. *Group 2*: February, May, September, November, and December. *Group 3*: March, June, and October. ASA, American Society of Anaesthesiologists; AJCC, American Joint Committee on Cancer, 8th edition (2018). Statistics presented as median (range) or n (%). Significant values are in bold.

summer to be an independent risk factor for SSIs after controlling for other known risk factors[9–11]. Conversely, the study carried out by Turan et al. including 2919 patients undergoing colorectal surgery failed to demonstrate an association between SSIs and perioperative vitamin D levels or season[30]. Our study could not reveal an evident cyclical pattern in SSIs, so seasonality or a peak incidence during the summer months could not be proven. These findings may be explained by the Mediterranean coastal setting, where seasons overlap without noticeable boundaries.

Nonetheless, the concept of seasonality extends to cyclic patterns other than meteorological conditions. Conceptually it involves a period when an event occurs regularly on a periodic cyclical basis, and beyond weather phenomena could therefore include holiday periods and staff turnover dates. Apart from these annual variations, pressure reported by hospitals was also found to present intra-annual cyclicity, with the period of highest pressure consistently observed in winter and lowest in summer. Inadequate staffing and high bed occupancy rates may affect quality of care and result in worse postoperative outcomes[6,13].

Although our study focuses on identifying cyclical trends, it is plausible that external factors, such as seasonal variations in institutional workload, staff turnover, and socioeconomic pressures, play a role. For instance, months with increased postoperative complications may coincide with heightened healthcare system demands or changes in staffing. While we did not measure these variables directly, understanding their influence could provide additional context for our findings and should be a focus for future research.

The identification of a cyclical pattern in CRC surgery outcomes has several clinical implications. Recognizing months with higher postoperative complication rates enables institutions to take proactive measures to mitigate risks. For instance, during the identified months (Group 3: March, June, and October), our hospital could optimize resource allocation, bed occupancy, increase staff preparedness, and enhance patient monitoring protocols. Interventions might include prioritizing highly experienced teams for complex cases, reinforcing early detection protocols for complications like anastomotic leak, and scheduling additional postoperative care support. In our institution, awareness of this cyclical trend could guide decision-making, allowing tailored approaches to improve patient outcomes during higher-risk months. While the precise mechanisms underlying these cyclical variations remain unclear, their identification allows institutions to implement targeted strategies aimed at improving patient care and reducing morbidity.

For example, healthcare systems in Mediterranean coastal settings, like the one analyzed in this study, often experience overlapping seasons without sharp meteorological boundaries. However, cyclical hospital pressures during summer vacations or holiday periods (e.g., the *August effect*) may still influence outcomes due to reduced staffing levels. Importantly, our findings suggest that maintaining consistent surgical team presence, as in our colorectal unit, mitigates potential adverse effects. This reinforces the importance of ensuring continuity of care and adequate supervision during vulnerable periods.

The so called "July effect", a hypothesis in the USA that an influx of less experienced trainees in teaching hospitals at the beginning of each academic year results in poorer surgical outcomes, has been widely refuted[31–34]. A similar theory, the "August effect" has been described in Europe, when senior staff are more likely to be on holiday and there are fewer hospital personnel. Nonetheless, research is inconsistent regarding the correlation between holiday months and postoperative morbidity, mortality or length of hospital stay[12,27,35]. The absence of the "August effect" in our institution, despite its prevalence Europe, underscores the importance of local healthcare structures and training models. Although staffing levels are reduced in our hospital during holiday months, there are at least two experienced colorectal surgeons attending in the colorectal unit throughout this period. Coincidently, during summer vacation elective surgeries are reduced in our institution, but oncological surgeries maintain normal activity. This approach to staff and operation scheduling may explain the absence of July or August effect in our series. Regarding the impact of new trainees on surgical outcomes, all residents at our centre are continuously supervised by consultants and are progressively involved in surgeries with increasing complexity, which minimizes the effect on postoperative outcomes.

The periodicity in surgical outcomes observed in the present study may raise the question of whether the worse outcomes observed in Group 1 were attributable to periodic changes in patient factors (such as exacerbation of previous comorbidities), to cyclic pressure on health care systems or to a peak in the incidence of other risk factors. The potential causes for any seasonal variation are likely to be multifactorial and other cyclic phenomena may interact and explain the periodicity. Future multicenter studies are needed to evaluate whether similar cyclical patterns exist in other geographical and institutional settings and to identify region-specific factors influencing surgical outcomes.

While socioeconomic data and institutional changes were not the primary focus of our study, the socioeconomic implications of cyclical surgical outcomes cannot be overlooked. Postoperative complications contribute significantly to prolonged hospital stays, increased healthcare costs, and greater resource utilization. Identifying months with higher complication risks allows healthcare administrators to anticipate potential financial burdens and adapt budget planning accordingly. For instance, targeted prehabilitation programs, aimed at optimizing patient comorbidities before surgery, could be prioritized during higher-risk months to mitigate complications and reduce healthcare expenditures.

As far as we know, this is the first study revealing month of surgery as an independent predictor of anastomotic leak. Likewise, a large series study of isolated lung cancer resections found that risk-adjusted patient morbidity and mortality following surgical resection was independently influenced by operative season[8]. In contrast, Peng et al. could not identify season of surgery as an independent prognostic factor in patients who underwent gastrectomy at a single centre[29].

Moreover, complications like anastomotic leak, identified in our study as significantly influenced by month clustering, impose substantial economic and social costs. Beyond direct financial impacts, these complications result in delayed recovery, loss of productivity, and decreased quality of life for patients. Understanding cyclical trends empowers policymakers and clinicians to develop measures, such as enhanced patient education, stricter perioperative protocols, and improved resource allocation, to minimize these adverse outcomes.

To our best knowledge, this one of the few studies to identify a cyclical pattern in CRC short-term outcomes. The main strength of our study is the use of non-supervised learning techniques to objectively identify surgery month groups with different postoperative outcomes, thus avoiding researcher bias in pooling consecutive months according to seasons or holiday periods based on preconceived ideas. Emergency surgery was excluded from the study to obtain a consistent series. The study cohort was homogeneous, with similar management for all patients, carried out by experienced colorectal surgeons over a long period.

This study should be interpreted in the light of certain limitations. It is an observational, single-centre study, conducted in a specific geographical region, in a cohort likely representative of the Spanish population. The presence of a cyclical pattern could be extrapolated to other areas, although the grouping of months would not necessarily be replicated in other areas of the world, depending on other local factors in each region, such as meteorological conditions, staff distribution, and holidays. Analysis involving climate change was not feasible for this study. Additionally, the sample size was limited to a health catchment area of about 350,000 inhabitants. Larger, multicenter studies are required to validate these findings and explore additional confounding variables, such as socioeconomic status, climate variations, and staffing models. Moreover, the lack of nurse-to-patient ratio data restricts the ability to evaluate the impact of staffing on postoperative outcomes.

Future research should focus on identifying specific mechanisms underlying cyclical variability, including the role of seasonal exacerbations of comorbidities, variations in hospital workload, and patient-related factors. Prospective studies analyzing the impact of preoperative optimization strategies during higher-risk months could provide actionable insights for improving surgical outcomes.

In conclusion, this study provides novel evidence of a cyclical pattern in short-term outcomes following CRC surgery, identifying month clustering as an independent risk factor for anastomotic leak. While the mechanisms remain unclear, these findings have significant practical implications, offering opportunities to optimize surgical care, resource allocation, and patient outcomes. Proactive measures, such as enhanced perioperative monitoring and targeted patient optimization programs, could mitigate complication risks during higher-risk months, ultimately improving healthcare efficiency and patient recovery.

Data availability

Data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Author contributions

JMA and SGB made data curation and formal analysis DMV, VPM and LPS wrote the main manuscript text DCR prepared figures and tables LPGH, FCI and JSSL recorded data CMC acquired and analyzed data All authors reviewed the manuscript.

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Competing interests

Jose Martín-Arévalo reports a relationship with Johnson and Johnson and Medtronic that includes paid expert testimony. David Moro-Valdezate reports a relationship with Johnson and Johnson and Medtronic that includes paid expert testimony and a relationship with Sanofi that includes travel reimbursement. Stephanie Garcia-Botello reports a relationship with Johnson and Johnson that includes paid expert testimony. Leticia Perez-Santiago reports a relationship with Johnson and Johnson that includes funding grants. Vicente Pla-Marti reports a relationship with Johnson and Johnson, Medtronic and B Braun Medical Inc. that includes consulting or advisory and paid expert testimony and a relationship with Takeda Pharmaceutical Co. Ltd. that includes travel reimbursement. David Casado-Rodrigo, Luisa Garzón-Hernández, Francisco Castillejos-Ibáñez, José Saúl Sánchez-Lara, and Carolina Martínez-Ciarpaglini declare they have no financial interests.

Consent statement

Due to the retrospective nature of the study, the Institutional Review Board of the University Clinic Hospital of Valencia waived the need of obtaining informed consent.

Additional information

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