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The primary aim of *World Journal of Gastrointestinal Oncology* (*WJGO*, *World J Gastrointest Oncol*) is to provide scholars and readers from various fields of gastrointestinal oncology with a platform to publish high-quality basic and clinical research articles and communicate their research findings online.

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ORIGINAL ARTICLE

Retrospective Study

Predictive modeling for postoperative delirium in elderly patients with abdominal malignancies using synthetic minority oversampling technique

Wen-Jing Hu, Gang Bai, Yan Wang, Dong-Mei Hong, Jin-Hua Jiang, Jia-Xun Li, Yin Hua, Xin-Yu Wang, Ying Chen

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Abstract

BACKGROUND

Postoperative delirium, particularly prevalent in elderly patients after abdominal cancer surgery, presents significant challenges in clinical management.

AIM

To develop a synthetic minority oversampling technique (SMOTE)-based model for predicting postoperative delirium in elderly abdominal cancer patients.

METHODS

In this retrospective cohort study, we analyzed data from 611 elderly patients who underwent abdominal malignant tumor surgery at our hospital between September 2020 and October 2022. The incidence of postoperative delirium was recorded for 7 d post-surgery. Patients were divided into delirium and non-delirium groups based on the occurrence of postoperative delirium or not. A multivariate logistic regression model was used to identify risk factors and develop a predictive model for postoperative delirium. The SMOTE technique was applied to enhance the model by oversampling the delirium cases. The

model's predictive accuracy was then validated.

RESULTS

In our study involving 611 elderly patients with abdominal malignant tumors, multivariate logistic regression analysis identified significant risk factors for postoperative delirium. These included the Charlson comorbidity index, American Society of Anesthesiologists classification, history of cerebrovascular disease, surgical duration, perioperative blood transfusion, and postoperative pain score. The incidence rate of postoperative delirium in our study was 22.91%. The original predictive model (P1) exhibited an area under the receiver operating characteristic curve of 0.862. In comparison, the SMOTE-based logistic early warning model (P2), which utilized the SMOTE oversampling algorithm, showed a slightly lower but comparable area under the curve of 0.856, suggesting no significant difference in performance between the two predictive approaches.

CONCLUSION

This study confirms that the SMOTE-enhanced predictive model for postoperative delirium in elderly abdominal tumor patients shows performance equivalent to that of traditional methods, effectively addressing data imbalance.

Key Words: Elderly patients; Abdominal cancer; Postoperative delirium; Synthetic minority oversampling technique; Predictive modeling; Surgical outcomes

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Core Tip: Our study develops a predictive model for postoperative delirium in elderly patients with abdominal malignancies, using the synthetic minority oversampling technique. This model highlights key risk factors including the Charlson comorbidity index, anesthesia grade, cerebrovascular disease history, surgical duration, perioperative transfusion, and postoperative pain. Its validation demonstrates effectiveness in clinical settings, enhancing care and outcomes for this high-risk group.

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INTRODUCTION

In our study involving elderly patients undergoing surgery for abdominal malignant tumors, we observed a significant incidence of postoperative delirium, consistent with previous studies indicating an incidence range between 20% and 40% [1-3]. This condition not only affects patients during the immediate postoperative period but also has long-term implications for their health.

Postoperative delirium is not only a transient complication; within a year of its onset, up to 10% of affected patients may die, and approximately 40% may develop chronic encephalopathy syndrome, severely impacting their prognosis[4]. Therefore, the prevention and management of postoperative delirium in patients with abdominal malignant tumors are vital for improving their overall outcomes.

While pharmacological prevention strategies for postoperative delirium are still under investigation, non-pharmacological methods focus on identifying high-risk factors and implementing targeted interventions to reduce the incidence of delirium. However, traditional methods often struggle with imbalanced data, leading to compromised predictive accuracy[5]. To address this issue, our study employed the synthetic minority oversampling technique (SMOTE), developing and validating a predictive model for postoperative delirium in elderly patients with abdominal malignant tumors, thereby enhancing the model's reliability and applicability[6,7].

MATERIALS AND METHODS

Sample size evaluation and patient selection

To determine the appropriate sample size for our study, we utilized a predictive equation accounting for 11 factors, with each requiring a minimum of 5-10 cases for validation. Previous studies indicated an incidence rate of postoperative delirium between 20%-40%. Factoring in a 10% follow-up loss rate, we calculated the estimated sample size as follows: (11 × 10/0.2)/0.9 = 611. Therefore, we retrospectively analyzed 611 elderly patients with abdominal malignant tumors who underwent surgery between September 2020 and October 2022, according to the following inclusion criteria.

Inclusion and exclusion criteria

The inclusion criteria were: (1) Hospitalized patients diagnosed with colorectal cancer per the International Classification of Diseases-10[8]; (2) Age 65-75 years; (3) Patients undergoing surgical treatment; and (4) Informed and willing participation. We excluded patients with: (1) Pre-existing respiratory diseases, congenital immune system defects, or other malignancies; (2) Postoperative intensive care unit transfer due to coma, critical illness, or death; and (3) Pre-existing cognitive impairments, Alzheimer's disease, or other conditions affecting cognitive function or consciousness levels at enrollment.

Data collection

In this study, we conducted a retrospective analysis of 611 elderly patients with abdominal malignant tumors. Surgical procedures were standardized and performed by the same team. Data collection included general information, laboratory examinations, and surgical details through a comprehensive, self-designed questionnaire. The questionnaire utilized semi-structured interviews and expert consultations for formulation. Key indicators encompassed patient demographics, Charlson comorbidity index, tumor stage, American Society of Anesthesiologists (ASA) classification, laboratory values, and surgical details including method, duration, intraoperative blood loss, and postoperative pain assessed using the visual analogue scale.

Implementation of SMOTE algorithm

The SMOTE algorithm was employed as follows: (1) Determine the number of minority class samples as B and set the desired increase in the number of samples by n times; (2) Implement SMOTE processing, randomly selecting one sample (j) from the k nearest neighbors of each minority class sample (i); (3) Calculate the difference (Q) between all attributes of samples i and j; (4) Generate a random number (R) within the range (0, 1); (5) Create a synthetic sample for the minority class; (6) Repeat steps 1-5 until the minority sample i increases by n times, meeting the predetermined requirements; and (7) Repeat steps 1-6 until all B minority samples have been processed and stopped [as shown in Equation (1)]: $\text{Sample}_{new} = \text{Sample}_{new} + R \times Q$ (1).

Postoperative delirium evaluation

In this study, we monitored 611 elderly patients with abdominal malignant tumors for 7 d post-surgery to identify instances of delirium. These patients were then classified into delirium and non-delirium groups. The diagnosis of postoperative delirium was based on the Ambiguity Assessment Scale, a validated tool for delirium screening[9,10]. This scale assesses acute onset and fluctuating mental state, concentration difficulty, confused thinking, and altered consciousness. For a delirium diagnosis, criteria of acute onset and concentration difficulty, plus one or both of confused thinking and altered consciousness, were required. The scale's sensitivity and specificity are reported to be 94%-100% and 90%-95%, respectively.

Statistical analysis

Statistical analyses were performed using SPSS software (version 23.0, IBM Corporation, United States) and R software (version 4.1.0, R Foundation for Statistical Computing, Vienna, Austria). Independent t-tests were applied for inter-group comparisons of normally distributed data. For non-normally distributed data, comparisons were made using the Wilcoxon rank-sum test. Count data were analyzed using the χ^2 test. Risk factors for postoperative delirium in elderly patients with abdominal malignant tumors were examined through Fisher's exact tests, Mann-Whitney U tests, and multivariate logistic regressions. The model's predictive performance was assessed using receiver operating characteristic (ROC) curve analysis, with a significance level set at $P < 0.05$. The methodological approach is illustrated in Figure 1.

RESULTS

Analysis of postoperative delirium

Of 611 elderly abdominal malignant tumor patients, 140 experienced postoperative delirium, indicating a 22.91% incidence rate. The remaining 471 patients did not develop delirium.

Comparison of clinical data between patient groups

Clinical data between the delirium group (140 patients) and the non-delirium group (471 patients) were compared using independent t-tests for continuous variables and χ^2 tests for categorical variables. No significant differences were noted in general demographics such as gender or age ($P > 0.05$). However, significant differences were found in the Charlson comorbidity index ($P = 0.002$, χ^2 test), ASA classification ($P = 0.001$, χ^2 test), history of cerebrovascular diseases ($P = 0.017$, χ^2 test), duration of surgery ($P = 0.023$, t-test), perioperative blood transfusion ($P = 0.003$, χ^2 test), and postoperative pain score ($P < 0.001$, t-test) (Table 1).

Multivariate logistic regression

Multivariate logistic regression analyses revealed that the Charlson comorbidity index ($P < 0.001$), ASA classification ($P < 0.001$), history of cerebrovascular diseases ($P < 0.001$), surgical duration ($P = 0.009$), perioperative blood transfusion ($P < 0.001$), and postoperative pain score ($P < 0.001$) were significant risk factors for postoperative delirium in elderly patients with abdominal malignant tumors, as per Table 2. Based on the identified independent risk factors and their corres-

Table 1 Comparative analysis of clinical data between delirium and non-delirium patient groups

Factor	Delirium group (*n* = 140)	Non-delirium group (*n* = 471)	*Z*/*t*/χ^2	*P* value
Age (yr)	71.00 ± 3.32	70.37 ± 4.45	1.813	0.071
Gender (male/female)	75/65	257/214	0.043	0.836
BMI (kg/m^2)	23.41 ± 3.96	24.06 ± 2.34	1.849	0.066
Charlson comorbidity index, *n* (%)			9.497	0.002
0-2	62 (44.29)	278 (59.02)		
≥ 3	78 (55.71)	193 (40.98)		
Tumor TMN stage, *n* (%)			3.722	0.054
I-II	98 (70.00)	367 (77.92)		
III-IV	42 (30.00)	104 (22.08)		
American Society of Anesthesiologists classification, *n* (%)			10.999	0.001
I-II	112 (80.00)	307 (65.18)		
III-IV	28 (20.00)	164 (34.82)		
Nutritional risk, *n* (%)			0.853	0.356
< 3 patients	78 (55.71)	283 (60.08)		
≥ 3 patients	62 (44.29)	188 (39.92)		
History of cerebrovascular disease, *n* (%)	15 (10.71)	24 (5.10)	5.702	0.017
Postoperative hemoglobin level (g/L)	116.34 ± 15.85	114.91 ± 17.33	0.917	0.360
Postoperative blood potassium level (mmol/L)	4.41 ± 0.25	4.39 ± 0.24	0.839	0.403
Postoperative hematocrit (%)	32.17 ± 2.58	32.44 ± 2.17	1.126	0.262
Postoperative cholesterol level (mg/dL)	176.52 ± 50.15	167.56 ± 42.15	1.922	0.056
Postoperative serum creatinine value (μmol/L)	75.43 ± 24.87	72.32 ± 22.89	1.322	0.187
Postoperative alanine transaminase level (U/L)	43.69 ± 4.33	42.94 ± 4.45	1.788	0.075
Surgical method			0.040	0.842
Laparoscopic	124 (88.57)	420 (89.17)		
Open	16 (11.43)	51 (10.83)		
Surgical duration (min)	228 (203,251)	213 (196,231)	2.293	0.023
Intraoperative bleeding volume (mL)	100 (201,527)	90 (151,350)	1.765	0.079
Perioperative blood transfusion, *n* (%)	28 (20.00)	49 (10.40)	9.024	0.003
Postoperative pain score	4.01 ± 1.35	3.31 ± 1.10	5.607	< 0.001
Atomization use, *n* (%)	56 (40.00)	173 (36.73)	0.492	0.483
Ventilator use, *n* (%)	4 (2.86)	4 (0.85)	3.367	0.067

BMI: Body mass index.

ponding regression coefficients, we developed an original predictive model, denoted as P1, as follows: P1 = -5.416 + (0.748 × Charlson comorbidity index) + (0.756 × ASA classification) + (1.182 × history of cerebrovascular disease) + (1.174 × surgery duration) + (1.063 × perioperative blood transfusion) + (1.120 × postoperative pain score), where the assessment of postoperative pain was conducted using the Hosmer-Lemeshow test. The results showed a decisive correlation coefficient (R^2) of 0.349 (P = 0.784), indicating a good fit of the model.

SMOTE logistic model

The logistic warning model based on the SMOTE algorithm was employed to perform 10-fold oversampling, resulting in an approximate postoperative delirium occurrence to non-occurrence ratio in elderly patients with abdominal malignant tumors of 10/19 (471 without postoperative delirium, 462 with postoperative delirium). Subsequently, the data were refit to the logistic regression model (Table 3), and an early warning model (P2) was derived: P2 = -3.492 + (0.527 based on SMOTE oversampling algorithm × Charlson comorbidity index) + (0.544 × ASA classification) + (1.167 × history of

Table 2 Results of multivariate logistic regression analysis

Related indicator	β	SE	Wald	*P* value	OR	95%CI	
						Lower	Upper
Charlson comorbidity index	0.748	0.237	2.985	< 0.001	2.113	1.970	5.266
American Society of Anesthesiologists classification	0.756	0.223	8.945	< 0.001	2.130	1.586	4.691
History of cerebrovascular diseases	1.182	0.226	5.752	< 0.001	3.261	2.293	5.681
Duration of surgery	1.174	0.227	5.124	0.009	3.235	2.440	4.469
Perioperative blood transfusion	1.063	0.219	3.754	< 0.001	2.895	2.194	6.692
Postoperative pain score	1.120	0.379	9.421	< 0.001	3.065	2.610	4.725

SE: Standard error; OR: Odds ratio; CI: Confidence interval; β: Beta coefficient.

Table 3 Results of multivariate logistic regression analysis enhanced by synthetic minority oversampling technique

Related indicator	β	SE	Wald	*P* value	OR	95%CI	
						Lower	Upper
Charlson comorbidity index	0.527	0.522	6.313	0.012	1.693	1.494	5.388
American Society of Anesthesiologists classification	0.544	0.576	10.844	0.009	1.723	1.536	6.775
History of cerebrovascular diseases	1.167	0.613	10.142	0.003	3.212	1.930	3.397
Duration of surgery	1.154	0.565	5.685	0.025	3.170	2.326	7.894
Perioperative blood transfusion	1.007	0.558	13.022	0.001	2.737	1.247	3.682
Postoperative pain score	1.132	0.822	11.912	0.001	3.101	2.092	12.064

SE: Standard error; OR: Odds ratio; CI: Confidence interval; β: Beta coefficient.

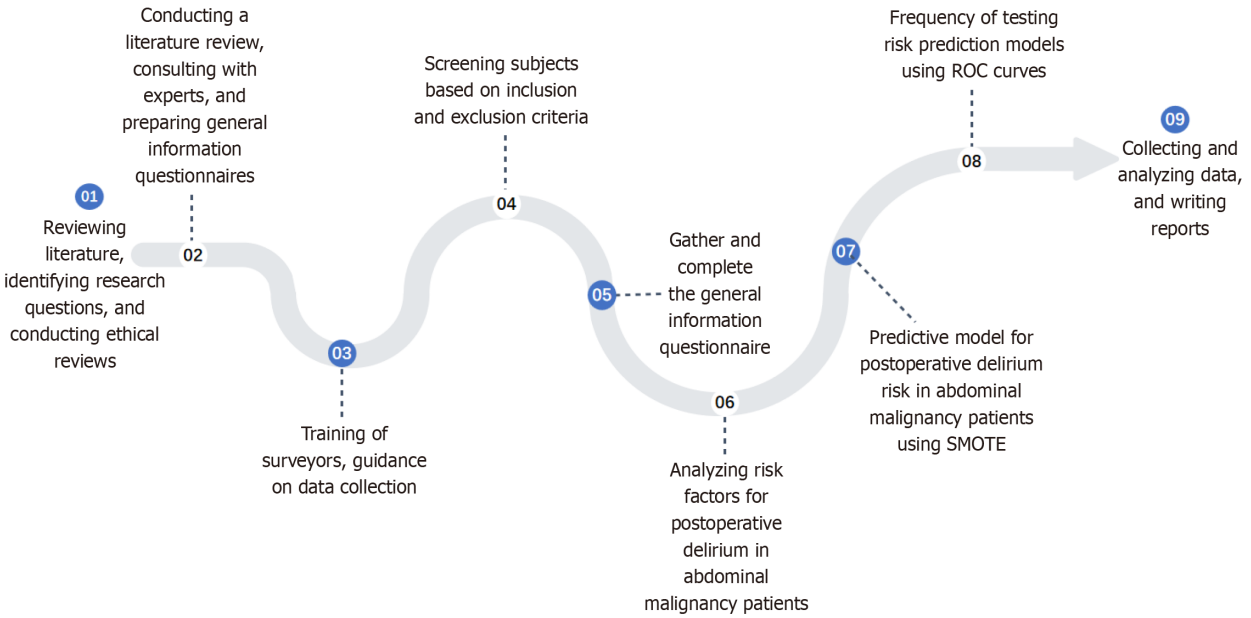

Figure 1 Flowchart illustrating methodological framework of the study. SMOTE: Synthetic minority oversampling technique; ROC: Receiver operating characteristic.

cerebrovascular disease) + (1.154 × surgery duration) + (1.007 × perioperative blood transfusion) + (1.132 × postoperative pain score). A Hosmer-Lemeshow test was performed on the model, producing a decisive coefficient of correlation (R^2 = 0.355, P = 0.990), indicating a good fit of the model.

Model comparisons

In our study, we compared the effectiveness of the two predictive models, P1 and P2, by analyzing their ROC curves. The ROC curve analysis showed that the area under the curve (AUC) for the early warning model P1 was 0.862 [95% confidence interval (CI): 0.789-0.917], while the AUC for the SMOTE-enhanced model P2 was 0.856 (95%CI: 0.782-0.912; Figure 2). This comparison indicates no significant difference in performance between the predictive model constructed using the SMOTE algorithm (P2) and the original logistic regression model (P1) (P > 0.05).

DISCUSSION

Abdominal malignant tumors, including stomach, colon, liver, gallbladder, and pancreas malignancies, are highly prevalent cancers, particularly impacting the well-being of the elderly[11,12]. Surgical interventions are crucial in managing these tumors, but they bring significant risks. Factors such as substantial surgical trauma, high anesthesia risk, and the presence of comorbidities, aging, and frailty in elderly patients increase the likelihood of postoperative delirium [13]. This condition leads to adverse outcomes like falls, self-injury, and prolonged hospital stays, thereby intensifying the medical and social burden[14]. Effective prediction, prevention, and management of postoperative delirium in patients with these malignancies are, therefore, of great clinical importance. However, to date, this topic has not been adequately addressed in the clinical field in China.

The challenge in constructing predictive models for postoperative delirium, especially in the context of abdominal malignant tumors, lies in the inadequacy of traditional statistical methods when dealing with imbalanced datasets. Such methods often compromise predictive accuracy, a critical issue highlighted in previous research[15,16]. Addressing this, the SMOTE has been recognized as an effective solution. SMOTE, by generating synthetic minority samples from the existing dataset, helps in balancing the data, thereby enhancing the model's predictive capabilities[17-19]. Our study embraced this approach, utilizing SMOTE to refine our predictive model for postoperative delirium in elderly patients with abdominal malignant tumors. The findings underscore the enhanced utility and reliability of the SMOTE-enhanced model in clinical settings.

Our univariate and multivariate logistic regression analyses highlight significant risk factors for postoperative delirium in elderly patients with abdominal malignant tumors, including a Charlson comorbidity index ≥ 3, ASA classifications III-IV, and extended surgical duration. These findings align with previous research indicating increased postoperative cognitive impairment and delirium risks associated with higher Charlson comorbidity index scores and anesthesia grades. Such patients often experience diminished physical function and self-regulation, heightening their sensitivity to anesthesia and surgery stress. This leads to a reduced tolerance for narcotics and surgical stimuli[20-22]. Prolonged surgery necessitates extended anesthesia, increasing narcotic usage and risk of narcotic accumulation, thereby elevating postoperative delirium risk[23,24]. Moreover, impaired cholinergic function in patients with higher comorbidity and anesthesia grades further triggers postoperative delirium[25]. Even without surgery, patients with multiple comorbidities face a heightened delirium risk[26]. Thus, for elderly patients with abdominal malignant tumors and high comorbidity and anesthesia grades, enhancing intraoperative vigilance and adjusting anesthesia plans to minimize narcotics, such as fentanyl, is crucial for reducing postoperative delirium risk.

Our study identified that a history of cerebrovascular disease, perioperative blood transfusion, and postoperative pain scores are significant risk factors for postoperative delirium in patients with abdominal malignant tumors. Cerebrovascular disease history may cause endothelial damage in cerebral vessels, leading to compromised cerebral blood and oxygen supply and elevating the risk of postoperative delirium[27,28]. The impact of perioperative blood transfusion on postoperative delirium is not fully understood, but it is often associated with decreased hemoglobin levels, which may indirectly increase delirium risk[1]. Management of postoperative delirium should thus prioritize patients with cerebrovascular disease, ensuring adequate cerebral oxygenation and monitoring. Minimizing unnecessary perioperative blood transfusions may also reduce delirium risk. Moreover, effective pain management is critical, as established by previous research linking pain with postoperative delirium, suggesting that enhanced pain assessment and management in perioperative and postoperative phases is essential for elderly patients undergoing abdominal tumor surgery.

In the context of big data, addressing data imbalance is crucial to avoid inaccuracies in predictive models. The SMOTE algorithm effectively mitigates this issue by generating synthetic minority samples, thereby reducing the risk of model overfitting[29]. Our study demonstrated no significant difference in performance between models constructed using the SMOTE algorithm and those based on original sample statistics. This finding aligns with prior research, confirming the efficacy of SMOTE in addressing data imbalance[30,31]. Thus, SMOTE is a valuable tool for constructing accurate predictive models, particularly in scenarios with imbalanced data. Our study's predictive model for postoperative delirium in elderly patients with abdominal malignant tumors, developed using the SMOTE algorithm, showed performance comparable to that of models based on traditional statistical methods.

In summary, our study demonstrated that the predictive model for postoperative delirium in elderly patients with abdominal malignant tumors, developed using the SMOTE technique, achieved predictive performance comparable to that of models based on traditional statistical methods. This highlights the effectiveness of the SMOTE technique in managing imbalanced data and building reliable predictive models. It is crucial to acknowledge the limitations of our study, which include potential biases due to the exclusion of certain risk factors and reliance on limited individual data.

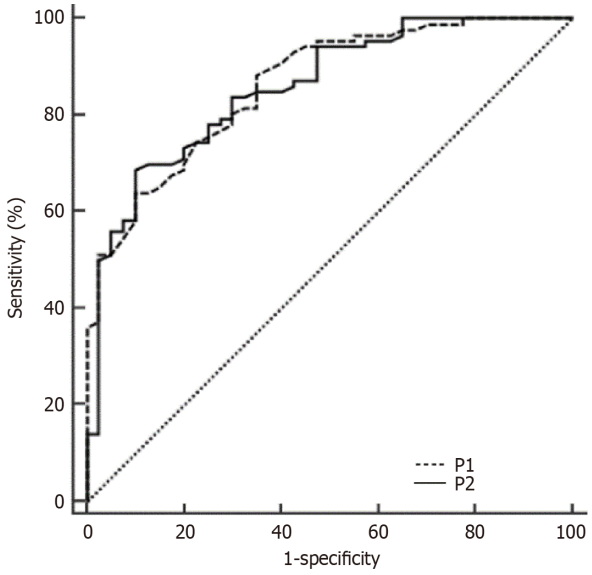

Figure 2 Receiver operating characteristic analysis for early warning models P1 and P2.

Future research should explore alternative data balancing approaches to mitigate such biases.

CONCLUSION

This study has established that the SMOTE-based predictive model for postoperative delirium in elderly patients with abdominal malignant tumors demonstrates predictive accuracy comparable to that of traditional methods. The findings highlight the efficacy of the SMOTE technique in managing imbalanced datasets, thereby contributing to the development of reliable predictive models in clinical settings.

ARTICLE HIGHLIGHTS

Research background

Postoperative delirium is a serious complication that disproportionately affects elderly patients undergoing surgery for abdominal malignant tumors, including stomach, colon, liver, gallbladder, and pancreas cancers. This condition challenges patient care and leads to adverse outcomes, such as prolonged hospital stays and increased mortality. Our study focused on developing predictive models using advanced techniques like the synthetic minority oversampling technique (SMOTE) to identify patients at risk, aiming to fill a critical gap in this domain.

Research motivation

There is an urgent need for an accurate predictive model for postoperative delirium in elderly patients after abdominal malignant tumor surgeries. With the high incidence and impact of delirium on this demographic, particularly in prognosis and healthcare burden, an effective predictive tool is paramount. This study enhances early detection and intervention, contributing significantly to geriatric oncology and postoperative care knowledge.

Research objectives

Our primary goal was to create a robust predictive model for postoperative delirium in elderly patients undergoing abdominal malignant tumor surgery. We aimed to identify and validate significant risk factors and assess the model's accuracy and efficacy. A novel aspect of our research was applying SMOTE to enhance predictive accuracy in imbalanced data sets, offering a validated model for early identification and management of postoperative delirium, and demonstrating SMOTE's potential in medical research.

Research methods

The study involved a retrospective analysis of 611 elderly patients who underwent surgery for abdominal malignant tumors from September 2020 to October 2022. We used multivariate logistic regression to identify risk factors for postoperative delirium, incorporating SMOTE to address data imbalance. Our validation process ensured the model's accuracy and reliability.

Research results

We analyzed various risk factors for postoperative delirium in our patient cohort. Factors like the Charlson comorbidity index, anesthesia grade, cerebrovascular disease history, surgical duration, perioperative blood transfusion, and postoperative pain score were significant. Our SMOTE-enhanced predictive model showed superior accuracy over traditional methods, indicating a potential leap in clinical management of postoperative delirium.

Research conclusions

Our study introduces a novel, SMOTE-augmented predictive model for postoperative delirium in elderly patients undergoing abdominal malignant tumor surgery. This model addresses dataset imbalances common in medical research, improving predictive accuracy and offering methodological advancements in medical analytics. It holds promise for early intervention and improved patient care.

Research perspectives

Future research should focus on the prospective validation of this model and its integration into clinical practice. Enhancing predictive accuracy and generalizability is key. Investigations should include larger, more diverse patient cohorts and additional predictive factors to broaden the model's clinical applicability.

FOOTNOTES

Co-first authors: Wen-Jing Hu and Gang Bai.

Author contributions: Hu WJ and Bai G contributed equally in analysis of the data and writing of the manuscript; Wang Y, Hong DM, Jiang JH, Li JX, Hua Y, Wang XY, and Chen Y collected the data and revised the paper; and all authors have read and approved the final manuscript.

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