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Development of an estimation formula for preparation time of anesthesia induction and surgery accounting for clinical department factors in optimal surgery schedule management

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Efficient operating room management is essential and requires precise surgery scheduling. We hypothesized that an estimation formula for the preparation time for anesthesia induction and surgery could be developed by incorporating anesthesia and surgical factors, as well as the 'clinical department,' into the formula. This retrospective observational study analyzed 12,528 scheduled surgical cases. A regression analysis that included the clinical department, six anesthesia factors, and five surgical factors was conducted. This analysis aimed to develop both an analytical framework and an equation for estimating the time required for both anesthesia induction and surgical preparation. Our estimation formula wielded high accuracy ($R^2 = 0.801$). Particularly, there was only a difference of less than 3 min for surgeries under general anesthesia. In addition, modeling preparation time using "medical interventions performed in the operating room" as a factor instead of patient characteristics was found to be beneficial. It was possible to develop a highly accurate formula for estimating preparation time of anesthesia induction and surgery by analyzing the anesthesia factors and the surgical factors and incorporating the clinical department as an estimation factor. However, this study represents the development phase of the estimation formula. A multicenter study is essential to validate its generalizability and robustness across different settings before broader application.

Keywords Anesthesia induction time, Surgery preparation time, Clinical department, Optimal surgery schedule management, Time estimation formula

Recently, to maintain efficient and stable management of medical institutions and to improve the quality of medical care and nursing for patients, specialists such as doctors, nurses, medical technicians, and administrators have been striving to achieve efficient management of medical institutions[1]. Particularly, surgical medicine requires the investment of considerable medical resources and accounts for a large proportion of hospital income[2]. Frequently, the efficiency of an operating room is discussed solely on the basis of the total number of operations performed. However, previous studies have not adequately considered the complexity of individual surgeries and patient factors, limiting the accuracy of scheduling models[3]. Recent research has focused on more comprehensive models, incorporating variables like surgery duration, patient condition, and staff availability, but these models still struggle to predict irregular preparation times efficiently[4,5]. It is necessary to analyze efficiency from various viewpoints such as expansion of human and material resources (input of medical resources such as

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operating rooms and staff) and analysis of time division in operating rooms[6,7]. In the United States of America, various indicators for efficient management of the surgical department have been reported, such as personnel cost, delay in starting surgery, surgery cancellation rate, and replacement time[8]. For more efficient operation room management, it is important to create an accurate operation schedule[9–12].

Time definitions and terminologies for the operating room have been standardized by the American Association of Clinical Directors (AACD). To operate the operating room more efficiently, clarity on the time division for surgery and anesthesia enables the preparation of accurate operation schedules[13–15]. Efforts have been made to standardize operating room efficiency, such as surgical techniques and performing thorough medical background checks of the staff and to estimate preoperative time and PACU time[16,17]. Therefore, to estimate the exact time associated with the operating room, models have been developed to estimate the preoperative time[18]. However, recent models have shown limitations in generalizability, often focusing on specific surgical departments or anesthesia types, making them difficult to apply universally across different clinical settings. Consequently, accurate estimation of the preparation time for both anesthesia induction and surgery enhance operating room staff efficiency. Moreover, proper staffing strategies can result in reduced personnel costs associated with overtime work.

Previous studies have also reported difficulties in estimating time in the operating room[19]. These studies typically focus on factors like surgery type or patient condition, but fail to capture department-specific variations, which can significantly impact preparation times. However, the preparation time for anesthesia induction and surgery (including the preparation time of patient for anesthesia and the time for positioning of the patient for surgery) may be irregular depending on the clinical department, the type of anesthesia to be administered, requirement for peripheral venous catheter insertion, arterial catheter insertion, and required surgical position. In a study that estimated the anesthetic induction time for non-cardiac surgery, 12 preoperative factors—including difficulty in intubation and the presence or absence of coronary artery disease—were used to create an anesthetic preparation time model, but only moderate cognitive ability was reported[20]. Further research has sought to incorporate more dynamic variables, such as real-time patient data and staff availability, but these efforts have yet to significantly improve predictive accuracy across all surgical specialties. To estimate the unpredictable preparation time needed for anesthesia induction and surgeries, we previously developed an estimation formula. This formula analyzed various factors, including the type and number of anesthesia and the insertion of peripheral venous catheters, along with surgical factors like the position of surgery and the preparation of surgical equipment. However, this initial model yielded limited accuracy, with an R^2 value of 0.701 [21].

In this study, we hypothesized that incorporating not only anesthesia and surgical factors but also the 'clinical department' into the estimation formula would enable us to accurately predict the preparation time required for anesthesia induction and surgery. This research represents the development phase of the estimation formula. This study serves as a preliminary step, and a multicenter study will be necessary to validate its generalizability and robustness across different settings before broader application.

Method

Study design and ethical considerations

The study was a retrospective observational study conducted at a medical operating center. This study was approved by the Ethics Committee of the medical center (no. 2020016), where the research was conducted. The opt-out method of consent was used; information about the study was made public (presented in the hospital and posted on the hospital website) to ensure that there was an opportunity to be excluded from the study. It adhered to the Strengthening the Reporting of Observational Studies in Epidemiology guidelines. A statistical plan was established before the data were accessed, then data were collected and analyzed. This study was also complied with principles enshrined in the Declaration of Helsinki (2013 amendment). The requirement for informed consent was waived due to the retrospective nature of the study. This decision was made by the ethics committee.

Study setting and population

This investigation encompassed 12,604 surgical instances observed from April 2019 to December 2022 at a singular medical center. The criteria for inclusion were delineated as follows: (1) individuals of every age and demographic, slated for surgical intervention; (2) a comprehensive array of anesthesia modalities, encompassing general, spinal, local infiltration, intravenous sedation, epidural, and nerve block anesthesia; (3) an extensive spectrum of clinical departments, including Cardiology, Cardiovascular Surgery, Cranial Nerve Surgery, Dermatology, Gastroenterology, General Surgery, Nephrology, Obstetrics and Gynecology, Ophthalmology, Orthopedic Surgery, Otorhinolaryngology, Plastic Surgery, Psychiatry, Thoracic Surgery, and Urology. The dataset from April 2019 to March 2020 was designated as the training set for the formulation of the model, while the dataset from April 2020 to December 2021 was utilized as a distinct test set for model validation.

The study design adhered to the SQUIRE guidelines[22]. The sample size was estimated with a power calculation based on the number of planned operations per year at the medical center. Sudden changes in the patient's condition, medical device abnormalities, and discontinuation of surgery before the start of surgery are all instances that may affect the anesthetic induction operation preparation time, and they were, therefore, excluded from the study.

Data collection and processing

The clinical information (clinical department, anesthesia factor, operation factor) was acquired from the medical records. The time at which the patient entered the operating room, time at which anesthesia was administered, and time at which operation was started were obtained. The anesthesia factors were as follows: type of anesthesia, insertion of epidural catheters, insertion of peripheral venous catheter (1st), insertion of peripheral venous catheter (2nd), insertion of arterial catheter insertion, and insertion of central venous catheter. The surgical factors were use of endoscope, surgery position, use of preoperative mobile biplane X-ray imaging, use of preoperative ultrasound diagnostic device, and use of preoperative surgical navigation systems. To address bias sources, researchers audited the accuracy of data input.

The primary endpoint of this investigation was delineated as the preparation duration for anesthesia induction and surgery. Within the scope of this study, the 'preparation time for anesthesia induction and surgery' is characterized as the interval commencing when the patient is introduced into the operating chamber until the initiation of the surgical procedure.

Statistical methods

"Preparation time of anesthesia induction and surgery" as the primary endpoint was the dependent variable; clinical department, anesthesia factors and surgical factors were the explanatory variables. The regression model was then used to develop an analysis and an equation for estimating the time required for anesthesia induction surgery. We have incorporated additional diagnostics to further evaluate our model's performance and validity. This includes the analysis of residual plots, which were conducted on the separate test set encompassing data from April 2020 to December 2021. The residual plot analysis helps us identify any patterns that might indicate non-linearity, heteroscedasticity, or outliers that could affect the model's accuracy and reliability. By examining the residuals—the differences between observed and predicted values—we can assess whether the assumptions of our regression model hold true across the data set. We conducted tests for multicollinearity among the independent variables using the Variance Inflation Factor (VIF). We established a threshold whereby any variable with a VIF exceeding 10 would be considered to exhibit significant multicollinearity and thus be excluded from the estimation equation to ensure the integrity of our model.

Significance was determined at a level of 5%. JMP ® 15 statistical software (SAS Institute Inc., Cary, NC, USA) was used for statistical analysis. To judge the validity of the estimation formula obtained by statistical analysis, the results of anesthesia induction surgery preparation time obtained by (i) the estimation formula and (ii) the actual measured preparation time for anesthesia induction operation were presented as mean ± standard deviation and then compared. The effect quantity of the estimation formula of this study was set at 0.5, the significance level at 0.05, and the power at 0.8. Sample size was 26 based on power analysis, and therefore, we decided to analyze a sample size of 26 or more.

Results

Attributes of research subject

Of the 12,605 surgical cases registered at our center from April 2019 to December 2021, 76 were excluded on account of the following reasons: sudden changes in the patient's condition, $n = 54$; medical device abnormalities, $n = 12$; discontinuation of surgery, $n = 10$. Consequently, 12,528 cases were used for final data analysis. We utilized a dataset comprising 7,921 cases from April 2019 to March 2020 as the training set for the development of our model. For model validation, we employed datasets that contained 4607 cases, spanning from April 2020 to December 2021 (Fig. 1).

Analyzing anesthesia induction preparation time: training dataset

The anesthesia and surgical determinants of the model development training cohort are presented in Tables 1 and 2, correspondingly. Figure 2 delineates the requisite duration for anesthesia induction and surgical preparation across various clinical departments. The analysis of the preparation period for anesthesia induction and surgery, alongside anesthesia and surgical variables, was conducted utilizing a regression model, achieving an R^2 value of 0.801. A pronounced correlation was established between the preparation time for anesthesia induction and surgery, and various factors: clinical department, endoscope application, surgical positioning, employment of ultrasound diagnostic devices, utilization of surgical navigation systems, anemia classification, implementation of epidural catheter, first and second insertions of peripheral venous catheters, arterial catheter placement, and central venous catheter insertion, as elucidated in Table 3. During the multicollinearity assessment, 'Surgery position' was found to have a VIF exceeding 10, indicating significant multicollinearity. Consequently, 'Surgery position' was excluded from the estimation formula to enhance the predictive accuracy and validity of our model. The following is the estimation formula of the preparation time of anesthesia induction and surgery developed in this study.

Estimation formula for the preparation time of anesthesia induction and surgery (min) =62.8 + (Anesthesia type) (General anesthesia: 10.48, Spinal anesthesia: 11.60, Local infiltration anesthesia: – 7.11, Intravenous sedation: – 11.91, Epidural anesthesia: – 5.43, Nerve block anesthesia: 2.37).

+ *(Clinical department)* (Cardiology: 10.15, Cardiovascular surgery: – 6.43, Cranial nerve surgery: 16.67, Dermatology: 0.32, General surgery: 1.19, Gastroenterology: – 3.34, Nephrology: –1.37, Obstetrics and gynecology: 3.74, Ophthalmology: – 6.49, Orthopedic surgery: 8.26, Otorhinolaryngology: 2.32, Plastic surgery: – 3.52, Psychiatry: – 25.91, Thoracic surgery: 5.05, Urology: – 0.64).

+ *(Use of endoscope)* (1: 0.07, 0: – 0.07).

+ *(Epidural catheters insertion)* (1: 6.98, 0: – 6.98).

+ *(Peripheral venous catheter insertion 1st)* (1: 2.28, 0: – 2.28).

+ *(Peripheral venous catheter insertion 2nd)* (1: 3.24, 0: – 3.24).

+ *(Arterial catheter insertion)* (1: 4.13, 0: – 4.13).

+ *(Central venous catheter insertion)* (1: 5.26, 0: – 5.26).

+ *(Use of mobile biplane X-ray imaging)* (1: 0.10, 0: – 0.10).

+ *(Use of ultrasound diagnostic device)* (1: 3.42, 0: – 3.42).

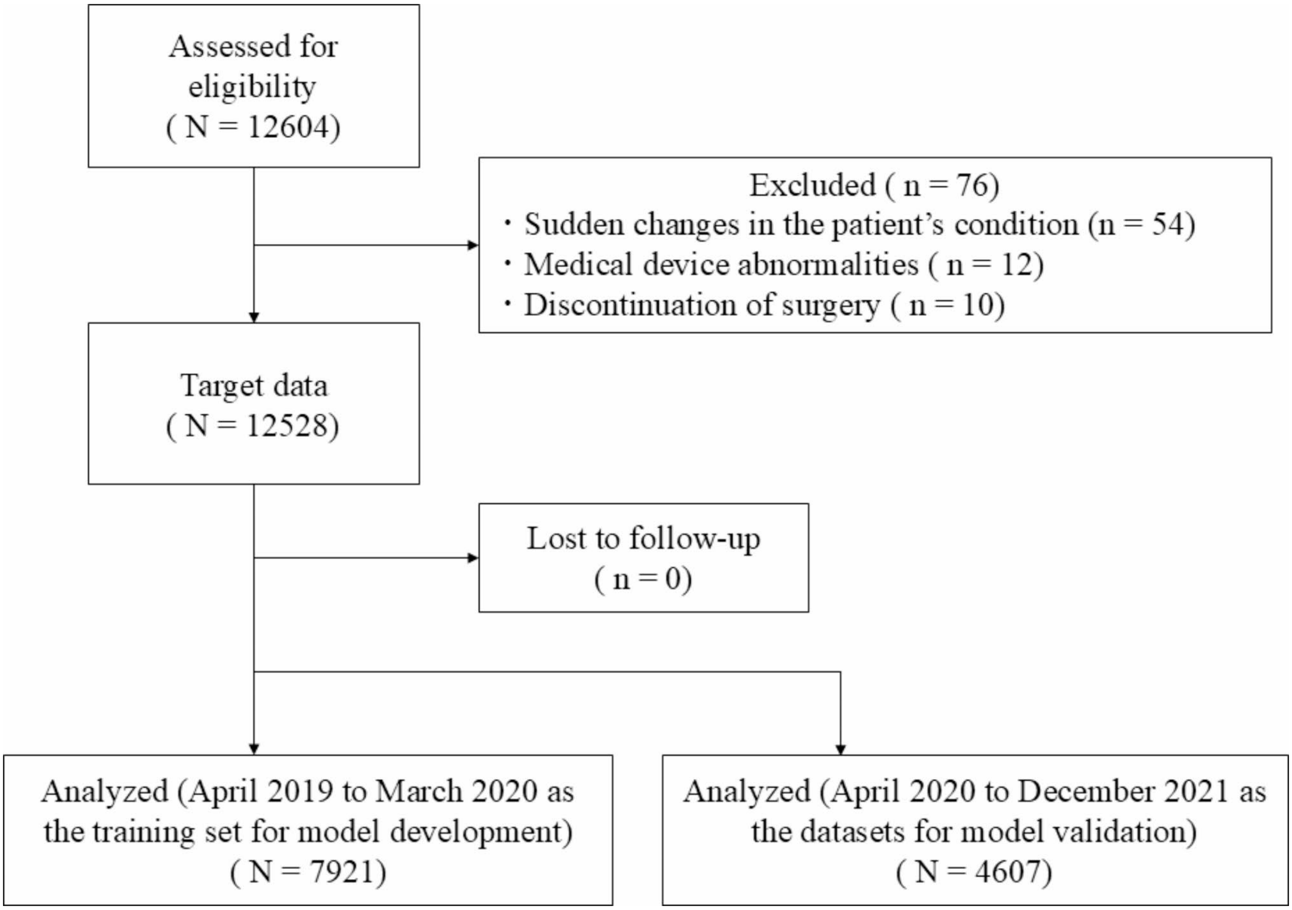

Fig. 1. Flowchart of participant selection.

+ *(Use of surgical navigation systems)* (1: 12.10, 0: – 12.10).

Examination of validity of the estimation formula for the preparation time of anesthesia induction and surgery

Using a dataset including 4,607 cases from April 2020 to December 2021, we compared measured and estimated anesthesia induction and surgery preparation times. These were obtained using (i) measured anesthesia induction preparation times and (ii) the Analyzing Anesthesia Induction and Surgery Preparation Time: Training Dataset from this study (Table 4).

Analysis of residual plots with datasets for model validation

The results of our analysis using residual plots, conducted on the datasets containing 4,607 cases from April 2020 to December 2021, are presented in Fig. 3. The residual quantile plot indicated an adherence to normality in the data.

Discussion

Hospitals spend significant resources to ensure efficient use of operating room time[23–25]. Therefore, it is important to accurately estimate the time required in the operating room and to schedule it effectively; thereby, greatly reduce the cost of personnel, etc[26]. Deviations in the scheduled time for surgery should be avoided because variations or changes in the schedule can cause undesirable situations for patients, wards, and other relevant departments[27,28]; a thorough analysis of the scheduling problem is crucial[29]. Until now, it has been difficult to estimate the preparation time required for anesthesia induction and surgery to ensure efficient use of the operating room; however, the formula developed by us, based on the data analyzed in this study was very accurate ($R^2 = 0.801$)[3,4]. Previous studies have primarily focused on individual factors such as anesthesia type or patient condition, often neglecting the complexity of incorporating multiple variables, such as clinical department-specific variations. For example, earlier models struggled with low accuracy, particularly when applied to specialized departments with lower case volumes or unique procedural requirements. This limitation hindered their generalizability and accuracy. In contrast, our study incorporated clinical department factors, which significantly improved the predictive accuracy, particularly in departments with high case volumes, such as general surgery and orthopedics. However, for certain departments, such as hepatology, the number of cases was below the required 26, thus they were excluded from the analysis in our study. The comparison between

	Cardiology (*n* = 51)	Cardiovascular surgery (*n* = 181)	Cranial nerve surgery (*n* = 400)	Dermatology (*n* = 150)	Gastroenterology (*n* = 25)	General surgery (*n* = 1622)	Nephrology (*n* = 79)	Obstetrics and gynecology (*n* = 545)	Ophthalmology (*n* = 1292)	Orthopedic surgery (*n* = 885)	Otorhinolaryngology (*n* = 574)	Plastic surgery (*n* = 722)	Psychiatry (*n* = 24)	Thoracic surgery (*n* = 246)	Urology (*n* = 1125)
Anesthesia type															
General anesthesia	4 (7.8%)	166 (91.7%)	366 (91.5%)	1 (0.7%)	25 (100%)	1401 (86.4%)	0	250 (45.9%)	36 (2.8%)	478 (54.0%)	506 (88.2%)	345 (47.8%)	24 (100%)	246 (100%)	358 (31.8%)
Spinal anesthesia	0	0	0	2 (1.3%)	0	20 (1.2%)	0	221 (40.6%)	0	241 (27.2%)	0	37 (5.1%)	0	0	295 (26.2%)
Local infiltration anesthesia	47 (92.2%)	15 (8.3%)	34 (8.5%)	147 (98%)	0	199 (12.3%)	79 (100%)	5 (0.9%)	1256 (97.2%)	87 (9.8%)	68 (11.8%)	335 (46.4%)	0	0	279 (24.8%)
Intravenous sedation	0	0	0	0	0	2 (0.1%)	0	69 (12.6%)	0	6 (0.7%)	0	0	0	0	0
Epidural anesthesia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	193 (17.2%)
Nerve block anesthesia	0	0	0	0	0	0	0	0	0	73 (8.3%)	0	5 (0.7%)	0	0	0
Epidural catheters insertion															
Yes	0	0	0	0	0	59 (3.6%)	0	313 (57.4%)	0	0	2 (0.3%)	0	0	0	4 (0.4%)
No	51 (100%)	181 (100%)	400 (100%)	150 (100%)	25 (100%)	1563 (96.4%)	79 (100%)	232 (42.6%)	1292 (100%)	885 (100%)	572 (99.7%)	722 (100%)	24 (100%)	246 (100%)	1121 (99.4%)
Peripheral venous catheter insertion (1st)															
Yes	3 (5.9%)	116 (64.1%)	218 (54.5%)	3 (2.0%)	12 (48.0%)	981 (60.5%)	2 (2.5%)	309 (56.7%)	20 (1.5%)	346 (39.1%)	286 (49.8%)	172 (23.8%)	20 (83.3%)	206 (83.7%)	214 (19.0%)
No	48 (94.1%)	65 (35.9%)	182 (45.5%)	147 (98.0%)	13 (52.0%)	641 (39.5%)	77 (97.5%)	236 (43.3%)	1272 (98.5%)	539 (60.9%)	288 (50.2%)	550 (76.2%)	4 (16.7%)	40 (16.3%)	911 (81.0%)
Peripheral venous catheter insertion (2nd)															
Yes	0	140 (77.3%)	195 (48.8%)	0	0	618 (38.1%)	0	152 (27.9%)	0	62 (7.0%)	52 (9.1%)	23 (3.2%)	0	220 (89.4%)	161 (14.3%)
No	51 (100%)	41 (22.7%)	205 (51.2%)	150 (100%)	25 (100%)	1004 (61.9%)	79 (100%)	393 (72.1%)	1292 (100%)	823 (93.0%)	522 (90.9%)	699 (96.8%)	24 (100%)	26 (10.6%)	964 (85.7%)
Arterial catheter insertion															
Yes	0	142 (78.5%)	171 (42.8%)	0	0	577 (35.6%)	0	446 (81.8%)	0	23 (2.6%)	30 (5.2%)	20 (2.8%)	0	216 (87.8%)	152 (13.5%)
No	51 (100%)	39 (21.5%)	229 (57.2%)	150 (100%)	25 (100%)	1045 (64.4%)	79 (100%)	99 (18.2%)	1292 (100%)	862 (97.4%)	544 (94.8%)	702(97.2%)	24 (100%)	30 (12.2%)	973 (86.5%)
Central venous catheter insertion															
Yes	0	130 (71.8%)	4 (1.0%)	0	0	97 (6.0%)	0	543 (99.6%)	0	3 (0.3%)	15 (2.6%)	0	0	4 (1.6%)	16 (1.4%)
No	51 (100%)	51 (28.2%)	396 (99.0%)	150 (100%)	25 (100%)	1525 (94.0%)	79 (100%)	2 (0.4%)	1292 (100%)	882 (99.7%)	559 (97.4%)	722 (100%)	24 (100%)	242 (98.4%)	1109 (98.6%)

Table 1. Analysis of data by anesthesia factors for each clinical department. Data are presented as number of anesthesia factors (%).

	Cardiology ($n=51$)	Cardiovascular surgery ($n=181$)	Cranial nerve surgery ($n=400$)	Dermatology ($n=150$)	Gastroenterology ($n=25$)	General surgery ($n=1622$)	Nephrology ($n=79$)	Obstetrics and gynecology ($n=545$)	Ophthalmology ($n=1292$)	Orthopedic surgery ($n=885$)	Otorhinolaryngology ($n=574$)	Psychiatry ($n=24$)	Plastic surgery ($n=722$)	Thoracic surgery ($n=246$)	Urology ($n=1125$)
Surgery position															
Supine position	51 (100%)	169 (93.4%)	358 (89.5%)	111 (74.0%)	0	1225 (75.5%)	27 (34.2%)	216 (39.6%)	1292 (100%)	665 (75.2%)	574 (100%)	24 (100%)	590 (81.7%)	11 (4.5%)	280 (24.9%)
Lithotomy position	0	0	0	2 (1.3%)	0	368 (22.7%)	0	326 (59.8%)	0	0	0	0	7 (1.0%)	0	754 (67.0%)
Lateral position	0	11 (6.1%)	22 (5.5%)	8 (5.3%)	25 (100%)	11 (0.7%)	0	3 (0.6)	0	180 (20.3%)	0	0	38 (5.3%)	235 (95.5%)	84 (7.5%)
Prone position	0	1 (0.5%)	20 (5.0%)	29 (19.4%)	0	18 (1.1%)	52 (65.8%)	0	0	40 (4.5%)	0	0	87 (12.0%)	0	7 (0.6%)
Use of Endoscope															
Yes	0	7 (3.9%)	5 (1.3%)	0	25 (100%)	768 (47.3%)	0	51 (9.4%)	0	47 (5.3%)	81 (14.1%)	0	3 (0.4%)	246 (100%)	603 (53.6%)
No	51 (100%)	174 (96.1%)	395 (98.7%)	150 (100%)	0	854 (52.7%)	79 (100%)	494 (90.6%)	1292 (100%)	838 (94.7%)	493 (85.9%)	24 (100%)	719 (99.6%)	0	522 (46.4%)
Use of Mobile biplane X-ray imaging															
Yes	47 (92.2%)	0	1 (0.3%)	0	0	151 (9.3%)	1 (1.3%)	4 (0.7%)	0	518 (58.5%)	1 (0.2%)	0	11 (1.5%)	0	347 (30.8%)
No	4 (7.8%)	181 (100%)	399 (99.7%)	150 (100%)	25 (100%)	1471 (90.7%)	78 (98.7%)	541 (99.3%)	1292 (100%)	367 (41.5%)	573 (99.8%)	24 (100%)	711 (98.5%)	246 (100%)	778 (69.2%)
Use of Ultrasound diagnostic device															
Yes	0	57 (31.5%)	0	0	0	458 (28.2%)	66 (83.5%)	2 (0.4%)	0	75 (8.5%)	30 (5.2%)	0	16 (2.2%)	0	211 (18.8%)
No	51 (100%)	124 (68.5%)	(100%)	150 (100%)	25 (100%)	1164 (71.8%)	13 (16.5%)	543 (99.4%)	1292 (100%)	810 (91.5%)	544 (94.8%)	24 (100%)	706 (97.8%)	246 (100%)	914 (81.2%)
Use of Surgical navigation systems															
Yes	0	0	20 (5.0%)	0	0	0	0	0	0	0	2 (0.3%)	0	0	0	0
No	51 (100%)	181 (100%)	380 (95.0%)	150 (100%)	25 (100%)	1622 (100%)	79 (100%)	545 (100%)	1292 (100%)	885 (100%)	572 (99.7%)	24 (100%)	722 (100%)	246 (100%)	1125 (100%)

Table 2. Analysis of data by surgical factors for each clinical department. Data are presented as number of surgical factors (%).

Factors	Partial regression coefficient	Standard error	*p* value	VIF
Intercept	64.90	1.30	< 0.001*	
Anesthesia type				
General anesthesia	10.60	0.43	< 0.001*	6.89
Spinal anesthesia	11.40	0.46	< 0.001*	4.49
Local infiltration anesthesia	− 6.63	0.46	< 0.001*	6.32
Intravenous sedation	− 12.49	1.10	< 0.001*	2.35
Epidural anesthesia	− 6.30	0.84	< 0.001*	2.67
Nerve block anesthesia	3.43	1.06	< 0.001*	2.35
Clinical Department				
Cardiology	11.04	1.38	< 0.001*	3.94
Cardiovascular surgery	− 5.48	0.91	< 0.001*	4.24
Cranial nerve surgery	17.71	0.58	< 0.001*	5.35
Dermatology	0.08	0.84	0.873	3.72
Gastroenterology	− 6.39	1.95	< 0.01*	5.59
General surgery	2.25	0.40	< 0.001*	4.54
Nephrology	− 3.45	1.21	0.004*	3.82
Obstetrics and gynecology	3.59	0.75	< 0.001*	7.76
Ophthalmology	− 5.52	0.46	< 0.001*	5.32
Orthopedic surgery	8.32	0.49	< 0.001*	9.05
Otorhinolaryngology	3.68	0.50	< 0.001*	6.66
Plastic surgery	− 3.14	0.46	< 0.001*	7.68
Psychiatry	− 24.65	1.92	< 0.001*	5.70
Thoracic surgery	2.79	0.85	< 0.01*	4.79
Urology	− 0.85	0.47	0.067	9.89
Surgery position				
Supine position	− 2.96	0.27	< 0.001*	94.93
Lithotomy position	− 0.52	0.39	0.179	66.07
Lateral position	1.97	0.45	< 0.001*	37.56
Prone position	1.50	0.55	0.006*	35.98
Use of Endoscope	0.23	0.20	0.251	2.39
Epidural catheter insertion	7.32	0.39	< 0.001*	2.20
Peripheral venous catheter insertion (1st)	2.31	0.14	< 0.001*	1.56
Peripheral venous catheter insertion (2nd)	2.98	0.31	< 0.001*	4.98
Arterial catheter insertion	4.06	0.33	< 0.001*	5.07
Central venous catheter insertion	5.59	0.40	< 0.001*	1.73
Use of Mobile biplane X-ray imaging	0.04	0.22	0.855	1.79
Use of Ultrasound diagnostic device	3.49	0.26	< 0.001*	2.24
Use of Surgical navigation systems	12.52	1.09	< 0.001*	1.05

Table 3. Estimated value of preparation time of anesthesia induction and surgery for each factor.

the actual measured mean and the estimated mean of the time required to prepare for anesthesia induction and surgery revealed a difference of within 1 min for intravenous sedation, epidural anesthesia, and nerve block anesthesia; within 3 min for general anesthesia in ophthalmology; 3 min for spinal anesthesia in plastic surgery; and 8 min for local infiltration anesthesia in cranial nerve surgery. The normality of the residue plots has also been recognized, and in our opinion, has good potential for clinical implementation. This formula can be used to improve clinical practices by aiding in the creation of more precise surgery schedules, allowing hospitals to optimize staffing and resource allocation. In addition, by incorporating clinical department-specific factors, the formula can help reduce unexpected delays and overtime work, contributing to better time management in operating rooms. For example, hospitals can apply this model to adjust their daily schedules based on department-specific variations in preparation times, leading to more efficient operation room turnover and patient flow. This practical application is expected to reduce personnel costs and enhance overall patient care.

One of the strengths of our study was the inclusion of "clinical department" as an estimation factor for preparation time of anesthesia induction and surgery. Specialists of every clinical department have specific protocols to monitor the patients and to induce anesthesia; this leads to variations in the preparation time of anesthesia induction surgeries[30]. Neural block depending on the surgical site may be performed before surgery[31,32]. In addition, use of an ultrasound diagnostic device during spinal anesthesia and use of a video laryngoscope during intubation have been reported[33]. Therefore, even if the same procedure of anesthesia

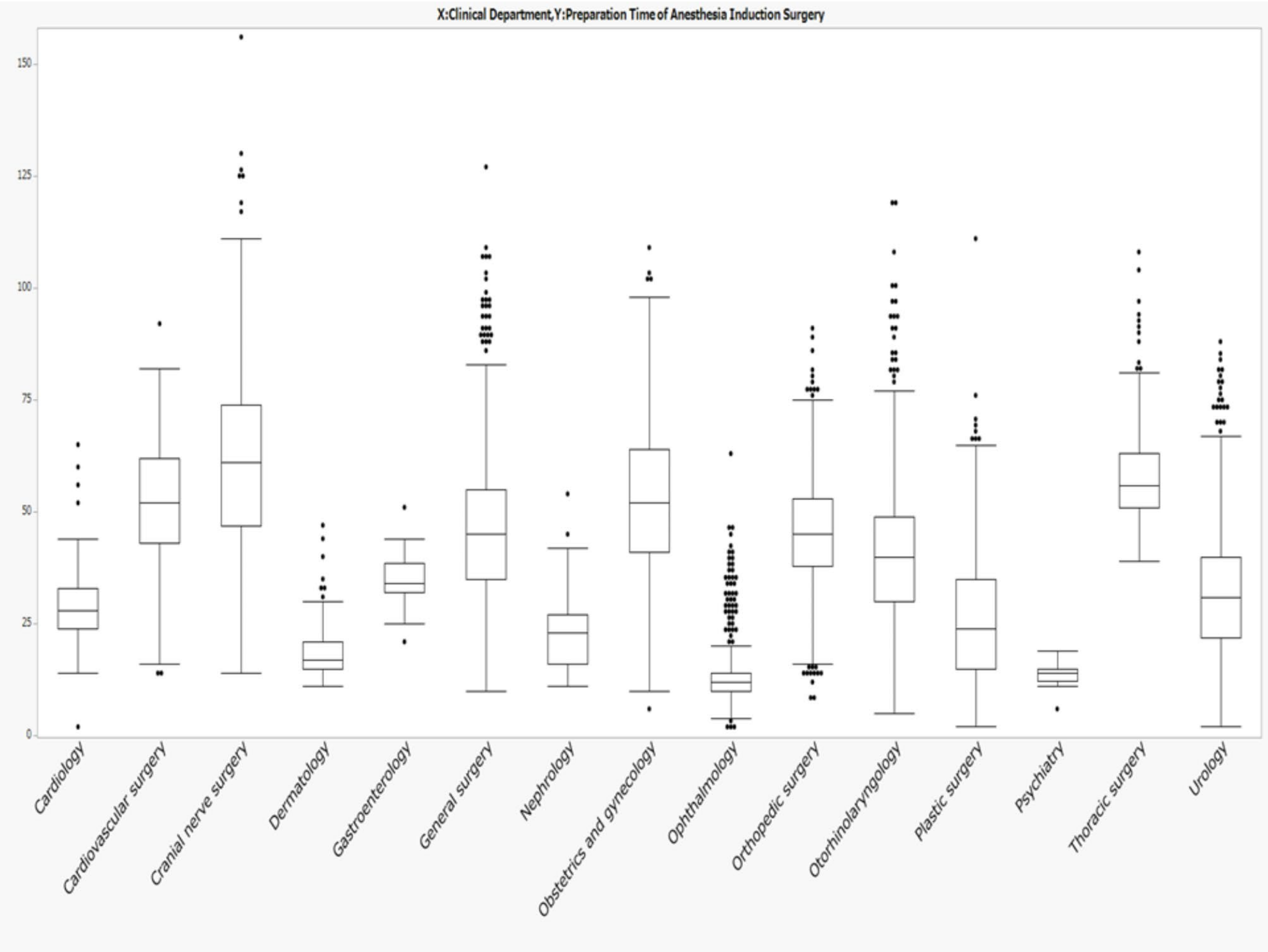

Fig. 2. Preparation time of anesthesia induction and surgery by clinical department. The results of the measured preparation time for anesthesia induction surgery in each clinical department have been depicted in minutes. The “y” shows the mean of the preparation time for anesthesia induction surgery and the bar in the boxplot is the median. The true values are shown with the dashed horizontal line.

introduction is performed every time, the anesthesia introduction time may still be irregular for each clinical department. Considering the management time of each surgeon, time taken for interventions such as fixations, is completely different even if the patients are fixed in the same position as per protocol for each clinical department[34]. To estimate the management time of a surgeon, it is necessary to analyze data from a clinical department that integrates special posture fixation and the use of medical equipment as parameters. In fact, for the estimation formula developed in this study, depending on the clinical department, the preparation time was adjusted between − 24 min to + 17 min for all clinical departments. This shows that there are large differences among the preparation times required by individual clinical departments even if they have the same anesthesia and surgery factors. The inclusion of “clinical department” as a factor in the estimation formula is considered to be essential for adjusting the peculiarities of each clinical department.

Second, rather than directly including patient characteristics, we included medical interventions for patient characteristics as factors in the estimation formula, which led to increased accuracy. This uncertain information—individual patient characteristics as factors— may affect the estimation formula[12]. In cases requiring strict circulatory management, it is relatively easy to identify medical interventions, such as arterial catheterization and arterial pressure management in the operating room. Therefore, it became possible for us to estimate the added preparation time that would be required for anesthesia induction and surgery by simply determining the required medical intervention for various factors of each patient. In the operating room, the time before surgery may not account for unexpected events related to patient factors[20]. Consequently, we infer that our estimation formula will account for unexpected events related to patient characteristics by focusing on medical interventions, and thereby, it will help to recalibrate the preparation time for anesthesia induction and surgery. For this reason, we consider it apt to model the preparation time for anesthesia induction and surgery using medical interventions performed in the operating room as a factor instead of patient characteristics. Furthermore, our objective was to forge a model that encapsulates an extensive array of surgical interventions across diverse specialties to ensure broad applicability and utility in varied clinical contexts. This approach includes the integration of specialties that traditionally rely on regional anesthesia, aiming to construct a

Anesthesia type for each clinical department	Measured value (in minutes)	Estimated value (in minutes)	Difference between the measured value and the estimated value (in minutes)
General anesthesia			
Cardiovascular surgery (n = 94)	55.12 (12.38)	54.84 (10.26)	0.28
Cranial nerve surgery (n = 202)	64.88 (19.09)	63.86 (10.87)	1.02
General surgery (n = 781)	49.22 (15.02)	49.17 (9.43)	0.05
Obstetrics and gynecology (n = 178)	60.75 (16.74)	59.20 (11.43)	1.55
Otorhinolaryngology (n = 293)	42.75 (17.29)	42.14 (5.66)	0.64
Orthopedic surgery (n = 297)	47.36 (11.43)	47.92 (4.96)	0.56
Plastic surgery (n = 218)	34.49 (11.65)	35.34 (4.57)	0.85
Thoracic surgery (n = 148)	57.65 (11.62)	58.05 (5.12)	0.40
Urology (n = 194)	45.19 (13.96)	44.50 (9.09)	0.69
Spinal anesthesia			
Obstetrics and gynecology (n = 125)	51.13 (11.04)	51.37 (6.85)	0.24
Orthopedic surgery (n = 167)	46.45 (10.94)	46.43 (3.12)	0.02
Urology (n = 295)	36.01 (9.33)	37.06 (2.44)	1.05
Local infiltration anesthesia			
Cardiology (n = 29)	27.56 (7.81)	28.56 (0.99)	1.00
Dermatology (n = 99)	18.52 (4.73)	18.60 (2.25)	0.08
General surgery (n = 101)	26.86 (9.97)	26.97 (3.17)	0.11
Nephrology (n = 33)	23.12 (8.68)	22.69 (4.52)	0.43
Ophthalmology (n = 690)	11.55 (3.09)	11.74 (0.52)	0.19
Orthopedic surgery (n = 65)	26.46 (9.87)	26.71 (2.19)	0.25
Otorhinolaryngology (n = 39)	22.09 (5.95)	24.51 (3.49)	2.42
Plastic surgery (n = 168)	15.47 (6.57)	15.08 (2.31)	0.39
Urology (n = 140)	19.45 (5.94)	18.27 (3.52)	1.18
Intravenous sedation			
Obstetrics and gynecology (n = 41)	18.60 (4.82)	19.54 (3.32)	0.94
Epidural anesthesia			
Urology (n = 125)	26.53 (6.57)	26.43 (2.18)	0.10
Nerve block anesthesia			
Orthopedic surgery (n = 59)	43.25 (7.99)	43.43 (1.79)	0.18

Table 4. Comparison of measured and estimated values of preparation time of anesthesia induction and surgery by anesthesia type for each clinical department. Values are presented as mean (standard deviation).

comprehensive model that accurately predicts preparation times for both common and less prevalent surgical scenarios, enhancing the efficiency of surgical scheduling. In addressing exceptions within clinical practice, it is acknowledged that while a majority of dermatological and ophthalmological procedures typically proceed under local anesthesia without venous access, certain complex cases defy this norm. Specifically, intricate ophthalmic operations, such as retinal detachment repairs, and significant dermatological interventions, including extensive resections with grafting, demand a more elaborate anesthetic approach. These scenarios may necessitate the employment of general anesthesia and monitored anesthesia care, incorporating peripheral venous access. Our model is designed to accommodate these exceptions, thereby providing a versatile and adaptable framework capable of addressing a wide spectrum of clinical situations, underscoring its comprehensive utility in surgical preparation and scheduling.

However, this study has certain limitations. First, it is a single-center retrospective observational study, and therefore the generalizability of the estimation formula beyond the single center could not be tested. A multicenter study is essential to validate the generalizability and robustness of the formula across different settings and to ensure that the impact of the clinical department factor is consistent. Second, the study does not account for the anesthesiologist's skill level and the patient's age, both of which can significantly influence anesthesia preparation time. The retrospective nature of our study limited our ability to capture detailed data on these factors. Future research should incorporate these variables to enhance the accuracy and applicability of the estimation formula. Third, although we have developed an estimation formula for scheduled surgery, we believe that an additional estimation formula for emergency surgery can have a greater impact on the scheduling of surgery. Unlike scheduled surgery, emergency surgery involves changes in the number of medical teams involved and interventions. Previous studies have also developed a mixed integer linear programming approach to reschedule for emergency surgery, and the potential difference in preoperative preparation time between scheduled and emergency surgery has also been described[35]. Moreover, literature has indicated that in the realm of scheduled surgeries, honing in on operating room utilization can enable the derivation of algorithms

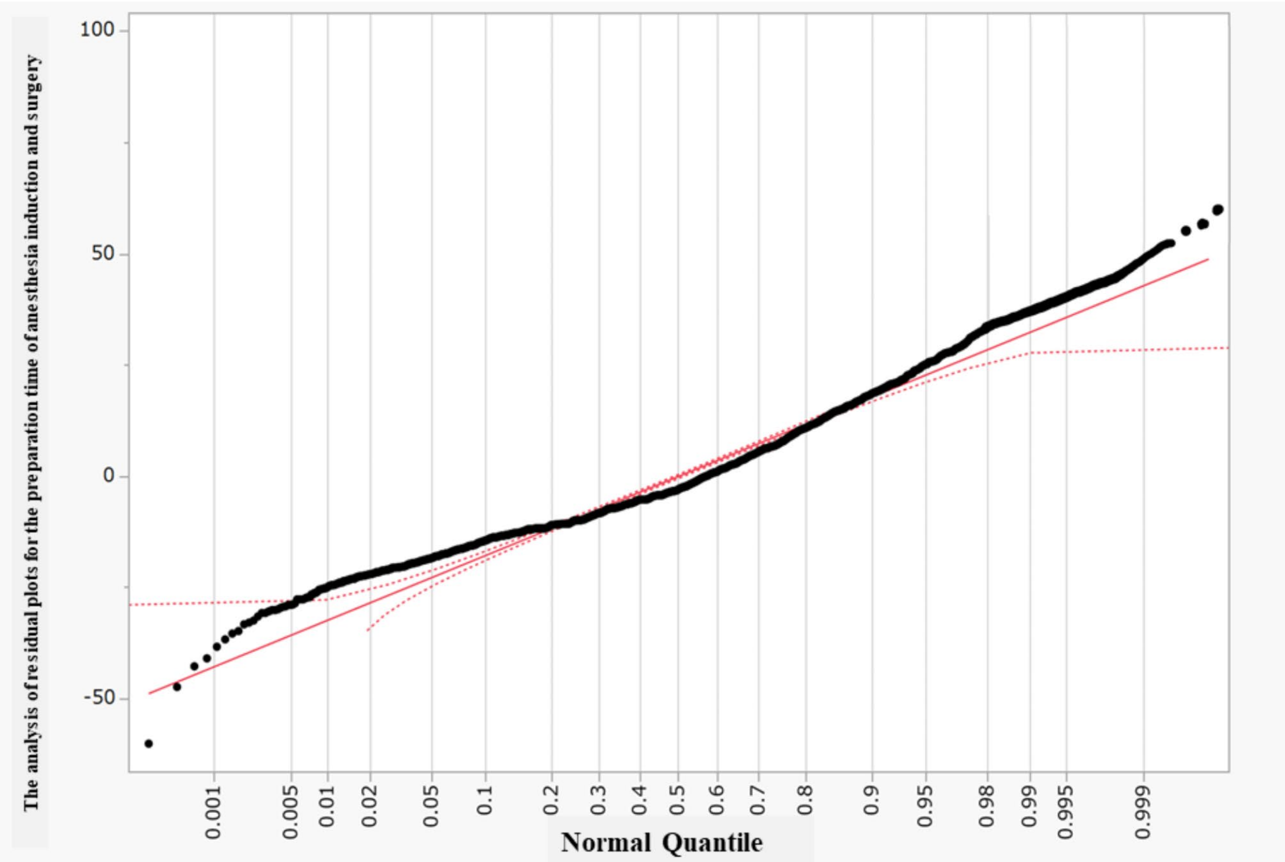

Fig. 3. The analysis of residual plots for the preparation time of anesthesia induction and surgery. The residual quantile plot indicated an adherence to normality in the data.

for enhanced predictive accuracy[36]. Consequently, while not utilized within the current investigation, the deployment of a parallel algorithm that accentuates operating room usage, coupled with a formula to approximate the time needed for anesthesia induction and surgery preparation, could refine the precision of daily operational planning. Furthermore, we aim to augment our model by integrating these supplementary parameters in future research endeavors. We posit that this expansion will not only bolster the model's practical utility and prognostic capability but also allow for the accommodation of the diverse preoperative preparation times observed across various surgical disciplines. Such advancements promise to significantly improve and refine the intricacies of surgery scheduling systems. Finally, it is important to note that this study represents the development phase of the estimation formula. Future work will involve validating this formula in multiple centers to ensure its broader applicability and reliability.

Conclusion

This study successfully created an accurate formula to estimate anesthesia induction and surgery preparation times, incorporating anesthesia, surgical factors, and notably, 'clinical department' aspects, demonstrating an R^2 value of 0.801. The minimal discrepancy between predicted and actual times across various procedures highlights the formula's reliability and clinical applicability. Acknowledging clinical department specifics enhances the model's precision, improving surgery scheduling efficiency. This formula signifies a significant step towards optimizing operating room resource management through precise and adaptable modeling. However, it is important to note that this research represents the development phase of the estimation formula. A multicenter study is essential to validate its generalizability and robustness across different settings before broader application.

Data availability

Hara, Kentaro (2021), "Development of an Estimation Formula for Preparation Time of Anesthesia Induction and Surgery Accounting for Clinical Department Factors in Optimal Surgery Schedule Management", Mendeley Data, V3, doi: https://doi.org/10.17632/ywgrfkbssz.3. https://data.mendeley.com/datasets/ywgrfkbssz/3.

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Author contributions

Author contributionsKentaro Hara, Reika Tachibana, and Shohei Kaneko were responsible for the organization and coordination of the study. Kentaro Hara was the chief investigator and also responsible for the data analysis. Michiko Yamaguchi provided the study data. Masaki Fujioka, Tamotsu Kuroki, Sumihisa Honda, and Terumitsu Sawai made critical revisions to incorporate relevant information. All authors contributed to the writing of the final manuscript and have approved it.

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Declarations

Competing interests

The authors declare no competing interests.

Ethical considerations

This study was approved by the ethics committee of the Nagasaki Medical Center (no. 2020016), where the research was conducted. The opt-out method of consent was used; information about the study was made public (presented in the hospital and posted on the hospital website) to ensure that there was an opportunity to be excluded from the study. It adhered to the Strengthening the Reporting of Observational Studies in Epidemiology guidelines. A statistical plan was established before the data were accessed, then data were collected and analyzed. This study was also complied with principles enshrined in the Declaration of Helsinki (2013 amendment). The requirement for informed consent was waived due to the retrospective nature of the study. This decision was made by the ethics committee of the Nagasaki Medical Center.

Additional information

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