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Risk factors for complications associated with canine hepatic mass resection: A study of 96 cases

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Abstract

Objective: To identify pre- and intraoperative risk factors for complications occurring within 2 weeks following hepatic mass resection in dogs.

Study design: Retrospective case series.

Animals: A total of 96 client-owned dogs that underwent hepatic mass resection.

Methods: The evaluated preoperative variables were the signalment, clinical signs, presence of underlying diseases, blood test results (e.g., hematocrit), and computed tomography (CT) findings (mass location, maximum diameter, mass volume, and distance between the mass and the caudal vena cava [CVC]). The evaluated intraoperative variables were the surgical time, procedure details (e.g., surgical techniques), presence of intraoperative hypotension and hypoxemia, and blood transfusion. Comparisons were made between dogs with severe postoperative complications (including mortality) and those with mild or moderate complications. Univariable logistic regression was performed, and significant variables were used to construct multivariable models by combining them.

Results: Severe postoperative complications were observed in 17 dogs (17.7%), including six deaths (6.3%). Multivariable logistic regression analyses identified the presence of underlying diseases (OR: 2.703; $p = .007$), corrected distance from the mass to the CVC (OR: 0.666 per 0.1 cm/kg increase; $p = .017$), and intraoperative hypotension (OR: 3.589; $p = .019$) as risk factors for severe postoperative complications.

Conclusion: Among preoperative variables, both the presence of underlying diseases and the corrected distance from the mass to the CVC were associated with severe postoperative complications.

Clinical significance: Preoperative CT evaluation of the distance between the hepatic mass and the CVC, along with screening for underlying diseases, may contribute to improve the prediction of surgical risk.

1 | INTRODUCTION

Hepatic masses in dogs include primary, metastatic, and non-neoplastic masses such as hematomas and abscesses. Primary liver tumors account for 0.6%–1.3% of all tumors in dogs, with hepatocellular carcinoma being the most common primary tumor.[1,2] Hepatocellular carcinoma is classified morphologically into massive, nodular, and diffuse types.[1] Surgical resection is recommended for massive tumors, and it has been reported to have good long-term outcomes if the perioperative period is successfully managed.[3] Because other malignant tumors and benign tumors are known causes of spontaneous hemoabdomen,[4] cases where the hepatic mass is present should be carefully evaluated, and surgical intervention should be considered when appropriate. In cases where the hepatic mass is confined to a single liver lobe, surgical resection is generally recommended.

The surgical outcomes of hepatic mass resection in dogs have been reported, with a postoperative mortality rate of 5.6%–1.5% and a complication rate of 6.0%–28.7% within 2 weeks postoperatively.[5–8] Identified risk factors for perioperative mortality and complications include resection of right divisional masses, liver lobectomy including hilar resection, extension of the laparotomy incision to the thorax, and perioperative anemia.[5,6,9] However, in some studies, resection of right divisional masses was not considered a risk factor for postoperative complications.[5,6] These reports suggest that the anatomical proximity of right divisional masses to the caudal vena cava (CVC) contributes to an increased risk of perioperative complications. Additionally, the complexity of the vascular structures in the hilus of the central divisional lobes is related to the challenges associated with liver lobectomy. On the basis of our own clinical experience, masses at the edges of the liver lobes are typically easier to resect than those located near the hilus. However, in previous studies,[3,5–9] the actual distance between the mass and the CVC was not measured. Therefore, in the present study, we quantitatively measured the distance between the mass and the CVC on computed tomography (CT) images. We hypothesized that the proximity of this distance is a risk factor for postoperative complications and aimed to identify the risk factors for poor outcomes within 2 weeks following hepatic mass resection.

2 | MATERIALS AND METHODS

2.1 | Criteria for inclusion

In this retrospective study, medical records were reviewed and data were extracted from cases of canine hepatic mass resection at University of Miyazaki from April 2010 to January 2024. One author read through the surgical and anesthesia records to identify cases of hepatic mass resection and gathered detailed data on these cases from electronic and paper medical records. The evaluated information comprised the signalment (breed, age, sex, weight), clinical signs, underlying diseases, blood test results, CT findings, anesthesia records, surgical records, and postoperative outcomes. A total of 115 dogs underwent hepatic mass resection during the study period. Among them, one dog that simultaneously underwent thoracic surgery (lung lobectomy) and 18 dogs that did not undergo CT or had insufficient contrast enhancement or unclear vascular structures on CT images were excluded. Consequently, 96 dogs were included in the final analysis.

2.2 | Preoperative evaluation

Age and weight were recorded on the day before surgery. Clinical signs were based on the owner's report and included lethargy, anorexia, gastrointestinal signs (diarrhea, vomiting), respiratory signs (coughing), and polyuria/polydipsia. Blood tests were conducted on the day before surgery or the day of surgery to measure the hematocrit, alanine aminotransferase concentration (ALT), aspartate aminotransferase concentration, alkaline phosphatase concentration (ALP), gamma-glutamyltransferase concentration (GGT), glucose concentration, albumin concentration, total bilirubin concentration, prothrombin time (PT), activated partial thromboplastin time (APTT), fibrinogen concentration (FIBC), D-dimer concentration, and fibrin degradation product (FDP) concentration. However, some blood tests were not conducted for all cases. As of April 2021, the method for measuring ALP was changed from the Japan Society of Clinical Chemistry to the International Federation of Clinical Chemistry standard method; therefore, ALP values measured before this date were converted to the ALP values calculated using the new method.[10] As the reference values for PT, APTT, and FIBC vary depending on the measuring device used, the values were recorded as multiples of the upper limit of the reference values. Underlying diseases were recorded at the time of admission and included endocrine diseases (hyperadrenocorticism, hypoadrenocorticism, hypothyroidism), cardiovascular diseases (mitral valve insufficiency, tricuspid valve regurgitation), respiratory diseases (tracheal collapse, hypoxemia, hypercapnia), hypoglycemia, and disseminated intravascular coagulation (DIC; defined by the presence of at least three coagulation abnormalities[11]). All CT scans were performed under general anesthesia, in sternal recumbency while maintaining end-expiration. On the CT images, the maximum diameter of the mass in the axial view, volume of the mass, divisional location of liver masses, and shortest distance from the mass to the CVC (the junction of the right and left hepatic veins) were measured (Figure 1). The distance from the mass to the CVC was recorded as the actual distance, while the value obtained by dividing the actual distance by the bodyweight (kg) was referred to as the corrected distance. Mass volume was measured using AZE Virtual Place (Canon Medical Systems, Japan). For divisional location, the left lateral lobe, left medial lobe, and papillary process of the caudate lobe were categorized as the left division; the quadrate lobe and right medial lobe were categorized as the central division; and the right lateral lobe and caudate process of the caudate lobe were categorized as the right division. A combination of left and central divisional masses was defined as the central division, while combined central and right divisional masses were defined as the right division.[5] If masses were located independently in different hepatic lobes and both were resected, the mass closer to the CVC and its corresponding liver division were selected for statistical analysis.

2.3 | Anesthesia and anesthesia monitoring

The anesthesia protocol varied between cases. Preanesthetic medications included atropine (0.04 mg/kg), morphine (0.5 mg/kg), ketamine (5 mg/kg), fentanyl (5 μg/kg), and midazolam (0.2 mg/kg), either individually or in combination. Induction was performed with propofol (1–6 mg/kg) or alfaxalone (1–4 mg/kg). Inhalant anesthetics such as

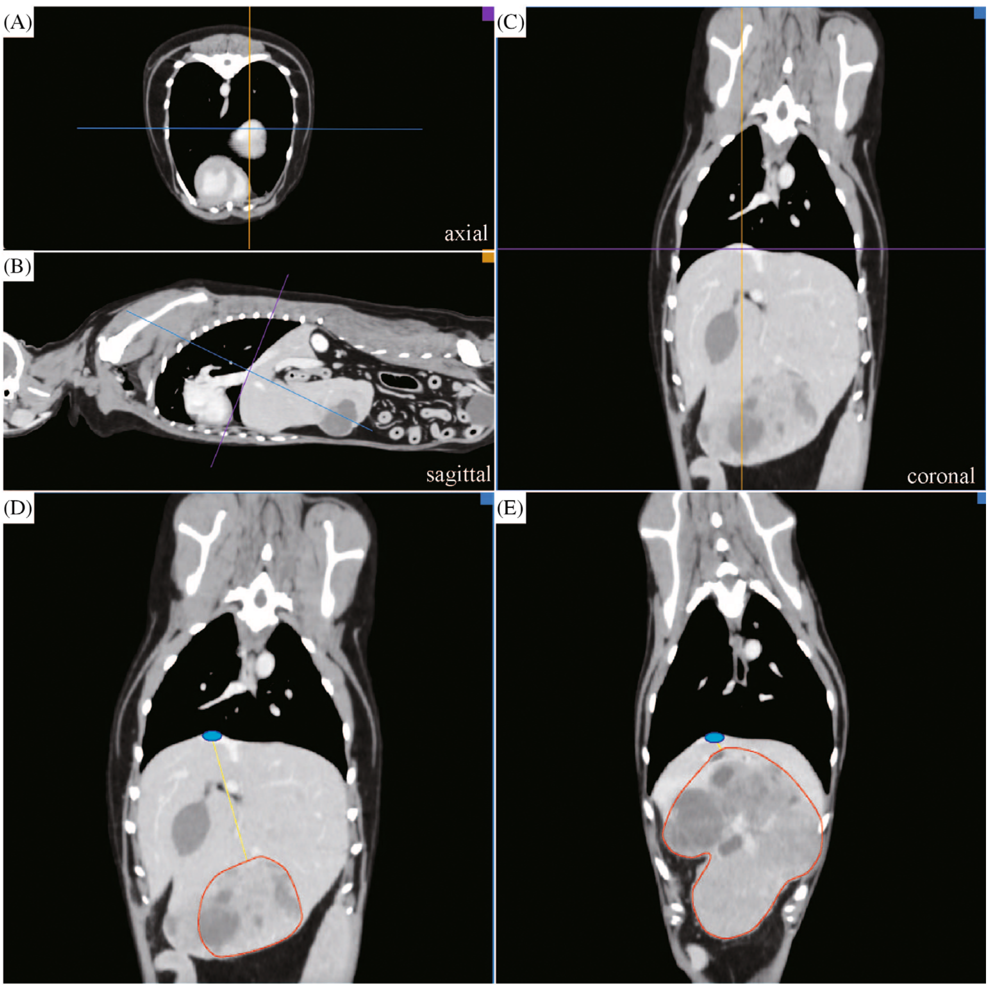

FIGURE 1 Shortest distance from the caudal vena cava (junction of the left and right hepatic veins) to the hepatic mass. Measurement methods. (1) Identify the caudal vena cava (junction of the left and right hepatic veins) on the axial view (A). (2) Using the caudal vena cava as the reference point, explore the sagittal (B) and coronal (C) views to find the view in which the mass is closest to the caudal vena cava, and measure the distance from the mass to the caudal vena cava. (D) Mass at the edge of the liver lobe. (E) Mass at the hilus of the liver lobe. Blue circle, caudal vena cava (junction of the left and right hepatic veins); red circle, mass; yellow line, shortest distance from the mass to the caudal vena cava.

isoflurane or sevoflurane were used for maintenance, and fentanyl (24–42 μg/kg/h) alone, remifentanil (5 μg/kg/h) alone, or combinations of fentanyl (24–42 μg/kg/h) and ketamine (5 μg/kg/min) or remifentanil (5 μg/kg/h) were administered via continuous intravenous infusion. Bradycardia or hypotension during anesthesia was managed with atropine, dopamine, dobutamine, norepinephrine, vasopressin, or epinephrine as needed. The variables monitored during anesthesia were the mean arterial pressure (MAP) using invasive arterial pressure measurements, and the percutaneous oxygen saturation (SpO_2) using a pulse oximeter. Hypotension (MAP <60 mmHg) and hypoxemia ($SpO_2 < 95\%$) were recorded if the condition persisted for more than 5 min during the procedure.

2.4 | Surgery

Complete hepatic lobectomy (including hilar resection) or partial liver lobectomy was performed by two surgeons. The method of resection was chosen at the discretion of the surgeon. For complete lobectomy, the hilar vessels were first identified, and the Glissonean pedicle (including the portal vein, hepatic artery, and bile duct) was dissected and ligated en masse. The hepatic vein was subsequently exposed and ligated individually. Ligation methods included sutures, vascular clips, or vessel-sealing devices. The surgical time was measured from skin incision to wound closure. If other non-thoracic abdominal surgeries were performed simultaneously, excluding liver biopsy from different lobes, these were recorded. In cases where thoracotomy (e.g., median sternotomy or diaphragmatic incision) was performed to obtain access to the mass, this was recorded as thoracotomy. Cases in which whole blood or component blood transfusion was performed pre-/intra-/postoperatively were recorded as having a blood transfusion. The resected masses were subjected to histopathologic examination.

2.5 | Postoperative outcomes

Postoperative complications and death within 2 weeks were defined as postoperative complications and postoperative death, respectively. On the basis of the Accordion severity grading system, complications were classified as level 1 (mild), level 2 (moderate), level 3 (severe), or level 4 (death).[12] To account for potential bias due to increased surgical proficiency over time, cases were stratified into two periods: before and after August 2018. The cutoff point was set as July 2018, which resulted in an approximately equal distribution of cases in each period.

2.6 | Statistical analysis

For statistical analysis, clinical signs, underlying diseases, intraoperative hypotension, and hypoxemia, surgical procedures (simultaneous surgery, thoracotomy), and blood transfusion were treated as dichotomous variables based on their presence or absence. Sex, liver division, and lobectomy technique were considered individual variables. Age, bodyweight, preoperative blood test results (hematocrit, ALT, AST, ALP, GGT, glucose, albumin, total bilirubin, PT, APTT, fibrinogen, D-dimer, and FDP), CT findings (maximum diameter, tumor volume measured using image analysis software, the shortest distance from the mass to the caudal vena cava measured at the junction of the right and left hepatic veins), and surgical time were analyzed as continuous variables. Dogs were classified into two groups; the relevant group (levels 3 and 4 using the Accordion severity grading system) and the non-relevant group (levels 1 and 2). For continuous variables, data are expressed as median (interquartile range [IQR]). Logistic regression analysis was performed to identify risk factors associated with postoperative complications. Initially, univariable logistic regression was performed for all variables, and those with $p < .05$ were considered statistically significant and selected for further evaluation. To prevent overfitting due to the limited number of events, multivariable logistic regression models were constructed by combining two significant variables at a time from the univariable results. Multiple models were generated based on different combinations of variables, and the top five models with the lowest Akaike information criterion (AIC) values were presented. ORs and 95% CI were calculated using logistic regression, with the following reference categories: female (for sex), absence (for dichotomous variables), and left liver division (for liver division). In addition, the accuracy of distinguishing between the relevant and non-relevant groups using the actual distance from the mass to the CVC was assessed by receiver operating characteristic (ROC) analysis, with the optimal cutoff value determined by the Youden index.

Statistical analysis was performed using JMP Pro 17 (SAS, Cary, North Carolina).

3 | RESULTS

3.1 | Signalment

A total of 17 dogs (17.7%) experienced severe postoperative complications, including six deaths (6.3%).

The most common pure breeds among the 96 included dogs were Miniature Dachshund ($n = 12$, 12.5%), Toy

Poodle ($n = 10$, 10.4%), Beagle ($n = 7$, 7.3%), Shih Tzu ($n = 6$, 6.3%), and Chihuahua ($n = 6$, 6.3%). Additionally, 17 dogs (17.7%) were classified as mixed breed.

3.2 | Preoperative evaluation

The presence of underlying diseases was associated with postoperative complications in univariable logistic regression analysis (OR: 2.821; 95% CI: 1.504–5.291; $p = .001$; Table 3).

The PT was associated with postoperative complications (OR: 1.105 per 1.01 times increase; 95% CI: 1.025–1.191; $p = .009$; Table 3), although its values remained within the normal range (Table 1).

Of the liver divisions, the left division was most commonly affected (53 cases), followed by the right division (22 cases) and the central division (20 cases) (Table 2). Univariable logistic regression analysis showed no association between liver division and postoperative complications. The ORs for the central and right divisions, relative to the left division, were 1.061 (95% CI: 0.458–2.460; $p = .890$) and 1.249 (95% CI: 0.562–2.775; $p = .586$), respectively (Table 3).

Clinical signs and underlying diseases were recorded in 89 cases. Clinical signs included lethargy and reduced appetite ($n = 27$), gastrointestinal symptoms ($n = 9$), lethargy alone ($n = 8$), polyuria/polydipsia ($n = 7$), reduced appetite alone ($n = 3$), respiratory symptoms ($n = 1$). Some dogs exhibited more than one clinical sign. A total of 30 dogs presented with 35 comorbidities, including hyperadrenocorticism ($n = 8$), mitral valve disease ($n = 6$), hypoglycemia ($n = 7$), hypothyroidism ($n = 6$), tracheal collapse ($n = 2$), hypoxemia ($n = 2$), DIC ($n = 1$), tricuspid regurgitation ($n = 1$), hypercapnia ($n = 1$), and hypoadrenocorticism ($n = 1$).

3.3 | Anesthesia and intraoperative monitoring

Intraoperative hypotension (OR: 4.000; 95% CI: 1.421–11.259; $p = .009$) and intraoperative hypoxemia (OR: 2.143; 95% CI: 1.215–3.781; $p = .009$) were associated with postoperative complications (Table 3).

Anesthetic agents were documented in 87 cases. The premedication and induction agents included propofol (45 cases), alfaxalone (27 cases), midazolam + propofol (5 cases), midazolam + alfaxalone (3 cases), morphine + alfaxalone (3 cases), ketamine + propofol (2 cases), midazolam + ketamine + alfaxalone (1 case), morphine + propofol (1 case), and ketamine alone (1 case). Inhalation anesthetics included isoflurane (76 cases) and sevoflurane (11 cases). Intraoperative analgesic agents included fentanyl alone (76 cases), fentanyl + ketamine (9 cases), fentanyl + remifentanil (1 case), and remifentanil alone (1 case). Vasopressors used included dopamine alone (70 cases) and combinations of dopamine with norepinephrine, vasopressin, or epinephrine (14 cases).

Intraoperative hypotension was observed in 54 dogs, and intraoperative hypoxemia in 20. These events were managed with appropriate interventions, including the administration of vasoactive agents for hypotension and mechanical ventilation for hypoxemia.

3.4 | Surgery

No dogs died intraoperatively, and all 96 dogs survived the surgical procedure.

Thoracotomy was not associated with postoperative complications (OR: 1.700; 95% CI: 0.944–3.061; $p = .077$).

There were 42 cases in which abdominal surgeries were performed simultaneously with liver mass resection, with 53 procedures comprising splenectomy ($n = 8$), cholecystectomy ($n = 8$), subcutaneous nodule excision ($n = 5$), castration ($n = 4$), adrenalectomy ($n = 3$), ovariohysterectomy ($n = 3$), cystolithotomy ($n = 3$), pancreatic biopsy ($n = 3$), mammary tumor excision ($n = 3$), gastrotomy ($n = 3$), bile duct lavage ($n = 2$), gastric tumor excision ($n = 2$), congenital portosystemic shunt ligation ($n = 2$), colonic tumor excision ($n = 1$), nephrectomy ($n = 1$), mesenteric tumor excision ($n = 1$), and bladder tumor excision ($n = 1$).

Thoracotomy was performed in 25 cases. Histopathologic diagnoses were obtained for 94 cases and comprised hepatocellular carcinoma ($n = 43$), hepatocellular adenoma ($n = 27$), nodular hyperplasia ($n = 11$), hemangiosarcoma ($n = 3$), bile duct cystadenoma ($n = 1$), adenocarcinoma ($n = 1$), cholangiocarcinoma ($n = 1$), bile duct adenoma ($n = 1$), undifferentiated sarcoma ($n = 1$), myxoid liposarcoma ($n = 1$), extraskeletal osteosarcoma ($n = 1$), metastatic tumors (fibrohistiocytic nodule, fibrosarcoma) ($n = 1$), and hemangioma ($n = 1$).

3.5 | Postoperative outcomes

There were 17 dogs in the relevant group classified as level 3 (severe complications, $n = 11$) and level 4 (death, $n = 6$). The non-relevant group comprised 79 dogs classified as level 1 (mild complications, $n = 72$) and level 2 (moderate complications, $n = 7$). The cause of death was DIC/suspected thrombotic events (3 dogs), hemorrhage (2 dogs), and hypotension (1 dog). Severe complications were acute kidney injury (AKI; 4 dogs), jaundice of

TABLE 1 Descriptive statistics for all factors in the entire study population.

Factors		Missing data
Signalment		
Age (month), median (IQR)	144 (121.8–160.5)	-
Sex, *n* (%)		-
Female	14 (14.6)	
Female (spayed)	41 (42.7)	
Male	12 (12.5)	
Male (castrated)	29 (30.2)	
Weight (kg), median (IQR)	7.3 (4.9–12.9)	-
Clinical signs, *n* (%)		7 (7.3%)
Present	47 (52.8)	
Absent	42 (47.2)	
Underlying diseases, n (%)		7 (7.3%)
Present	30 (33.7)	
Absent	59 (66.3)	
Blood test results		
Hematocrit (%), median (IQR)	40.5 (35.3–45.1)	-
ALT (U/L), median (IQR)	121 (51–393)	5 (5.2%)
AST (U/L), median (IQR)	66 (39–193)	7 (7.3%)
ALP (U/L), median (IQR)	538 (221–1208)	6 (6.3%)
GGT (U/L), median (IQR)	12 (8.0–30.5)	11 (11.5%)
Glucose (mg/dL), median (IQR)	106 (95.5–117.0)	7 (7.3%)
Albumin (g/dL), median (IQR)	3.5 (3.1–3.9)	27 (28.1%)
Total bilirubin (mg/dL), median (IQR)	0.3 (0.2–1.2)	84 (87.5%)
PT (per 1× upper limit), median (IQR)	0.8 (0.74–0.85)	1 (1.0%)
APTT (per 1× upper limit), median (IQR)	0.81 (0.65–0.90)	1 (1.0%)
Fibrinogen (per 1× upper limit), median (IQR)	1.01 (0.78–1.25)	1 (1.0%)
D-dimer (μg/kg), median (IQR)	1.4 (0.5–3.8)	69 (71.9%)
FDP (μg/kg), median (IQR)	5.2 (0.9–12.7)	69 (71.9%)
Computed tomography imaging findings		
Maximum diameter (cm), median (IQR)	7.06 (5.24–9.44)	-
Volume (cm^3), median (IQR)	147.9 (51.6–368.2)	-
Actual distance (cm), median (IQR)	3.52 (1.44–4.91)	-
Corrected distance (cm/kg), median (IQR)	0.37 (0.21–0.64)	-
Liver division, n (%)		1 (1.0%)
Right	22 (23.1)	
Central	20 (21.1)	
Left	53 (55.8)	
Intraoperative factors		
Surgical time (min), median (IQR)	127.5 (94.5–179.3)	10 (10.4%)
Lobectomy technique, n (%)		25 (26.0%)
Complete	57 (80.3)	
Partial	14 (19.7)	

TABLE 1 (Continued)

Factors		Missing data
Simultaneous surgery, n (%)		2 (2.1%)
Present	42 (44.7)	
Absent	52 (55.3)	
Thoracotomy, *n* (%)		12 (12.5%)
Present	25 (29.8)	
Absent	59 (70.2)	
Intraoperative hypotension, *n* (%)		3 (3.1%)
Present	54 (58.1)	
Absent	39 (41.9)	
Intraoperative hypoxemia, *n* (%)		5 (5.2%)
Present	20 (22.0)	
Absent	71 (78.0)	
Blood transfusion, *n* (%)		1 (1.0%)
Present	39 (41.1)	
Absent	56 (58.9)	

Abbreviations: ALP, alkaline phosphatase concentration; ALT, alanine aminotransferase concentration; APTT, activated partial thromboplastin time; AST, aspartate aminotransferase concentration; ATIII, antithrombin III concentration; FDP, fibrin degradation product concentration; GGT, gamma-glutamyltransferase concentration; IQR, interquartile range; PT, prothrombin time.

TABLE 2 Number of masses, complication rate, mortality rate, and corrected distance by liver division.

Liver division	Total cases (*n*)	Complications (*n*, %)	Corrected distance (median [IQR] [cm/kg])		
			All dogs	Relevant group	Non-relevant group
Left	53	8 (15.1)	0.418 (0.255–0.744)	0.324 (0.200–0.404)	0.565 (0.281–0.787)
Central	20	4 (20.0)	0.254 (0.050–0.514)	0.045 (0.020–0.135)	0.277 (0.107–0.538)
Right	22	5 (22.7)	0.396 (0.219–0.668)	0.237 (0.199–0.458)	0.483 (0.238–0.661)

Note: IQR, interquartile range; relevant group, dogs with levels 3 or 4 complications using the Accordion severity grading system within 2 weeks after hepatic mass resection; non-relevant group, dogs with levels 1 or 2 complications.
Abbreviation: IQR, interquartile range.

suspected liver failure (3 dogs), hypoxemia of unknown cause (2 dogs), suspected pulmonary thromboembolism (1 dog), and hypoglycemia (1 dog).

3.6 | Multivariable analysis

Multivariable logistic regression analysis was performed using combinations of two variables selected from those that showed statistical significance ($p < .05$) in univariable analysis. The following variables were used to construct the models: presence of underlying diseases, PT, corrected distance, surgical time, intraoperative hypotension, intraoperative hypoxemia, and blood transfusion.

A total of 28 models were constructed, and the five models with the lowest AIC values are presented in Table 4. The best-fit model (AIC = 61.513) included underlying diseases (OR: 2.703; 95% CI: 1.316–5.551; $p = .007$) and surgical time (OR: 1.011; 95% CI; 1.000–1.022; $p = .052$). Other variables included in these models were intraoperative hypotension, corrected distance, PT, and surgical time. Corrected distance was incorporated in the third-best model (AIC = 65.182; OR: 0.666 per 0.1 cm/kg increase; 95% CI: 0.476–0.930; $p = .017$). Multicollinearity was assessed using the variance inflation factor (VIF). All VIFs were below 2.0, indicating that there was no multicollinearity among the selected variables.

3.7 | ROC analysis

ROC analysis was performed using the measured actual distance from the mass to the CVC, with complications defined as positive. The area under the ROC curve was

TABLE 3 Univariate logistic regression analysis for risk factors associated with postoperative complications.

Factors	OR (95% CI)	*p*-value
Signalment		
Age (month)	1.005 (0.987–1.023)	.590
Sex (male vs. female)	1.113 (0.658–1.884)	.690
Weight (kg)	0.931 (0.841–1.031)	.171
Clinical signs	1.411 (0.789–2.534)	.244
Underlying diseases	2.821 (1.504–5.291)	.001
Blood test results		
Hematocrit (%)	1.013 (0.939–1.092)	.742
ALT (U/L), per 100 U/L increase	1.044 (0.974–1.118)	.221
AST (U/L), per 100 U/L increase	1.079 (0.971–1.199)	.159
ALP (U/L), per 100 U/ L increase	0.944 (0.961–1.027)	.708
GGT (U/L), per 100 U/L increase	1.119 (0.926–1.353)	.244
Glucose (mg/dL)	0.997 (0.975–1.020)	.792
Albumin (g/dL)	0.521 (0.179–1.522)	.233
Total bilirubin (mg/dL)	0.984 (0.245–3.941)	.981
PT (per 1× upper limit), per 1.01 times increase	1.105 (1.025–1.191)	.009
APTT (per 1× upper limit), per 1.01 times increase	0.991 (0.964–1.019)	.525
Fibrinogen (per 1× upper limit), per 1.01 times increase	1.002 (0.987–1.017)	.792
D-dimer (μg/kg), per 0.1 μg/kg increase	0.995 (0.944–1.049)	.857
FDP (μg/kg)	0.953 (0.765–1.186)	.663
Computed tomography imaging findings		
Maximum diameter (cm)	0.942 (0.799–1.110)	.475
Volume (cm^3), per 10 cm^3 increase	0.993 (0.976–1.010)	.404
Actual distance (cm)	0.672 (0.494–0.913)	.011
Corrected distance (cm/kg), per 0.1 cm/kg increase	0.741 (0.583–0.942)	.014
Liver division (central vs. left)	1.061 (0.458–2.460)	.890
Liver division (right vs. left)	1.249 (0.562–2.775)	.586
Intraoperative factors		
Surgical time (min)	1.015 (1.005–1.025)	.002
Lobectomy technique	1.960 (0.677–5.674)	.217
Simultaneous surgery	0.892 (0.509–1.565)	.691
Thoracotomy	1.700 (0.944–3.061)	.077
Intraoperative hypotension	4.000 (1.421–11.259)	.009
Intraoperative hypoxemia	2.143 (1.215–3.781)	.009
Blood transfusion	1.809 (1.045–3.131)	.034

Note: Reference categories: Female (for sex), absence (for dichotomous variables, e.g., underlying diseases, hypotension), left (for liver division).
Abbreviations: ALP, alkaline phosphatase concentration; ALT, alanine aminotransferase concentration; APTT, activated partial thromboplastin time; AST, aspartate aminotransferase concentration; ATIII, antithrombin III concentration; FDP, fibrin degradation product concentration; GGT, gamma-glutamyltransferase concentration; PT, prothrombin time.

0.751 (95% CI: 0.608–0.892; $p = .003$). The optimal cutoff value determined using the Youden index was 1.43 cm (sensitivity: 0.647, specificity: 0.835). When the sensitivity and specificity were each set to 90%, the cutoff values were 5.02 cm (sensitivity: 0.882, specificity: 0.253) and 1.18 cm (sensitivity: 0.471, specificity: 0.899), respectively.

TABLE 4 Top five multivariable logistic regression models with lowest AIC.

No.	Factor	OR (95% CI)	*p*-value	AIC
1	Underlying diseases	2.703 (1.316–5.551)	.007	61.513
	Surgical time (min)	1.011 (1.000–1.022)	.052	
2	Underlying diseases	2.704 (1.389–5.263)	.003	64.381
	Intraoperative hypotension	3.589 (1.236–10.421)	.019	
3	Underlying diseases	2.935 (1.500–5.744)	.002	65.182
	Corrected distance (cm/kg), per 0.1 cm/kg increase	0.666 (0.476–0.930)	.017	
4	PT (per 1× upper limit), per 1.01 times increase	1.107 (1.017–1.205)	.019	67.885
	Surgical time (min)	1.015 (1.005–1.026)	.004	
5	Underlying diseases	2.739 (1.428–5.253)	.002	68.916
	PT (per 1× upper limit), per 1.01 times increase	1.093 (1.004–1.189)	.040	

Note: Reference categories: absence (for underlying diseases, intraoperative hypotension, PT).
Abbreviations: AIC, Akaike information criterion; PT, prothrombin time.

4 | DISCUSSION

The postoperative mortality rate in the present study was 6.3%, and the postoperative complication rate was 17.7%. These results are consistent with previous reports, which indicate postoperative mortality rates ranging from 5.6% to 11.5% and postoperative complication rates ranging from 6.0% to 28.7%.[5–8]

As hypothesized, a shorter distance between the mass and the CVC was identified as a risk factor for postoperative complications following hepatic mass resection. The distance in the present study represented the shortest distance between the mass and the CVC, using the base of the mass as the reference point. This metric likely reflects the distance between the vessels requiring surgical manipulation during the procedure and the CVC. When the mass is in close proximity to the CVC, the vessels requiring ligation or sealing become shorter, which increases the risk of inadvertent CVC injury during dissection. The difficulty in securing these vessels may lead to a prolonged operative time, greater parenchymal and surrounding tissue damage, and greater risk of hemorrhage, all of which could contribute to a higher incidence of postoperative complications. Previous studies have identified resection of right divisional masses as a poor prognostic factor or a risk factor for intraoperative complications during hepatic mass resection. This has been attributed to the anatomical proximity of the right divisional to the CVC.[3,5,6] These findings align with our results, which suggest that a shorter distance from the mass to the CVC is a significant risk factor for postoperative complications.

Factors previously reported as risk factors for postoperative complications, such as hilar resection or thoracotomy,[5,6] were not associated with complications in the present study. Hilar resection is generally performed when the mass is located at the hilus of the liver lobe and is used to improve surgical exposure.[6] The proximity of the mass to the CVC indicates its location at the hilus of the liver lobe. In the present study, hilar resection was performed in many cases. However, it is plausible that masses located closer to the hilus of the liver lobe might pose a higher risk of complications, even with the same surgical approach. Thoracotomy, including median sternotomy and diaphragmatic incision, is used when the visualization of the mass base vasculature cannot be secured through caudal or ventral retraction of the mass.[13] This procedure improves exposure. A previous report indicated that these procedures are more frequently required for right divisional masses.[5] However, in the present study, 25 cases involved thoracotomy for left divisional masses (7 cases), central divisional masses (7 cases), and right divisional masses (11 cases). This suggests that securing adequate visibility may be challenging not only for right divisional masses but also for masses situated at the liver lobe hilus. These findings support the conclusion that a shorter distance from the mass to the CVC contributes to the onset of postoperative complications. The distance from the mass to the CVC is a preoperative finding obtained by CT imaging and may be a useful variable in assessing the surgical difficulty.

In addition, the presence of underlying diseases was identified as a risk factor for postoperative complications. In the present study, most of the dogs categorized as having underlying diseases were likely to be classified as American Society of Anesthesiologists (ASA) physical status III or higher. An increase in ASA class is known to be associated with higher odds of anesthesia-related mortality in dogs and cats.[14] Therefore, the finding that underlying diseases contributed to the onset of postoperative complications is consistent with previous evidence and appears to be a reasonable result.

Intraoperative hypotension was also identified as being associated with postoperative complications. To the best of our knowledge, no previous reports have directly evaluated the association between measured intraoperative hypotension and perioperative complications and mortality in dogs undergoing hepatic mass resection. In humans, intraoperative hypotension is observed in 85% of patients undergoing hepatic mass resection and is influenced by blood loss and surgical techniques.[15–17] Manipulation of the mass during canine hepatic mass resection has been reported to alter venous return,[18] and our clinical experience suggests that mass manipulation often induces hypotension. When a mass is located near the CVC, the manipulation of the mass may be more extensive, which could potentially lead to the induction of greater hypotension.

Hypotension may also be attributed to anesthesia. In dogs, intraoperative hypotension is a common anesthetic complication.[19] In human medicine, a MAP of below 80 mmHg for more than 10 min increases the risk of organ dysfunction, with the risks escalating with further decreases in MAP.[20] Moreover, hypotension is a recognized risk factor for postoperative AKI following hepatic mass resection in humans.[21] Given the frequency of hypotension in our study population, further studies are warranted to assess whether blood pressure monitoring could help minimize the risk of undetected hypotension and its associated complications.

The present study had several limitations. First, as a retrospective study, missing records are inevitable. Additionally, given the small sample size of the complications group in this study, the possibility of a type II error cannot be ruled out. Although our comprehensive approach allowed for the generation of hypotheses, the large number of variables assessed introduces a greater risk of spurious associations, and the potential for false associations is increased compared to more conservative analysis. Furthermore, the definitions of underlying diseases and complications were based on existing records without standardized diagnostic criteria. Regarding imaging, although CT scans were performed under standardized conditions, the measurement of distance may have been influenced by the positions of adjacent organs and the movement of the liver lobes, which could not be fully controlled. Furthermore, although we used the shortest distance from the mass to the CVC as a surrogate measure of anatomical proximity, this linear measurement may not fully capture the three-dimensional vascular path or account for intraoperative tissue mobility. The directionality of the mass relative to the CVC and the extent to which the mass can be mobilized during surgery may affect the actual impact on vascular manipulation and risk. The measurement method used in the present study may be particularly affected in dogs with caudate lobe masses because some masses may be adjacent to the CVC but distant from the junction, potentially impacting accuracy. On the basis of the intraoperative records, it was difficult to assess bleeding, which is a major intraoperative complication during hepatic mass resection, and it is possible that small to moderate bleeding was not recorded. However, there were no records of major vessel injury, and no dogs received blood transfusions due to significant bleeding. Additionally, the anesthetic protocols varied and potentially influenced the outcomes, particularly with respect to the incidence of intraoperative hypotension. Regarding the variability in results between the two surgeons, statistical analysis showed no significant difference in complication rates due to standardization within the same institution (Fisher's exact test; $p = .108$). The present findings require confirmation in future prospective studies that consider these study limitations.

In conclusion, the present study suggests that a shorter distance between the mass and the CVC may be associated with an increased risk of postoperative complications after canine hepatic mass resection. Intraoperative hypotension and underlying diseases may also contribute to the onset of complications. Preoperative CT evaluation of the proximity of the mass to the CVC appears to be an important factor for prognosis that warrants further investigation for clinical application.

AUTHOR CONTRIBUTIONS

Konno R, DVM: Identified suitable medical records, recorded demographic information, compiled and interpreted all data, and drafted and edited the manuscript. Kaneko Y, DVM, PhD: Contributed to the study design, assisted with the preparation and editing of the final manuscript, and was responsible for the surgical management of cases and providing patient data, including surgical details. Osuga T, DVM, PhD: Proposed the statistical study design and assisted with statistical analysis. Torisu S, DVM, PhD, Yamamoto S, DVM, PhD, and Okadera R, DVM: Were responsible for the surgical management of cases and provided patient data, including surgical details. Naganobu K, DVM, PhD: Provided patient data, including anesthetic details, and assisted with the preparation and editing of the final manuscript. All authors critically reviewed the manuscript and approved the final version.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest related to this report.

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REFERENCES

1. Patnaik AK, Hurvitz AI, Lieberman PH. Canine hepatic neoplasms: a clinicopathologic study. *Vet Pathol*. 1980;17:553-564.
2. Hirose N, Uchida K, Kanemoto H, Ohno K, Chambers JK, Nakayama H. A retrospective histopathological survey on canine and feline liver diseases at the University of Tokyo between 2006 and 2012. *J Vet Med Sci*. 2014;76(7):1015-1020.
3. Liptak JM, Dernell WS, Monnet E, et al. Massive hepatocellular carcinoma in dogs: 48 cases (1992–2002). *Jama*. 2004;225(8):1225-1230.
4. Reist AM, Reagan JK, Fujita SK, Walny AM. Histopathologic findings and survival outcomes of dogs undergoing liver lobectomy as treatment for spontaneous hemoabdomen secondary to a ruptured liver mass: retrospective analysis of 200 cases (2012–2020). *J Am Vet Med Assoc*. 2023;261(2):237-245.
5. Moore VW, White J, Marchevsky AM. Association between divisional location and short-term outcome of liver mass resection in 124 dogs. *Vet Surg*. 2023;52(4):513-520.
6. Linden DS, Liptak JM, Vinayak A, et al. Outcomes and prognostic variables associated with central division hepatic lobectomies: 61 dogs. *Vet Surg*. 2019;48(3):309-314.
7. Kinsey JR, Gilson SD, Hauptman J, Mehler SJ, May LR. Factors associated with long-term survival in dogs undergoing liver lobectomy as treatment for liver tumors. *Can Vet J*. 2015;56(6):598-604.
8. Lapsley JM, Wavreille V, Barry S, et al. Risk factors and outcome in dogs with recurrent massive hepatocellular carcinoma: a veterinary Society of Surgical Oncology case-control study. *Vet Comp Oncol*. 2022;20(3):697-709.
9. Hanson KR, Pigott AM, Linklater AKJ. Incidence of blood transfusion requirement and factors associated with transfusion following liver lobectomy in dogs and cats: 72 cases (2007–2015). *J Am Vet Med Assoc*. 2017;251(8):929-934.
10. Hata A, Fujitani N, Takeshita M, et al. Comparison of regression for blood ALP levels using methods of the Japan Society of Clinical Chemistry and the International Federation of Clinical Chemistry and Laboratory Medicine in bovine, canine, feline, and human testing. *PLoS One*. 2021;16(6):e0253396. doi:10.1371/journal.pone.0253396
11. Goggs R, Mastrocco A, Brooks MB. Retrospective evaluation of 4 methods for outcome prediction in overt disseminated intravascular coagulation in dogs (2009–2014): 804 cases. *J Vet Emerg Crit Care*. 2018;28(6):541-550.
12. Strasberg SM, Linehan DC, Hawkins WG. The accordion severity grading system of surgical complications. *Ann Surg*. 2009;250(2):177-186.
13. Mayhew PD, Weisse C. Liver and biliary system. In: Johnston SA, Tobias KM, eds. *Veterinary Surgery Small Animal*. 2nd ed. Elsevier; 2018:1828-1852.
14. Matthews NS, Mohn TJ, Yang M, et al. Factors associated with anesthetic-related death in dogs and cats in primary care veterinary hospitals. *J Am Vet Med Assoc*. 2017;250(6):655-665.
15. Cata JP, Soni B, Bhavsar S, et al. Forecasting intraoperative hypotension during hepatobiliary surgery. *J Clin Monit Comput*. 2024;39:107-118. doi:10.1007/s10877-024-01223-5
16. Alkozai EM, Lisman T, Porte RJ. Bleeding in liver surgery: prevention and treatment. *Clin Liver Dis*. 2009;13(1):145-154.
17. Shirabe K, Kajiyama K, Harimoto N, Tsujita E, Wakiyama S, Maehara Y. Risk factors for massive bleeding during major hepatectomy. *World J Surg*. 2010;34(7):1555-1562.
18. Self I. Gastrointestinal, laparoscopic and liver procedures. In: Duke-Novakovski T, Vries M, Seymour C, eds. *BSAVA Manual of Canine and Feline Anaesthesia and Analgesia*. 3rd ed. British Amall Animal Veterinary Assosiacion; 2016:343-355.
19. Redondo JI, Rubio M, Soler G, Serra I, Gomez-Villamands J. Normal values and incidence of cardiorespiratory complications in dogs during general Anaesthesia. A review of 1281 cases. *J Vet Med A Physiol Pathol Clin Med*. 2007;54(9):470-477.
20. Wesselink EM, Kappen TH, Torn HM, Slooter AJC, van Klei WA. Intraoperative hypotension and the risk of postoperative adverse outcomes: a systematic review. *Br J Anaesth*. 2018;121(4):706-721.
21. Liao P, Zhao S, Lyu L, et al. Association of intraoperative hypotension with acute kidney injury after liver resection surgery: an observational cohort study. *BMC Nephrol*. 2020;21(1):456.

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