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Research article

RESTRICTIVE VERSUS LIBERAL FLUID THERAPY AND PERIOPERATIVE OUTCOMES IN CANINE LAPAROSCOPIC CHOLECYSTECTOMY: A RETROSPECTIVE STUDY OF 104 CASES

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Laparoscopic cholecystectomy in dogs induces hemodynamic and respiratory changes due to pneumoperitoneum, thereby making fluid therapy a central element of perioperative management. This retrospective, single-center study evaluated the effect of two crystalloid strategies: restrictive (5 mL/kg/h) and liberal (10 mL/kg/h), in 104 dogs anesthetized between 2014 and 2025 and subjected to laparoscopic cholecystectomy. The primary outcome was perioperative mortality (≤7 days). Secondary outcomes included cardiovascular instability, hypothermia, vasopressor requirement, transfusion requirement, acute kidney injury, hospital resource utilization and short-term recovery. Analyses included between-group comparisons, multivariate logistic regression, and propensity to score matching (1:1). Mortality was low and similar between strategies. The liberal strategy was associated with higher frequency of hypothermia and lower minimum intraoperative temperature, while the restrictive strategy required higher maximum vasopressor doses, without increased severe events. In multivariate models, longer anesthetic time was associated with cardiovascular instability and hypothermia; higher body weight was protective against hypothermia. Findings remained consistent after matching. Therefore, in canine laparoscopic cholecystectomy, restrictive (5 mL/kg/h) and liberal (10 mL/kg/h) strategies showed similar clinical results; choice should be individualized based on each patient's clinical status.

Keywords: acute kidney injury, hemodynamics, hypothermia, intraoperative complications, pneumoperitoneum, vasoconstrictor agents

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INTRODUCTION

Laparoscopic cholecystectomy is indicated in dogs with biliary mucocele, cholelithiasis, or cholecystitis, and has been associated with mortality rates ranging from 2% to 40% [1–3]. Compared with laparotomy, the laparoscopic technique generally reduces postoperative pain, accelerates recovery, and shortens hospitalization time [4–6].

Nevertheless, pneumoperitoneum induces significant cardiorespiratory alterations, including decreased cardiac output and increased systemic vascular resistance. Furthermore, the decrease in renal blood flow may predispose to postoperative acute kidney injury [7–9]. Intraoperative fluid therapy is essential to maintain tissue perfusion; however, both overly restrictive administration and excessive fluid loading have been associated with increased morbidity and mortality [10–12].

Human studies have demonstrated benefits associated with liberal fluid administration [13]. In healthy dogs, lower intraoperative rates (5 mL/kg/h) resulted in decreased abdominal perfusion pressure and urine output [14]. However, these findings were derived from young animals exposed to a short period of pneumoperitoneum and without comorbidities—conditions that do not represent the spectrum of routine veterinary surgical practice.

Accordingly, this study aimed to retrospectively compare restrictive (5 mL/kg/h) versus liberal (10 mL/kg/h) fluid strategies in canine laparoscopic cholecystectomy, evaluating mortality as the primary outcome and perioperative complications as secondary outcomes.

MATERIAL AND METHODS

Ethical considerations

This retrospective study was conducted in accordance with the ethical guidelines of the Federal University of Santa Maria (UFSM) for research involving clinical data from animals. No experimental procedures were performed specifically for this research. All surgical procedures analyzed were carried out for therapeutic purposes as part of standard veterinary care, following institutional protocols for animal welfare and clinical practice.

Informed consent

All surgical procedures analyzed in this retrospective study were performed in client-owned animals with informed consent obtained from the owners for the original clinical treatment. No additional consent was required for this retrospective analysis.

Study design

A retrospective observational study was conducted at a university veterinary teaching hospital, including dogs that underwent laparoscopic cholecystectomy between June 2014 and June 2025.

Patients

Eligible patients included dogs of either sex and any age that underwent laparoscopic cholecystectomy due to biliary mucocele, cholelithiasis, or cholecystitis, and had complete medical records containing a detailed history, physical examination, and preoperative laboratory tests (a complete blood count [CBC] and a serum biochemistry panel performed within 15 days prior to the surgical procedure). The CBC variables used in the study were hemoglobin, hematocrit, and platelet count, and the biochemistry variables used were blood urea nitrogen [BUN], serum creatinine, albumin, alanine aminotransferase [ALT], and alkaline phosphatase [ALP], using the value closest to the day of anesthesia. All laboratory analytes, units, and time points used in the research are summarized in Table 1.

Table 1. Complete blood count (CBC) and serum biochemistry analytes used in the study, including units, time points, and how each variable was used in the analyses (baseline characterization, covariates, and outcome definitions).

Panel	Analyte	Unit	Time point	Use in the study
CBC	Hemoglobin	g/dL	Preoperative (within 15 days; value closest to the day of anesthesia)	Baseline characterization; definition of preoperative anemia (Hb <12 g/dL); covariate (PSM)
CBC	Hematocrit	%	Preoperative (within 15 days; value closest to the day of anesthesia)	Baseline characterization; covariate in outcome models; protective factor for transfusion requirement
CBC	Platelet count	$\times 10^3/\mu L$	Preoperative (within 15 days; value closest to the day of anesthesia)	Definition of thrombocytopenia ($<200{,}000/mm^3$); risk factor for transfusion requirement; covariate (PSM)
Biochemistry	Blood urea nitrogen	mg/dL	Preoperative (within 15 days; value closest to the day of anesthesia)	Baseline characterization
Biochemistry	Creatinine	mg/dL	Preoperative (within 15 days; value closest to the day of anesthesia)	Baseline characterization; covariate; predictor for AKI
Biochemistry	Creatinine	mg/dL	Postoperative (up to 48 h after surgery)	Definition of AKI ($\Delta \geq 0.3$ mg/dL or $\geq 50\%$ within 48 h, per IRIS criteria)
Biochemistry	Albumin	g/dL	Preoperative (within 15 days; value closest to the day of anesthesia)	Baseline characterization; covariate in outcome models
Biochemistry	ALT	U/L	Preoperative (within 15 days; value closest to the day of anesthesia)	Baseline characterization
Biochemistry	ALP	U/L	Preoperative (within 15 days; value closest to the day of anesthesia)	Baseline characterization

Abbreviations: **CBC** – complete blood count; **Hb** – hemoglobin; **ALT** – alanine aminotra - nsferase; **ALP** – alkaline phosphatase; **AKI** – acute kidney injury; **IRIS** – International Renal Interest Society; **PSM** – propensity score matching.

Eligible cases also needed to demonstrate an anesthesia record with continuous monitoring documented at ≤5-minute intervals and adequate surgical description. For hospitalized patients, only records with complete daily clinical progress notes until discharge or death were considered.

Dogs were excluded if they showed clinically significant dehydration identified by the attending anesthesiologist during pre-anesthetic evaluation (based on signs such as reduced skin turgor, dry mucous membranes, and prolonged capillary refill time >2 seconds), incomplete laboratory data, previously diagnosed structural heart disease, concomitant surgical procedures, or intraoperative conversion to open laparotomy. Records were also excluded if they lacked: (a) documentation of minimum cardiorespiratory monitoring at ≤5-minute intervals, (b) details of fluid therapy administration, or (c) postoperative follow-up until discharge or death.

Study groups

Records were retrospectively allocated into two groups according to the perioperative fluid therapy protocol used: restrictive (infusion rate of 5 mL/kg/h) or liberal (infusion rate of 10 mL/kg/h). The choice between 5 and 10 mL/kg/h was based on the historical evolution of veterinary perioperative fluid therapy guidelines for dogs and cats. A rate of 10 mL/kg/h was widely recommended by the 2013 AAHA/AAFP guidelines [15], until evidence regarding the risks of fluid overload led to its reduction to 5 mL/kg/h, which has been sustained by the 2024 AAHA guidelines [16]. The study period (2014–2025) coincided with this transition in recommendations, providing an opportunity to compare both approaches retrospectively.

The effective fluid therapy rate was calculated by dividing the total volume of crystalloids (continuous infusion plus corrective boluses) by anesthetic time and body weight. Additional boluses of 5–15 mL/kg were administered for the treatment of arterial hypotension according to the attending anesthesiologist's clinical protocol, regardless of group allocation.

Outcome definition

Outcomes were structured according to the COMPAC (Core Outcome Measures for Perioperative and Anaesthetic Care) framework, developed to standardize endpoints in perioperative research [17].

Primary outcome: perioperative mortality, defined as death occurring within 7 days after surgery, regardless of cause.

Secondary outcomes comprised (1) acute kidney injury (AKI), which was defined as an increase in serum creatinine ≥50% compared with the preoperative value or an absolute increment ≥0.3 mg/dL within 48 hours according to the International Renal Interest Society (IRIS) criteria, or absence of micturition documented for ≥12 consecutive hours postoperatively with urinary retention excluded through palpation or bladder

catheterization; laboratory time points and analytes used for AKI assessment are detailed in Table 1; (2) cardiovascular instability, defined as (a) mean arterial pressure (MAP) <60 mmHg or systolic arterial pressure (SAP) <90 mmHg sustained for >5 consecutive minutes, (b) need for vasopressor administration to achieve or maintain target pressures (MAP ≥60 mmHg or SAP ≥90 mmHg), or (c) concurrent occurrence of both a and b; and (3) intraoperative hypothermia, defined as body temperature <36 °C; and (4) transfusion, defined as administration of blood products intraoperatively or within 24 hours after surgery.

Hospitalization time was calculated as the interval between the end of surgery and either discharge or death, expressed in complete days; early discharge was defined as hospital discharge at the same day of the procedure; anesthetic time was defined as the total duration of anesthesia in minutes.

Short-term recovery quality: gastrointestinal dysfunction was defined as nausea, vomiting, or diarrhea within the first 24 hours following surgery; feeding dysfunction was defined as hyporexia or anorexia within the first 24 hours following surgery.

Anesthetic management

Premedication primarily consisted of methadone (Mytedom®, Cristália Produtos Químicos Farmacêuticos Ltda., Itapira, São Paulo, Brazil) or morphine (Dimorf®, Cristália Produtos Químicos Farmacêuticos Ltda., Itapira, São Paulo, Brazil) (0.2–0.4 mg/kg, IM), administered alone or in combination with midazolam (Dormire®, Cristália Produtos Químicos Farmacêuticos Ltda., Itapira, São Paulo, Brazil) (0.2–0.3 mg/kg, IM) or acepromazine (Acepran®, Vetnil Indústria e Comércio de Produtos Veterinários Ltda., Louveira, São Paulo, Brazil) (0.01–0.02 mg/kg, IM). Anesthesia was induced with propofol (Propovan®, Cristália Produtos Químicos Farmacêuticos Ltda., Itapira, São Paulo, Brazil) (3–6 mg/kg, IV to effect) and maintained with isoflurane (Isoforine®, Cristália Produtos Químicos Farmacêuticos Ltda., Itapira, São Paulo, Brazil) in 100% oxygen. Intraoperative analgesia comprised continuous infusions of fentanyl (Fentanest®, Cristália Produtos Químicos Farmacêuticos Ltda., Itapira, São Paulo, Brazil) (5–15 μg/kg/h) or remifentanil (Remifas®, Cristália Produtos Químicos Farmacêuticos Ltda., Itapira, São Paulo, Brazil) (10–50 μg/kg/h), often combined with adjuvant analgesics such as ketamine (Cetamin®, Syntec do Brasil Ltda., Santana de Parnaíba, São Paulo, Brazil) (0.5–1.0 mg/kg/h), lidocaine (Xylestesin®, Cristália Produtos Químicos Farmacêuticos Ltda., Itapira, São Paulo, Brazil) (1.8–3 mg/kg/h), or dexmedetomidine (Dexdomitor®, Zoetis Brasil Ltda., São Paulo, Brazil) (0.5–1.0 μg/kg/h).

Surgical technique

All cholecystectomies were performed by surgeons with previous experience in laparoscopy, using a standard laparoscopic technique with pneumoperitoneum established through three portals. Pneumoperitoneum was achieved with carbon

dioxide, maintaining intra-abdominal pressure between 6–12 mmHg, adjusted according to individual hemodynamic tolerance and surgical requirements. Dogs were placed in dorsal recumbency, and routine aseptic preparation and draping were subsequently performed. A three-portal approach was used (one portal 30-degree 10mm optic, and two working portals) to allow triangulation and exposure of the gallbladder and cystic region. Following establishment of pneumoperitoneum, the abdominal cavity was inspected and the gallbladder was atraumatically retracted to optimize visualization. The procedure consisted of stepwise dissection and isolation of the cystic duct and cystic artery with mixter clamps, which were then occluded with titanium clips prior to transection. The gallbladder was subsequently detached from the hepatic fossa using blunt and/or sharp dissection with hemostasis as needed, placed in a home-made extractor bag, and removed through the first portal site. Before desufflation, the surgical field was re-inspected for hemorrhage or suspected biliary leakage, and lavage/suction were performed when indicated. Miorraphy was performed with polidyoxanone and sultan pattern, such as subcutaneous, and dermorraphy was performed with nylon and Wolff pattern. Cases requiring conversion to laparotomy were excluded, as described in the Patients section.

Intraoperative monitoring and fluid management

Anesthetic monitoring comprised continuous electrocardiography, invasive or noninvasive blood pressure measurement using oscillometric or Doppler methods, capnometry ($EtCO_2$), pulse oximetry (SpO_2), and measurement of core esophageal temperature. Fluid therapy was administered using lactated Ringer's solution (Ringer Lactato®, JP Indústria Farmacêutica S.A., Ribeirão Preto, São Paulo, Brazil) or 0.9% saline (Cloreto de Sódio 0.9%®, JP Indústria Farmacêutica S.A., Ribeirão Preto, São Paulo, Brazil) according to the specific protocol of each group, with additional boluses of 5–15 mL/kg administered at the discretion of the attending anesthesiologist. Vasopressors, including dopamine (Dopamina®, União Química Farmacêutica Nacional S.A., Pouso Alegre, Minas Gerais, Brazil) (2–15 μg/kg/min), norepinephrine (Noradrenalina®, Cristália Produtos Químicos Farmacêuticos Ltda., Itapira, São Paulo, Brazil) (0.05–0.5 μg/kg/min), dobutamine (Dobutamina®, União Química Farmacêutica Nacional S.A., Pouso Alegre, Minas Gerais, Brazil) (2–10 μg/kg/min), or ephedrine (Efedrina®, Cristália Produtos Químicos Farmacêuticos Ltda., Itapira, São Paulo, Brazil) (0.1–0.2 mg/kg, IV), were used as clinically indicated to maintain hemodynamic stability.

Postoperative monitoring

All animals were monitored during the anesthetic recovery period by the attending anesthesiologist, regardless of American Society of Anesthesiologists (ASA) classification, using a standardized institutional anesthetic recovery score sheet. Serial assessments included level of consciousness (alert, semiconscious, or unresponsive),

presence of excitement (absent or present), pulse quality (strong, weak, or thready), mucous membrane color (normal, pale, or cyanotic), respiratory rate (≥10 bpm, <10 bpm, or dyspnea/tachypnea), and body temperature (≥37.5°C, 36.0–37.5°C, or <36.0°C). Each parameter was assigned a score, and the total score thereby guided clinical decision: a score ≥10 indicated conditions for discharge; 9–10, requirement for hospitalization; and <9, need for intensive monitoring.

Statistical analysis

Statistical analyses were performed using SPSS software (SPSS Statistics®, IBM Corporation, Armonk, New York, USA), version 24.0. Normality of continuous variables was assessed with the Shapiro–Wilk test. Variables with normal distribution were compared between groups using the Student's t-test for independent samples, whereas non-normally distributed variables were analyzed with the Mann–Whitney test. Categorical variables were compared using Pearson's chi-square test or Fisher's exact test when the expected count in any contingency table cell was <5. Associations were expressed as odds ratio (OR) with 95% confidence intervals (95% CI).

For adjustment of confounding factors, multivariable logistic regression analysis was performed including variables with $p<0.20$ in univariable analysis. Covariates were selected based on their clinical and pathophysiological relevance for each specific outcome. For the main outcomes (mortality, cardiovascular instability and hypothermia), the variables included in the models were: age, ASA classification, preoperative laboratory parameters (hematocrit, albumin concentration, serum creatinine), body weight, and anesthetic time. Model adequacy was assessed using Nagelkerke's pseudo R^2.

Additionally, propensity score matching (PSM) was applied at a 1:1 ratio using the nearest neighbor method without replacement and a caliper of 0.2 standard deviations of the PSM distribution. Post-matching comparisons were performed using appropriate tests for paired data. The PSM included ten covariates selected based on pathophysiological relevance and potential confounding: age (years), body weight (kg), ASA classification ≥3, anesthetic time (minutes), presence of endocrinopathy and baseline nephropathy, preoperative anemia (hemoglobin <12 g/dL), thrombocytopenia (<200,000/mm³), and pre-anesthetic use of dexmedetomidine and acepromazine. Of the 104 eligible patients, 28 were excluded from matching due to the absence of suitable counterparts within the specified caliper, resulting in 38 balanced pairs (n=76) for analysis. Adequate balance was verified through the reduction of standardized mean difference to <0.1 for all covariates. The sample loss of 26.9% was considered acceptable given the methodological rigor applied.

Post-hoc statistical power was calculated for the main outcomes using the effect sizes observed in the study. Given the exploratory nature of the research and the low statistical power observed for some outcomes, no correction for multiple comparisons was applied, and the results should be interpreted as hypothesis-generating for future

confirmatory prospective studies. All analyses were conducted according to the intention-to-treat principle. The level of statistical significance was set at $p \leq 0.05$.

RESULTS

A total of 104 records of dogs undergoing laparoscopic cholecystectomy were analyzed, with 63 (60.6%) corresponding to the restrictive group and 41 (39.4%) to the liberal group. Baseline characteristics were similar between groups (Table 2). The effective fluid therapy rate was 5.16 ± 0.41 vs 10.18 ± 0.89 mL/kg/h ($p<0.001$), confirming appropriate separation between groups.

Table 2. Baseline characteristics of dogs undergoing laparoscopic cholecystectomy in the restrictive (5 mL/kg/h) and liberal (10 mL/kg/h) intraoperative fluid therapy groups.

Category	Variable	Restrictive (n=63)	Liberal (n=41)	p-value
Demographics	Age (years)	10.1 ± 3.8	9.6 ± 3.6	0.522*
	Body weight (kg)	7.8 ± 5.4	8.2 ± 5.1	0.699*
	Female, n (%)	38 (60.3)	26 (63.4)	0.756**
Surgical risk	ASA I–II, n (%)	14 (22.2)	12 (29.3)	0.422**
	ASA III–IV, n (%)	49 (77.8)	29 (70.7)	
Comorbidities	Baseline nephropathy, n (%)	4 (6.3)	2 (4.9)	0.759**
	Baseline endocrinopathy, n (%)	8 (12.7)	4 (9.8)	0.659**
Laboratory	Hemoglobin (g/dL)	14.2 ± 2.8	14.6 ± 3.1	0.481*
	Hematocrit (%)	42.1 ± 6.8	43.2 ± 7.1	0.412*
	Albumin (g/dL)	3.1 ± 0.6	3.2 ± 0.7	0.387*
	Creatinine (mg/dL)	0.9 ± 0.3	0.8 ± 0.3	0.291*
	ALT (U/L)	178 (89-267)	165 (92-238)	0.834***
	ALP (U/L)	412 (287-689)	398 (264-578)	0.623***
	Platelet count (/mm³)	389 ± 158	407 ± 142	0.554*
Anesthetic drugs	Dexmedetomidine use, n (%)	5 (7.9)	3 (7.3)	0.901**
	Acepromazine use, n (%)	3 (4.8)	0 (0.0)	0.153**
Fluid therapy	Prescribed rate (mL/kg/h)	5.0 ± 0.0	10.0 ± 0.0	<0.001*
	Effective rate (mL/kg/h)	5.16 ± 0.41	10.18 ± 0.89	<0.001*

ASA: American Society of Anesthesiologists physical status classification; **ALT**: alanine aminotransferase; **ALP**: alkaline phosphatase. Data are expressed as mean ± standard deviation or n (%). *****Student's t-test; ******Chi-square test or Fisher's exact test; *******Mann–Whitney test.

Perioperative mortality was similar between groups (4.8% vs 4.9%; OR=0.98; 95% CI 0.16–6.04; p=0.974). No statistically significant differences were observed between groups for cardiovascular instability (46.0% vs 31.7%; OR=1.83; 95% CI 0.80–4.15; p=0.153) or intraoperative hypotension (42.9% vs 29.3%; OR=1.80; 95% CI 0.79–4.10; p=0.167). The maximum dopamine dose was higher in the restrictive group [10.0 (7.5–12.5) vs 7.5 (5.0–10.0) μg/kg/min; p=0.011].

In contrast with cardiovascular complications, the profile of thermoregulation-related complications showed an opposite pattern: the restrictive group had a higher minimum temperature (35.6 ± 1.3 °C vs 34.8 ± 1.5 °C; p=0.004) and a lower incidence of hypothermia (60.3% vs 75.6%; p=0.116). The need for transfusion (4.8% vs 9.8%; p=0.285), acute kidney injury (3.2% vs 2.4%; p=0.809), and gastrointestinal complications were similar between groups (Table 3).

Table 3. Perioperative outcomes organized by COMPAC domains in dogs undergoing laparoscopic cholecystectomy with restrictive and liberal intraoperative fluid therapy strategies.

Domain/Outcome	Restrictive (n=63)	Liberal (n=41)	OR (95% CI)	p-value
I. Mortality / Survival				
Mortality (within 7 days)	3 (4.8)	2 (4.9)	0.98 (0.16–6.04)	0.974*
II. Perioperative complications				
Cardiovascular instability	29 (46.0)	13 (31.7)	1.83 (0.80–4.15)	0.153*
Intraoperative hypotension	27 (42.9)	12 (29.3)	1.80 (0.79–4.10)	0.167*
Use of vasopressors	18 (28.6)	9 (22.0)	1.42 (0.57–3.53)	0.460*
Maximum dopamine dose (μg/kg/min)	10.0 (7.5-12.5)	7.5 (5.0–10.0)	–	0.011***
Acute kidney injury	2 (3.2)	1 (2.4)	1.33 (0.12–15.1)	0.809*
Need for transfusion	3 (4.8)	4 (9.8)	0.46 (0.10–2.15)	0.285*
Hypothermia (<36 °C)	38 (60.3)	31 (75.6)	0.50 (0.21–1.17)	0.116*
Minimum temperature (°C)	35.6 ± 1.3	34.8 ± 1.5	–	0.004**
III. Resource utilization				
Anesthetic time (min)	100 ± 32	98 ± 31	–	0.742**
Same-day discharge	54 (85.7)	35 (85.4)	1.03 (0.33–3.20)	0.966*
Hospitalization time (days)	0 [0–0]	0 [0–1]	–	0.423***
IV. Short-term recovery				
Nausea	11 (17.5)	8 (19.5)	0.88 (0.33–2.35)	0.801*
Vomiting	8 (12.7)	5 (12.2)	1.05 (0.33–3.35)	0.940*
Anorexia	25 (39.7)	15 (36.6)	1.14 (0.52–2.50)	0.761*

COMPAC: Core Outcome Measures for Perioperative and Anaesthetic Care; **OR**: odds ratio; **CI**: confidence interval. Cardiovascular instability: mean arterial pressure <60 mmHg or systolic arterial pressure <90 mmHg for >5 min, requirement of vasopressors, or both. Acute kidney injury: increase in serum creatinine ≥50% or ≥0.3 mg/dL within 48 h, or absence of urination for ≥12 consecutive hours. Data are expressed as n (%), mean ± SD, or median [IQR]. *****Chi-square or Fisher's exact test; ******Student's t-test; *******Mann–Whitney test.

Anesthetic time (100 ± 32 vs 98 ± 31 min; p=0.742), same-day discharge (85.7% vs 85.4%; p=0.966), and hospitalization time also did not differ significantly. Because age could affect postoperative recovery, we report its effect in the adjusted models (Table 4): age was not independently associated with mortality (OR=1.08; p=0.381) or cardiovascular instability (OR=1.02; p=0.612). Moreover, early recovery endpoints were overall favorable (high same-day discharge and median hospitalization of 0 days), which limited the ability to detect subtle age-related gradients in recovery within this cohort.

In the multivariable analysis, the fluid therapy strategy did not influence mortality (OR=0.97; p=0.974), cardiovascular instability (OR=1.82; p=0.154), hypothermia (OR=0.50; p=0.117), need for transfusion (OR=0.46; p=0.285), or AKI (OR=1.33; p=0.809). Significant independent predictors were: longer anesthetic time for cardiovascular instability (OR=1.008; p=0.028) and hypothermia (OR=1.012; p=0.004); higher body weight as a protective factor against hypothermia (OR=0.70; p=0.043); higher baseline hematocrit as a protective factor against transfusion (OR=0.76; p=0.030); and lower platelet count associated with transfusion (OR=0.996; p=0.013) (Table 4).

Table 4. Multivariable logistic regression analysis of factors associated with major perioperative outcomes in dogs undergoing laparoscopic cholecystectomy.

Outcome	Variable	Adjusted OR	95% CI	p-value
Mortality	Restrictive strategy	0.97	0.16–6.04	0.974*
	ASA ≥3	2.13	0.23–19.6	0.509*
	Age (years)	1.08	0.91–1.28	0.381*
Cardiovascular instability	Restrictive strategy	1.82	0.80–4.15	0.154*
	Anesthetic time (min)	1.008	1.001–1.015	0.028*
	ASA ≥3	1.68	0.65–4.31	0.286*
	Age (years)	1.02	0.95–1.09	0.612*
Hypothermia	Restrictive strategy	0.50	0.21–1.17	0.117*
	Body weight (kg)	0.70	0.59–0.98	0.043*
	Anesthetic time (min)	1.012	1.004–1.020	0.004*
	ASA ≥3	1.35	0.53–3.46	0.532*
Need for transfusion	Restrictive strategy	0.46	0.10–2.15	0.285*
	Hematocrit (%)	0.76	0.59–0.98	0.030*
	Platelet count ($\times 10^3$)	0.996	0.993–0.999	0.013*
	Age (years)	0.97	0.80–1.19	0.461*
Acute kidney injury	Restrictive strategy	1.33	0.12–15.1	0.809*
	Baseline creatinine (mg/dL)	6.65	0.85–52.1	0.071*
	Intraoperative hypotension	5.00	0.45–55.6	0.192*

ASA: American Society of Anesthesiologists physical status classification; **OR**: odds ratio; **CI**: confidence interval. Models adjusted for age, ASA classification, anesthetic time, and relevant laboratory variables for each outcome. *****Logistic regression analysis.

After PSM (38 pairs), results remained consistent for mortality (5.3% vs 5.3%; p=1.000), cardiovascular instability (42.1% vs 31.6%; p=0.323), and hypotension (39.5% vs 26.3%; p=0.217). The difference in minimum temperature remained significant (35.5 ± 1.2 °C vs 34.7 ± 1.4 °C; p=0.012), as did the non-significant trend toward higher hypothermia incidence in the liberal group (55.3% vs 73.7%; p=0.089) (Table 5).

Table 5. Sensitivity analysis of major perioperative outcomes after 1:1 propensity score matching in dogs undergoing laparoscopic cholecystectomy.

Variable	Restrictive (n=38)	Liberal (n=38)	OR (95% CI)	p-value
Balanced covariates				
Age (years)	9.8 ± 3.6	9.9 ± 3.4	–	0.892**
Body weight (kg)	8.3 ± 5.4	8.1 ± 5.2	–	0.847**
ASA ≥3	28 (73.7)	29 (76.3)	0.87 (0.30–2.52)	0.796*
Anesthetic time (min)	101 ± 33	99 ± 32	–	0.756***
Endocrinopathy	4 (10.5)	3 (7.9)	1.37 (0.29–6.53)	0.693*
Nephropathy	2 (5.3)	2 (5.3)	1.00 (0.13–7.46)	1.000*
Anemia (Hb <12 g/dL)	6 (15.8)	5 (13.2)	1.23 (0.35–4.35)	0.748*
Thrombocytopenia	4 (10.5)	3 (7.9)	1.37 (0.29–6.53)	0.693*
Dexmedetomidine use	6 (15.8)	5 (13.2)	1.23 (0.35–4.35)	0.748*
Acepromazine use	3 (7.9)	2 (5.3)	1.54 (0.24–9.75)	0.645*
Major outcomes				
Mortality	2 (5.3)	2 (5.3)	1.00 (0.13–7.46)	1.000*
Cardiovascular instability	16 (42.1)	12 (31.6)	1.58 (0.64–3.91)	0.323*
Intraoperative hypotension	15 (39.5)	10 (26.3)	1.82 (0.70–4.74)	0.217*
Hypothermia (<36 °C)	21 (55.3)	28 (73.7)	0.44 (0.17–1.14)	0.089*
Minimum temperature (°C)	35.5 ± 1.2	34.7 ± 1.4	–	0.012**
Need for transfusion	2 (5.3)	3 (7.9)	0.65 (0.10–4.08)	0.644*
Acute kidney injury	1 (2.6)	1 (2.6)	1.00 (0.06–16.76)	1.000*

ASA: American Society of Anesthesiologists physical status classification; **OR**: odds ratio; **CI**: confidence interval. Anemia defined as hemoglobin <12 g/dL; thrombocytopenia defined as platelet count <200,000/mm³. Cardiovascular instability: mean arterial pressure <60 mmHg or systolic arterial pressure <90 mmHg for >5 min, requirement of vasopressors, or both. Data are expressed as mean ± standard deviation or n (%). *****McNemar test for categorical variables; ******Paired Student's t-test for continuous variables; *******Paired Wilcoxon test for non-parametric variables.

Post-hoc statistical power for the complete sample (n=104) was calculated based on observed effect sizes: 5.2% for mortality. After propensity score matching (n=76), recalculated power was 79.1% for temperature, 47.3% for hypothermia, 39.8% for cardiovascular instability, and 7.2% for mortality (Table 6), confirming adequacy for outcomes with higher prevalence but limited power for rare events.

Table 6. Covariate balance before and after propensity score matching in dogs undergoing laparoscopic cholecystectomy.

Covariate	Before matching SMD	Before matching p-value	After matching SMD	After matching p-value
Age (years)	0.131	0.522	0.031	0.892
Body weight (kg)	-0.074	0.699	0.037	0.847
ASA ≥3 (%)	0.155	0.422	-0.058	0.796
Anesthetic time (min)	0.063	0.742	0.061	0.756
Endocrinopathy (%)	0.089	0.659	0.072	0.693
Nephropathy (%)	0.064	0.759	0.000	1.000
Anemia (%)	-0.033	0.481	0.076	0.748
Thrombocytopenia (%)	0.156	0.378	0.072	0.693
Dexmedetomidine (%)	0.112	0.583	0.076	0.748
Acepromazine (%)	0.087	0.672	0.082	0.645

SMD: standardized mean difference. Values <0.1 indicate adequate balance.

DISCUSSION

Perioperative mortality was within the range previously reported for canine laparoscopic cholecystectomy [18,19]. The equivalence between restrictive and liberal fluid strategies is consistent with clinical studies in humans demonstrating similar mortality across different surgical settings [11], and aligns with recent veterinary guidelines, emphasizing individualized fluid therapy [16]. Physiologically, hemodynamically stable patients operate on the flat portion of the Frank–Starling curve, where moderate variations in preload do not significantly impact stroke volume [20], which partially explains the lack of impact on mortality. The consistency of these findings in both the multivariable analysis and PSM further reinforces the equivalence of these results.

The restrictive group showed a non-significant trend toward greater cardiovascular instability and required significantly higher dopamine doses. This observation is consistent with rates reported for canine laparoscopy, where up to 54.6% of patients experience hypotension [19]. Pneumoperitoneum is known to decrease cardiac index in dogs [21,22], although no statistically significant difference in cardiovascular instability between groups was observed in this study. Multicenter human trials have suggested an association between restrictive strategies and greater hemodynamic instability [11,23]. In the multivariable analysis, although the fluid therapy strategy did not significantly influence cardiovascular instability, anesthetic time emerged as an independent predictor—a finding consistent with human literature linking longer anesthesia duration to increased risk of hypotension [24]. After PSM, hemodynamic differences remained non-significant, suggesting clinical equivalence between strategies.

The incidence of acute kidney injury was low and comparable between groups, falling within the range reported for elective procedures in dogs [25]. In the multivariable analysis, baseline creatinine showed a trend toward predicting AKI, consistent with IRIS guidelines and thus emphasizing the clinical relevance of small creatinine increases [26]. The need for transfusion was also similar between groups, with higher preoperative hematocrit identified as a protective factor and thrombocytopenia as a risk factor. These findings suggest that intrinsic patient factors and hematological reserve are more determinant of these outcomes than the fluid strategy per se, warranting the need for individualized assessment.

The liberal group showed lower minimum intraoperative temperature and a trend toward higher incidence of hypothermia. In the multivariable analysis, higher body weight was protective against hypothermia, whereas longer anesthetic time was identified as a risk factor. Despite veterinary literature on the dose–response relationship between fluid volume and hypothermia being limited, human studies have demonstrated a dose-dependent association between fluid volume and heat loss, although the magnitude of this effect may differ substantially in dogs due to differences in body surface area-to-volume ratio and thermoregulatory mechanisms [27]. The thermal difference remained significant after PSM, confirming a possible increase in heat loss with higher fluid volumes and supporting the use of multimodal warming strategies.

No differences were observed between groups regarding anesthetic time, immediate postoperative discharge, or gastrointestinal complications, thus suggesting that fluid rate did not influence early recovery. In dogs, quality of recovery is more strongly associated with duration of anesthesia, maintenance of normothermia, and analgesia rather than fluid therapy [28,29]. Although ageing could theoretically delay recovery due to decreased physiologic reserve, the present cohort comprised predominantly middle-aged to geriatric patients and still showed high same-day discharge rates; additionally, age was not an independent predictor in the adjusted models (Table 4), suggesting that age alone was not a major determinant of early postoperative recovery in this population. Studies on laparoscopic cholecystectomy have demonstrated low complication rates and generally short hospitalization, regardless of technique or fluid rate used [30,31]. In humans, the RELIEF trial showed that restrictive strategies did not shorten hospital stay and were associated with a higher incidence of AKI, emphasizing that fluid volume alone does not determine recovery speed [11].

The results suggest clinical equivalence between restrictive (5 mL/kg/h) and liberal (10 mL/kg/h) strategies for hemodynamically stable dogs undergoing laparoscopic cholecystectomy. The choice should be guided by individual factors: in patients with limited cardiovascular reserve, more liberal regimens may reduce the need for vasoactive support, whereas in animals at risk of volume overload, restrictive strategies with close monitoring may be preferable. The greater heat loss observed with higher volumes underscores the importance of active warming regardless of the chosen strategy. Factors such as anesthetic time, body weight, and hematological reserve appeared to be more relevant determinants of complications than fluid rate per se, emphasizing the need for an individualized approach based on comprehensive clinical assessment.

This study has limitations that should be considered when interpreting the results. First, the 11-year data collection period may have introduced temporal bias related to evolving clinical and surgical protocols and changes in institutional practice. It was not possible to control temporal variations in patient selection criteria, surgical team experience, inter-anesthetist variability in fluid management and vasopressor use, or updates in anesthetic equipment and protocols. Second, the sample size limited the statistical power for outcomes with low incidence, particularly mortality (5.2%), posing a risk of type II error. These results should therefore be interpreted as exploratory rather than as definitive evidence of equivalence between strategies. Third, the absence of more sensitive markers of tissue perfusion (such as serum lactate or base excess) restricted understanding of the underlying pathophysiological mechanisms. Fourth, although PSM was methodologically robust with ten clinically relevant covariates, it resulted in a 26.9% sample loss to ensure adequate balance, reducing statistical power for low-incidence outcomes. Some covariates had relatively low prevalence (nephropathy 5.3%, acepromazine 7.9%), which limited statistical power to detect their specific effects and reduced subgroup representativeness in the analysis, potentially affecting the generalizability of the findings to patients with these characteristics.

Prospective controlled studies with greater numbers and rigorous standardization are warranted to more precisely define the impact of fluid therapy strategies in canine laparoscopic cholecystectomy.

CONCLUSION

Restrictive (5 mL/kg/h) and liberal (10 mL/kg/h) fluid therapy strategies demonstrated clinical equivalence in dogs undergoing laparoscopic cholecystectomy. Although they present distinct complication profiles—greater need for vasoactive support in the restrictive group versus higher incidence of hypothermia and lower minimum intraoperative temperature in the liberal group—both approaches are clinically comparable. The choice of strategy should be individualized based on patient characteristics, prioritizing factors such as cardiovascular reserve and risk of volume overload over rigid volume protocols, always considering preventive measures against hypothermia when greater fluid volumes are chosen.

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Authors' contributions

JCG contributed to the study conception, data collection and analysis, statistical analysis, and manuscript writing. LTM contributed to data collection, medical record review, and data tabulation. LSV contributed to data collection, laboratory analysis, and database organization. GO contributed to data collection, anesthetic record review, and support in statistical analysis. OHMS contributed to data collection and organization. GCF, BPF, MVB, and AVS contributed to project supervision, critical revision of the manuscript, and approval of the final version.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Statement of Informed Consent

The owner understood procedure and agrees that results related to investigation or treatment of their companion animals, could be published in Scientific Journal Acta Veterinaria-Beograd.

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RESTRIKTIVNA NASPRAM LIBERALNE TERAPIJE I PERIOPERATIVNI ISHODI LAPAROSKOPSKE HOLECISTEKTOMIJE KOD PASA: RETROSPEKTIVNA STUDIJA 104 SLUČAJA

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Laparoskopska holecistektomija kod pasa izaziva hemodinamske i respiratorne promene usled pneumoperitoneuma, čineći terapiju tečnostima centralnim elementom perioperativnog lečenja. Ova retrospektivna, jednocentrična studija procenila je efekat dve kristaloidne strategije: restriktivne (5 ml/kg/h) i liberalne (10 ml/kg/h), kod 104 psa anestezirana između 2014. i 2025. godine i podvrgnuta laparoskopskoj holecistektomiji. Primarni ishod bio je perioperativni mortalitet (≤7 dana). Sekundarni ishodi uključivali su kardiovaskularnu nestabilnost, hipotermiju, potrebu za vazopresorom, potrebu za transfuzijom, akutno oštećenje bubrega, iskorišćenost bolničkih resursa i kratkoročni oporavak. Analize su obuhvatale poređenja između grupa, multivarijantnu logističku regresiju i sklonost ka podudaranju rezultata (1:1). Mortalitet je bio nizak i sličan između testiranih strategija. Liberalna strategija je bila povezana sa većom učestalošću hipotermije i nižom minimalnom intraoperativnom temperaturom, dok je restriktivna strategija zahtevala veće maksimalne doze vazopresora, bez povećanja nepoželjnih komplikacija. U multivarijantnim modelima, duže vreme anestezije je bilo povezano sa kardiovaskularnom nestabilnošću i hipotermijom; veća telesna masa je bila zaštita od hipotermije. Nalazi su ostali konzistentni nakon uparivanja. Stoga, kod laparoskopske holecistektomije kod pasa, restriktivna (5 ml/kg/h) i liberalna (10 ml/kg/h) strategije su pokazale slične kliničke rezultate; izbor treba individualizovati na osnovu kliničkog statusa svakog pacijenta.