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CLINICAL RESEARCH

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Risk factors for neonatal mortality prior to hospital discharge in brachycephalic and nonbrachycephalic dogs undergoing cesarean section

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Abstract

Objectives: To compare neonatal survival to discharge rates between brachycephalic and nonbrachycephalic dogs undergoing cesarean section (c-section) and identify risk factors for neonatal mortality.

Study design: Retrospective study.

Animals or sample population: A total of 480 puppies from 90 bitches undergoing 106 c-sections.

Methods: Medical records of c-sections performed between January 2012 and September 2021 were reviewed. Data collected included brachycephalic versus nonbrachycephalic breed, elective versus emergency c-section, litter size (c-section and total [including those born prior to and via c-section]), and neonatal survival to discharge. A generalized linear mixed model (univariable and multivariable) was performed to evaluate variables versus neonatal survival.

Results: Overall neonatal survival to discharge was 93.1% (447/480); survival was similar between brachycephalic and nonbrachycephalic breeds ($p = .221$, 202/213 [94.8%] brachycephalic survival, 245/267 [91.8%] nonbrachycephalic survival). Puppies delivered via elective c-section were more likely to survive compared to emergency c-section ($p < .001$, 238/240 [99.2%] elective survival, 209/240 [87.1%] emergency survival). Puppies delivered in larger c-section litters were more likely to survive ($p < .004$) compared to smaller litters. Total litter size had no effect on survival.

Conclusion: Brachycephalism had no effect on neonatal survival. Puppies delivered via elective c-section were more likely to survive compared to puppies delivered via emergency c-section.

Clinical significance: Outcomes following c-section are similar between brachycephalic and nonbrachycephalic breeds. While it is preferable to encourage selective breeding for bitches that are able to whelp naturally,

elective c-section should be considered in bitches at high risk for dystocia to maximize neonatal survival.

1 | INTRODUCTION

Cesarean section (c-section) is a common procedure performed in the bitch on both an elective basis and in the emergency setting for management of dystocia. Elective c-section is often recommended in brachycephalic breeds due to their inherent risk for dystocia.[1,2] Nearly all female English bulldogs require c-section for delivery of pups and French bulldogs have been shown to be 16 times more likely to suffer from dystocia compared to mixed breed dogs.[2,3] Abnormal pelvic conformation, narrow pelvic canal, and large biparietal diameter have been documented in brachycephalic breeds, and these anatomic differences contribute to the predisposition for complications during natural delivery.[3–5] Lack of taut abdominal musculature in the English bulldog has also been described, further complicating labor in this breed.[6] Brachycephalic obstructive airway syndrome may also precipitate respiratory complications during strenuous or difficult birth, posing significant risks for the bitch.[7]

Several studies have investigated outcomes following c-section in dogs, with neonatal mortality across all breeds reported at 2.3%–8%.[8,9] Previously identified risk factors for neonatal death include emergency c-section for treatment of dystocia, obstructive dystocia, older age of the bitch, primiparous history, and increasing duration of anesthesia and surgery.[8,10,11] Despite the relatively low rate of neonatal death reported in previous studies across all breeds, neonatal outcomes in brachycephalic dogs appear to be worse when compared to nonbrachycephalic breeds. Results of one study showed that that brachycephalic bitches had half the odds of survival of all puppies in the litter at 2 hours post-c-section compared to litters from nonbrachycephalic bitches.[8] English bulldogs were reported to have a neonatal mortality rate of 14.9% following c-section in one study.[3] In another study, a neonatal mortality rate of 11.6% at 24 hours postoperatively was identified in English and French bulldogs.[12] It has been theorized that worse outcomes may occur in brachycephalic neonates due to brachycephalic obstructive airway syndrome leading to hypoxia, respiratory collapse, and death in the early postoperative period.[8] A high frequency of birth defects in brachycephalic neonates relative to nonbrachycephalic neonates may also contribute to neonatal mortality following c-section.[13,14] In one study, birth defects accounted for over 50% of brachycephalic neonatal deaths following c-section.[12] It is the authors' clinical impression that puppy survival with c-section is similar in brachycephalic breeds compared to nonbrachycephalic breeds, despite the literature indicating a higher mortality rate. Few previous studies were identified during review of the literature that have directly compared neonatal outcomes between brachycephalic and nonbrachycephalic dog breeds undergoing c-section.

The objective of this retrospective observational study was to compare neonatal survival to discharge rate between brachycephalic and nonbrachycephalic dog breeds undergoing c-section and to identify risk factors associated with neonatal mortality. The first hypothesis was that the neonatal survival to discharge rate would be similar between brachycephalic breeds and nonbrachycephalic breeds following c-section. The second hypothesis was that the neonatal survival to discharge rate would be lower in both brachycephalic and nonbrachycephalic breeds undergoing c-section for emergency treatment of dystocia compared to elective c-section.

2 | MATERIALS AND METHODS

2.1 | Inclusion criteria

Medical records were retrospectively reviewed to identify bitches that underwent c-section between January 2012 and September 2021. Data from each c-section were collected as unique events if included bitches underwent multiple c-sections within the defined study period; each event was counted as a separate bitch. Bitches were excluded from the study if there was incomplete information on neonatal mortality in the medical record, if they underwent surgery for retained known nonviable fetuses, if they were mixed breed (unable to determine brachycephalic or nonbrachycephalic), or if they were bitches with a variable phenotype which could include both brachycephalic and nonbrachycephalic traits (e.g., American bully).

2.2 | Surgery and aftercare

All c-sections were performed in an academic veterinary teaching hospital. Anesthetic protocols were chosen by the attending board-certified anesthesiologist and included preoxygenation, induction with propofol or alfaxalone, maintenance with inhalant gas in 100% oxygen (only isoflurane, sevoflurane, or desflurane were in use during the study period), crystalloid fluid

administration, and a pure mu opioid administered following delivery of all puppies. Some bitches received a lumbosacral epidural with lidocaine at the anesthesiologist's discretion. All c-sections were performed by either a board-certified surgeon, a surgery resident, or a theriogenology resident supervised by a board-certified surgeon. Following delivery, puppies were resuscitated and cared for by a separate team supervised by a board-certified theriogenologist, a theriogenology resident, a board-certified emergency and critical care clinician, and/or an emergency and critical care resident. Resuscitation and care of the puppies included suctioning of the nares, drying and active warming, provision of flow-by oxygen, ligation of the umbilical cords, and administration of atropine or epinephrine when deemed necessary by the attending clinician. Once recovered from surgery, the bitch and puppies were supervised in the intensive care unit with frequent encouragement of the puppies to nurse. The bitch and puppies were then discharged from the hospital when the bitch was fully recovered from anesthesia and at the earliest convenience of the owner, generally within 2–6 hours of extubation.

2.3 | Data collection

Data collected for each bitch included: age at time of c-section, breed, brachycephalic or nonbrachycephalic, bodyweight, number of previous litters, estimated gestation length, serum progesterone level, stage of labor, whether medical management of dystocia with oxytocin was implemented prior to surgery, maternal heart rate on presentation, maternal blood pressure on presentation, lowest fetal heart rate on presentation, mean fetal heart rate on presentation, whether c-section was elective or emergency, anesthetic induction drugs, whether an epidural was performed, time from anesthetic induction until delivery of the final puppy, litter size (c-section and total [including puppies born prior to and via c-section]), number of surviving puppies, and puppy weights. Surviving puppies were considered those alive at the time of discharge from the hospital. Maternal survival to discharge was also recorded.

Estimated gestation length was based on either ovulation date, date of first rise in serum progesterone, breeding date, or gestation length reported by the client. If the bitch had multiple breedings or artificial inseminations, the date of the last breeding or insemination was used to calculate estimated gestation length. Definition of stage of labor was modified from the previously described classification system.[1] In brief, dogs displaying changes in behavior including panting, restlessness, nesting, anorexia, or vomiting were classified as being in stage 1 labor; dogs displaying active straining or abdominal efforts denoting myometrial contractions were classified as being in stage 2 labor; dogs who delivered a puppy prior to or shortly after presentation were classified as being in stage 3 labor. Dogs presenting for elective c-section showing no signs of labor were classified as being in stage 0 labor. Average fetal heart rate was calculated when multiple heart rates were provided in the medical record. If only one fetal heart rate was provided, this value was considered both the lowest and average fetal heart rates. If time of delivery of the last puppy was not provided in the anesthetic record, time of administration of the first dose of intraoperative opioids was used to calculate duration of time from anesthetic induction to the delivery of the last puppy. C-section was considered elective if directly stated in the medical record or if the decision for surgery was based upon clinical factors such as estimated duration of gestation and serum progesterone measurement. Elective c-section was performed for bitches with known ovulation and breeding dates and gestation length approaching 63 days post-ovulation, when serial serum progesterone levels approached or fell below 2.0 ng/ml, or when serial reproductive ultrasounds suggested fetal maturity (well delineated fetal intestines with peristalsis). Additionally, c-sections performed on bitches displaying signs consistent with stage 1 labor were considered elective. C-section was considered an emergency if directly stated within the medical record, if the bitch presented with dystocia, if the bitch was in stage 2 or 3 labor, or if fetal distress was diagnosed based on assessment of fetal heart rates. One bitch in stage 2 labor was classified as elective because the bitch developed stage 2 labor immediately prior to planned c-section.

2.4 | Statistical analysis

Statistical analysis was performed with a commercially available software program (JMP version 16, SAS Institute Inc., Cary, North Carolina). Normality of continuous data was assessed by visual inspection of the histogram and normal quantile plot. Continuous data that are normally distributed are presented as mean ± SD; continuous data that are non-normally distributed are presented as median (range). Categorical variables are reported as a fraction (%). Each puppy was assigned a yes/no for survival and a generalized linear mixed model (binomial, logit) was performed to evaluate variables of interest as fixed effects versus the outcome of puppy survival with a random effect of c-section event to account for within litter correlation. $p < .05$ was considered significant. A multivariable generalized linear mixed model was performed similarly,

TABLE 1 Comparison of descriptive variables among 47 brachycephalic and 59 nonbrachycephalic bitches undergoing c-section

Variable	Brachycephalic (213 puppies)	Nonbrachycephalic (267 puppies)
Age, mean (years)	2.8 ± 1.0	4.0 ± 1.8
Bodyweight (kg)	19.2 ± 9.5	25.7 ± 13.2
Previous litters		
Nulliparous	18/37 (48.6%)	22/44 (50.0%)
Primiparous	19/37 (51.4%)	22/44 (50.0%)
1 litter	13/19 (68.4%)	18/22 (81.8%)
2 litters	4/19 (21.1%)	3/22 (13.6%)
3 litters	2/19 (10.5%)	1/22 (4.5%)
Estimated gestation (days)	62.7 ± 2.3	61.9 ± 2.5
Stage of labor		
Stage 0	23/47 (48.9%)	12/59 (20.3%)
Stage 1	14/47 (29.8%)	9/59 (15.3%)
Stage 2	5/47 (10.6%)	8/59 (13.6%)
Stage 3	5/47 (10.6%)	30/59 (50.8%)
Maternal heart rate (bpm)	137 ± 26.0	133 ± 24.0
Maternal blood pressure (mmHg)	138 ± 29.4	149 ± 34.3
Average fetal heart rate (bpm)	185 + 28.8	167 ± 33.3
Lowest fetal heart rate (bpm)	172 ± 30.8	153 ± 40.6
Preoperative medical management	2/47 (4.3%)	6/59 (10.2%)
Anesthetic induction drugs		
Propofol	42/45 (93.3%)	59/59 (100%)
Alfaxalone	3/45 (6.7%)	--
Epidural	12/44 (27.3%)	16/59 (27.1%)
Emergency versus elective c-section (emergency)	12/47 (25.5%)	46/59 (78.0%)
Time from induction to delivery of last puppy (min)	21.5 ± 6.9	24.9 ± 9.9
C-section litter size	4.5 ± 2.2	4.5 ± 3.4
Overall c-section survival rate (by puppy)	202/213 (94.8%)	245/267 (91.8%)
Total litter size	5.0 ± 2.4	6.1 ± 3.3

Note: Variables reported are mean ± SD for normally distributed continuous variables or proportion (%) of puppies for categorical variables for which data was available. For dichotomous variables, the variable of interest is reported in parenthesis following the variable name; where not reported, the variable is dichotomous yes or no with the portion reported for those with the response of yes.
Abbreviation: bpm, beats per minute.

using variables that were considered significant on univariable analysis. When multicollinearity was present between a group of variables, a single variable from the group was chosen by excluding variables where every outcome was not represented in the model (e.g., stage 3 labor and medical management were not represented in dogs undergoing elective c-section, thus stage of labor and medical management were excluded and emergency versus elective c-section was included) until three variables remained for inclusion. Variables that were not significant in the multivariable model were subsequently excluded and the model rerun without that variable. Odds ratios (OR) and 95% confidence intervals (CI) are provided where available.

3 | RESULTS

3.1 | Study population

A total of 101 bitches undergoing 117 c-sections were identified in the study period. Eleven bitches were excluded from analysis due to known nonviable fetuses ($n = 5$), mixed breed of the bitch ($n = 4$), concurrent gastrointestinal linear

TABLE 2 Comparison of descriptive variables among 48 bitches undergoing elective c-section and 58 bitches undergoing emergency c-section

Variable	Elective (240 puppies)	Emergency (240 puppies)
Brachycephalic versus nonbrachycephalic (brachycephalic)	35/48 (72.9%)	12/58 (20.7%)
Age (years)	3.3 ± 1.6	3.5 ± 1.7
Bodyweight (kg)	21.3 ± 10.9	23.5 ± 13.0
Previous litters		
Nulliparous	19/40 (47.5%)	21/42 (50.0%)
Primiparous	21/40 (52.5%)	21/42 (50.0%)
1 litter	14/21 (66.7%)	18/21 (85.7%)
2 litters	5/21 (23.8%)	2/21 (9.5%)
3 litters	2/21 (9.5%)	1/21 (4.8%)
Estimated gestation (days)	63.1 ± 1.9	59.2 ± 11.3
Stage of labor		
Stage 0	34/48 (70.8%)	1/56 (1.8%)
Stage 1	13/48 (27.1%)	10/56 (17.9%)
Stage 2	1/48 (2.1%)	10/56 (17.9%)
Stage 3	–	35/56 (62.5%)
Maternal heart rate (bpm)	125.3 ± 22.2	137.3 ± 29.1
Maternal blood pressure (mmHg)	130.5 ± 11.0	141.0 ± 4.7
Average fetal heart rate (bpm)	193.8 ± 19.8	159.5 ± 38.8
Lowest fetal heart rate (bpm)	180.5 ± 22.7	146.7 ± 44.0
Preoperative medical management	–	10/58 (17.2%)
Anesthetic induction drugs		
Propofol	44/46 (95.6%)	57/58 (98.3%)
Alfaxalone	2/46 (4.3%)	1/58 (1.7%)
Epidural	14/45 (31.1%)	13/58 (22.4%)
Time from induction to delivery of last puppy (min)	21.2 ± 5.6	25.2 ± 10.5
C-section litter size	5.0 ± 3.2	4.1 ± 2.7
Total litter size	5.0 ± 3.2	6.1 ± 2.7
Overall c-section survival rate (by puppy)	238/240 (99.2%)	209/240 (87.1%)

Note: Variables reported are mean ± SD for normally distributed continuous variables or proportion (%) of puppies for categorical variables for which data was available. For dichotomous variables, the variable of interest is reported in parenthesis following the variable name; where not reported, the variable is dichotomous yes or no with the portion reported for those with the response of yes.
Abbreviation: bpm, beats per minute.

foreign body obstruction leading to intraoperative euthanasia ($n = 1$), and manual extraction of a puppy lodged within the birth canal followed by surgery revealing no additional puppies in the reproductive tract ($n = 1$). Therefore, 90 bitches undergoing 106 c-sections were included in the study, with 47 c-sections in brachycephalic bitches and 59 c-sections in nonbrachycephalic bitches (Table 1). All bitches survived to discharge. A total of 480 puppies were delivered, of which 240 were delivered from 48 elective c-sections and 240 were delivered from 58 emergency c-sections (Table 2). The overall rate of neonatal survival to discharge was 93.1% (447/480), with 33 puppies not surviving to discharge.

3.2 | Brachycephalic c-sections

The most common brachycephalic breed was the English bulldog ($n = 27$), followed by the French bulldog ($n = 12$), Japanese Chin ($n = 4$), Shih Tzu ($n = 2$), and Pug ($n = 2$). Eight brachycephalic bitches (8/47, 17.0%) underwent multiple c-sections with five bitches having two c-sections each and three bitches having three c-sections each. There were 213 puppies born to brachycephalic bitches, with 202 puppies surviving to discharge (202/213, 94.8%). Of puppies born to brachycephalic bitches undergoing elective c-section, 166/168 (98.8%) survived to hospital discharge while 37/46 (80.4%) puppies born to brachycephalic bitches undergoing emergency c-section survived to hospital discharge.

3.3 | Nonbrachycephalic c-sections

The most common nonbrachycephalic breed was the Golden Retriever ($n = 17$), followed by Labrador Retriever ($n = 4$), Dachshund ($n = 4$), Yorkshire Terrier ($n = 4$), Goldendoodle ($n = 3$), German Shepherd ($n = 3$), Doberman Pinscher ($n = 2$), Collie ($n = 2$), Corgi ($n = 2$), American Pit Bull Terrier ($n = 2$), Portuguese Water Dog ($n = 2$), and one of each of the following breeds: Basset Hound, Beagle, Border Collie, Chesapeake Bay Retriever, English Cream Retriever, German Shorthaired Pointer, Giant Schnauzer, Miniature Bull Terrier, Miniature Dachshund, Miniature Schnauzer, Münsterländer, Papillon, Pomeranian, and Shetland Sheepdog. Three nonbrachycephalic bitches (3/53, 5.7%) underwent two c-sections each. There were 267 puppies born to nonbrachycephalic bitches, with 245 puppies surviving to discharge (245/267, 91.8%). Of puppies born to nonbrachycephalic bitches undergoing elective c-section, 73/73 (100.0%) survived to hospital discharge while 172/194 (88.7%) puppies born to brachycephalic bitches undergoing emergency c-section survived to hospital discharge.

TABLE 3 Results of univariable analysis of variables evaluated versus survival to discharge in 480 puppies born via c-section

Variable	Surviving puppies (447 puppies)	Nonsurviving puppies (33 puppies)	*p*-value
Number of puppies born prior to c-section	0 (0–9)	1 (0–9)	<.001
Elective versus emergency (emergency)	209/447 (46.8%)	31/33 (93.9%)	<.001
C-section litter size	6.6 ± 3.2	3.8 ± 2.1	<.001
Medical management	18/447 (4.0%)	6/33 (18.2%)	.002
Stage of labor			
Stage 0	177/438 (40.4%)	3/33 (9.1%)	.003*
Stage 1	108/438 (24.7%)	6/33 (18.2%)	.020*
Stage 2	47/438 (10.7%)	4/33 (12.1%)	.232*
Stage 3	108/438 (24.7%)	20/33 (6.1%)	
Maternal heart rate (bpm)	131.1 ± 21.3	148.5 ± 25.3	.014
Lowest fetal heart rate (bpm)	161.3 ± 39.1	129.2 ± 50.8	.056
Average fetal heart rate (bpm)	176.2 ± 30.5	148.5 ± 46.2	.101
Time from induction to delivery of last puppy (min)	25.0 ± 8.9	27.0 ± 10.2	.202
Brachycephalic versus nonbrachycephalic (brachycephalic)	202/447 (45.2%)	11/33 (33.3%)	.269
Maternal bodyweight (kg)	25.0 ± 11.2	25.4 ± 11.6	.282
Maternal blood pressure (mmHg)	147.4 ± 37.6	158.0 ± 39.9	.342
Number of previous litters	1 (0–3)	0 (1–3)	.431
Estimated gestation length (days)	62.2 ± 2.2	61.6 ± 2.4	.458
Maternal age (years)	3.4 ± 1.5	3.4 ± 1.7	.534
Puppy deaths prior to c-section	30/97 (30.9%)	8/20 (40.0%)	.566
Epidural	119/432 (27.5%)	7/33 (21.2%)	.781
Total litter size	7.1 ± 3.1	6.7 ± 2.8	.759

Note: Variables reported are mean ± SD for normally distributed continuous variables or proportion (%) of puppies for categorical variables for which data was available. For dichotomous variables, the variable of interest is reported in parenthesis following the variable name; where not reported, the variable is dichotomous yes or no with the portion reported for those with the response of yes.

Abbreviation: bpm, beats per minute.

*Indicates comparison to stage 3 labor.

3.4 | Statistical analysis

Univariable analysis was performed to identify candidate variables for the multivariable model (Table 3). Because elective c-sections were more frequent in brachycephalic bitches and emergency c-sections were more frequent in nonbrachycephalic bitches, a multivariable model including both variables (brachycephalic or nonbrachycephalic breed and elective or emergency c-section) was performed to determine any association between these two variables. In this model, only having an emergency c-section was significant for neonatal mortality ($p < .001$, OR 8.48, 95% CI: 2.66–27.07), confirming brachycephalism had no influence on neonatal survival to discharge ($p = .221$). When brachycephalic bitches were considered alone, having an elective c-section was associated with increased neonatal survival to discharge compared to emergency c-section ($p = .001$, OR 8.17, 95% CI: 2.39–27.92). Statistical analysis could not be performed on the nonbrachycephalic group alone as there were no deaths in the elective c-section group. Three variables were included in the final multivariable analysis: elective versus emergency c-section, c-section litter size, and maternal heart rate. Maternal heart rate was subsequently removed as it was nonsignificant, and the model was reanalyzed with elective versus emergency c-section and c-section litter size. Elective versus emergency c-section ($p < .001$, OR 4.75, 95% CI: 1.93–11.67) and c-section litter size ($p = .004$, OR 1.57, 95% CI: 1.17–2.12) were both significantly associated with neonatal survival to discharge in the multivariable model.

4 | DISCUSSION

In this study, the overall neonatal survival to discharge rate was 93.1%, with similar survival rates between brachycephalic (94.8%) and nonbrachycephalic (91.8%) breeds. Brachycephalism had no effect on neonatal survival to discharge and puppies delivered via elective c-section were more likely to survive compared to puppies delivered via emergency c-section, thus both hypotheses were accepted. In previous studies, outcomes following c-section were worse in brachycephalic bitches compared to other breeds. In one study, a neonatal mortality rate of 14.9% was found in English bulldogs following c-section.[3] In that study, c-section was performed under sedation rather than general anesthesia in 70.4% of bitches, which offers less control of hemodynamics and ventilation for the bitch and could have contributed to poor overall neonatal survival. Additionally, classifications of emergency or elective c-section in that study differed from the criteria used in the present study. Although they stated that c-section was elective in 89.2% of bitches and was an emergency in 10.8%, using the classification scheme of the present study, 78.8% of c-sections would have been considered elective and 21.3% would have been considered emergency c-sections, which is similar to the proportion of elective and emergency c-sections performed in the brachycephalic dogs of the present study. Despite having a large proportion of elective c-sections in the previously reported study,[3] neonatal mortality was higher than that reported for nonbrachycephalic or mixed populations of brachycephalic and nonbrachycephalic bitches (2.3%–8%),[8,9] and was also higher than that reported in the dogs of the present study. The results of another study showed that odds of all neonates in a litter surviving in the first two hours following c-section was half that in brachycephalic bitches relative to nonbrachycephalic bitches.[8] One reason for the higher mortality rate in that study was a disproportionately high number of bitches receiving methoxyflurane were brachycephalic, which was associated with stillbirth, and may have contributed to the high neonatal mortality rate among brachycephalic bitches compared to nonbrachycephalic bitches.[8] In the present study, the anesthetic protocols were similar in brachycephalic and nonbrachycephalic bitches. Although inhalant type for each c-section was not included in statistical analysis, isoflurane, sevoflurane, and desflurane were the only inhalants used for anesthetic maintenance during the study time period. Methoxyflurane was not available at the authors' institution during the study period and no patients would have received this inhalant. Additionally, the outcome analyzed in the present study was survival of each puppy whereas the unit of analysis in this previous study[8] was each litter, which may have skewed the results negatively if all puppies in the litter did not survive. Regular availability of separate anesthesia, surgery, and neonatal resuscitation teams during c-section at the authors' institution may have also contributed to improved survival in the current study. In another study, a neonatal mortality rate of 11.6% was identified with elective c-section in English and French bulldogs.[12] Although they reported a 5.0% neonatal mortality rate when excluding birth defects as a cause of mortality, other studies do not differentiate birth defects from other causes of death, making this a difficult number to compare across studies. Future studies evaluating the incidence of birth defects and their contribution to the neonatal mortality rate in brachycephalic breeds undergoing c-section are necessary.

In the current study, neonates were more likely to survive to discharge following elective c-section compared to emergency c-section and this was true for both brachycephalic and nonbrachycephalic bitches. This finding is consistent with previous studies. The results of one study showed the probability of having all puppies alive at birth following emergency c-section was 1/3 as likely compared to elective c-section.[8] Another study also reported that litters born from emergency c-section were more likely to have neonatal mortality than those born from elective c-section.[12]

Stage of labor, number of puppies born prior to c-section, medical management of dystocia prior to surgery, and maternal heart rate were significantly associated with neonatal mortality on univariable analysis. This may have been due to the close relationship of these variables with emergency c-section, which was significantly associated with neonatal mortality on multivariable analysis. With these variables combined, the results from the current study and previous studies indicate that planned c-section should be considered whenever possible in bitches who are considered high risk for dystocia to minimize complications with parturition and improve chances of neonatal survival.[1–3]

When considering puppies born via c-section only, puppies delivered within a larger litter were more likely to survive to discharge compared to smaller litter size. Several studies have shown that increasing litter size has a negative impact on neonatal survival following both natural birth and c-section. Litter size greater than 12 puppies was found to significantly increase the risk for neonatal mortality in one study. Furthermore, in that study, it was found that odds of stillbirth increased with each additional puppy in the litter, with the greatest mortality observed in litters larger than 12 puppies and the least mortality observed in litters of seven puppies.[15] The mean c-section litter size of surviving puppies in

this study was 6.6 puppies; however, the mean c-section litter size of nonsurviving puppies was 3.8 puppies. In the current study, many bitches who underwent emergency c-section delivered puppies naturally prior to development of dystocia and subsequent treatment. As a result, litter size delivered via c-section in these bitches may have been smaller and not representative of the total litter size. Thus, the significant effect of smaller litter size on neonatal mortality was probably influenced by the effect of emergency indication for surgery after already having delivered puppies naturally. This is consistent with the finding that the total litter size (including puppies born prior to and via c-section) was not different between surviving and nonsurviving puppies, with both having a mean of approximately seven puppies. This mean litter size is consistent with the lowest incidence of mortality in that previous study.[15] Additionally, it is possible the current study had an insufficient number of large litters to detect an increase in mortality with larger litter size, as only four bitches delivered 12 or more puppies.

Other previously reported risk factors for neonatal mortality following c-section, such as older age of the bitch[10] and primiparous history,[11] were not significantly associated with neonatal survival to discharge in the current study on univariable analysis. Previous studies have identified increasing duration of anesthesia and surgery as risk factors for neonatal mortality.[10] In the present study, time from anesthetic induction to delivery of the last puppy did not have an effect neonatal survival. Greater than 30 minutes between induction and the start of surgery was associated with greater neonatal mortality in a previous study.[10] In the current study, mean duration from induction to delivery of the last puppy was <30 minutes in both surviving and nonsurviving puppies. It is likely that anesthesia and surgery times were too short to identify an effect on neonatal survival. Differences in anesthetic protocols may have also contributed to discrepancy of results with previous studies. Maternal age was low overall in the current study and mean age was not significantly different between surviving and nonsurviving puppies. A study with more older bitches may be required to determine significance of this variable.

Limitations of this study include the retrospective study design. Medical records may have been incomplete, and all variables of interest were not available for all included patients. No follow-up outcome assessments were performed following hospital discharge. Screening for mortality at later time points in the neonatal period could be considered in future investigations but was not included in the present study as those factors would be unlikely related to the c-section itself. Preoperative management, anesthetic protocols, surgical techniques, surgeon experience, and post-natal care were not standardized, which may have affected neonatal outcomes. Cause of dystocia, which may have a significant impact on neonatal survival, was not able to be determined from most medical records and was unable to be analyzed statistically. Cause of neonatal death was not examined, and euthanasia performed immediately post-operative for reasons such as congenital defects could have influenced survival rates, but this is similar to previous studies which do not separate congenital defects from other causes of neonatal mortality. Neonatal resuscitation requirements following delivery were not recorded or included in the statistical analysis, which could also have an effect on survival. Further studies with standardized outcome assessments, such as neonatal Apgar scores, are necessary. Although the proportion of emergency c-sections performed on nonbrachycephalic bitches (78.0%) was over three times that of brachycephalic bitches (25.5%), brachycephalism did not have a significant effect on neonatal survival to discharge based on multivariable analysis comparing brachycephalic or nonbrachycephalic breed to elective or emergency c-section. Another limitation of this study was the low number of neonatal deaths, limiting the number of variables that could be included in the multivariable analysis.

This study may have had an increased neonatal survival rate for all puppies due to the multidisciplinary care team working together on the bitch and the neonates, with separate teams attending to anesthesia, surgery, and neonatal resuscitation. In a setting in which specialists are not available to help manage the neonates immediately following birth, neonatal mortality rates may be increased. It is unknown if this would influence brachycephalic neonates more so than nonbrachycephalic neonates. Future studies detailing interventions required to resuscitate or assist neonates during this critical time period are necessary to help answer this question. When possible, the authors recommend such a multidisciplinary care team with separate experienced staff overseeing anesthesia, surgery, and neonatal resuscitation following c-section.

Although some countries have developed programs to improve the health of brachycephalic dogs, and to decrease their need for c-sections,[16,17] in the authors' country, no restrictions on the breeding of brachycephalic dogs exist. While the authors acknowledge the need to reform breed standards for brachycephalic breeds, the goal of this study was not to evaluate the ethics of brachycephalic breeding but rather to focus on maximizing successful outcomes with c-section in these breeds. Further work is necessary to promote selective breeding of dogs who can conceive and deliver naturally.

Results of the current study suggest neonatal survival following c-section in brachycephalic dogs is higher than what has been previously reported and is similar to nonbrachycephalic dogs. Neonatal survival for all puppies is significantly better with elective c-section than emergency c-section. This information may be useful for client counseling during breeding management; planned c-section should be considered for high-risk bitches to improve the odds of neonatal survival.

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CONFLICT OF INTEREST

The authors declare no conflict of interest or financial support related to this report.

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