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Modified lateral enucleation technique—Surgery without ligation or clamping of the optic nerve: Technique description, complication rate and risk factors, and intraoperative blood loss estimation in companion animals

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Abstract

Purpose: The purpose of this study is to describe modification of the lateral enucleation technique without ligation or clamping of the optic nerve, document the incidence of complications, estimate intraoperative blood loss and identify possible risk factors for the developments of complications.

Methods: Medical records of dogs, cats, and rabbits undergoing lateral enucleation without clamping of the optic nerve were identified and retrospectively reviewed for post-operative complications (2000–2022). The significance of possible risk factors for the development of complications, including species, sex, age, eye, surgeon, presumed ocular surface infection, cultures, follow-up, antibiotics, NSAIDs, complications and diabetes mellitus was examined in a subset of these patients (2019–2022). As a prospective study, intraoperative blood loss was estimated by gravimetric analysis in an additional subset.

Results: Records of 1296 enucleations were retrospectively reviewed and detailed evaluation regarding potential risk factors was performed in 446 enucleations. The overall complication rate and surgical site infection rate was 2.31% and 2.08% respectively. Only *Pseudomonas* spp. bacterial culture was associated with development of complications. Estimated relative intraoperative blood loss was 2.2% and 4.1% in 43 dogs and 29 cats respectively.

Conclusions: The modified lateral enucleation technique is a safe and fast procedure with minimal risk of postoperative complications in dogs, cats, and rabbits. Based on the anatomy of the orbital vasculature ligation or clamping of the optic nerve and surrounding tissue is contraindicated.

KEYWORDS

bacterial culture, companion animals, globe surgery, orbital vasculature, *pseudomonas spp*, surgical site infection

1 | INTRODUCTION

Enucleation is a commonly performed surgical procedure in veterinary medicine for numerous conditions requiring removal of the globe. However, reports about surgical techniques for enucleation[1–3] or their complications[4–6] are sparse. In the literature, two widely used surgical approaches are most commonly described, viz. the transpalpebral and the transconjunctival technique. The transconjunctival approach[3,7] involves an incision in the upper and lower palpebral conjunctiva with subsequent dissection of the eyelids, while the transpalpebral approach[1] starts with a sharp transection of the lid skin and subcutaneous dissection. In 1972, Bellhorn described a lateral approach which allows for a better orientation during dissection of the orbital tissues.[2] This technique was then included in Gelatt's textbook (1991).[8]

However, most current textbooks mention only the transconjunctival and transpalpebral techniques and indicate the necessity of clamping of the optic nerve, in analogy to enucleation procedures described in human ophthalmology.[9,10] Allgoewer (2006) introduced a modification of Bellhorn's lateral enucleation technique. The unique feature of the modification was the omission of the ligation or clamping of the optic nerve and surrounding tissues.[11]

The purpose of this study is to review the modified lateral enucleation technique in detail, to evaluate the associated blood loss, to present a retrospective review of the complications and to evaluate possible risk factors for complications after enucleation with the modified lateral approach.

The anatomical background of the orbital vasculature is described as an introduction for the surgical technique.

1.1 | The orbital vasculature

The arterial blood supply to the eyeball and its accessory organs is provided by various arteries which in the cat arise from the rete mirabile arteriae maxillaris, whereas in the dogs and rabbits they arise from the external ophthalmic artery. The latter runs through the orbit to the dorsal side of the optic nerve, where it ramifies into several branches and connects with the weak internal ophthalmic artery. Additional branches from the malar artery, which originates from the maxillary artery and runs ventromedially in the orbit, contribute to the supply of the eyelids, the conjunctiva and nictitating membrane.[12]

Within the orbit, the external ophthalmic artery gives off its branches in the following ways: (1) various rami musculares for the eye muscles; (2) the lacrimal artery, which runs laterally along the eye muscle cone to the lacrimal gland; (3) the supraorbital artery, which is absent in the dog and emerges from the orbit rostrodorsally; (4) the external ethmoidal artery, which runs through the ethmoid foramen to the nasal cavity; (5) the supraorbital artery, which exits the orbit rostrodorsally; and (6) the anastomotic branch with the internal ophthalmic artery, which is often referred to as the "ramus bulbi" because most of the arteries for the eyeball branch off from this branch. The internal ophthalmic artery is only responsible for the vascular supply of the eye cup during fetal development and postnatally it becomes rudimentary. It arises intracranially from the rostral cerebral artery and only supplies the optic nerve, with which it enters the orbit through the optic canal.[12] The corresponding ophthalmic artery is the main artery for the eye in humans.[13]

The venous blood of the eyeball and its accessory organs collects within the orbit in an ophthalmic plexus which is surrounded by the periorbita and is formed by the external dorsal and ventral ophthalmic veins, the internal ophthalmic vein which is often duplicated and the numerous connections between these three major veins.

The ophthalmic plexus (in dogs and cats) or ophthalmic sinus (in rabbits) has several connections with the intracranial cavernous sinus as well as with the facial and maxillary veins. The ophthalmic venous plexus or sinus drains all the venous blood from the eyeball as well as venous branches from the eye muscles, the lacrimal vein from the lacrimal gland and the conjunctival veins, which drain blood from the conjunctiva in a variable manner. On the other hand, blood from the eyelids is drained through the palpebral veins to the facial vein (Figures 1 and 2).[12]

1.2 | Surgical procedure

The surgery is performed under general anesthesia. The animal is placed in lateral recumbency with the head positioned on a vacuum cushion pointing towards the end of the table. The surgical area is clipped and disinfected by a repeated application of a 2% povidone-iodine solution. For the modified lateral enucleation, a lateral canthotomy is performed in preparation for blunt cleavage of the outer layer of the eyelids from the inner. The temporal canthus is clamped with a hemostat (Figure 3A) and then cut with Metzenbaum scissors (Figure 3B). Blunt cleaving of both eyelids is performed by introducing and advancing Metzenbaum scissors from the temporal to the nasal canthus (Figure 3C,E). The tips of the scissors are introduced into the plane of cleavage between the orbicularis

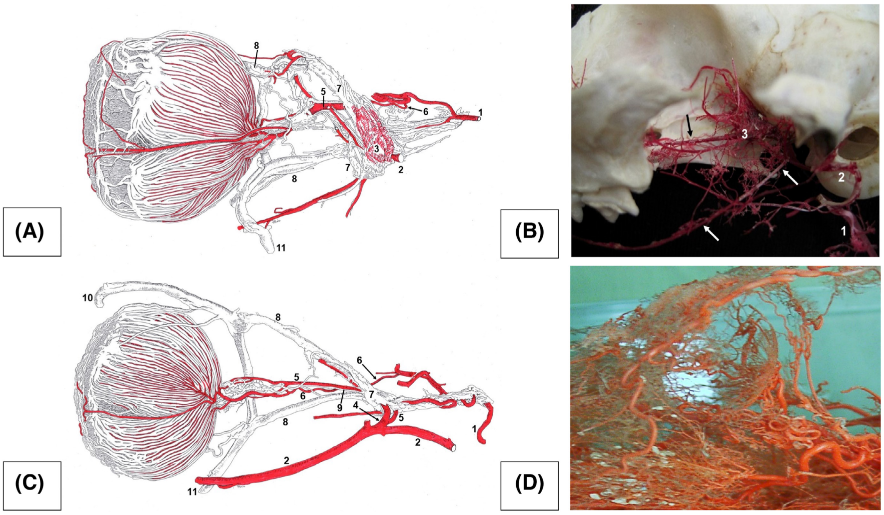


FIGURE 1 Corrosion casts of the orbital arteries (red) and veins in cat (A, B) and dog (C, D). (A) Lateral view of the left ocular and retrobulbar vessels of a cat (*drawing*). (B) Lateral view of the major arteries in the left feline orbit (*the infraorbital and lingual arteries are indicated by black and white arrows, respectively*). (C) Lateral view of the left ocular and retrobulbar vessels of a dog (*drawing*). (D) Dorsal view of the right orbital vasculature in a dog, consisting of vessels of smaller diameter only. 1. A. carotis externa; 2. A. maxillaris; 3. Rete mirabile a. maxillaris; 4. A. ophthalmica externa; 5. Ramus bulbi (Ramus anastomoticus cum a. ophthalmica interna); 6. A. ophthalmica interna; 7. Plexus ophthalmicus; 8. V. ophthalmica externa; 9. V. ophthalmica interna; 10. V. angularis oculi; 11. V. profunda faciei.

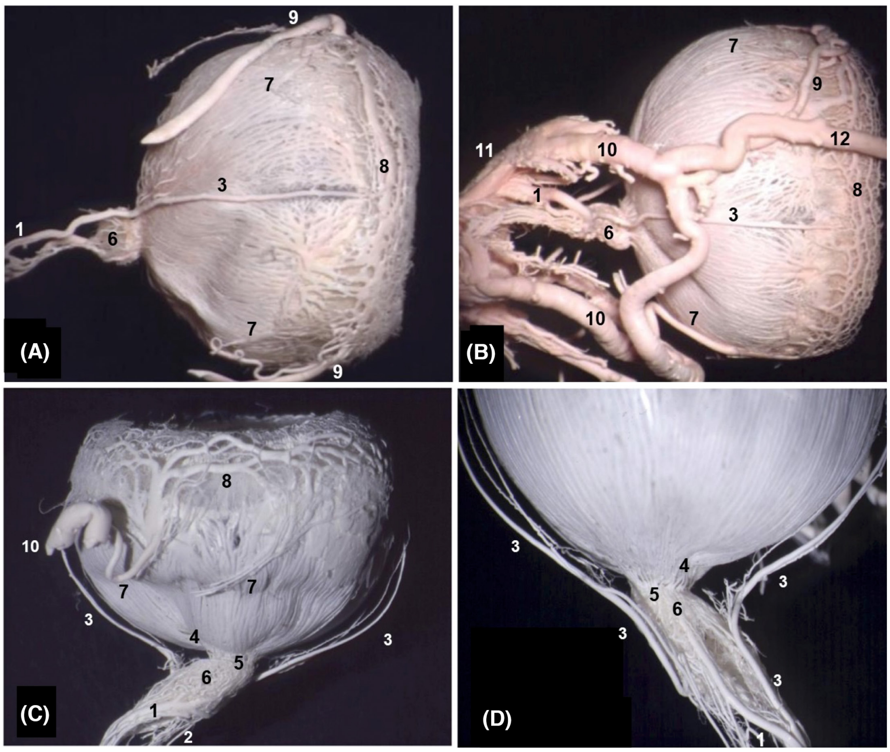


FIGURE 2 Corrosion casts of the orbital and ocular vasculature (P. Simoens 2006). (A) Left eye of a dog, medial view. (B) Left eye of a cat, medial view. (C) Left eye of a cat, ventral view. (D) Posterior aspect of the left eye of a cat, dorsal view. 1. Ramus bulbi (Ramus anastomoticus cum a. ophthalmica interna); 2. A. ophthalmica interna; 3. A. ciliaris posterior longa; 4. Aa. ciliares posteriores breves; 5. Aa. and Vv. cilioretinales; 6. Plexus vasculosus n. optici; 7. V. vorticosa; 8. Plexus venosus sclerae; 9. V. ciliaris anterior; 10. V. ophthalmica externa; 11. Plexus ophthalmicus; 12. V. angularis oculi.

muscle and the tarsal plate. With blunt dissection, this plane of separation is carried from the temporal to the medial canthus for both the upper and the lower eyelids. (Figure 3D,F). Metzenbaum scissors are utilized to cut the skin parallel and close to the lid margin. This incision is so extended nasally until the region of the medial canthus is reached. Thus, the subconjunctival tissues have now been exposed for further dissection of the periocular tissues.[2] (Video 1).

The eyelids are clamped together with a hemostat just proximal to the lid margin (Figure 4A). The nasal canthus is then circumcised with the scissors. The globe is gently rotated inwards (nasally) to improve access to the lateral canthal ligament which is transected with scissors

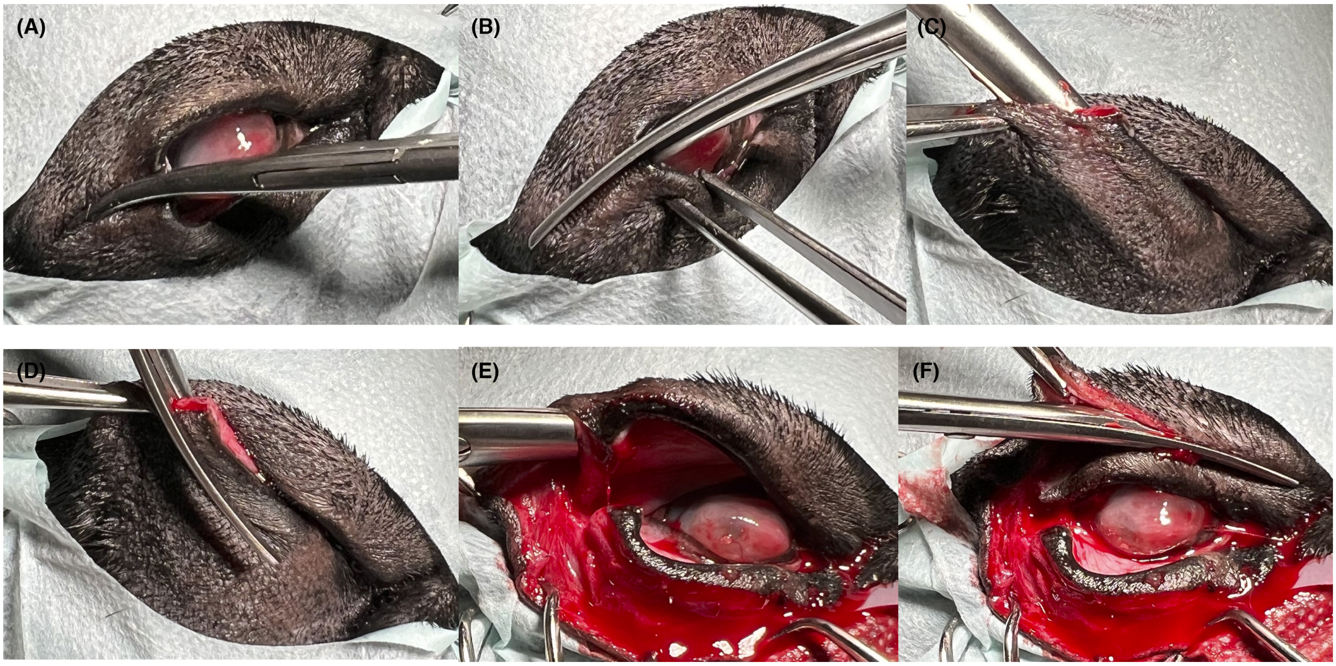


FIGURE 3 Enucleation of the right eyeball with lateral approach as described by Bellhorn (1972): (A) Lateral canthotomy starting with clamping hemostat on the temporal canthus. (B) Temporal canthotomy performed with scissors. (C) Blunt subcutaneous separation of the upper lid tissues between a skin and orbicularis muscle layer anteriorly and a tarsal plate and conjunctival layer posteriorly with a Metzenbaum scissors. (D) Incision of the anterior skin and orbicularis muscle layer of the lower lid with scissors. (E, F) Repetition of steps C and D for the upper lid: Blunt separation of the lid tissues and incision of the skin and orbicularis muscle layer.

facilitating further inward rotation. The subconjunctival tissues are then dissected down through the Tenon's capsule to the sclera just behind the limbus starting temporally (Figure 4B). This dissection close to the sclera extends all around the globe except for the region adjacent to the medial canthus.[2] (Video 1).

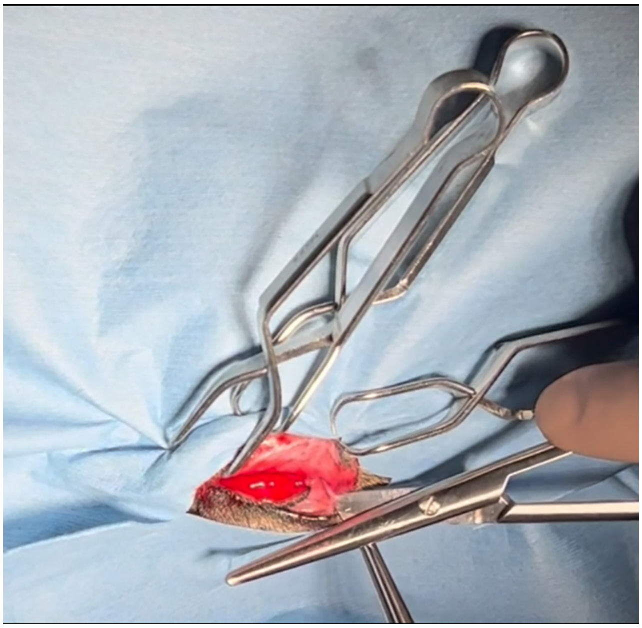
The remnant of the lateral canthal ligament, where it inserts into the Tenon's capsule is grasped by a forceps and the globe can now be rotated further inwards, superiorly, or inferiorly as needed to expose the various muscular and tendinous tissues where they attach to the sclera. There is no need to identify individual extraocular muscles while dissecting down into the orbit.[2] (Video 1).

By leaving the medial attachments in place, further rotation outward of the posterior segment of the globe is readily accomplished. This exposes the temporal portions of the retractor bulbi.[2] The remaining retractor bulbi and the optic nerve with surrounding tissues is transected with curved scissors without prior clamping or ligation. The posterior pole of the globe is then easily rotated outward. At this time the medial canthal ligament is transected and the medial periocular tissues are readily dissected. The remaining subconjunctival tissue and the nictitating membrane are excised and the globe lifted free.[2] (Video 1).

Inspection of the exterior surfaces of the globe and examination the exposed orbital tissues is followed by orbital packing with gauzes. Then the peripheral remnants of the Tenon's capsule and orbital septum are drawn together in a cruciate pattern with a 3-0 resorbable suture starting nasally. The cruciate pattern allows for good adaptation as well as a quick closure.

Care is taken to accurately adapt the remaining periocular tissues in a watertight fashion. Before completing the deep suture temporally, the gauzes are retrieved. The more superficial layers are closed with single interrupted sutures. For all sutures resorbable suture material is used (i.e. Vicryl® 3-0 and 4-0, Ethicon, Johnson & Johnson Surgical Technologies). Hemorrhage is usually minor unless eyes with long-standing disease process have caused many smaller orbital vessels to enlarge.[2] Finally, the incised edges of the eyelids are sutured together over the fascial sheath with single interrupted sutures. The eyelids may be trimmed as necessary to approximate the cut edges. Locoregional anesthesia may be optionally applied.

The surgery is performed as an ambulatory procedure. A non-steroidal anti-inflammatory (NSAID) (i.e. Carprofen, Rimadyl®; Zoetis) and a broad-spectrum antibiotic (i.e. amoxicillin clavulanic acid, Synulox®, Zoetis) are administered at the time of anesthesia induction and continued orally for 5–7 days after surgery. After the surgery, the wound is not covered. An Elizabethan collar is not used. The patients are typically discharged within 2 h after recovery from anesthesia.



VIDEO 1 A lateral canthotomy is performed in preparation for blunt cleavage of the outer layer of the eyelids from the inner. Therefore, the temporal canthus is clamped with a hemostat and then cut with Metzenbaum scissors. Blunt cleaving of both eyelids is performed by introducing and advancing Metzenbaum scissors from the temporal to the nasal canthus. The tips of the scissors are introduced into the plane of cleavage between the orbicularis muscle and the tarsal plate. With blunt dissection, this plane of separation is carried from the temporal to the medial canthus for both the upper and the lower eyelids. Metzenbaum scissors are utilized to cut the skin parallel and close to the lid margin. This incision is so extended nasally until the region of the medial canthus is reached. Thus, the subconjunctival tissues have now been exposed for further dissection. The eyelids are clamped together with a hemostat just proximal to the lid margin. The nasal canthus is then circumcised with the scissors. The globe is gently rotated inwards. This makes the lateral canthal ligament accessible. It is then severed with the scissors so as to allow further inward rotation. The subconjunctival tissues are then dissected down through the Tenon's capsule to the sclera just behind the limbus. This dissection close to the sclera extends all around the globe except for the region adjacent to the medial canthus. The remnant of the lateral canthal ligament where it inserts into the Tenon's capsule is grasped by a forceps and the globe can now be rotated further inwards, superiorly, or inferiorly as needed to expose the various muscular and tendinous tissues where they attach to the sclera. There is no need to identify the extraocular muscles while dissecting down into the orbit. By leaving the medial attachments in place, further rotation outward of the posterior segment of the globe is readily accomplished. This exposes the temporal portions of the retractor bulbi. The remaining retractor bulbi and the optic nerve with surrounding tissues is transected with curved scissors without prior clamping or ligation. The posterior pole of the globe is then easily rotated outward. At this time the medial canthal ligament is transected and the medial periocular tissues are readily dissected. The remaining subconjunctival tissue and the nictitating membrane are excised and the globe lifted free. Inspection of the exterior surfaces of the globe and examination the exposed orbital tissues is followed by orbital packing with gauzes. The peripheral remnants of the Tenon's capsule and orbital septum are drawn together in a cruciate pattern with a 3-0 resorbable suture starting nasally. The cruciate pattern allows for good adaptation as well as a quick closure.

2 | MATERIALS AND METHODS

2.1 | Retrospective evaluation of complications and evaluation of potential risk factors

A retrospective evaluation of cases that underwent the surgical procedure described above was performed. Cases with a minimum follow-up of 7 days were included.

This evaluation was completed in two parts. First, the overall complication rate was evaluated in dogs, cats, and rabbits for the period of 2000–2022. In this evaluation, the complications were graded as: minor (seroma formation, focal suture dehiscence, subcutaneous orbital emphysema, skin necrosis, wound dehiscence after stitch removal), moderate (superficial wound infection, deep focal suture reaction), severe (orbital infection, orbital infection requiring orbital revision) and self-trauma to the wound. Cases treated by the same procedure but without follow-up were excluded from this retrospective evaluation.

Second, a detailed review of cases in dogs, cats, and rabbits for the four-year period 2019–2022 was performed. In this evaluation, a possible influence of risk factors on the development of complications was researched. The following variables were noted: species, breed, sex, spay or neuter status, age, left and right eye, enucleation of both eyes at the same time, enucleation of both eyes consecutively, operating surgeon, reason for enucleation (with a maximum of two equivalent reasons being noted; glaucoma, ocular infection/perforation, retinal detachment and uveitis, phthisis bulbi or microphthalmos, lens luxation, proptosis bulbi, neoplasia, other), presumed ocular surface infection ("non-clean" eye), bacterial culture results, follow-up length, NSAID treatment length, antibiotic treatment length, antibiotic used (amoxicillin-clavulanate, enrofloxacin, cefovecin, marbofloxacin, azithromycin, doxycycline, trimethoprim-sulfonamide, none), diabetes mellitus status. Complication grading and recording of specific complications were the same as stated above for the overall complications. Moreover, days until development of the complication and days until resolution were noted. Exclusion criteria were identical to the above stated. The retrospective study was performed

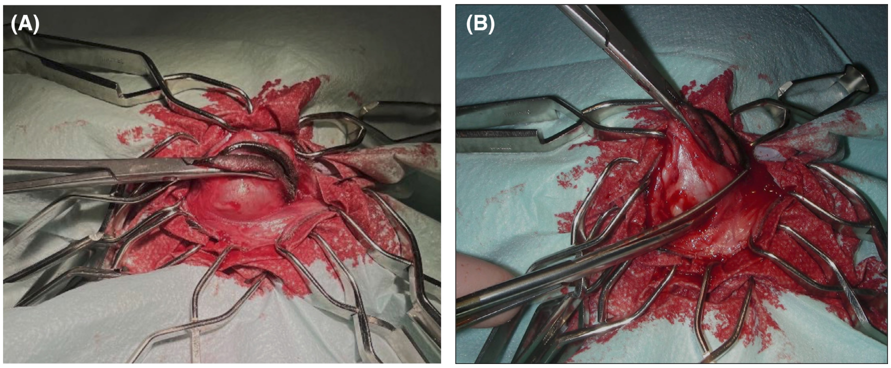


FIGURE 4 Enucleation with lateral approach continued: (A) Clamping of palpebral fissure with a hemostat. (B) Careful dissection close to the globe starting laterally and continuing into the sub-Tenon's space. Blunt and sharp dissection of the orbital tissues and sharp transection of the extraocular muscles.

according to GERVO guidelines and was approved by the responsible authority (Landesamt für Gesundheit und Soziales, Berlin, Germany) under the registration number StN^{o} 009-2023.

2.2 | Statistical analysis

The detailed review (2019–2022) was statistically evaluated. Any association was determined between the presence of postoperative complications and species, sex, age (in years), the surgeon effect, left versus right eye, enucleation of both eyes at the same time, enucleation of both eyes consecutively (animals that occurred twice in the data were considered in the statistical analysis by cluster robust standard errors instead of independently and identically distributed errors), reason for enucleation, presumed ocular surface infection, antibiotics used, length of antibiotic use and length of anti-inflammatory medications. Metric data is reported as the mean ± standard deviation, since no outliers were detected. Categorical variables are represented as percentages. Presence of postoperative complications versus variables was investigated by logistic regression with cluster robust standard errors and the coefficients were tested by Wald-test. In the case of presence of quasi-complete separation, Fisher's exact test was used. This condition occurred for the following variables: enucleation of both eyes consecutively, lens luxation, phthisis bulbi/microphthalmos, proptosis.

Additionally, the association of the presence of postoperative complications after enucleation with cultured bacteria strains was investigated on a subset of original data (cases with bacterial culture). The investigation was made by logistic regression with homoscedastic standard errors and the coefficients were tested by Wald-test. The case of quasi-complete separation did not occur. Statistical significance for all tests was set at 0.05. R version 4.2.3 was used for analysis.[14–16]

Statistical analysis was performed by Novustat GmbH (Wollerau, Switzerland).

2.3 | Estimation of blood loss during modified lateral enucleation procedure

Absolute and relative blood loss were estimated in a prospective study according to a previously published study design by Lenihan et al.[17] on cases operated by the modified lateral enucleation technique between January and August 2023. Briefly, blood loss was estimated by gravimetric method.[18] Prior to the surgery, the dry weight of swabs and draping was weighed using a dedicated calibrated digital accuracy weighing scale (AMIR Brifit, Hongkong Feytin Technology Co Ltd) with a precision of 0.01 g. The same was performed directly after surgery and the difference was noted as absolute blood loss (ABL). The assumption of 1 g of blood equaling 1 mL of blood was used.[19] No additional fluids were used during the surgery to flush the surgical site. The relative blood loss (RBL) was calculated as percentage of blood loss from the total estimated circulating blood volume. For dogs and rabbits, 85 mL/kg of body weight was used in the equation[17] whereas for cats, 65 mL/kg was used.[20] In the observation period, all client-owned dogs, cats, and rabbits presenting for enucleation as a treatment of their ocular disease were included in the study. The following criteria were subsequently used to exclude cases: orbital surgery differing from the regular procedure (e.g. exenteration), cases with clinical or histopathologic evidence of scleral rupture and/or orbital bleeding, and cases with incomplete weighing data. The prospective part of the study was approved by the responsible authority (Landesamt für Gesundheit und Soziales, Berlin, Germany) under the registration number StN^{o} 009-2023.

3 | RESULTS

3.1 | Overall complication rate

A medical history search of the clinical database for enucleation procedures from 2000 to 2022 was performed. 1296 eyes that were removed by lateral enucleation and had a minimum follow up of 7 days were included in the study (762 dog, 502 cat and 32 rabbit procedures). An overall complication rate of 2.31% was noted (30/1296). Ten cases were minor complications (seroma formation in three dogs and one cat, focal suture dehiscence in two dogs and one cat, subcutaneous orbital emphysema in 1 dog, skin necrosis in 1 dog, wound dehiscence after stitch removal in 1 cat). Thirteen cases were moderate complications (superficial wound infection $n=10$ dogs, deep focal suture reaction, $n=3$ cats). Seven complications were severe (orbital infection $n=4$ dogs, orbital infection requiring orbital revision, $n=3$ dogs). The overall complication rate was 3.15% (24/762) for dogs and 1.20% (6/502) for cats, whereas for rabbits no surgery related complications were reported. The incidence of surgical site infection was 2.08% (27/1296). Self-trauma to the wound, as a separate category, was observed in 2.39% of cases (31/1296), that is, in 0.92% of dogs (7/762) and in 4.78% of cats (24/502). This phenomenon, especially in cats, did not happen directly after the surgery, but appeared between day 4 and 12 postoperatively. In one case, it disappeared only 2 months after surgery, when the primary wound had already healed for 45 days.

3.2 | Evaluation of risk factors on the development of complications

A detailed review of enucleation cases for the years 2019–2022 was performed. In these 4 years, altogether 484 enucleation procedures were performed. Thirty-eight cases did not meet the inclusion criteria and were excluded. The final dataset contained 446 enucleation procedures, procedures, which were performed in 279 dogs, 159 cats and 8 rabbits. Two hundred and twenty five right eyes and two hundred and twenty one left eyes were removed and complications occurred in 7 instances on each side. Bilateral enucleation was performed in 17 patients. In seven cases, both eyes were removed in two separate procedures. In dogs, the median age was 10.04 years (0.2–16.5 years), 60 eyes were removed from intact males, 66 from intact females, 64 from castrated males und 89 from spayed females. In our dataset, the most common breeds were French Bulldogs ($n=30$), Jack Russell Terriers ($n=20$) and Shih-Tzus ($n=16$). In cats, median age was 9.55 years (0.3–21.5 years), 9 eyes were removed from intact males, 12 from intact females, 79 from castrated males und 59 from spayed females. The most common breeds in our dataset were domestic shorthair ($n=117$), British shorthair ($n=18$) and Persian cats ($n=7$). In rabbits, median age was 3.45 years (1.2–9.7), 2 eyes were removed from intact males, 4 from intact females and 2 from castrated males. Complications were seen after 14 enucleations: 3.94% in dogs (11/279), and 1.89% in cats (3/159). Since there were only eight operations on rabbits and no complications were observed, these were excluded in the logistic regression model with species as covariable. Seven surgeons performed the surgeries. Surgeon A had a complication rate of 3.70% (6/161), surgeon B 5.26% (5/95), surgeon C 1.20% (1/83), surgeon D 2.22% (1/45), surgeon E 3.33% (1/30). Surgeons F and G did not have any complications (0/20 and 0/12) and both were excluded for the consideration of a surgeon effect due to non-representative number of operations. Reasons for enucleation are detailed in Figure 5. Presumed ocular infection prior to surgery was present in 86 cases and four of those developed complications (4.65%), whereas non-infection was present in 360 cases and ten of those developed complications (2.78%). Standard peri- and postoperative therapy with amoxicillin-clavulanate was used in 369 cases, 13 with complications (3.52%). Cefovecin was used in 51 indicated cases, none of which developed complications. Enrofloxacin was used in indicated cases according to pre-operative, peri-operative or post-operative bacterial testing or due to concurrent systemic indication in 30 dogs, out of which seven had complications (23.33%). Enrofloxacin was the most commonly used secondary antibiotic after surgical site infection developing under the therapy with primary antibiotic. Other antibiotics (marbofloxacin, azithromycin, doxycycline, trimethoprim-sulfonamide) or no antibiotics were used sporadically. The average duration of antibiotic therapy was 7.2 ± 3.49 days. The average systemic anti-inflammatory therapy length was 9.1 ± 2.35 days. None of the patients that developed complications were diabetic.

Pre-, peri- or post-operative bacterial cultures were available for 48 out of 446 cases. Thirteen cultures did not show any bacterial growth. The most commonly isolated bacteria were *Pseudomonas* spp. 7 cases (*P. aeruginosa* $n=5$, *P. monteillii* $n=1$, *P. orizyhabitans* $n=1$) pathogenic *Staphylococcus* spp. 12 cases (*S. pseudintermedius* $n=9$, *S. aureus* $n=1$, *S. felis* $n=1$, *S. haemolyticus* $n=1$), beta hemolytic *Streptococcus* spp. 6 cases, *E. coli* 3 cases, *Pasteurella* spp. 3 cases (*P. multocida* $n=2$, *P. canis* $n=1$). Other bacterial isolates were cultured only once, specific information can be found in Table S1. Bacterial groups being cultured three times and less were removed from statistical analysis.

Average follow-up was 128.7 days with a median of 12.0 days (7–1245 days). Postoperative complications developed as following: Minor complications developed in seven cases (seroma formation $n=1$ dog, focal suture dehiscence $n=2$ dogs and 1 cat, subcutaneous orbital emphysema $n=1$ dog, skin necrosis $n=1$ dog, wound dehiscence after suture removal $n=1$ cat). Five cases were moderate complications (superficial wound infection $n=4$ dogs, deep focal suture reaction $n=1$ cat). Two

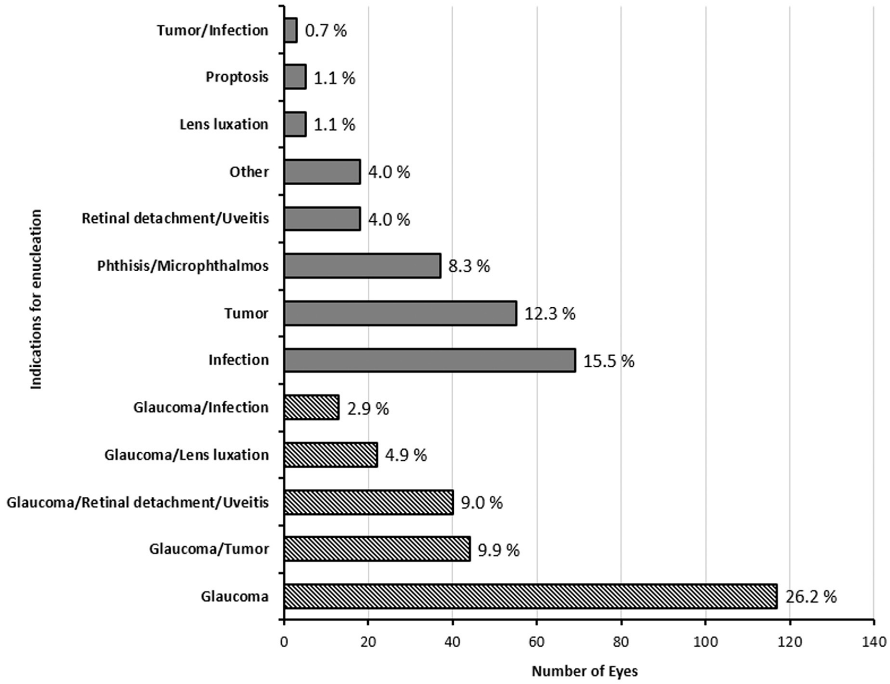


FIGURE 5 Indications for enucleation. Hatched area for glaucoma.

were severe complications (orbital infection $n=2$ dogs). Postoperative complications developed after a median time lapse of 12 days after surgery (4–75 days). Resolution of the complication was achieved after median time lapse of 10 days after diagnosis (4–30 days).

Detailed logistic regression statistical evaluation results are listed in Table 1 and full R code is included in Data S1. The majority of the potential risk factors did not reach statistical significance. The following three variables were statistically significantly associated with cases that developed complications: positive *Pseudomonas* spp. bacterial culture ($p<.05$), treatment with enrofloxacin ($p<.001$) and duration of antibiotic therapy ($p<.001$). Neither the surgeon nor presumed ocular infection were associated with higher complication rates.

3.3 | Estimation of blood loss during modified lateral enucleation

Altogether 84 animals were enrolled within the study period (January 2023–August 2023). From those, 11 animals had to be excluded from the final dataset, the most common exclusion criterion being scleral rupture. The final dataset contained 43 dogs, 29 cats, and one rabbit. One dog and one cat have undergone bilateral enucleation; thus, the final number of enucleated eyes was 75. In dogs, absolute blood loss (ABL) range was 1.92–100.64 mL (median 19.1 mL), while relative blood loss (RBL) range was from 0.19% to 7.74% of estimated circulating blood (median 2.2%). In cats, ABL ranged from 1.54 to 38.48 mL (median 11.42 mL), and RBL ranged from 0.51 to 11.80% of estimated circulating blood volume (median 4.1%). In the rabbit case, ABL and RBL was 11.72 mL and 6.6%, respectively. In the canine case of bilateral enucleation, RBL totaled 4% whereas in the feline case, RBL totaled 2.3%. All cases received a standard surgery rate crystalloid infusion of 5–10 mL/kg bodyweight. No postoperative complications were noted. For further details of the individual cases see Table S2.

4 | DISCUSSION

The enucleation techniques mostly mentioned in the literature are the transconjunctival approach as well as the transpalpebral approach. The transconjunctival approach has advantages of being simple, fast and associated with reduced bleeding, while the disadvantages mentioned are less exposure of orbital tissues,[21] possible increased traction on the optic nerve[22,23] as well as possible contamination from the ocular surface.[21] Another disadvantage is the risk of inadvertently leaving conjunctival tissue in orbit which may then induce formation of cystic tissue.[24,25] Advantages of the transpalpebral approach are a limited risk for contamination from the ocular surface and an increased exposure of orbital tissues and the optic nerve, while the disadvantages are increased bleeding and the procedure being slower than the transconjunctival approach.[21] The lateral transpalpebral enucleation technique was first described in 1972 by Bellhorn[2] and listed as an alternative technique in Gelatt.[8] The lateral approach was later included in Gelatt's ophthalmic surgery book and is well illustrated in the current edition of Veterinary

TABLE 1 Logistic regression statistical analysis: Evaluation of potential risk factors for development of postoperative complications. Calculation of odds ratio (OR), confidence intervals (CI), and statistical significance ($p < .05$).

Categorial variables	No. of operations	No complications		Complications		OR (95% CI)	*p*-value
		n	%	*n*	%		
Species (dogs vs. cats vs. rabbits)[a]	446	268/156/8	62.0/36.1/1.9	11/3/0	78.6/21.4/0.0	0.47 (0.10–1.53)	.2507
Sex (female vs. female spayed vs. male vs. male neutered)[b]	446	79/145/68/140	18.3/33.6/15.7/32.4	3/3/3/5	21.4/21.4/21.4/35.7	0.54 (0.10–3.00) 1.16 (0.21–6.46) 0.94 (0.22–4.68)	.4649 .8566 .9345
Comparison of 5 surgeons[c]	414	155/90/82/44/29	38.8/22.5/20.5/11.0/7.3	6/5/1/1/1	42.9/35.7/7.1/7.1/7.1	1.43 (0.40–4.90) 0.32 (0.02–1.89) 0.59 (0.03–3.56) 0.89 (0.05–5.49)	.5603 .2892 .6267 .9163
Eye (OS vs. OD)	446	214/218	49.5/50.5	7/7	50.0/50.0	1.02 (0.34–3.02)	.9728
Bilateral enucleation (no vs. yes)	446	399/33	92.4/7.6	13/1	92.9/7.1	0.93 (0.05–4.90)	.9444
Consecutive enucleation (no vs. yes)	446	418/14	96.8/3.2	14/0	100.0/0.0		1.0000
Retinal detachment and uveitis (no vs. yes)	446	375/57	86.8/13.2	13/1	92.9/7.1	0.51 (0.03–2.62)	5163
Glaucoma (no vs. yes)	446	203/229	47.0/53.0	7/7	50.0/50.0	0.89 (0.30–2.63)	.8244
Ocular infection/perforation (no vs. yes)	446	351/81	81.3/18.8	10/4	71.4/28.6	1.73 (0.47–5.33)	.3630
Lens luxation (no vs. yes)	446	403/29	93.3/6.7	14/0	100.0/0.0		.6136
Phthisis bulbi or microphthalmos (no vs. yes)	446	407/25	94.2/5.8	13/1	92.9/7.1	1.25 (0.07–6.69)	.8325
Proptosis bulbi (no vs. yes)	446	427/5	98.8/1.2	14/0	100.0/0.0		1.0000
Neoplasia (no vs. yes)	446	332/100	76.9/23.1	12/2	86.7/14.3	0.55 (0.09–2.07)	.4440
Other cause for enucleation (no vs. yes)	446	415/17	96.1/3.9	13/1	92.9/7.1	1.88 (0.10–10.31)	.5552
Presumed infected (no vs. yes)	446	350/82	81.0/19.0	10/4	71.4/28.6	1.71 (0.46–5.25)	.8845
Amoxicillin-clavulanate (no vs. yes)	446	76/356	17.6/82.4	1/13	7.1/92.9	2.78 (0.54–50.80)	.3294
Enrofloxacin (no vs. yes)	446	409/23	94.7/5.3	7/7	50.0/50.0	17.78 (5.66–56.27)	.0000006
Cefovecin (no vs. yes)	446	381/51	88.2/11.8	14/0	100.0/0.0		.3856
Pseudomonas spp.(no vs. yes)	48	36/5	87.8/12.2	3/4	42.9/57.1	9.60 (1.68–63.1)	.0120
Staphylococcus (no vs. yes)	48	30/6	83.3/16.7	9/3	75.0/25.0	1.67 (0.30–7.79)	.5246

Metric variables	No. of operations	No complications		Complications		OR (95% CI)	*p*-value
		n	Mean	*n*	Mean		
Age (years)	443	432	9.20	14	8.77	0.97 (0.87–1.11)	.6708
Antibiotic therapy length (days)	446	432	7.03	14	10.86	1.21 (1.09–1.36)	.0002

(Continues)

TABLE 1 (Continued)

Metric variables	No. of operations	No complications		Complications		OR (95% CI)	*p*-value
		n	Mean	*n*	Mean		
Anti-inflammatory therapy length (days)	446	432	9.01	14	10.21	1.15 (0.97–1.34)	.1551

Abbreviations: CI, confidence interval, OD, right eye, OR, odds ratio; OS, left eye.

[a]CI and *p*-value were computed without the rabbits.

[b]OR is in comparison to female.

[c]Surgeons with few operations and no complications excluded.

Ophthalmic Surgery (2021).[26] An advantage of this approach is a better overview of the orbital tissues during dissection. Nonetheless, these texts still suggested clamping of the optic nerve. The lateral approach was mentioned again when a modified lateral technique was presented.[11] The ophthalmic artery is the main artery for the eye in humans.[13] In companion animals, the corresponding internal ophthalmic artery becomes rudimentary after birth and is supplemented by a larger external ophthalmic artery. The blood supply of the eyeball and its accessory organs is provided by several smaller arteries that branch within the orbit (Figures 1, 2). Therefore, a mass ligation or clamping of the orbital vasculature and the optic nerve will be relatively ineffective. Based on this, the authors of this paper believe that attempts to clamp the vasculature associated with the optic nerve are not necessary. The modified lateral technique described in the present paper is Bellhorn's lateral approach omitting clamping and/or ligation of the optic nerve and surrounding tissues. This is described here for the first time in the literature after it was previously presented in 2006.[11]

As mentioned earlier, according to the literature, one of the differences between the subconjunctival and transpalpebral enucleation technique is the blood loss during the procedure[21] with the blood loss being higher in the transpalpebral technique. However, only recently a first peer reviewed publication estimating blood loss during enucleation in dogs has been published.[17] The authors reported a median RBL of 1.3% (0.1%–6.7%) with a mean RBL of 1.3 ± 1.2% ($n = 112$) for the subconjunctival approach and a mean RBL of 2.2 ± 1.6% ($n = 18$) for the transpalpebral approach. In that study, hemostasis with electrocautery was routinely used by 3 out of 8 surgeons, whereas 3/8 surgeons routinely placed mosquito forceps around the apical vasculature and optic nerve before transection. Ligation was not performed by any of the surgeons. In our canine data, we achieved a similar RBL (median 2.2%, 0.19%–7.74%) when compared to the transpalpebral enucleation technique, which is not surprising as the lateral enucleation technique was developed as a modification of the transpalpebral approach.[2] However, in our study, neither did we use clamping of the vasculature and optic nerve nor did we employ electrocautery. Moreover, authors reported a difference in RBL between a retrobulbar block and a splash block (1.0% ± 0.8% and 1.9% ± 1.5% respectively).[17] In our study, no additional locoregional anesthesia was applied. To the best of our knowledge, our study is the first one to report ABL and RBL after enucleation in cats as 1.54–38.48 mL (median 11.42 mL) and 0.51%–11.80% (median 4.1%). The numbers are higher for cats than for dogs, partly because the reported circulating blood volume per kg is lower than in dogs.[17,20] Despite this numerical difference, no increased postoperative or post anesthesia complications were noted in comparison to dogs.

Complications of enucleation surgery described in the literature include surgical site infection (SSI)[4] or likewise mentioned orbital cellulitis,[5] cystic tissue formation,[24,25] orbital emphysema,[27,28] blindness and optic neuropathy in the contralateral eye[22,23] as well as implant migration and extrusion in orbits with silicone prosthesis.[5] A limitation of our study could be the mean follow-up time of 128.7 days with median of 12 days (7–1245 days). Long-term complications might be missed. However, owners were instructed to report back if any long-term complications would occur.

Generally, in soft tissue surgery, the incidence of SSI in dogs was reported to be up to 8.7%.[29] For enucleations in dogs, Dacanay reported an SSI of 5% (14/280),[4] Palmer noted an SSI rate of 6.5% (14/215),[5] whereas our data revealed a much lower incidence of SSI of 2.08% with approximately five times more cases (27/1296). Reported median follow-up was 14 days[4] which is similar to our median of 12 days, whereas Palmer reported a median follow-up of 147 days.[5] It is noteworthy that 50% of dogs developing complications had concurrent diabetes mellitus (27.5% complication incidence in diabetes mellitus cases)[5] whereas none of the dogs in our risk factors evaluation that developed complications had a known diabetic status. We had a very low incidence of orbital emphysema in 0.08% cases (1/1296). No cases of cystic tissue formation were observed after the modified approach[25] while a recent retrospective evaluation of 201 enucleations revealed five cases of orbital cysts (2.5%), all of them after transconjunctival approach.[24] We assume that due to the inherent nature of these techniques, the modified lateral approach as well as the transpalpebral approach are not prone to leaving conjunctival tissue behind and thus do not cause cyst development. Also, we did not experience a single case of blindness or optic neuropathy in the contralateral eye after enucleation. As described, the lateral approach was developed to increase exposure of the orbital structures, especially the optic nerve.[2] The modification of the lateral technique by abandoning ligation or clamping of the optic nerve adds safety to the procedure as the risk of damage of the optic nerve and chiasm is reduced. Strictly speaking, ligation or clamping of the optic nerve and surrounding tissues during enucleation is contraindicated as it may result in rostral traction with chiasmal injury leading to blindness in the contralateral eye. This has been described in the cat.[22]

In our detailed review of enucleation cases, we strove to identify risk factors for the development of postsurgical complications. Most of the potential risk factors did not influence the development of complications (Table 1). Three variables were statistically significantly associated with cases that developed complications: duration of antibiotic therapy ($p<.001$), animals treated with enrofloxacin ($p<.001$), and positive *Pseudomonas* spp. bacterial culture ($p<.05$). Understandably, the length of the antibiotic therapy was directly correlated to complications, as most of the complication cases were surgical site infections that required prolonged antibiotic therapy. This variable is also connected to the second one that is, animals treated with enrofloxacin. Enrofloxacin, a fluoroquinolone antibiotic with indication restriction, was used in 10.45% of the cases (30/287, no cats having been treated with enrofloxacin). In 23 cases, enrofloxacin was the first postoperative antibiotic based on preoperative bacterial culture or concurrent systemic disorder. In seven cases, it was used as a second line treatment after developing complications after the first line antibiotics. Therefore, it is clear that the statistical significance of enrofloxacin results is more of a consequence than a cause of complications as it was used in cases that were already prone to the development of complications. We believe that this finding is similar to the previously published statistical significance of postoperative use of cephalexin.[4] The latter antibiotic was only used in 6.8% of cases in the present study (13/191) and three of those developed complications. The third statistically significant variable was positive *Pseudomonas* spp. bacterial culture (which summarized both pre- and perioperative for those "presumed infected" cases or postoperative when SSI develop). *Pseudomonas* spp. was cultivated from 44.4% (4/9) of cases with complications as compared to 7.69% (3/39) of cases without complications. Different *Pseudomonas* spp. are a known cause of surgical site and nosocomial infections in both humans and animals,[30–32] so this finding is not surprising. To compare the risk factor evaluation, Dacanay et al. concluded that no risk factors have been identified to guide clinical decision-making for prevention of surgical site infections.[4] Apart from a *Pseudomonas* bacterial culture, we conclude that no other risk factors had influence on the development of complications in our study.

One potential risk factor that did not reach statistical significance but should receive special attention is presumed ocular surface infection (or as mentioned by Dacanay et al.[4] as "non-clean enucleation"). An important consideration when deciding to use transconjunctival versus transpalpebral enucleation technique is the presumed ocular surface infection. Transpalpebral approach is generally believed to be cleaner than transconjunctival approach.[9,21] Dacanay et al. found no statistical significance between these two approaches and SSI. Nevertheless, they evaluated the dataset in univariable fashion and relationship between surgical approach in "clean" and "non-clean" eyes was not shown.[4] Our data did not find any statistical significance between presumed ocular infection and incidence of SSI. Moreover, given the fact that SSI incidence in our study was much lower than SSI rate reported in other studies utilizing both transpalpebral and subconjunctival approach,[4,5] we believe that even though the surgical field in the lateral approach must be considered contaminated, it does not increase risk for development of SSI even in presumed ocular surface infection. We believe that the choice of the surgical approach does not play such an important role as previously stated.[9,21]

A special category that was included in the present study was postoperative self-trauma to the wound/pruritus with local erythema and alopecia. We wanted to define what percentage of animals scratch their wound or surgical area after enucleation, as no E-collar was used in our clinical setting. Dogs were scratching their wound in 0.92% of cases (7/762) whereas cats had a higher incidence of 4.78% (24/502). This phenomenon, especially in cats, did not happen directly after the surgery, but it appeared between days 4 and 12 postoperatively. In one case, it disappeared as late as 2 months after surgery, when the primary wound had already healed for 45 days. In literature, post-enucleation pruritus was described in 28.6% (4/14) of cats, presumably due to the resorptive phase of the suture.[33] In a recent retrospective enucleation evaluation presented by Bott et al., 2.5% of cases (5/201) also developed "severe pruritus" postoperatively without any further specification.[24] Cats seem to be overrepresented for that phenomenon and periocular Herpesvirus FHV-1 infection may play a role in the etiopathogenesis of the pruritus.[34]

In summary, this comprehensive study confirms that modified lateral enucleation without clamping of the optic nerve head and its surrounding tissues is a safe procedure with minimal complications and blood loss comparable to a routine transpalpebral technique. Based on anatomical considerations, ligation or clamping is not necessary when an enucleation is performed in small animals.

AUTHOR CONTRIBUTIONS

Ingrid Allgoewer: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; resources; supervision; validation; visualization; writing – original draft; writing – review and editing. **Petr Soukup:** Conceptualization; data curation; formal analysis; investigation; methodology; validation; visualization; writing – original draft; writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data available in article supplementary material.

ETHICS STATEMENT

The study was performed according to GERVO guidelines and was approved by the responsible authority (Landesamt für Gesundheit und Soziales, Berlin, Germany) under the registration number StN° 009-2023.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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