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Vergleich zweier Methoden zur operativen Entfernung kryptorchider Hoden

Comparison between two methods for surgical removal of cryptorchid testes

Diplomarbeit

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vorgelegt von

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Eigenständigkeitserklärung:

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1. Abstract

The aim of this diploma thesis was to compare surgical duration and complications of laparoscopic and open cryptorchidectomy in dogs. Information about the patient (identification number, age, body weight, breed, surgery date), surgical duration, surgical method, surgical site, intra- and postoperative complications, mean arterial blood pressure (MAP), endtidal CO_2, ($EtCO_2$), ventilation mode and body temperature during surgery was gathered retrospectively. Surgical duration was evaluated via a linear model with an interaction between weight and methods. Complications were analyzed using Fisher's exact test for count data, binary logistic regression, Poisson regression models and linear mixed models. MAP was specifically analyzed via a linear model with an interaction between ventilation mode and body weight. There were 46 cases: 22 laparotomies and 24 laparoscopies. Surgical duration increased with body weight. This effect was stronger in laparotomies (p=0.0006) but was also seen in laparoscopies (p=0.034). Surgical duration also increased with age (p=*0.03*). Mean arterial pressure was lower in laparoscopies (p=0.031). For ventilated dogs, MAP decreased with body weight (p=0.0012). Higher body weight was associated with lower odds of developing moderate hypothermia but a greater likelihood of mild hypothermia (p=0.029). Temperature was lower in older animals (p=0.019) and higher for prolonged surgical durations (p=0.036). Patients that breathed exclusively spontaneously had higher body temperatures than dogs that were exclusively ventilated (p=0.014). Endtidal CO_2 decreased with age (p=0.007). In conclusion, larger dogs may profit from laparoscopic approach.

In dieser Diplomarbeit wurden Operationsdauer und Komplikationen bei laparoskopischen und offenen Kryptorchidektomien bei Hunden verglichen. Dafür wurden retrospektive Informationen zum Tier (Identifikationsnummer, Alter, Gewicht, Rasse, Operationsdatum), die Dauer des Eingriffs, die Methode, der Situs, intra- und postoperativen Komplikationen und der intraoperative mittlere arterielle Blutdruck (MAP), Entidales CO_2 ($EtCO_2$), Ventilationsmodus und innere Körpertemperatur gesammelt. Die Operationsdauer wurde mithilfe eines linearen Modells analysiert, das die Interaktion zwischen Körpergewicht und Operationsmethode berücksichtigte. Komplikationen wurden mittels Fisher's Exact Test für Zähldaten, binärer logistischer Regressionsmodelle, Poisson-Regressionsmodelle und linearen gemischten Modellen analysiert. MAP wurde zusätzlich mit einem linearen Modell mit Interaktion zwischen Ventilationsmodus und Gewicht analysiert. Insgesamt wurden 46 Fälle aufgenommen, bestehend aus 22 Laparotomien und 24 Laparoskopien. Es konnte gezeigt werden, dass schwerere Hunde längere Operationsdauern hatten. Dieser Effekt bestand stärker für die

offenen Eingriffe (p=0,0006), aber auch für Laparoskopien (p=0,034). Außerdem dauerte die OP bei älteren Hunden länger (p=0,03). Der MAP war niedriger in Laparoskopien (p=0,031). Bei ventilierten Hunden sank der MAP abhängig vom Gewicht (p=0,0012). Schwerere Hunde hatten eine geringere Wahrscheinlichkeit für moderate Hypothermie (p=0,029). Zudem war das Alter negativ mit der Temperatur assoziiert (p=0,019), während die OP-Dauer positiv mit der Temperatur assoziiert war (p=0,036). Patienten, die nur spontan atmeten, hatten höhere Temperaturen als jene, die ausschließlich ventiliert wurden (p=0,014). Das Alter war negativ mit dem Endtidalen CO_2 assoziiert (p=0,007). Vor allem größere Hunde könnten von einer laparoskopischen Entfernung des kryptorchiden Hodens profitieren, da hier Zeit eingespart werden kann.

2. List of abbreviations

Abbreviation	Full term
AMH	Anti-Mullerian-hormone
ASA	American-Society-of-Anesthesiologists
cm	centimeters
CO_2	Carbon dioxide
DEHP	di(2-ethylhexyl)phthalate
EDC	Endocrine-disrupting chemicals
$etCO_2$	End-tidal carbon dioxide
Fig.	Figure
hCG	Human chorionic gonadotropin
HMGA2	High-mobility-group-AT-hook 2
INSL3	insuline-like-peptide-3
KAT6	Lysin-acetyltransferase 6
kg	kilogram
KLF4	Kruppel-like-factor-4
mm	millimeters
mmHg	millimeter mercury
mRNA	messenger ribonucleic acid
NSAID	Non-Steroidal Anti-Inflammatory Drug
PCB	Polychlorinated-biphenyl-153
RXFP2	Relaxin-like-family-peptide-receptor-2
SNP	Single-nucleotide-polymorphism
TIS	Tierspitalinformationssystem
TP53	tumor-protein-p53

3. Introduction

In recent years, minimal invasive surgeries have become increasingly common in veterinary medicine. The advantages of minimal invasive techniques include reduced tissue trauma and pain, shorter recovery times and better cosmetic results (1–5). Incidence for cryptorchidism in dogs ranges from 1–15 % (6, 7). An undescended testicle carries an increased risk of testicular neoplasia and torsion, and should therefore be removed (7). Although the removal of abdominal testes is feasible for laparoscopic surgery and is routinely performed, studies directly comparing open and laparoscopic cryptorchidectomy specifically for this indication are scarce (1).

The aim of this thesis is to compare intraoperative and postoperative complications, surgical duration, mean arterial pressure, endtidal CO_2 ($EtCO_2$), ventilation modes and body temperature in dogs undergoing laparoscopic versus open cryptorchidectomy for abdominal cryptorchidism. To date, these parameters have not been compared in dogs undergoing laparoscopic cryptorchidectomy using a one-port-system with the modified Hasson-technique. The hypothesis is that laparoscopic cryptorchidectomy is associated with shorter surgical times and fewer complications than open cryptorchidectomy.

Medical history, anaesthetic and surgical records of dogs with one or two abdominally retained testes surgically removed between 2001 and 2024 at the University of Veterinary Medicine Vienna were retrospectively analyzed. Among other parameters, surgical duration, complications, mean arterial blood pressure, $EtCO_2$, ventilation modes and body temperature were extracted from the university's digital medical information platform (TIS) and analysed.

4. Literature review

4.1 Definition and Epidemiology

Cryptorchidism describes a disorder of testicular descent in male mammals in which one or both testes do not reach the scrotal sac. It can be bilateral or unilateral, with the right testicle being more frequently affected (6, 7). The testicle either lies inside the abdominal cavity or in the inguinal ring or inguinal canal (7).

Tannouzi et al. examined 4924 male dogs in Rio de Janeiro via sonography over 13 years and concluded that 8.2 % were cryptorchids, of which the vast majority (93.5 %) were pure bred dogs. 59.5 % were inguinal cryptorchids, 38.4 % abdominal cryptorchids and 70 % one-sided. Small dogs were more likely to be inguinal cryptorchids while medium-sized and large dogs were more likely to be abdominal cryptorchids. Almost 60 % of the unilateral cryptorchids were right-sided. In 86.8 % of bilateral cryptorchids both testes had the same location (6). Romagnoli and Tannouzi et al. described Toy Poodle, Yorkshire Terrier, Miniature Pinscher and Dachshund as the four most affected breeds (7, 6). 70.5 % of all cryptorchid dogs weighed under 10 kilograms (kg) (6). Romagnoli (1991) reported incidences of canine cryptorchidism from 1 to 15 % depending on study location and breed distribution (7).

Hip dysplasia, patellar luxation, umbilical hernia and disorders of sexual development such as defects of the penis and prepuce are associated with canine cryptorchidism. The majority of testicular tumors were Sertoli-cell-tumors and seminomas (12, 7). In a study investigating portosystemic shunts in dogs, half of affected patients were additionally cryptorchid (13).

4.2 Etiology and Pathogenesis

Cryptorchidism is thought to be caused by abnormal development of the *Gubernaculum testis* during testicular descent. An underdeveloped gubernaculum leads to insufficient migration of the testicle in the abdominal cavity. Usually this occurs unilateral and results in abdominal cryptorchidism (11, 7).

In some cases, gubernacular outgrowth develops in atypical directions. Instead of extending distally into the scrotal sac, it may grow proximally from the inguinal canal into the abdominal cavity. As a result, the testicle fails to migrate transabdominally and remains caudal to the kidney. Consequently, the external spermatic fascia remains empty, and the vaginal process is inverted into the abdominal cavity. In other instances, the gubernaculum may proliferate completely or partly within the inguinal canal, leading to its widening; or even extend between

the internal and external oblique abdominal muscles. These aberrant growth patterns usually cause only minor interference with testicular descent. The testis most often lies in the abdominal cavity close to the internal inguinal ring, which can also be referred to as low abdominal cryptorchidism. Alternatively, the testicle can be found in the inguinal canal, or its migration may only be delayed. However, the widened inguinal canal predisposes affected individuals to inguinal hernias (11, 7, 14).

Lastly, the *Gubernaculum testis* may extend too much inside the inguinal canal and the *Fascia spermatica externa* and its regression may be delayed. The affected dogs are inclined to inguinal hernias due to the widened inguinal canal and the testicle may take longer to reach its final position or never fully descent (11).

The hormonal regulation of testicular descent is not fully understood. For normal gubernacular outgrowth the presence of testes is crucial. It cannot be facilitated solely by testosterone supplementation. However gubernacular regression is primarily regulated by testosterone in puppies (11, 8, 7). It is concurrent with a slight increase of plasma testosterone in dogs (15). In humans and rodents, the inguinoscrotal phase of testicular migration is thought to be controlled by the androgen-sensitive genitofemoral nerve. It releases calcitonin-gene-related-peptide (CGRP), which facilitates the regression of the *Gubernaculum testis* in the scrotal sack by reducing the extracellular matrix, increasing collagen and causing contraction of the ligament. Further it might act as a chemotactic signal, leading the gubernaculum into the *Scrotum* (16).

Insuline-like-peptide-3 (INSL3) is released by Leydig-cells. Its receptor is the relaxin-family-peptide-receptor-2 (RXFP2) and it is located on the muscle and mesenchymal tissue cells of the *Gubernaculum testis*. Immunoreactivity for RXFP2 and was found on day 35–45 *post conceptionem* on the gubernaculum*,* which is the same period in which anti-INSL3 immunoreactivity was seen in Leydig-cells of canine fetuses. In the same study, RXFP2-immunoreactivity was not found on gubernacular residues in adult cryptorchids, while androgen and INSL3 presence was confirmed in the same testicular tissue (17, 18). According to the review of Lăptoiu et al. (2023) the INSL3-RXFP2 complex plays an important role in the transabdominal phase of testicular migration by controlling gubernacular swelling. The RXFP2-gene was experimentally disturbed in mice, which resulted in failure of transabdominal migration of the testicle and subsequently in cryptorchidism. However, the gene sequence in dogs is homolog in cryptorchid and normal dogs. A different study found that INSL3 messenger

ribonucleic acid (mRNA) levels are higher in undescended canine testes compared to normal testes, while RXFP2 mRNA levels are lower in cryptorchid gonads. This could mean that the disturbed descend in dogs is rather related to low expression of RXFP2, instead of low secretion levels of INSL3 (19, 18). In humans the fetal production of INSL3 starts earlier than in healthy individuals, the secretion stops prematurely. In humans and mice the timing of INSL3 levels plays an important role for normal testicular descent (10).

Anti-Mullerian-hormone (AMH) is produced by Sertoli cells and can be used as a marker to confirm the presence of gonadal tissue in dogs. In unilateral cryptorchids, serum AMH levels are higher than in intact males. This may be due to lower testosterone levels, since AMH is down-regulated by testosterone (10, 20, 21). However, some studies on peripheral and spermatic venous testosterone concentrations in cryptorchid dogs could not show significantly lower testosterone levels in peripheral and spermatic venous blood (21, 22, 18). Khan et al. (2018) reported a study in which plasma testosterone and INSL3 levels were lower in bilateral cryptorchid dogs, compared to unilateral cryptorchids and normal dogs. Further, an in-vitro investigation showed that scrotal testicles produced more testosterone and INSL3 in response to Human chorionic gonadotropin (hCG) stimulation than undescended gonads (18).

When compared to scrotal testes of cryptorchid and normal dogs, undescended testes are smaller, and the functional testicular tissue is atrophic. Bilateral cryptorchid dogs are predominately infertile, whereas unilateral cryptorchids can still be fertile (23, 18, 7). According to a recent review, a histological examination concluded that the descended testes of cryptorchids contained all testicular cell types and showed no signs of maldevelopment, while Romagnoli stated that 40 % had similar lesions as the undescended testicle (18, 7).

Higher temperatures in the abdominal cavity disturb all testicular cell types except Sertoli-cells. Therefore, a majority of abdominal cryptorchid testes are composed of Sertoli-cells-only-tubules (18). This also explains the higher incidence of Sertoli cell tumors in this type of cryptorchidism. The temperature in the inguinal canal stimulates germ-cell-lines, facilitating the occurrence of seminomas. Interstitial testicular tumors are not dependent on temperature; therefore, incidence does not differ between cryptorchidism types. Cryptorchidism increases the risk of testicular neoplasia by 9.6–13.6 times. Additionally, in abdominal testes, there is an increased risk for testicular torsion due to higher weight and size, especially in case of tumors (7, 18).

Cryptorchidism can be heritable and could be reduced by genetic selection. It most likely is a polygenic autosomal recessive trait. Other possible causes include exogenous chemicals and hormones or spontaneous mutations (18). In humans, among other things, a smoking mother and low birth weight are discussed as possible risk factors (24). There have been multiple genome analyses of cryptorchid dogs. These studies found associations between cryptorchidism and a single-nucleotide-polymorphism (SNP) in the High-mobility-group-AT-hook-2-gene (HMGA2) and another missense SNP in the KAT6-gene (lysin-acetyltransferase 6-gene). HMGA2 is known for its role in body weight distribution in dogs; however, there was no association found between this SNP-variant and body weight in dogs. KAT6 encodes the histone acetylase, an enzyme that contributes to the epigenetic regulation of multiple developmental processes, including epididymal descent. In humans it was shown that disruption of the descent of the epididymis can consequently lead to abdominal cryptorchidism (10).

The mRNA-expression of tumor-protein-p53-(TP53)- and Kit-ligand-(KTLG)-genes have been found to be increased in inguinal testes compared to the scrotal testes of cryptorchid dogs, while the Kruppel-like-factor-4 (KLF4) gene has a lower mRNA-expression-rate in the inguinal testicles. TP53 plays a role in cancer development while KTLG has been associated with an increased risk in testicular germ cell tumors. KLF4 is part of the mechanisms decreasing the risk of tumorigenesis (10).

There was no mutation found on the gene encoding the INSL-3 associated to cryptorchidism in dogs. Nevertheless, altered expression levels could have an effect on testicular descent (10).

Endocrine-disrupting chemicals (EDC) might be external factors contributing to the development of canine cryptorchidism. Testicular dysgenesis syndrome has been described in multiple species including dogs and humans. It is defined as a symptom complex consisting of increasing rates of cryptorchidism, hypospadias, testicular neoplasia and poor semen quality and has been linked to EDCs. A long-time-study has found decreasing sperm quality and concurrently increasing rates of cryptorchidism in a population of breeding dogs. Polychlorimated-biphenyl-153 (PCB) and di(2-ethylhexyl)phthalate (DEHP), two chemicals known for their effects on the reproductive system, have been found in elevated concentrations in canine testes and commercial dog food (25, 26). Treatment of hypoluteoidism in pregnant bitches typically involves progesterone

supplementation. However, cryptorchidism in male puppies has been reported as a potential side effect of such therapy, alongside with masculinization of female puppies. The authors specifically advise against the use of synthetic progestins, as there is not much information on dosage, pharmacology and monitoring of blood levels in dogs (27).

4.3 Treatment

It is recommended to remove the cryptorchid testis surgically, once the dog is fully grown, as it can become neoplastic. Some authors recommend bilateral gonadectomy to make sure the affected dog will not reproduce, as cryptorchidism can be hereditary (7, 18). Alternatively, the descended testis may undergo vasectomy.

4.3.1 Open cryptorchidectomy

4.3.1.1 Surgical methods

In bilateral cryptorchids the abdominal cavity is opened via midline approach, while unilateral cryptorchid testicles can also be removed through a paramedian approach. If the testicle cannot be safely located via imaging preoperatively, the superficial inguinal ring is inspected beforehand and the incision can be extended into the abdomen if necessary (29).

Either the *Ductus deferens*, the testicular vessels, which originate from the area around the kidney, or the gubernaculum, which derives from the vaginal process in the inguinal area, can be followed to locate the cryptorchid testicle (29, 37).

For the midline approach the skin and subcutis are incised on midline, cranial and paramedian to the prepuce. The branches of the external pudendal vessel are cauterized, and the outer rectus fascia is identified. The *Linea alba* is incised to approach the abdominal cavity and the bladder is retroflexed. If the testicle cannot be found following the mentioned structures, it may lie in the inguinal canal. In this case external pressure can be applied on the inguinal area and careful traction can be applied to the *Ductus deferens* and testicular vessels to relocate the gonad into the abdomen. After location of the testis, the vessels and *Ductus deferens* are ligated two times and transected or cauterized. Then the testicle is removed. The abdominal wall is closed in three layers (29, 37).

The paramedian approach used in unilateral cryptorchids is related to more complications, such as increased damaging of muscle tissue and bleeding. For this method the skin incision is done lateral to the prepuce, just cranial to the inguinal ring. The outer fascia of the *M. rectus abdominis* is also identified and incised. Blunt dissection of the underlying muscle is performed

to expose the peritoneum, which is then elevated with forceps. The peritoneal incision can be carried out by using either scissors or a scalpel. The urinary bladder is moved medially. The testicle is located and removed. The abdominal wall is closed as previously described (29, 37).

An inguinal approach has been additionally described for dogs and cats, adapted from equine surgery. The skin incision is performed above the inguinal canal. The testis is located by dissection of the tissue in the inguinal area until the inguinal extension of the *Gubernaculum testis* or an intact vaginal process are found. The vaginal process is then opened and the *Epididymis*, *Ductus deferens* or epididymal ligament are pulled to reveal the abdominal testicle. The blood vessels and *Ductus deferens* are triple ligated and checked for bleeding before being released back into the abdomen. The superficial inguinal ring is closed by a simple interrupted suture, sparing the pudendal vessels on the caudal commissure. The subcutis and skin were then closed. This method was successfully used to remove abdominal testes in 15 dogs. Complications will be discussed below (38).

Five days after bilateral orchiectomy, ejaculates are azoospermic, although it is advised to wait up to 14 days before allowing contact with estrous females (29).

4.3.1.2 Complications

Known post- and intraoperative complications of paramedian and midline approach for cryptorchidectomies include surgical site infection, seroma, suture dehiscence, intra- and postoperative bleeding, hemoabdomen, involuntary trauma or removal of the prostate, urethral ligation and trauma, trauma of the urinary bladder, ureter ligation, uroabdomen, renal failure, anuria, stranguria and hematuria (29, 39).

In a retrospective study, the most common complication was trauma of the prostate gland. Paramedian skin incisions had a higher incidence for complications compared to parapreputial and midline approaches. Most complications were recorded 24–48 hours postoperatively (39). Especially trauma to the urethra, urinary bladder, ureter and prostate occur due to false identification of the cryptorchid testicle. There have been multiple case-reports of involuntary prostatectomy during cryptorchid surgery in dogs. Symptoms included lethargy, anuria and vomiting. Consequences can be euthanasia, urinary incontinence or urolithiasis if surgical revision is not successful (40–44).

Spay hooks have been used in the past for abdominal cryptorchid surgery. However this is not recommended anymore due to possible trauma to the prostate and inadequate exposure of the anatomical structures (39).

Overall incidence for surgical site infections in dogs and cats ranges between 3 and 5.8 %. Factors associated with surgical site infections are obesity, surgery duration, higher number of persons in the operating room, contamination of the surgical site, higher ASA-groups (American-Society-of-Anesthesiologists), hypothermia, hyperglycemia, steroidal anti-inflammatory drugs, early clipping of the surgical area, prolonged duration of postoperative intensive care and the need for wound drainage (45–47). Lower body temperatures at the end of the procedure are associated with prolonged recovery times (48). In a retrospective study investigating surgical site infections and hypothermia in dogs it was concluded that mild hypothermia had no effect on infection rates in dogs with clean wounds. However prolonged duration of anesthesia is associated with increased risk for infection (49, 50). A different survey found an association between hypothermia and surgical site infections in bitches undergoing mastectomies (4).

Anesthetic mortality was found to be at 0.69 % for dogs in an study that included multiple countries and different procedures (51). Medical history, age, clinical examination, breed, body weight and body condition play an important role in anesthetic management. Mortality risk is increased for pediatric and geriatric patients and obese dogs (51). Abdominal cryptorchidectomies are often elective surgeries in young dogs; however, in older dogs, testicular neoplasia has to be kept in mind and it might be necessary to perform additional blood work and search for metastasis beforehand (29).

Surgery related anesthetic complications include pain, hemorrhage, impaired breathing by diaphragmatic compression through Trendelenburg-positioning, vagal stimulation caused by pulling on the *Ductus deferens*, testicular vessels and *Gubernaculum testis*. Consequences of Trendelenburg-position for the respiratory system are a decreased residual functional capacity and compliance of the lung, a ventilation-perfusion-mismatch of the lung parenchyma and increased airway pressure. Additionally, this position leads to increased peripheral vascular resistance, initially cardiac output is increased, elevated intracranial and intraocular pressure and reduced peripheral circulation, especially in the caudal part of the body. The regurgitation risk is higher and patients could aspirate (52).

For this thesis, mean arterial pressure (MAP) and temperature measurements were collected. Hypotension is a very common anesthetic complication, with an incidence of 37.9 % for dogs undergoing various procedures (53, 54). Reported risk factors are low body mass, brachycephaly, bradycardia, invasive procedures, and higher ASA scores, while protective

factors include α2-agonist premedication and normal body temperature (55). Protocols using acepromazine with isoflurane showed a higher incidence than dexmedetomidine-based protocols (56, 57).

Hypothermia occurs in 80 % of anesthetized dogs that are not actively warmed (54). According to a study that compared temperature during ovariohysterectomies and orchiectomies, bitches experienced lower intraoperative temperatures compared to the males. This was ascribed to a bigger clipped surface and the opening of the abdominal cavity in females (58). Hypothermia is associated with ASA-groups above II, thoracic surgeries and imaging procedures, anesthesia duration and sternal and dorsal recumbency. The association for imaging procedures is likely due to low room temperature that is required for cooling the machines, while higher ASA-groups might struggle to regulate body temperature or are more likely to be subject to major procedures. Protective factors were identified as a higher pre-surgical body temperature and a low body surface due to less heat loss through radiation (59).

Finally, postoperative pain is higher in female dogs that underwent open ovariohysterectomies compared to laparoscopic-assisted procedures (60).

4.3.2 Laparoscopic cryptorchidectomy

4.3.2.1 Surgical methods

Approaches include single-port and two-port laparoscopic surgery and laparoscopic-assisted surgery. The abdomen can be accessed using three different surgical approaches. Regardless of the technique, the abdominal cavity and organs should always be inspected for injuries first, after establishment of the pneumoperitoneum (61, 52).

For visualization, 0° and 30 ° laparoscopes are most used, for single-port laparoscopic surgery, 30 ° scopes are preferred. They provide either a straight or more flexible view. Atraumatic Babcock-graspers are often used for manipulation of organs, while the sharp-teethed Babcock-graspers provide a firmer hold and are used to grasp the testis. In single-port laparoscopic surgery, articulating-graspers are often utilized, which have a flexible joint near the distal end. For hemostasis and transection, bipolar coagulation-instruments are particularly useful (52).

The Verres-technique is one of the open access methods and is performed with a Verres-needle. As depicted in Figure (Fig.) 1 it consists of an outer sharp cannula, a blunt obturator and a spring mechanism. When inserted into the body wall, the sharp cannula cuts through the tissue. As soon as the abdominal cavity is reached, the blunt obturator is pushed out and

protects the organs from being injured. At this point the gas tubular system is connected to the Verres-needle, a pneumoperitoneum is established and the first trocar can be inserted safely through the elevated body wall (61).

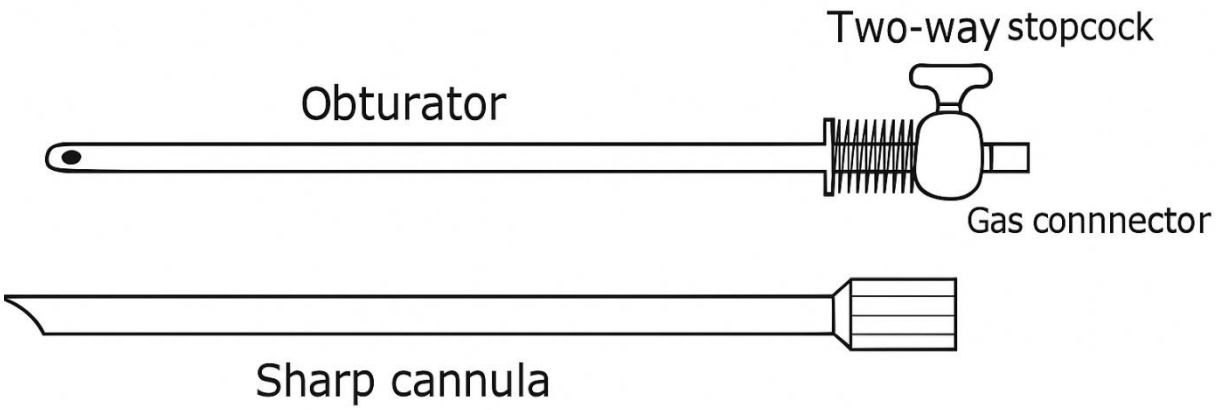


***Figure 1**: Verres-needle (62)*

For the modified Hasson-technique, or open access, the surgeon starts by placing stay sutures to elevate the abdominal wall. Next a mini laparotomy is performed, with the incision being 9–12 millimeters (mm) long. A cannula with a blunt obturator is inserted, the pneumoperitoneum is established by carbon dioxide (CO_2) insufflation through the cannula. Finally, the obturator is exchanged for a laparoscope (61).

A skin incision is performed for the Ternamian-visual-entry to expose the fascia of the *M. rectus abdominis*. Following incision, a threaded cannula is engaged with the muscle tissue by rotating it. A telescope is inserted into the cannula, and the body wall is subsequently penetrated by further rotation of the threaded canula under direct visualization. As soon as possible the abdominal cavity is inflated with CO_2 (61).

For pneumoperitoneum, CO_2 is most used. It is cost efficient and not flammable. Therefore, it can be used with electrocoagulation devices. The gas is insufflated into the abdominal cavity via a tubular system to elevate the body wall, improve vision and facilitate intraabdominal manipulation. The pressure used should be as low as possible, values above 7 millimeter mercury (mmHg) have been shown to not improve the sight (52, 63).

The patient is placed in dorsal recumbency. Trendelenburg-position of 10–15 ° can be used to shift abdominal organs cranially; however, this is not recommendable anymore (52). Additionally, the patient can be tilted laterally 20–45 ° to access the testicle (64).

In the two-port laparoscopic cryptorchidectomy, the first port is placed 1–2 centimeters (cm) caudal of the umbilicus in the midline. If the patient is a unilateral cryptorchid, the second port is placed 3–5 cm paramedian and caudally to the first port, on the opposite of the cryptorchid testicle. If it is a bilateral cryptorchid dog, the second port is inserted in the midline, caudal to the first port.

The testis is visualized, possibly by following the course of the *Vas efferens*. If the testis has already entered the inguinal canal, the surgeon can try to pull it back into the abdominal cavity. Once the gonad has been grabbed with the forceps it is pushed against the ipsilateral abdominal wall and can be secured by placing a percutaneous suture. A vessel sealing device is introduced into the abdominal cavity and the *Vas deferens*, *Gubernaculum* and all vessels are resected. Especially the *Plexus pampiniformis* should be checked for adequate coagulation. Afterwards, the forceps is reintroduced, and the testis is removed through or with the cannula. It might be necessary to enlarge the port, depending on the size of the testis (52).

The single-port laparoscopic cryptorchidectomy is performed by placing the port behind the umbilicus. There are multiple single-port devices available. Commercially available devices specifically manufactured for this purpose include the GelPOINT Access System (GelPOINT advanced access platform, Applied Medical Resources Corporation, USA), the SILS Port (SILS™ multiple access port, Medtronic, USA) or the TriPort System (TriPort+, Olympus America, USA).

For the laparoscopic-assisted approach via modified Hasson-technique, which was used in this study, a cannula is placed through an approximately 12 mm midline incision. An endoscope, with integrated working channel, and forceps are used to localize and grasp the abdominal testis, which is fixed from outside to the abdominal wall. The forceps is replaced by a sealing device, and the testis is finally removed through or together with the trocar. This

method was used in all patients considered for this diploma thesis. Another method is to remove the trocar and to push downward the abdominal wall to pull out the testis. The spermatic cord, vessels and gubernaculum are then ligated and resected extra-abdominally. Finally, the abdominal cavity must be examined for iatrogenic lesions and adequate hemostasis (2). Irrespective of the method, then the CO_2 should be massaged out of the incision before closure in three layers (52, 64, 2).

To decide which technique should be done, advantages and risks must be considered for the specific patient. Contraindications for laparoscopic surgery due to inability to tolerate pneumoperitoneum are increased intracranial pressure, hemodynamic instability and an impaired respiratory system. Additionally, abdominal adhesions due to previous surgeries can necessitate a conversion to open surgery. A neoplastic testis might pose a contraindication if it is too large for removal via the small incision; however, port-site metastasis has never been recorded in dogs. In humans, laparoscopic surgeries pose an increased risk for port-site metastasis due to a lower pH of peritoneal effusion. Lastly lack of experience or inadequate instruments can be a contraindication for a laparoscopy (1).

Advantages of laparoscopic surgeries compared to laparotomy are faster recovery times, less pain, less tissue trauma and smaller incision sizes, lower infection rates, less adhesions and better cosmetic results (1, 3, 65, 5).

4.3.2.2 Complications

Complications during abdominal entering were found in 20 % of laparoscopic surgeries and are hard to avoid, with 90 % being minor complications and splenic trauma being the most common complication (66).

The surgeon cannot visualize abdominal organs when using the Verres-technique to place the first trocar. Modified Hasson-technique is associated with frequent gas leakage, which can however be resolved easily by placing forceps (52). Ternamian-visual-entry is considered the safest entry technique, with complications being five and 27 times more likely for modified Hasson- and Verres-technique. Additionally complications are 11.7 times more likely when a paramedian entry was performed (61). Incision size smaller than 1.7 times the diameter of the cannula increases the risk of organ injury during abdominal entry, due to higher pressure applied to pass the device through the abdominal wall (1).

The most common complication in laparoscopic surgery is bleeding, which can necessitate conversion to open surgery, especially if the surgeon’s vision is compromised. The

compression of the abdominal veins by the increased abdominal pressure can mask bleeding and hemorrhage may appear only after reversion of pneumoperitoneum. In a study evaluating laparoscopic-assisted cryptorchidectomy, bleeding of the testicular artery occurred in one dog when the testis was exteriorized. Conversion to open surgery was necessary because vision was impaired. Further complications were minor iatrogenic splenic trauma during abdominal access and pneumoretroperitoneum due to false placement of the trocar (2). Subcutaneous emphysema is another common and painful complication and happens due to gas from the pneumoperitoneum being trapped in the subcutis. It usually resolves by itself but might necessitate additional analgesia. Pneumothorax, pneumopericardium and gas embolism are possible severe intraoperative complications (1). Another study comparing laparoscopic and open cryptorchidectomy reported postsurgical bleeding in one out six dogs in the laparoscopic group. The complication was diagnosed by sonography and the patient was reoperated (67). Two studies on laparoscopic assisted cryptorchidectomy did not record any complications (68, 69).

A study showed that postoperative complications occur in 16 % of 132 bitches undergoing single-port laparoscopic ovariectomy (70). Postoperative complications for various laparoscopic procedures are mostly linked to the incisio, for example seroma formation (12 %) and surgical site infection (4 %) (70, 66). A study comparing laparoscopic and open gastropexy in dogs, recorded no significant difference in postoperative complication rates (71).

Pneumoperitoneum is necessary for laparoscopic surgeries and impacts the respiratory and cardiovascular systems. Cardiac output and the blood flow in the caudal vena cava decrease during maintenance of pneumoperitoneum but return to normal shortly after exsufflation (1, 72). At a intraabdominal pressure of 10 mmHg cardiac output can generally be maintained by a raise of the heart rate, in some cases it can even be increased (73). In healthy dogs, mean arterial pressure and systemic vascular resistance is increased during maintenance of pneumoperitoneum (72, 52, 1, 73). It is important to emphasize that a reduction in cardiac output, and consequently in blood flow and oxygen delivery to the organs, does not necessarily result in a decrease in mean arterial pressure (73). While for an intraabdominal pressure of 10 mmHg cardiovascular parameters were found to be stable, starting at 15 mmHg the perfusion of organs, namely in the mesenteric artery, portal vein and renal perfusion, is compromised. At this pressure, a rise in plasma concentrations of liver and renal function parameters and reduced urine production have been noted. Histopathologic examination of

pancreas and kidney demonstrated pathological changes at 20 mmHg abdominal pressure (1, 52).

Increased intraabdominal pressure causes the diaphragm to shift cranially resulting in increased airway pressures, decreased minute volume and compliance and can cause atelectasis in the patients (74, 75, 69, 52).

In laparoscopic surgery, the mechanism of heat loss differs from open surgery, with convection to the insufflation gas and evaporation being the most important factors. Subsequently, heat loss depends on gas flow needed to maintain pneumoperitoneum. Additionally, heat is lost by evaporation due to saturation of the CO_2 particles. Contradictory findings have been reported. According to a 2020 review, heated and humidified CO_2 insufflation did not improve intraoperative body temperature in either an individual study or a meta-analysis (73). In contrast, a recent publication reported that heated, but not humidified, CO_2 insufflation reduced the impact of surgical, anaesthetic, and insufflation duration on postoperative body temperature (77).

Moreover, possible anesthetic complications are vasovagal reflexes with bradycardia during initial insufflation due to peritoneal stretching and pneumothorax due to gas leakage or barotrauma (1, 52).

5. Material and methods

This thesis is a retrospective investigation on complications, surgical duration, body temperature, MAP, $EtCO_2$ and ventilation-modes of dogs undergoing open or laparoscopic surgery for removal of abdominal cryptorchid testicles at the University of Veterinary Medicine Vienna.

5.1 Inclusion criteria

Male dogs with at least one abdominal testicle removed either by laparoscopic or open surgery between 2001 and 2024 were included in the evaluation. This included cases with additional procedures performed and bilateral cryptorchids with an inguinal testis (see Section 6.1).

One instance, which was a conversion from inguinal to abdominal cryptorchidectomy, was not included. For some cases, no anesthetic protocol could be found. In that event only complications found in the medical history could be evaluated (see Section 6.4), while surgical duration, body temperature, MAP, $EtCO_2$ and ventilation mode were not part of the analysis.

5.2 Data collection

As first step, the Tierspitalinformationssystem (TIS, AGFA Healthcare, Austria), which is the virtual information system of the University of Veterinary Medicine Vienna, was scanned for suitable patients by using key words. These cases were then manually checked to see if they were relevant.

Then surgery date, name, patient identification number, breed, body weight, age, type of cryptorchidism, surgical method, surgical site, medical history, additional procedures performed, incidences of post-surgical complications were extracted from the TIS and put into a table. Virtual surgical and anesthetic protocols were then searched for intraoperative complications, which were also noted. Analog anesthetic protocols are kept for every surgery after 2008 at the University of Veterinary Medicine Vienna and contain a variety of information, including data on surgical duration, body temperature, MAP, $EtCO_2$ and ventilation mode. MAP, body temperature, $EtCO_2$ and ventilation mode are noted every 5 minutes. Incision time and end of surgery are also recorded and were used to calculate surgical duration in minutes. Methods for measurement of arterial blood pressure and body temperature were not noted.

5.3 Statistical analysis

Statistical analysis was performed in R (R version 4.5.0) (78). A p-value of <0.05 was considered statistically significant. For visualization of the results, *ggplot2* was used (package

ggplot2, version 3.5.2, function *ggplot*) (79). Since most surgical complications (26 complications) were rare (see 6.4 Complications), associations between surgical complications and surgical method (laparotomy, laparoscopy), surgical site (bilateral abdominal cryptorchidectomy, bilateral abdominal and inguinal cryptorchidectomy, unilateral abdominal cryptorchidectomy and scrotal testectomy, unilateral cryptorchidectomy), ventilation mode (spontaneous, mandatory, mixed), age (in months), weight (in kg) and surgery duration (in minutes) were separately evaluated for each complication via Fisher's exact tests for count data (function *fisher.test* for method, surgical site and ventilation mode) or binary logistic regression models (function *glm*, option 'family = binomial(link = "logit") for age, weight and duration). Ventilation categories were ascribed depending on the ventilation type during cryptorchidectomy, ventilation during preparation for surgery or additional procedures were not taken into consideration. The "spontaneous" category describes patients that were exclusively breathing spontaneously, the "mandatory" category includes all dogs that were exclusively, either manually or mechanically, ventilated during the procedure. The "mixed" category includes patients that were breathing spontaneously and were manually or mechanically ventilated. Multiple association tests for each risk factor were corrected for multiple testing via the Bonferroni-Holm method (function *p.adjust*, method *holm*). The association between surgical method and ventilation mode was also evaluated via Fisher's exact tests for count data. The association between ventilation mode and age was evaluated via a general linear model (function *lm*).

For hypotension, hypothermia and hypoventilation only (that were not rare, see 6.4 Complications), effects of the aforementioned risk factors were also evaluated via binary logistic regression models that simultaneously included all risk factors (to account for confounding effects). Hypotension was recorded when there were two successive mean arterial pressure measurements below 60 mmHg (80). Hypoventilation was recorded when $EtCO_2$ measurements larger than 45 mmHg were recorded (81). Hypothermia was either recorded when temperature fell lower than 37.5 °C or described in more categories (82, 83):

- No hypothermia when temperature was larger than 38.5 °C
- Slight hypothermia when temperature was between 36.5 °C and 38.5 °C
- Moderate hypothermia when temperature was between 34 °C and 36.5 °C
- Severe hypothermia when temperature fell lower than 34 °C

Since mostly slight and moderate hypothermia were observed (see 6.6 Body temperature), this variable was also analyzed via a binary logistic regression model.

Effects on temperature, mean arterial pressure and $EtCO_2$ readings (without classification) were evaluated via general linear mixed models (package *lme4*, version 1.1.37, function *lmer*, option 'REML = FALSE') (84). Animal ID (38 animals) was fitted as random intercept to account for the covariance structure in the data, as all readings were obtained multiple times for each animal. Effects on the number of complications were evaluated via a Poisson regression model (function *glm*, option 'family = poisson (link = "log"). The aforementioned risk factors were fitted as fixed effects in all models. Effects on surgery duration (in minutes) were evaluated via a general linear model (function *lm*). The remaining risk factors were fitted as fixed effects in this model. The interactions between method and weight or ventilation mode and weight were also considered in all models to shed further light on method, ventilation mode and weight effects.

Assumptions about the residuals and random intercepts were visually evaluated. Multicollinearity between the fixed effects was evaluated via variance-inflation factors (package *car*, version 3.1.3, function *vif*) on models without interactions (85). For the Poisson regression model, overdispersion was also evaluated (package *performance*, version 0.13.0, function *check overdispersion*) (86). Pairwise comparisons between the levels of each categorical predictor were conducted via the estimated marginal means (package *emmeans*, version 1.11.0, function *emmeans*) (87). For presentation, estimated marginal means were back transformed (when applicable, e.g. from the *logit* scale, option 'type = "response"' in the function *emmeans*). Multiple pairwise comparisons (when applicable) were corrected for multiple testing via the Tukey method. Interaction effects were also evaluated via the package *emmeans* (functions *ref_grid*, *emmeans*, *emtrends* and *test*) and corrected for multiple testing via the Bonferroni-Holm method. Overall interaction effects were evaluated via a likelihood ration test using the function *anova*, comparing the model with the interaction to a model without the interaction.

6. Results

6.1 Study population

Forty-six cases from 2002–2023 were included, consisting of 22 laparotomies and 24 laparoscopies. Laparoscopies were performed more recently compared to laparotomies, as seen on Fig. 2.

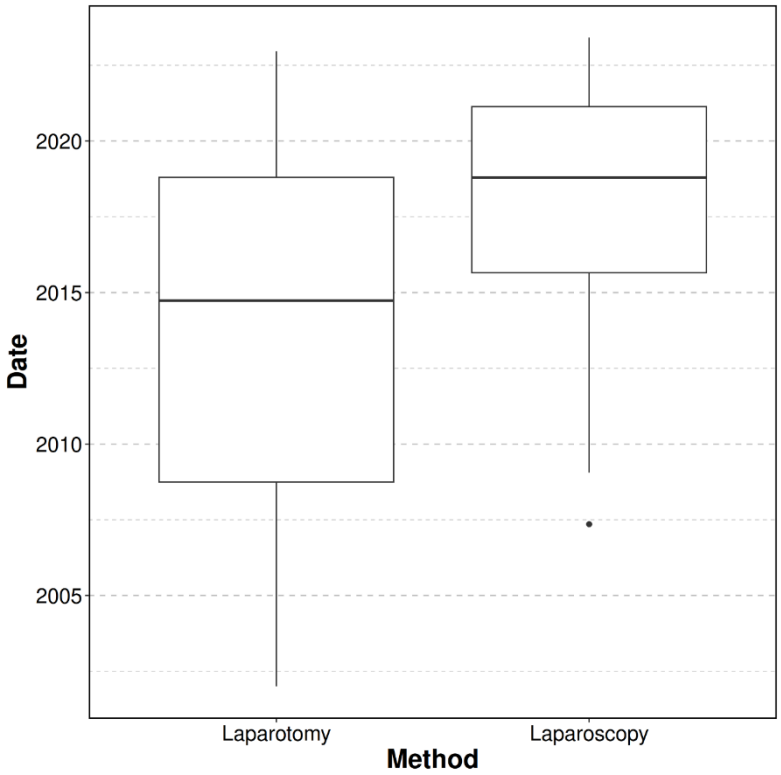


Figure 2: *Distribution of surgical methods over time. Laparoscopic cryptorchidectomies were performed more frequently in recent years in comparison to the laparotomic approach.*

Twenty-seven dogs were unilateral cryptorchids, in which both testicles were removed. Ten patients were unilateral cryptorchids, in which only the abdominal testes were removed. Further there were nine bilateral cryptorchids, of which four had one inguinal and one abdominal testicle and five were bilateral abdominal cryptorchids. In the bilateral cryptorchids, both testicles were removed in all nine cases. In Tab. 1 the distribution of laparoscopic and laparotomic surgery per site is shown.

Table 1: *Surgical site distribution of laparoscopic and laparotomic cases.*

	Surgical methods	
Surgical site	Laparotomies	Laparoscopies
Unilateral cryptorchidectomies and scrotal orchiectomy	14	13
Bilateral abdominal cryptorchidectomy	2	3
Abdominal and inguinal cryptorchidectomy	3	1
Unilateral abdominal cryptorchidectomy	3	7

The patient-age ranged between 5 and 122 months (ten years and two months), with a median age of 19.5 months. Body weight varied from 1.8 to 71 kg, with a median of 24.5 kg. For one dog age was not recorded. Twenty-five different breeds were included, with Chihuahuas (n=6) and German Shepherds (n=6) being the most common breeds, followed by Golden Retrievers (n=4) and mongrels (n=4).

Eight out of the 46 cases did not have anesthesia protocols; therefore, only intraoperative and postoperative complications could be recorded. Additionally, in three cases, temperature was not noted and in two cases, the MAP-values were missing. Further, cases with additional procedures were only included if the skin incision and end of surgery could clearly be distinguished for the cryptorchidectomy.

6.2 Anesthetic management

Anaesthetic protocols were comparable between laparoscopic and laparotomic cryptorchidectomies. Premedication predominantly consisted of an opioid (methadone, fentanyl or butorphanol) with or without an α2-agonist or acepromazine. Ketamine was used either as part of premedication or induction in 59 % of laparotomic and 41 % of laparoscopic procedures.

All dogs were induced with propofol to effect, except for one dog that received alfaxalone. All patients received intraoperative crystalloid infusions. The mean of the individual median end-tidal isoflurane concentrations was 1.16 ± 0.22 % for laparotomic and 1.11 ± 0.12 % for laparoscopic procedures.

Cardiovascular interventions were required in 24 % of laparotomic and 36 % of laparoscopic procedures. These interventions consisted of fluid boluses, one glycopyrrolate bolus, and one colloid infusion.

In 71 % of laparotomic and 64 % of laparoscopic procedures, intraoperative opioids were given. Opioid continuous rate infusions were more frequently used during laparoscopic surgeries, whereas opioid boluses were more common during open procedures. Local aesthesia was applied in 47 % of laparotomic and 36 % of laparoscopic cases. This included infiltration of the incision line, splash block, intratesticular infiltration, or a combination of these techniques.

Two of 17 (12 %) laparotomic cases did not receive any pre- or intraoperative μ-agonists or local anaesthesia. Both patients received ketamine and an α2-agonist, one received butorphanol preoperatively. One of 22 (5 %) laparoscopic cases did not receive any μ-agonists, local anaesthesia or ketamine. In this dog, premedication consisted of butorphanol and medetomidine, surgical duration was 20 minutes and it received a Non-Steroidal Anti-Inflammatory Drug (NSAID) shortly after end of surgery.

Two dogs presented with testicular torsion, one underwent laparoscopic and the other open surgery. In one of these cases, lidocaine was administered as part of the premedication and as a continuous rate infusion.

6.3 Duration of surgery

Surgical duration ranged from 15 to 135 minutes, with a median duration of 55 minutes. For laparotomic surgeries minimal duration was 20 minutes, while maximal duration was 135 minutes. Median duration was 55 minutes. For the laparoscopic surgeries minimal duration was 15 minutes, maximal duration was 95 minutes, and the median duration was 47.5 minutes.

Surgical duration was increased for older animals (p=0.03). For laparotomies, surgical duration increased by 2.02 minutes per kg body weight (p=0.0006), while the weight effect for laparoscopies was weaker (slope = 0.68 minutes per kg body weight (see Fig. 3), p=0.034, interaction p=0.025).

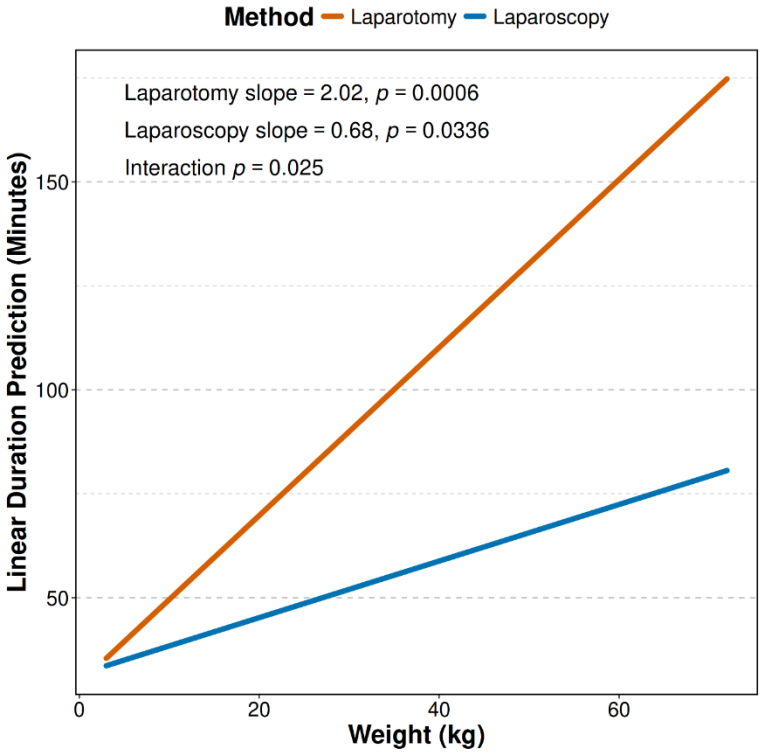


Figure 3: *Estimated surgical duration (minutes) in relation to body weight (kg) and surgical method, evaluated via a general linear model including the interaction between method and weight as a fixed effect (interaction p=0.025). Surgical duration increased by 2.02 minutes per kg body weight in laparotomies (p=0.0006), while the increase in laparoscopies was 0.68 min per kg body weight (p=0.0336).*

Tab. 2 shows the trends between body weight and estimated surgical duration for each method. Predicted surgical durations were comparable between methods in dogs with low body weight (p=0.64 at 25th weight percentile), as seen in Tab. 2, but increased more steeply for laparotomies with rising body weight (p<0.005 at median weight and 75th weight percentile).

***Table 2**: Estimated difference of estimated surgical duration for each surgical method. While surgical duration did not differ in dogs with low body weights, in larger dogs, the differences in surgical duration increased significantly.*

Weight percentiles	Estimated duration for laparotomies	Estimated duration for laparoscopies	Difference in estimated durations	p-value
25th weight percentile = 5.7 kg	40.9 min	35.5 min	5.4 min	p = 0.64
Median = 24.8 kg	79.4 min	48.5 min	31 min	p = 0.003
75th percentile = 33.15 kg	96.3 min	54.2 min	42 min	p = 0.002

6.4 Complications

A total of 26 intraoperative and postoperative complications were recorded, including hypotension, hypothermia and hypoventilation. The average number of complications per case is 2.27 for laparotomic and 2.63 for laparoscopic surgeries. No associations were detected for the total number of complications per dog. Most complications occurred only in a small number of cases (see Fig. 4). The most common complications for the open approach were hypoventilation (n=12), hypothermia (body temperature below 37.5 °C) (n=11) and surgical site infection (n=5). The most common complications for the laparoscopic surgeries were hypoventilation (n=18), hypothermia (body temperature below 37.5 °C) (n=12) and hypotension (n=7). No associations between complications and surgical methods, surgical site, ventilation mode, surgery duration, age or weight were detected.

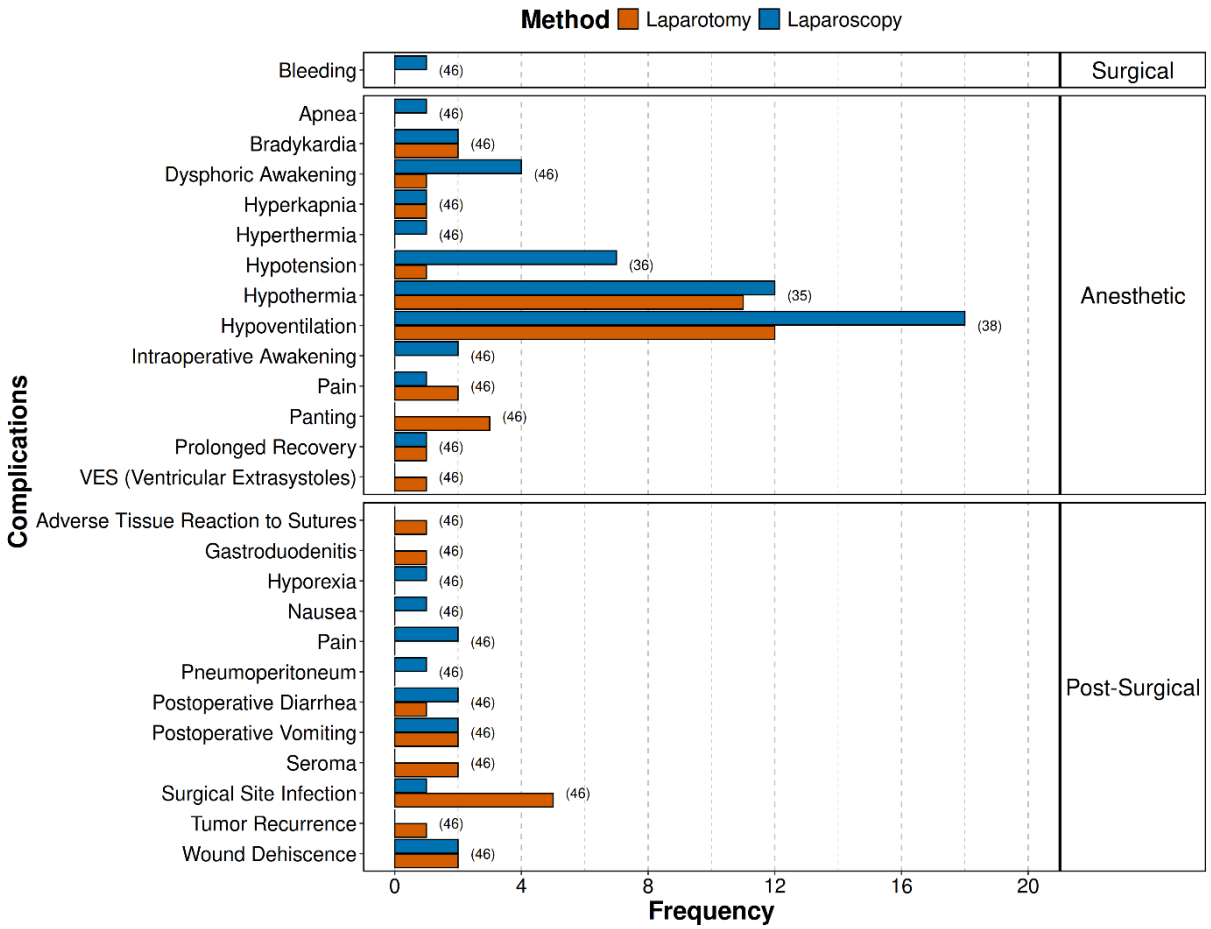


Figure 4: *Comparison of complication frequencies in open and laparoscopic cryptorchidectomies. The numbers in parentheses indicate the total number of cases evaluated for each complication. This figure provides a descriptive overview only, as most complications were rare.*

6.5 Mean arterial pressure (MAP)

Records of blood pressure were missing in ten out of 46 cases. For laparotomies, MAP ranged between a minimum of 50 and a maximum of 200 mmHg, with a median of 85 mmHg. For laparoscopies MAP ranged between 40 and 140 mmHg, with a median of 75 mmHg. Hypotension was recorded in eight out of 36 animals, occurring in seven out of 21 laparoscopic procedures (33 %) and one out of 15 open surgeries (6 %) (see Fig. 4).

The binary logistic regression model for hypotension showed no effects of surgical method, ventilation mode, age, weight, or surgical duration on hypotension (surgical site was not included in this model due to complete separation).

The general linear mixed model with an interaction between ventilation and weight detected a negative effect on average MAP with increasing weight for dogs that were exclusively mandatorily ventilated during surgery (see Fig. 5: mandatory-slope: p=0.0012, interaction p=0.052). For dogs that were spontaneously breathing or were part of the mixed ventilation group, this effect was not observed. Patients that were mandatorily ventilated had lower estimated MAP values than dogs that were in the mixed ventilation group (breathing spontaneously and being ventilated) at intermediate (body weight: 27.3 kg; estimated difference: -11.2 mmHg, p=0.03152) and higher body weights (body weight: 33.3 kg; estimated difference: -13.9 mmHg, p=0.01917). Furthermore, the average MAP was lower in laparoscopic surgeries than in laparotomic surgeries (p=0.031). The estimated average MAP for laparotomies was 81.8 mmHg, for laparoscopies it was 75.4 mmHg.

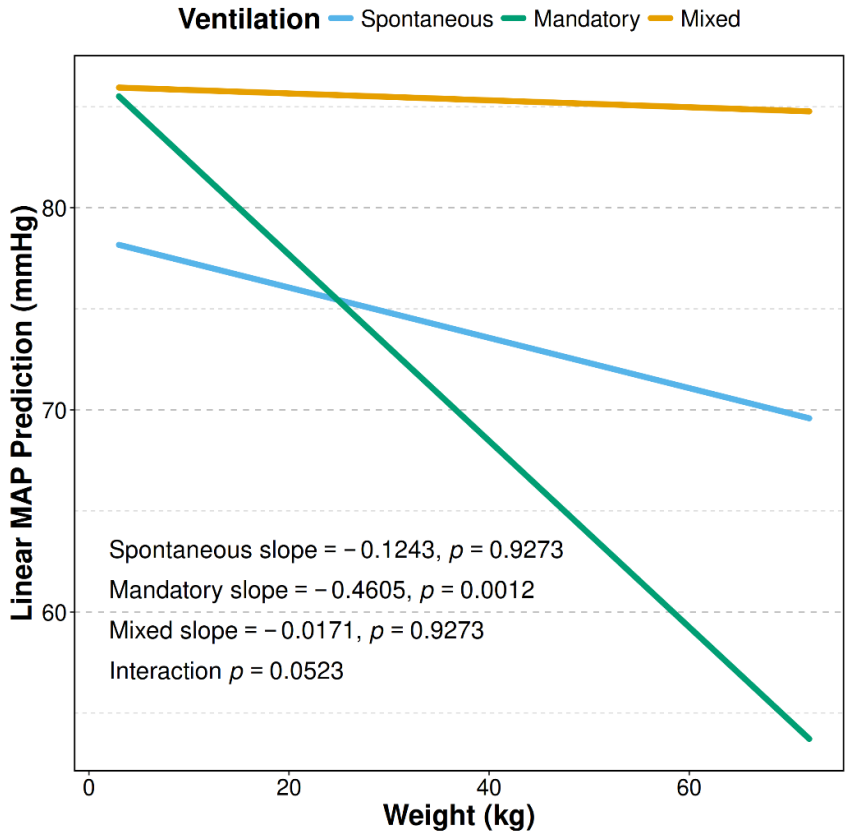


Figure 5: *Estimated mean arterial pressure (MAP) (mmHg) in relation to body weight (kg) and ventilation mode, evaluated via a general linear mixed model including the interaction between ventilation mode and weight as a fixed effect (interaction p=0.0523). MAP decreased by 0.46 mmHg per kg body weight in mandatorily ventilated patients, while the decrease in the spontaneously breathing dogs and mixed ventilation group was insignificant.*

6.6 Body temperature

Body temperature ranged between 34.5 °C and 39.40 °C for laparotomies, with a median of 37.3 °C. For laparoscopies, minimum body temperature was at 35.6 °C and maximum at 39.4 °C, with a median of 37.5 °C. Temperatures below 37.5 °C were recorded in eleven out of 15 animals (73 %) in the laparotomy group and twelve out of 20 animals (60 %) in the laparoscopy group (Fig. 4). When hypothermia was classified in four categories (no, mild, moderate and severe hypothermia, see Section 5.3), severe hypothermia was not recorded at all.

In the laparotomy group, one out of 15 animals had no hypothermia (7 %), nine out of 15 animals displayed slight hypothermia (60 %) and 5 out of 15 patients had moderate hypothermia (33 %). In the laparoscopy group, one dog out of 20 was not hypothermic (5 %), while 14 out of 20 patients displayed slight hypothermia (70 %) and five dogs had moderate hypothermia (25 %).

The binary logistic regression model for hypothermia (< 37.5 °C) showed no effects. However, the binary logistic regression model analyzing the two most frequent hypothermia categories (mild and moderate hypothermia) revealed that patients with higher body weights were less likely to develop moderate hypothermia (between 34 °C and 36.5 °C) (p=0.029).

In the general linear mixed model, age had a negative effect on body temperature, meaning the older the animal the lower the average body temperature (p=0.019). Surgical duration positively affected body temperature (p=0.036). Spontaneously breathing dogs had higher body temperatures (estimated difference of 1.25 °C) on average when compared to dogs that exclusively received mandatory ventilation (p=0.014).

6.7 Endtidal carbondioxide

The $EtCO_2$ ranged between 20 and 55 mmHg with a median 45 mmHg for laparotomies. For laparoscopies $EtCO_2$ ranged between 20 and 60 mmHg with a median of 48 mmHg. In the laparotomy group 12 out of 16 (75 %) patients experienced hypoventilation. In the laparoscopic group 18 out of 22 dogs (82 %) experienced hypoventilation.

No association between hypoventilation and surgical method, surgical site, age, weight, duration and ventilation mode was found in the binary logistic regression model. A negative association between age and average $EtCO_2$ was found (p=0.007) in the general linear mixed

model. No association was found between $EtCO_2$ levels and ventilation mode. Median $EtCO_2$ levels are shown descriptively in Fig. 6.

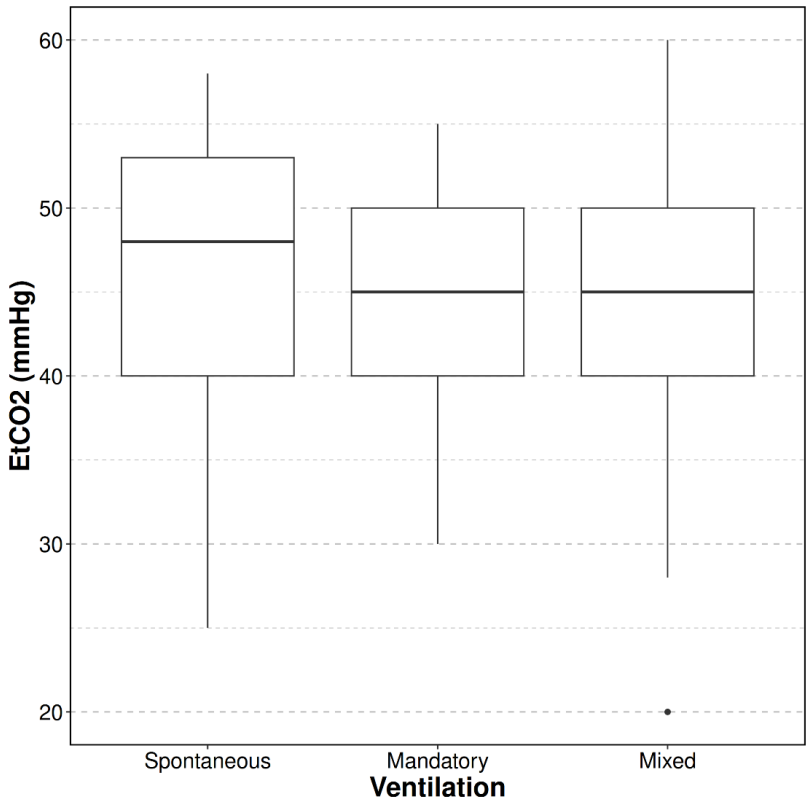


Figure 6: *$EtCO_2$ distribution by ventilation mode. No differences between ventilation modes were detected.*

6.8 Ventilation mode

No associations between surgical method and ventilation mode were found (p=1). Fig. 7 shows the distribution of ventilation modes for both surgical methods. Additionally, no association between ventilation mode and age was detected (p=0.1451). Fig. 8 is a descriptive illustration of age distribution of the ventilation groups.

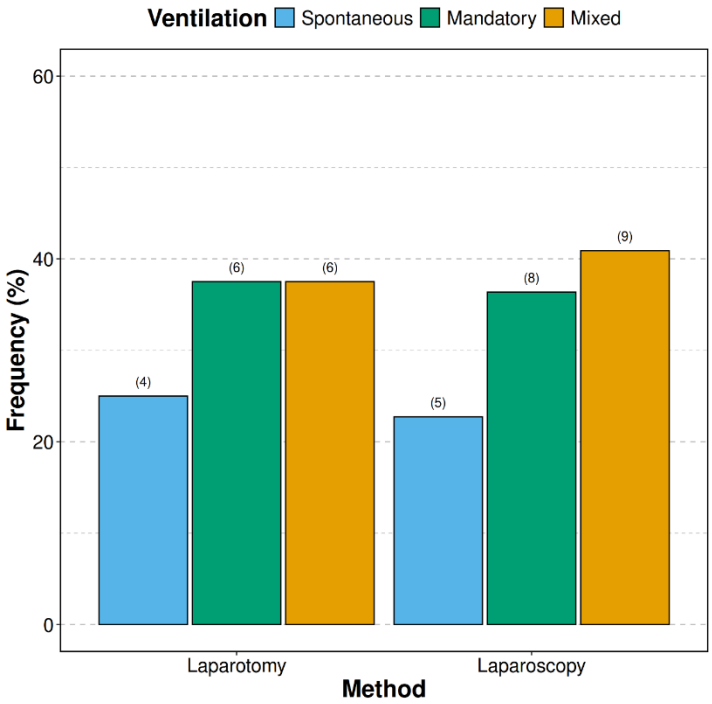


Figure 7: *Frequencies of ventilation modes for the laparotomy and laparoscopy group. The numbers in parenthesis indicate the absolute number of patients.*

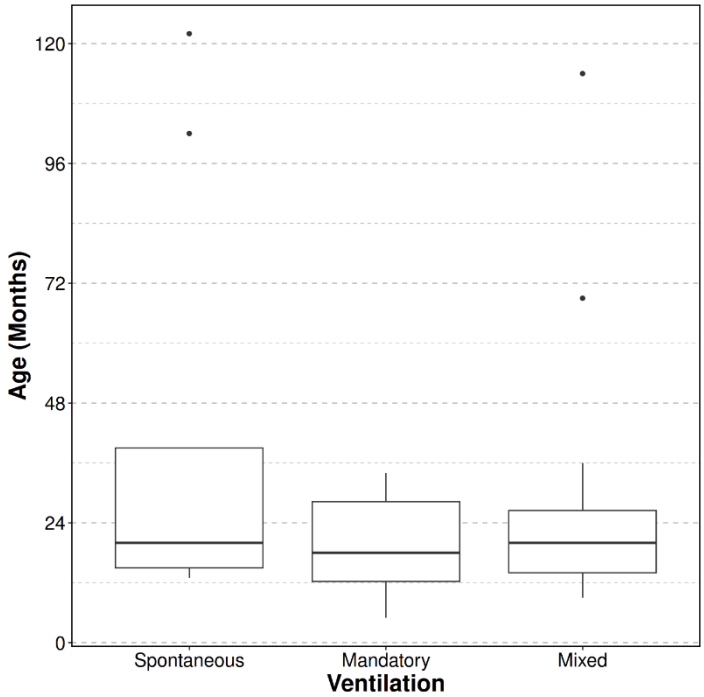


Figure 8: *Age distribution (in months) by ventilation mode. No differences between ventilation modes were detected*

7. Discussion

Fig. 9 offers an overview of the described associations between parameters.

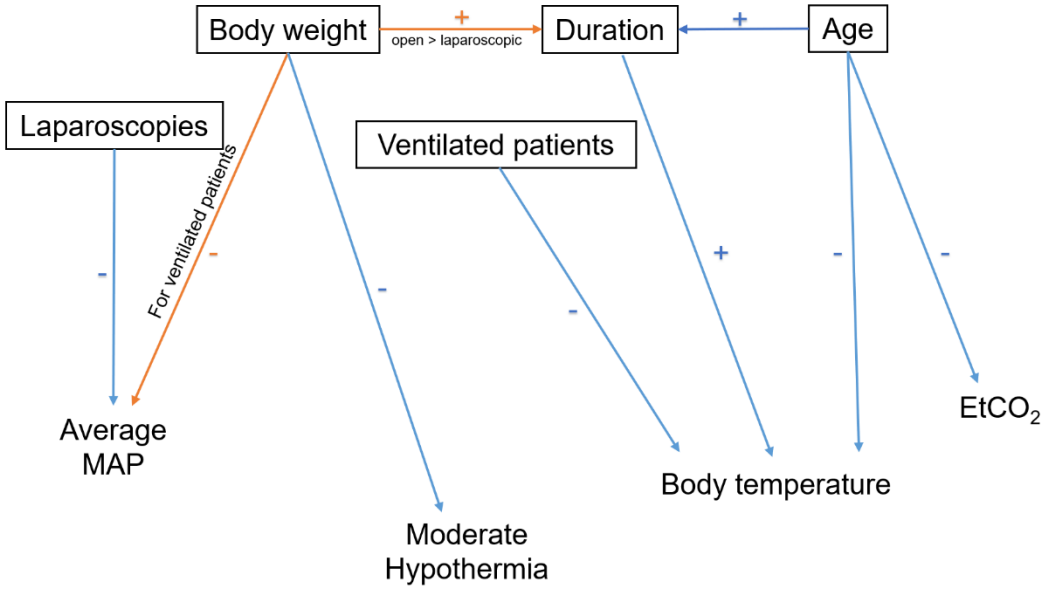


***Figure 9**: Overview of associations between variables. Arrows indicate statistically significant associations between variables. A plus sign (+) represents a positive association, a minus sign (–) represents a negative association. Orange arrows represent associations identified in statistical models including interaction terms; surgical duration increased with higher body weight, and this association was stronger in open cryptorchidectomies compared to laparoscopic procedures (see Fig. 3). Body weight was negatively associated with MAP in mandatorily ventilated patients (see Fig. 5).*

The initial hypothesis was that laparoscopic cryptorchidectomies take less time and lead to fewer complications compared to open cryptorchidectomies. The results partly support this assumption: in heavier dogs, surgical duration of laparotomies increased with body weight, whereas this weight effect was not as strong in the laparoscopic group (see Fig. 3 and 9 and Section 6.3). As discussed in Section 4.3.1.2, prolonged surgical time was shown to have a negative impact on surgical outcome, namely on surgical site infection rates and body temperature. It should therefore be kept as short as possible (50, 4). This suggests that larger patients may particularly benefit from the laparoscopic approach, since tissue layers are thicker and wound closure is more time-consuming in open surgery, while in smaller dogs, incision sizes are more comparable between laparoscopic and open techniques. In the literature,

contrasting results regarding the comparison of surgical times for minimally invasive and open procedures have been reported (67). Some studies have reported longer operative times, while others found shorter durations for laparoscopic versus open procedures (88, 71, 65). Notably, one study found that specifically open cryptorchidectomy was performed faster than the laparoscopic approach (67). Surgical duration; however, most likely partly depends on how proficient the surgeon is with minimally invasive techniques. Furthermore, the laparoscopic method in this retrospective study, the modified Hasson-technique with only one port (see Section 4.3.2.1), might save time and was not compared to open cryptorchidectomy previously.

One study on bitches undergoing ovariohysterectomy and ovariectomy found a positive association between body weight and both surgical duration and closure time, which supports the above-mentioned assumption. In contrast, body condition score was not associated with either variable (89).

Both methods went along with a comparable number of side effects during anaesthesia and post-surgery (see Fig. 4 and Section 6.4); some differences were associated to body weight, age and the mode of ventilation. This comprised MAP, body temperature and $EtCO_2$ (see Fig. 9). However, the number of complications was very low which may be owing to the institutions' routine and hygiene. As shown in Fig. 2, laparoscopic cryptrochidectomies were performed more frequently in recent years in comparison to the laparotomic approach; however, over years anesthesia protocols appeared comparable between groups (see Section 6.2).

Laparoscopic cryptorchidectomies were associated with lower average MAP (see Fig. 9 and Section 6.5). The estimated average MAPs for both surgical methods remained above 60 mmHg. When blood pressure drops below 60 mmHg organ perfusion is compromised. Since the estimated blood pressure is an average value, it might not accurately represent patients with acute decrease in MAP. However, no significant effect of surgical method on the incidence of hypotension was shown. This could indicate that laparoscopic procedures may be associated with a consistently lower MAP rather than hypotensive episodes.

Body weight was negatively associated to average MAP in ventilated dogs, as shown in Fig. 5 and 9. It was previously shown that high body condition score and a barrel-shaped thorax are associated with a decrease in lung compliance (90). Additionally, older or obese dogs and patients under general anaesthesia developed more collapsed lung regions (91). This may necessitate higher inspiratory pressure during mandatory ventilation (92). High airway

pressure during ventilation reduces venous return and cardiac output, which results in lower MAPs, especially in hypovolemic dogs (92, 93).

Furthermore, during laparoscopy, higher intraabdominal pressure might have been used in larger dogs, which could also necessitate mechanical ventilation (see Section 4.3.2.2). However, it was shown that the yield point during abdominal insufflation is not associated with body weight (63). Alternatively, heavier dogs may have been maintained at a deeper plane of anesthesia, which could have contributed to hypotension and hypoventilation and subsequently necessitated mandatory ventilation.

The negative association between body weight and average MAP was only observed in patients that were exclusively ventilated, while for dogs that were part of the mixed ventilation group (mandatory ventilation and spontaneous breathing) no effect on blood pressure was detected. This could indicate that the duration of mandatory ventilation plays a key role in its impact on blood pressure. Alternatively, it highlights the importance of frequent reassessment of ventilation strategies, particularly in larger or obese dogs, to minimize the risk of hypotension.

As shown in Fig. 7, dogs that were exclusively ventilated were evenly distributed between the two surgical methods (laparotomies: 6/16; laparoscopies: 8/22). This suggests that differences in ventilation mode do not fully explain the effect of surgical methods on average MAP. As discussed in Section 4.3.2.2, pneumoperitoneum can influence MAP by reducing venous return and cardiac output due to increased intraabdominal pressure and therefore could be an additional contributing factor.

Larger dogs developed less moderate hypothermia compared to small dogs (see Section 6.6 and Fig. 9). The positive association of body weight and body temperature has previously been reported in other studies (see Section 4.3.1.2). However, in one of the studies, low body condition scores specifically were not associated with increased heat loss (94, 95). Due to increased relative body surface in smaller dogs, they tend to lose heat more quickly than larger dogs (94).

While prolonged surgical duration was positively associated with body temperature in this thesis, older dogs had lower average intraoperative temperatures (see Fig. 9). This effect has been described in geriatric human patients before. However, age has not previously been identified as a risk factor for hypothermia in dogs (94, 59). A decreased metabolic rate and reduced ability to retain warmth in older patients have been discussed as causes for less heat

retention capabilities in the past. The positive correlation of surgical duration and body temperature likely reflects increased time for active warming measures and partial recovery from the initial anesthesia-induced temperature drop. In contrast to our findings, prolonged surgical duration has previously been described as a risk factor for hypothermia in anesthetized dogs, even when they were actively warmed (94, 59). Additionally, surgical duration was increased in older dogs (see Section 6.3 and Fig. 9). This could indicate that the positive effect of surgical duration is not sufficient to compensate the negative effect of age on temperature.

While this thesis did not show higher complication rates in older dogs, higher body condition scores in older animals may partly explain the detected positive effect of age on surgical duration (see Fig. 9) (96). As discussed above, more body fat can lead to prolonged closure times during surgery. Additionally, a more cautious surgical approach might be adopted in older animals, due to possibly more complex surgical dissection and due to the patients' decreased ability to compensate potential intraoperative complications.

Furthermore, dogs that breathed exclusively spontaneously had higher average body temperatures compared with dogs that were exclusively ventilated (see Fig. 9). This could be due to increased respiratory heat loss in ventilated patients, as mandatory ventilation is typically associated with higher respiratory rates and minute volumes. However, ventilation parameters, such as respiratory rate, minute volume, and airway pressures were not evaluated in this study. In support of this hypothesis, exclusively ventilated dogs showed lower median $EtCO_2$ values than other ventilation modes, suggesting increased alveolar ventilation (see Fig. 6 and Section 6.8) (97). However, a significant effect of the ventilation mode on $EtCO_2$ was not detected in the general linear mixed model. Lastly, age was negatively associated with $EtCO_2$ (see Fig. 9). This has not been reported before and could indicate that older dogs were ventilated more frequently. However, an effect of age on ventilation mode was not shown and age was distributed evenly between ventilation categories (see Fig. 8 and Section 6.7).

Despite all surgeries being performed by experienced surgeons at the same clinic, using an identical port system for laparoscopies and standardized incision sites (lateral to the penis) for laparotomies, the study was limited due to its retrospective nature.

Two dogs presented with testicular torsion and showed clinical signs such as diarrhoea, abdominal pain, apathy and hyporexia, although both were hemodynamically stable. One dog underwent open cryptorchidectomy including removal of the scrotal testicle and scrotal ablation. The second dog was treated laparoscopically with removal of the scrotal testicle. No

intraoperative surgical complications were reported in these cases. Histopathology of the cryptorchid testes revealed haemorrhagic tissue changes in both dogs, and one case was additionally diagnosed with a seminoma.

One dog underwent a concurrent gastropexy. However, this procedure could not be clearly separated from the laparoscopic cryptorchidectomy in the anaesthesia protocol, which may have influenced surgical duration especially. Additionally, two dogs in the laparotomy group and four dogs in the laparoscopic group showed mild gastrointestinal signs preoperatively.

Exact surgical techniques and medications used for anesthesia were not standardized and blood pressure and temperature measurement methods might have differed between cases. Furthermore, temperature management methods, ventilation parameters and body condition scores were not considered. Additionally, a higher number of cases could have improved the power of the study, as all complications had rare incidences and some measurements, especially MAP, $EtCO_2$ and body temperature, were missing.

Future research could further analyze trends suggested in this thesis, such as lower $EtCO_2$ in laparotomies and lower likelihood for hypotension in laparoscopies. Additionally, future studies could focus on details of surgical techniques such as incision length and placement and the access used in laparoscopic surgeries, as previous studies revealed differences in complication rates dependent on these factors (61, 66, 39). Lastly, respiratory rate, peak inspiratory pressure, positive end-expiratory pressure, minute volume and body condition score could be of interest. Ventilation parameters could help understanding the impact of ventilation on MAP in dogs with high body weights and body condition scores may help differentiating between large and obese dogs.

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