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Canine cardiopulmonary responses to one-lung ventilation during thoracoscopic diaphragmatic incision repair and two-lung ventilation during gasless laparoscopic diaphragmatic incision repair

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Canine cardiopulmonary responses to one-lung ventilation during thoracoscopic diaphragmatic incision repair and two-lung ventilation during gasless laparoscopic diaphragmatic incision repair

by

Churee Pramatwinai

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DEDICATION

MY PARENTS

BROTHERS, SISTERS, NEPHEWS,TAVEERAT

TEACHERS

AND

ANIMALS IN THIS STUDY

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ABSTRACT

Two minimally invasive surgical techniques for repair of diaphragmatic incisions and the cardiopulmonary responses during the surgical procedures were investigated in dogs.

1. The cardiopulmonary effects of one-lung ventilation (OLV) during thoracoscopic diaphragmatic incision repair (TDIR) and two-lung ventilation (TLV) for gasless laparoscopic diaphragmatic incision repair (GLDIR) in the dog were determined. The changes in cardiopulmonary function were less in the GLDIR with TLV group, although not statistically different from the TDIR with OLV. In addition, during OLV and thoracoscopy, right lung collapse with left lung ventilation may predispose to an increased risk of hypoxemia when compared to left lung collapse with right lung ventilation.

2.Two video-assisted surgical techniques are described for the repair of diaphragmatic incisions: a) gasless laparoscopy with an abdominal lifting device and b) thoracoscopy with one-lung ventilation. In this study, thoracoscopic approaches with OLV were feasible to repair the diaphragmatic incisions located in the ventral part of the right pars costalis and sternalis or left pars costalis and sternalis. Incisions that extended across the midline were more difficult to repair with this approach. The gasless laparoscopic approach was feasible to suture incisions located in the pars sternalis and ventral part of the right or left pars costalis. Incisions that extended across the midline were repairable with this approach. The two surgical approaches described have potential clinical application that would provide

a reduction in pain and recuperation times from diaphragmatic hernia repair for clinical patients.

CHAPTER ONE GENERAL INTRODUCTION

Introduction

Laparoscopic and thoracoscopic surgery has been gaining popularity in human medicine since 1988 with the help of video-camera systems and the development of laparoscopic cholecystectomy.[1] As generally accepted, its merits are the provision of a minimally invasive procedure, reduction in pain and cosmetic injury that facilitates early ambulating and rapid return to normal activities.

Traumatic diaphragmatic hernia is a common injury in small animals. Either laparotomy, thoracotomy, or combined techniques have been performed to repair these hernias. Traumatic diaphragmatic hernia has been successfully repaired in humans using video-assisted thoracoscopy[2] and laparoscopy with carbon dioxide (CO_2) pneumoperitoneum.[3] The goal of this project was to develop a technique for laparoscopic repair of diaphragmatic hernia in the dog without the use of CO_2 pneumoperitoneum and to compare that technique to the thoracoscopic approach.

Laparoscopic techniques need a working space in the abdomen which is established by pumping (insufflating) a pressurized gas into the cavity. In human and veterinary medicine, CO_2 pneumoperitoneum or capnoperitoneum is the primary technique used because it is highly soluble, inert and non-flammable. The increased intraabdominal pressure and arterial partial pressure of CO_2 due to gas absorption from the peritoneal cavity[4] are potential causes of hemodynamic and respiratory instability in patients. The cardiovascular changes that may accompany capnoperitoneum include a decrease in cardiac output[5-7] and splanchnic blood flow,[8]

increase in arterial blood pressure and systemic vascular resistance,[5-7] hypercapnia, acidosis and pulmonary hypertension.[4,9,10] In spite of the high solubility of CO_2 gas, it may cause embolism which, although rare, is potentially a life threatening complication.[11] To avoid the adverse effects of CO_2 pneumoperitoneum, gasless laparoscopy has been developed.

Gasless, isopneumic or apneumic laparoscopy was first described in 1991,[12,13] and involved lifting the patient's abdominal wall with a mechanical device instead of gas insufflation. Without the effect of pressurized carbon dioxide gas in the abdomen, gasless laparoscopy provided hemodynamic and respiratory function stability as well as being, theoretically, air embolism free when compared to capnoperitoneum.[14-16] In addition, a gas seal was not required and loss of the surgical exposure during continuous suction was not a problem with the gasless technique. Some conventional rather than laparoscopic surgical instruments can be utilized in gasless laparoscopy. Thus, minimizing the need for the purchase of laparoscopic instruments which may have financial benefits. Moreover, capnoperitoneum has the tendency to cause more metastatic spread of intraabominal tumors than the gasless technique in human patients.[17,18]

Thoracoscopy requires partial collapse of both lungs or complete collapse of one lung to provide working space. If one lung is collapsed, then one-lung ventilation (OLV) is utilized to provide gas exchange and inhalant anesthetic administration. OLV is an essential procedure for many human surgical procedures utilizing video-assisted thoracoscopic surgery (VATS). By collapsing one lung, the

surgeon has a better surgical field and access to the thoracic organs. However, arterial hypoxemia due to the deoxygenated blood from the collapsed lung may increase the patients' morbidity and mortality rate. The repair of a diaphragmatic incision using VATS requires OLV but the repair of a diaphragmatic incision using gasless laparoscopy would allow two-lung ventilation (TLV).

The advantages and disadvantages of the two approaches for diaphragmatic incision repair have not been investigated in dogs. In addition, a comparison of the cardiopulmonary responses during the two procedures has not been reported in either human or veterinary medicine. The present study involves two aspects: documenting the cardiopulmonary responses to the two different exposures of the diaphragm (thoracoscopy and gasless laparoscopy) and developing video-assisted surgical techniques for diaphragmatic incision repair in dogs.

Dissertation Organization

This dissertation has four chapters. Chapter One covers introduction, dissertation organization and literature review. Chapter Two and Three are two manuscripts that will be submitted to Veterinary Surgery. Chapter Four contains a summary of the studies.

Literature Review

Surgical techniques performed using thoracoscopy and laparoscopy for diagnostic and therapeutic purposes in small animals have been reviewed, including complications and contraindications. In addition, the cardiopulmonary responses to pneumoperitoneum are also included.

Thoracoscopy

Thoracoscopy has been performed in a limited number in animal patients. Thus, the complications and contraindications for thoracoscopy are not well developed. The primary indication for thoracoscopy has been the requirement of direct visualization of intrathoracic structures in order to obtain a definitive diagnosis while avoiding a thoracotomy.[19]

In human medicine, thoracoscopic biopsy has a very high sensitivity (80% - 100%) for both benign and malignant pleural diseases. It increases the diagnostic yield for effusions when thoracocentesis and closed pleural biopsy specimens are not definitive. Thoracoscopic lung biopsy is, also, an alternative to open biopsy when bronchoscopic transbronchial biopsy specimens are indeterminate. Thoracoscopy as opposed to bronchoscopy, can obtain larger pieces of lung tissue under direct visualization.[20]

In veterinary medicine, thoracoscopy has been performed for the diagnosis of diaphragmatic hernia, pericardial effusion, intrathoracic neoplasia, and spontaneous pneumothorax due to rupture of emphysematous bullae, for the determination of lesion location prior to performing a thoracic surgery and hilar lymph node examination. Thoracoscopy is considered to be a safe procedure in experienced hands.[19]

The lungs must be at least partially collapsed to prevent injury to underlying tissue during insertion of the trocar and to facilitate examination and surgical manipulation of intrathoracic contents. Two different techniques for thoracoscopy

have been reported: 1) partial lung collapse with passive entry of ambient air or CO_2 insufflation,[19,21] and 2) complete collapse of one-lung with an open chest[22] or CO_2 insufflation.[23] The increase in intrathoracic pressure produced by CO_2 insufflation can result in hemodynamic instability and hypoxia. Severe hypotension, hypoxemia and hypercarbia have been reported in human patients as the result of rapid CO_2 insufflation.[23]

Thoracoscopic tissue biopsy

McCarthy[19] described a veterinary technique for intrathoracic tissue biopsy. The thoracoscope, tissue grasper and biopsy instrument were placed in triangulation with the biopsy needle directly over the lesion. Tru-Cut biopsy needles worked well for collecting samples from large lung, mediastinal or hilar masses, but they were not suitable for small masses due to possible penetration of deeper structures. Standard hypodermic needles of sufficient length or Menghini needles can be used for fluid collection and fine needle aspiration.

For exposure of the canine left lung lobes, Garcia et al[22] proposed positioning the thoracoscope in the ventral third of the left 5th intercostal space because it provided a visual field similar to that obtained with a standard thoracotomy. A grasping forceps was introduced through a second port located in the dorsal third of the 5th intercostal space to help manipulate the lobes of the lung. When the lung lobes were displaced dorsally the mediastinal space was exposed. The heart with pericardium, aortic arch with the brachiocephalic trunk, left subclavian artery, thoracic aorta and left pulmonary artery were observed.

Visualization of the lobes of the lung in the opposite hemithorax was possible through the transparent mediastinum.[22]

For partial lung biopsy of the left cranial lobe, Garcia et al inserted a 12-mm diameter stapler (Auto Suture Espana) through a third port located in the 8th intercostal space. The cranial border of the apical lobe was positioned within the jaws of the stapler which, when activated, placed 3 rows of titanium staples on either side of the incision.[22]

Lung lobectomy

Garcia et al[22] also described thoracoscopic lung lobectomy in 8 dogs. The procedure was performed using one-lung ventilation with the dogs positioned in right lateral recumbency. The caudal portion of the caudal lobe of the left lung was thoracoscopically removed utilizing 4 operating portals which were positioned an equal distance from the hilus of the lung to facilitate dissection of the blood vessels and bronchus. The first port was located in the ventral third of the fifth intercostal space and was used for the thoracoscope. The second was placed in the dorsal third of the fifth intercostal space for the grasping forceps that was used to elevate the ventral border of the caudal lobe dorsally to expose the hilus. The third (12-mm) cannula was located in the dorsal third of the eight intercostal space for scissors which were used to dissect the hilus and later the same port was used to place the stapler for cutting and ligating the hilar structures. The fourth cannula was located in the middle third of the fourth intercostal space for the forceps which were used for securing the hilus of the lung and was also used for dissecting.

The most difficult procedure was dissection of the artery, vein and bronchus at the hilus. The authors used a pair of endocircle forceps (Auto Suture Espana) which is designed to dissect around circular structures, thus reducing the difficulty of dissecting the hilar structures under two-dimensional thoracoscopy. A 3.5-mm stapler (Endogia, Auto Suture Espana) was used to ligate and cut the hilar structures. Extraction of the pulmonary lobe was performed through the incision made for the 12-mm diameter cannula. The dogs were sacrificed after spontaneous respiration was established and necropsied to verify the position and condition of the sutures.

Laparoscopy

Laparoscopy is utilized for many diagnostic and surgical procedures in veterinary medicine because it provides an excellent view of the liver, gallbladder, common bile duct, pancreas and other abdominal organs.

Abdominal exploration and liver biopsy

Laparoscopic liver biopsy is generally indicated when direct visualization is required and when other non-invasive diagnostic techniques would not give a definitive diagnosis. Laparoscopy is more successful than a single blind biopsy in obtaining the correct diagnosis of focal lesions.[24]

The details of performing laparoscopy for abdominal exploration and liver biopsy in dogs has been described. [25-27] The normal and pathological appearance of the liver has also been published.[27]

For laparoscopy, dogs can be sedated and receive local or general anesthesia. Access to the abdominal cavity for exploration has been recommended to be performed from the right side to avoid the spleen.[25,27] Jones[25] rarely uses the ventral midline approach because the falciform ligament frequently obstructs the view of the liver.

For a right-sided approach the dog is positioned in left lateral recumbency and the entry site is located at the junction of the middle and ventral one-third of the abdominal wall and midway between the last rib and the iliac crest. The technique for performing pneumoperitoneum and insertion of a trocar-cannula has been described.[25] After placing the scope into the abdominal cavity, the organs and structures should be systematically explored to avoid omissions or errors. The abdominal organs which can be visualized include the right kidney, ovary, uterine horn, adrenal gland, caudate process of the caudate liver lobe, quadrate lobe, right liver lobe, gall bladder, pylorus, duodenum, right lobe of the pancreas, various parts of the small intestines, right colon (occasionally), right internal inguinal ring with its associated structures (spermatic cord and internal spermatic artery, vein, and nerves), urinary bladder and prostate gland. A palpating probe is a useful instrument for exploring the undersurface of the liver lobes, measuring the size of a structure, and assessing tissue consistency.

The liver surfaces should be inspected using a palpating probe to locate areas of pathology. Biopsies from the periphery of a focal lesion are more informative than from the center of a lesion. The biopsy needle is directed to enter

the liver surface at a 30-degree entry angle to avoid deeper regions and vessels. During the biopsy care should be taken not to penetrate the diaphragm because pneumothorax would be a serious complication.

The left lateral approach to the abdomen offers visualization of the left liver lobes, omentum, greater curvature of the stomach and spleen.[28]

Pancreas biopsy

Whether pancreatic biopsy causes pancreatitis is controversial.[29] Twedt[27] performed pancreatic biopsies in 6 clinical dogs and suggested laparoscopy is not indicated for the patient with obvious pancreatitis. No post-biopsy pancreatitis or exacerbation of the condition was detected in those 6 dogs.[27] Pancreatic biopsy is contraindicated if there is evidence of a bacterial peritonitis because of potential adhesions. Suspected pancreatic adenocarcinoma can be evaluated by biopsy, but Islet cell tumors, because of their small size, are often difficult to find.

Laparoscopic biopsy of the pancreas has been performed from the right lateral midabdominal approach. The right lobe of the pancreas is found adjacent to the duodenum under the omentum. The pancreas is uncovered by using a palpating probe or biopsy forceps inserted through an additional port. Generally, the right and only the proximal portion of the left lobe of the pancreas are visualized. Double spoon biopsy forceps with grasping teeth were utilized. Pancreatic biopsies should be taken from the margin of the distal portion of the right lobe. The pancreatic ducts located in the center of the gland should not be biopsied.

The complication rate for liver and pancreas biopsy is low (3.3% in 360 procedures).[27] The major complications reported include hemorrhage, air embolism, organ perforation, infection, gall bladder perforation, and diaphragmatic puncture (pneumothorax). The minor complications included instrument problems, subcutaneous emphysema, leakage of ascites and overdistention from the pneumoperitoneum. The mortality rate of laparoscopic liver biopsy was 1.4% in 213 dogs compared with the blind liver biopsy technique which was 3.5% in 228 dogs.[30]

Renal biopsy

An evaluation of laparoscopy for obtaining renal biopsies from 37 dogs and 1 cat revealed that adequate specimens for morphologic diagnosis were obtained in 37 cases (97%).[31] Eleven of the 38 animals were necropsied and the biopsy diagnosis was confirmed in 10 of the cases (91%). Excessive pericapsular hemorrhage and severe hematuria developed in 1 dog. Three dogs (8%) had macroscopic hematuria for 24 hours after biopsy. The renal biopsies were performed in dogs with neuroleptanalgesia and local anesthesia and the cat received inhalation anesthesia. Most of the animals had right kidney biopsies. The scope port was introduced into the abdomen through a 1-cm skin incision approximately 5 cm caudal to the 13th rib and 3 to 5 cm ventral to the border of the lumbar muscles. A 6-in Tru-Cut biopsy needle was percutaneously inserted to obtain the biopsy. The ideal kidney biopsy should contain an adequate number of glomeruli (renal cortex) in the specimen and avoid damage to the renal nerves and major vessels in the renal medulla.[32,33] The biopsy needle was directed away from the hilus

of the kidney at an oblique angle to the kidney capsule. The obturator (inner solid needle with specimen notch) was thrust through the capsule into the renal parenchyma. Without changing the spatial relation of the obturator, the cannula (outer hollow cutting needle) was quickly advanced over the obturator, thus cutting and isolating the biopsy specimen. Any excessive bleeding could be minimized by applying pressure with the tip of the scope over the biopsy site.[31]

Gastropexy

Recently, three separate studies have described laparoscopic gastropexy techniques.[34-36] These studies compared the strength and histological appearance of gastropexies performed by laparoscopy with the standard open (laparotomy) gastropexy technique. Thompson et al[34] performed laparoscopic stapled incisional gastropexy using three surgical trocar ports and an endoscopic linear cutter [Ethicon Endocutter (ELC60)] in four mongrel dogs. After creation of a subseromuscular tunnel in the stomach wall and an intramuscular tunnel in the body wall, the endoscopic linear cutter was used to create a stapled incisional gastropexy. With each firing, the cutter positioned 4 rows of surgical staples and simultaneously cut between the two middle rows. The remaining defect was closed using an endoscopic stapler (Ethicon EMS 30). A circumcostal gastropexy was performed on four control dogs. Gross necropsy, evaluation and measurement of the strength of the gastropexy site were performed 60 days after surgery (results were not included in the abstract). No complications were reported.

Hardie et al[35] performed a similar laparoscopic stapled gastropexy technique as reported by Thompson et al[34] in 14 dogs and compared the healing to an open incisional (permanent) gastropexy performed in 6 control dogs. A smaller laparoscopic stapling device (Endopath linear cutter 35) was used to attach the gastric antrum to the adjacent right lateral abdominal wall. Half of the dogs were euthanatized 7 days post surgery and the mean tensile load to failure of the laparoscopic stapled gastropexy was significantly lower than that of the incisional gastropexy. But, there was no significant difference at 30 days after the surgery when the remaining dogs were euthanatized. No difference in the amount of connective tissue could be detected histologically between the laparoscopic and open techniques. The surgical time for the laparoscopic procedure was significantly longer than that for the open procedure. The complications encountered during the laparoscopic gastropexy were associated with improper placement of the ports and difficulties with the dissection of the gastric submucosal tunnel. Stomach perforation (2 cases), splenic puncture (2 cases) and subcutaneous emphysema (4 cases) from CO_2 gas were reported.

Wilson et al[36] performed laparoscopic and an open belt-loop gastropexy in two groups of 4 dogs. Three operating portals were placed: one at the umbilicus for the laparoscope, one caudal to the right costal arch at the lateral edge of the rectus abdominis and the other 2 cm to the left of the midline and midway between the xiphoid and umbilicus for instrument portals. A 3 x 5 cm seromuscular flap of the stomach was laparoscopically created and exteriorized through the rent in the body

wall created by the right lateral port. The skin incision for the right lateral port was extended cranially and Metzenbaum scissors were used to undermine between the external and internal abdominal oblique muscles. The seromuscular flap was then tunneled between the two muscular layers and sutured to the external rectus fascia using simple interrupted sutures. Surgical time and maximal tensile strength and histological examination of the gastropexy site 50 days after surgery revealed no significant difference between the laparoscopic and belt-loop gastropexy. Each stomach was maintained in its normal anatomic position by the gastropexy although the laparoscopic gastropexies were approximately 1 to 1.5 cm more pendulous and allowed more movement than the belt-loop gastropexies. No morbidity was associated with either procedure.

All three studies utilized CO_2 pneumoperitoneum as the exposure technique. The tensile strength of the gastropexy site in the three studies was similar to that reported in previous studies, although, the actual force applied to a gastropexy adhesion in vivo is unknown.[35]

Small intestinal anastomosis

Thompson et al[37] performed laparoscopic end-to-end anastomosis of the small intestine in three mongrel dogs using an endoscopic linear cutter [Ethicon Endocutter (ELC60)]. The procedure was performed with CO_2 pneumoperitoneum. A segment of jejunum was elevated with laparoscopic Babcock forceps and the vessels supplying the segment were ligated with endoscopic ligating clips and divided. The endoscopic linear cutter was inserted through an 18 mm trocar port and

the jejunal segment was resected and anastomosed by applying the cutter across the bowel a total of four times. With each application, the cutter positioned four rows of surgical staples and simultaneously cut between the two middle rows. The resected segment of bowel was removed from the abdomen through the 18 mm port. The authors reported that manipulation of the endoscopic cutter was difficult due to its size. Abdominal contamination and hemorrhage were minimal. The dogs recovered without complications. At gross necropsy performed 14 days after surgery, the bowel lumen was patent and the anastomosis was intact.

Laparoscopic approach to the lumbar vertebrae

Laparoscopic retroperitoneal versus transperitoneal approaches to the lumbar vertebrae have been compared in 6 pigs.[38] Loss of pneumoretroperitoneum resulted in surgical termination in two of three pigs. In the remaining pig, difficulty was encountered in the exposure of the lumbar vertebrae and significant bleeding occurred. The transperitoneal approach resulted in rapid exposure of the lumbar vertebral bodies and intervertebral discs, L1 to L6 / L7. Complications included hemorrhage and difficulty in mobilization of the renal vascular pedicle. The authors indicated that the approach to the lumbar vertebrae was feasible and suggested that the transperitoneal approach was technically easier and associated with minimal morbidity. The retroperitoneal approach to the lumbar vertebrae was not recommended.

Fenestration of the lumbar and thoracic intervertebral discs (T9-L7)

Remedios et al[39] reported that laparoscopic and thoracoscopic approaches to lumbar and thoracic vertebrae were technically simple and associated with few complications. Pneumoperitoneum and pneumothorax with CO_2 were established in 5 dogs. The approach to the thoracolumbar region was complicated by the diaphragmatic attachment. Sixty-five percent of the nucleus pulposus was removed except for T13 – L1 where only 39% of the nucleus was evacuated. Using the laparoscope to fenestrate the intervertebral disc could be very beneficial because the current invasive technique is rarely used prophylactically. Post-operative lumbosacral myelogram showed no abnormalities. Postmortem dissection showed a dorsal hernia of the left diaphragmatic crus in each dog.

Reproductive laparoscopy

Seager[40] summarized the uses of laparoscopy as having two main purposes: 1) disease diagnosis, treatment and prevention, and 2) study of reproductive anatomy and function.

Reproductive organs and abnormal internal masses can be repeatedly photographed and measured to compare with subsequent laparoscopic examinations or can be biopsied / aspirated under direct visualization. Laparoscopy can be used to diagnosis pyometra and mummified or retained fetuses. Adhesions can often be broken down by the laparoscope, accessory probes or laser. Drugs can be directly administered intraperitoneally.[40]

The studies of reproductive anatomy and function included single or multiple observations of reproductive organs, stage of estrous, pregnancy diagnosis, determination of the number of developing embryo, reproductive tract fluid collection (uterine, oviductal and follicular), ovum collection, ovarian follicular fluid and cyst aspiration, intrauterine insemination and sex determination (bird & reptiles).[40]

Cryptorchidism

A laparoscopic cryptorchid castration technique was developed in six dogs.[41] After CO_2 pneumoperitoneum, a scope was inserted through the umbilicus with additional ports located in the left and right caudal abdominal wall. The testicular artery, vein and vas deferens of the cryptorchid testis were isolated and ligated using endoscopic ligating clips and a loop (Endoloop). The cryptorchid testis was placed in a pouch (Endopouch) and removed from the abdomen after the vessels and vas deferens were transected using an endoscopic scissors. Postoperative recovery was uncomplicated.

Ovariohysterectomy

Laparoscopic ovariohysterectomy has been described for the treatment of pyometra in two dogs.[42] The dogs received general anesthesia, CO_2 pneumoperitoneum (10 mm Hg) and were positioned in left oblique dorsal recumbency. Four ports were utilized, one for the 10 mm laparoscope, two lateral ports for grasping forceps and a suprapubic port for removal of the resected ovaries and uterine horns. To remove the ovary, it was immobilized with a grasping forceps while the suspensory ligament, mesovarium and mesometrium were resected using

an ultrasonic scalpel (Harmonic scalpel, Ethicon) inserted through one of the two lateral ports. Hemorrhage from the ovarian artery was controlled using clips. After the resected ovaries and uterine horns were exteriorized, the uterine arteries were ligated and the uterus was resected. The dogs recovered with no post-operative complications.

Laparoscopic sterilization

Laparoscopic sterilization of the male dog and cat involves occluding 1 to 2 cm of the ductus deferens bilaterally using bipolar forceps and electrocoagulation. Sperm counts in the dogs decreased to zero within 48 hours after the surgery, but it took 5 days in the cats.[43] The authors indicated that the species difference in the disappearance of spermatozoa occurred after the surgery because dog sperm resides in the epididymis, whereas the cat may store sperm in the proximal ductus deferens. In another report, approximately 2 cm of the ductus deferens were laparoscopically cauterized, cut and removed without complications in dogs.[44]

Laparoscopic sterilization of the female dog was successfully performed by occluding the uterine horns using electrocoagulation at the uterotubal junction adjacent to the ovarian bursae. The uterine horns appeared normal upon subsequent examinations 1, 2 and 4 years after the surgery.[45]

Intrauterine insemination

The success of laparoscopic intrauterine insemination compared to natural mating in bitches has been described.[46] All inseminated dogs become pregnant. The average litter size was similar in inseminated and naturally mated bitches (5 ± 1.8

and 4.8 ± 1.6 pups, respectively). Bitches that were inseminated versus naturally mated delivered 65.2 ± 0.8 and 65.4 ± 0.5 days, respectively, after the LH peak.

Laparoscopic complications

The major complications encountered in veterinary laparoscopy included: hemorrhage, air embolism, cardiac arrest, organ perforation, infection, pneumothorax due to diaphragmatic puncture, and introduction of gas into a hollow viscus. Minor complications included: instrumentation problems, subcutaneous emphysema, leakage of ascites and CO_2 overdistention due to pneumoperitoneum.[27,47]

The list of complications reported from human laparoscopy is quite long.[48]

A. Abdominal wall complications include trocar site hemorrhage, hernia, infection and fistula (e.g. biliary).

B. Visceral or vascular injuries include: thermal injuries, trocar / Veress needle injuries, visceral / vascular puncture and instrument trauma (eg., serosal tear of the bowel from a grasper).

C. Retained foreign bodies including instrument parts (clips, needle or suture material) and organic parts (lost gallstones, tissue fragments, blood clots).

D. Pneumoperitoneum related complications include cardiopulmonary compromise, renal failure, hypothermia, venous thrombosis and subcutaneous emphysema.

E. Inherent features of laparoscopy that may increase complications:

1. Altered visibility including the two-dimension view, limited depth of field, magnified view, small angle of view, laparoscopic "blind spot" in the abdomen, cautery smoke accumulation, fogged lens or lens soilage and equipment failure (light source, camera, monitor).
2. Reduced tactile sensation of the surgeon leads to an inability to dissect or diagnose disease (eg., intraluminal tumors of the colon, intraparenchyma tumors of the liver) by palpation.
3. Limited instrument movement due to the fulcrum effect of operating ports.

Laparoscopic contraindications

The contraindications for laparoscopy in animals include peritonitis, suspicion of extensive adhesions, coagulation defects, diaphragmatic and inguinal hernia, obesity and an inexperienced operator.[47]

Pneumoperitoneum

Pneumoperitoneum is the primary exposure technique that has been used for laparoscopy and laparoscopic surgery in human and veterinary medicine. Generally, pneumoperitoneum provides a good surgical field for laparoscopic surgery. CO_2 pneumoperitoneum has been used widely in humans and animals because it is highly soluble and non-flammable. Despite, its high solubility, gas embolism from CO_2 can occur at any time during a procedure as a consequence of an open venous channel and a pressure gradient between the abdominal cavity and the venous system.[49]

N_2O pneumoperitoneum

The use of nitrous oxide as an insufflating agent during laparoscopic surgery has declined over the last 20 years. The laparoscopy explosion hazard with N_2O pneumoperitoneum in human patients led to the gradual abandonment of this gas as an insufflating agent. Nitrous oxide is not flammable but it was theorized that hydrogen and methane diffusion from the bowel lumen into the peritoneal cavity could be ignited by a spark from the electrocautery causing an explosion. [50]

CO_2 pneumoperitoneum

The cardiopulmonary effect of CO_2 pneumoperitoneum has been studied extensively in humans and animals. The extent of the cardiovascular changes will depend on the intraabdominal pressure attained, the volume of CO_2 absorbed, the patient's intravascular volume, the ventilatory technique, surgical conditions and anesthetic agents employed.[51] Studies of the hemodynamic effects of CO_2 pneumoperitoneum have been investigated in normal dogs,[5,52] normal humans,[6,7] and human patients with cardiopulmonary problems.[53] These studies revealed that CO_2 pneumoperitoneum can result in a significant decrease in cardiac output (CO), and increases in mean arterial pressure and systemic vascular resistance. The possible mechanisms by which CO_2 pneumoperitoneum causes hemodynamic and respiratory changes are the effect of increased intraabdominal pressure[5-7], sympathetic nervous system activation by the carbon dioxide,[4,9,10] and the release of humoral factors.[7] The significant decrease in CO resulted from a decrease in venous return to the heart secondary to venous (eg. inferior vena cava,

portal vein) compression by the pressure of the intraabdominal gas.[5-7] Hypercapnia, respiratory acidosis and pulmonary hypertension developed as a consequence of CO_2 absorption from the peritoneal surface and the decrease in tidal volume due to the diaphragmatic elevation. Other mechanisms resulting from sympathetic stimulation, myocardial depression and the effect of acidemia may also come into play.[10] The increase of the systemic vascular resistance may result from the release of catecholamines, prostaglandins, renin-angiotensin, and vasopressin.[5]

Measurements of splanchnic blood flow during CO_2 pneumoperitoneum revealed a significant decrease in portal venous and superior mesenteric arterial blood flow.[8] Four mechanisms may contribute to this decrease in splanchnic blood flow. First, the elevation of intraabdominal pressure (IAP) by CO_2 insufflation causes direct mechanical compression of the splanchnic veins. According to Poiseuille's law, the blood flow in a vessel is proportional to the fourth power of its radius. Thus, a small decrease in vascular radius leads to a significant decrease in blood flow and a large increase in vessel resistance. Second, humoral-induced vasoconstriction may occur because of the increased IAP which has a direct stimulating effect on the brain resulting in the release of vasopressin which is a vasoconstrictor of renal, superior mesenteric, and celiac vasculature. The decreased venous return to the heart from the partially occluded portal vein and inferior vena cava is also thought to stimulate vasopressin release. Third, the splanchnic vessels possess a well-developed myogenic mechanism for local control of vascular tone. Compression of the venous outflow could elevate intravascular pressure and thereby trigger intrinsic

myogenically mediated vasoconstriction. Finally, activation of the sympathetic nervous system by an elevated arterial CO_2 partial pressure can cause vasoconstriction of the hepatic arteries.

To reduce complications caused by hemodynamic derangements, the safe intraabdominal pressure range of 8-12 mm Hg from CO_2 pneumoperitoneum is recommended.[54]

Many of the complications reported following CO_2 pneumoperitoneum, besides air embolism, including thromboembolism from venous stasis and mesenteric ischemia may involve the changes in splanchnic hemodynamics related to elevated intraabdominal pressure.[55]

References

1 MacFadyen BV and Ponsky JL: Laparoscopy for the general surgeon. Surg Cli North Am 72:(Preface), 1992

2 Smith RS, Fry WR, Tsoi EK, et al: Preliminary report on videothoracoscopy in the evaluation and treatment of thoracic injury. Am J Surg 166:690-3; discussion 693-5,1993

3 Frantzides CT and Carlson MA: Laparoscopic repair of a penetrating injury to the diaphragm: A case report. J Laparoendosc Surg 4:153-6, 1994

4 Liu S, Leighton T, Davis I, et al: Prospective analysis of cardiopulmonary responses to laparoscopic cholecystectomy. J Laparoendosc Surg 1:241-6, 1991

5 Ivankovich AD, Miletich DJ, Albreecht RF, et al: Cardiovascular effects of intraperitoneal insufflation with carbon dioxide and nitrous oxide in the dog. Anesthesiology 42:281-287, 1975

6 Critchley LA, Critchley JA and Gin T: Haemodynamic changes in patients undergoing laparoscopic cholecystectomy: measurement by transthoracic bioimpedance. Br J Anaesth 70:681-3,1993

7 Joris JL, Noirot DP, Legrand MJ, et al: Hemodynamic changes during laparoscopic cholecystectomy. Anesth Analg 76:1067-71, 1993

8 Ishizaki Y, Bandai Y, Shimomura K, et al: Changes in splanchnic blood flow and cardiovascular effects following peritoneal insufflation of carbon dioxide. Surg Endosc 7:420-3,1993

9 Ho HS, Christopher Saunders CJ, Corso FA, et al: The effects of CO_2 pneumoperitoneum on hemodynamics in hemorrhaged animals. Surgery 114:381-388, 1993

10 Bongard FS, Pianim NA, Leighton TA, et al: Helium insufflation for laparoscopic operation. Surg Gynecol & Obstet 177: 140-146, 1993

11 Lantz PE and Smith JD: Fatal carbon dioxide embolism complicating attempted laparoscopic cholecystectomy – Case report and literature review. J Forensic Sci 39:1468-80, 1994

12 Kitano S, Tomikawa M, Iso Y, et al: A safe and simple method to maintain a clear field of vision during laparoscopic cholecystectomy. Surg Endosc 6:197-198, 1992

13 Gazayerli MM: The Gazayerli endoscopic retractor model 1. Surg Laparosc Endosc 1:98-100, 1991

14 Martin IG and McMahon MJ: Gasless Laparoscopy. J R Coll Surg Edinb 41: 72-74, 1996

15 Koivusalo AM, Kellokumpu I, Scheinin M, et al: A comparison of gasless mechanical and conventional carbon dioxide pneumoperitoneum methods for laparoscopic cholecystectomy. Anesth Analg 86: 153-8, 1998

16 Couture P, Boudreault D, Girard F, et al: Haemodynamic effects of mechanical peritoneal retraction during laparoscopic cholecystectomy. Can J Anaesth 44 (5 Pt 1) :467-72, 1997

17 Watson DI, Mathew G, Ellis T, et al: Gasless laparoscopy may reduce the risk of port-site metastases following laparoscopic tumor surgery. Arch Surg 132:166-8, 1997

18 Bouvy ND, Marquet RL, Jeekel H, et al: Impact of gas (less) laparoscopy and laparotomy on peritoneal tumor growth and abdominal wall metastases. Ann Surg 224:694-71,1996

19 McCarthy TC and McDermaid SL: Thoracoscopy. Vet Clin North Am Small Anim Pract 20:1341-52, 1990

20 Harris RJ, Kavuru MS, Rice TW, et al: Reviews the diagnostic and therapeutic utility of thoracoscopy. Chest 108:828-41, 1995

21 Remedios AM and Ferguson J: Minimally invasive surgery: laparoscopy and thoracoscopy in small animals. Comp Cont Ed Practicing-Veterinarian 18:1191-99, 1996

22 Garcia F, Prandi D, Pena T, et al: Examination of the thoracic cavity and lung lobectomy by means of thoracoscopy in dogs. Can Vet J 39:285-91, 1998

23 Penden CJ and Prys-Roberts C: Capnothorax: implications for the anaesthetist. Anaesthesia 48:664-6, 1993

24 Jones BD: Liver biopsy – The laparoscopic approach. Vet Med Report 2:193-6, 1990

25 Jones BD: Laparoscopy. Vet Clin North Am Small Ani Pract 20:1243-63,1990

26 Jones BD: Hepatic biopsy. Vet Clin North Am Small Ani Pract 15:39-65,1985

27 Twedt DC: Laparoscopy of the liver and pancreas, in Todd Tams (1ed): Small Animal Endoscopy. St. Louis, C.V. Mosby, 1990 pp 377-386

28 Johnson GF and Twedt DC: Endoscopy and laparoscopy in the diagnosis and management of neoplasia in small animals. Vet Clin North Am Small Ani Pract 7:77-92, 1977

29 Bunch SE: The exocrine pancreas. in Nelson RW and Couto CG (1ed): Essentials of Small Animal Internal Medicine. St. Louis, Mosby-Year Book, 1992, pp 432-43

30 Lettow E: Laparoscopic examinations in liver diseases in dogs. Vet Med Rev 2:159-167, 1972

31 Grauer FG and Twedt DC: Evaluation of laparoscopy for obtaining renal biopsy specimens from dogs and cats. JAVMA 183: 677-679,1983

32 Grauer FG: Renal biopsy. In Nelson RW and Couto CG (1ed): Essentials of Small Animal Internal Medicine. St. Louis, Mosby-Year Book, 1992, pp 472-3

33 Osborne CA, Stevens JB and Perman V: Kidney biopsy. Vet Clin North Am Small Ani Pract 4:351-365,1974

34 Thompson SE, Freeman LJ, Gallagher LA, et al: Laparoscopic stapled incisional gastropexy. Vet Surg 21:407, 1992 (abstr)

35 Hardie RJ, Flanders JA, Schmidt P, et al: Biomechanical and histological evaluation of a laparoscopic stapled gastropexy technique in dogs. Vet Surg 25: 127-133, 1996

36 Wilson ER, Henderson RA, Montgomery RD, et al: A comparison of laparoscopic and belt-loop gastropexy in dogs. Vet Surg 25:221-27, 1996

37 Thompson SE, Trenka BS, Freeman LJ, et al: Laparoscopic small intestinal anastomosis. Vet Surg 21:407, 1992 (abstr)

38 Southerland SR, Remedios AM, McKerrell JG, et al: Laparoscopic approaches to the lumbar vertebrae: An anatomic study using a porcine model. Spine 20:1620-23, 1995

39 Remedios AM, Steinacher S, Ferguson JF, et al: Laparoscopic and thoracoscopic fenestration of the thoracolumbar intervertebral discs (T11-L7) in dogs. Vet Surg 24:439, 1995 (abstr)

40 Seager SWJ: Reproductive laparoscopy. Vet Clin North Am Small Anim Pract 20:1369-75, 1990

41 Gallagher LA, Freeman LJ, Trenka BS, et al: Laparoscopic castration for canine cryptorchidism. Vet Surg 25:411, 1995 (abstr)

42 Minami S, Okamoto Y, Eguchi H, et al: Successful laparoscopy assisted ovariohysterectomy in two dogs with pyometra. J Vet Med Sci 59:845-47, 1997

43 Wildt DE, Seager SWJ and Bridges CH: Sterilization of the male dog and cat by laparoscopic occlusion of the ductus deferens. Am J Vet Res 42:1888-1897, 1981

44 Silva LD, Onclin K, Donnay I, et al: Laparoscopic vasectomy in the male dog. J Reprod Fertil Suppl 47:399-401, 1993

45 Wildt DE and Lawler DF: Laparoscopic sterilization of the bitch and queen by uterine horn occlusion. Am J Vet Res 46:864-869, 1985

46 Silva LDM, Onclin K, Snaps F, et al: Laparoscopic intrauterine insemination in the bitch. Theriogenology 43:615-623, 1995

47 Patterson JM: Laparoscopy in small animal medicine, in Kirk RW: Current Veterinary Therapy VII Small Animal Practice, Philadelphia, PA, W.B. Saunders, 1980 pp 969-973

48 Eubanks S and Schauer PR: Laparoscopic surgery, in Sabiston DC and Lyerly KH (15th ed): Sabiston Textbook of Surgery – The Biological Basis of Modern Surgical Practice Philadelphia, PA, W.B. Saunders, 1997 pp 791-807

49 Hanley, ES: Anesthesia for laparoscopic surgery. Surgical Clinics of North America 72:1013-1019, 1992

50 Neuman GG, Sidebotham G, Negoianu E, et al: Laparoscopic exposure hazards with nitrous oxide. Anesthesiology 78:875-878,1993

51 Cunningham, AJ and Brull, SJ: Laparoscopic cholecystectomy: Anesthetic implications. Anesth Analg 76:1120-33, 1993

52 Williams MD and Murr PC: Laparoscopic insufflation of the abdomen depresses cardiopulmonary function. Surg-Endosc 7:126, 1993

53 Safran D, Sgambati S and Orlando III R: Laparoscopy in high-risk cardiac patients. Surg Gynecol & Obstet 176: 548-554,1993

54 Ishizaki Y, Bandai Y, Shimomura K, et al: Safe intraabdominal pressure of carbon dioxide pneumoperitoneum during laparoscopic surgery. Surgery 114: 549-54, 1993

55 Richmond BK, Lucente FC and Boland JP: Laparoscopy-associated mesenteric vascular events: description of an evolving clinical syndrome. J Laparoendosc Adv Surg Tech A 7:363-7,1997

CHAPTER TWO CANINE CARDIOPULMONARY RESPONSES TO ONE-LUNG VENTILATION DURING THORACOSCOPIC DIAPHRAGMATIC INCISION REPAIR AND TWO-LUNG VENTILATION DURING GASLESS LAPAROSCOPIC DIAPHRAGMATIC INCISION REPAIR

A paper to be submitted for publication in Veterinary Surgery

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Objective---The purpose of this study was to compare the cardiopulmonary responses to diaphragmatic incision repair by either gasless laparoscopy or thoracoscopy in dogs.

Design---Complete randomized block design

Animals--- Fifteen healthy young female dogs weighing 11.4 ± 0.5 kg (mean ± SE) were randomly assigned to three groups: control (CNT, n=5), thoracoscopic diaphragmatic incision repair (TDIR, n=5), and gasless laparoscopic diaphragmatic incision repair (GLDIR, n=5).

Methods---On day 1, the dogs were anesthetized, positioned in dorsal recumbency, instrumented, and ventilated to maintain a $PaCO_2$ of 40 ± 5 mm Hg. Data collections were performed at 15 minute intervals during the pretreatment (15 min), treatment (90 min) and post-treatment periods (30 min). The data collected included cardiopulmonary variables and arterial and venous blood gas samples. During the

treatment period, the CNT group received a pneumothorax and thoracoscopy with one-lung (left, n=3 or right, n=2) ventilation. The TDIR group received the same procedure and number of left and right lung ventilation as the CNT group plus a diaphragmatic incision with repair. The GLDIR group received a pneumothorax, gasless (abdominal wall lift) laparoscopy with two-lung ventilation (TLV), and a diaphragmatic incision with repair. On day 2, an arterial blood gas sample was collected 24 hours after the experiment in all dogs.

Results---The cardiopulmonary response of healthy dogs to thoracoscopy (with or without a diaphragmatic incision and repair) was not significantly different from gasless laparoscopy. The treatments in the three groups did cause significant cardiopulmonary change from baseline (intermittent positive pressure ventilation with a closed chest). In the CNT and TDIR groups, heart rate (HR), cardiac output (CO) (only CNT), mean pulmonary arterial pressure (MPAP), airway pressure (AWP) and % pulmonary shunt increased significantly and PaO_2 decreased significantly from the baseline during the treatment period. In the GLDIR group, MPAP and % pulmonary shunt increased significantly while PaO_2 decreased significantly from the baseline, but to a lesser extent in the GLDIR than in either the CNT or TDIR groups during the treatment period. The PaO_2 values with the right lung collapsed (CNT, TDIR; n=6) were significantly lower than those with the left lung collapsed (CNT, TDIR; n=4) at the 15 min ($P < .01$), 30 min ($P < .05$) and 45 min ($P < .05$) min sample times during the treatment period. However, when the data was examined with the Bonferroni's adjustment ($P = 0.05 / 6$) PaO_2 values only at the15-min

sample time with the right lung collapsed were significantly less than those with the left lung collapsed.

Conclusion--- The results in this study indicate that the adverse cardiopulmonary responses tended to be less in the GLDIR group, although not statistically different from the CNT and TDIR groups. In addition, during thoracoscopy, right lung collapse with left lung ventilation may predispose the dog to hypoxemia when compared to left lung collapse with right lung ventilation.

Introduction

Traumatic diaphragmatic hernia is a common injury in small animals. Either laparotomy, thoracotomy, or combined techniques have been performed to repair these hernias. With the advent of video-camera systems, minimally invasive laparoscopic or thoracoscopic surgery for repair of diaphragmatic hernia may be feasible and offers the patient reduced post-operative pain and shorter recovery time when compared with conventional surgery. Traumatic diaphragmatic hernia repair has been performed clinically in human patients by using video-assisted thoracoscopic surgery[1] and a laparoscopic technique with carbon dioxide (CO_2) pneumoperitoneum[2]. A gasless laparoscopic technique for traumatic diaphragmatic hernia has not been reported.

In human medicine, the vast majority of laparoscopic surgical procedures have been carried out utilizing CO_2 pneumoperitoneum (capnoperitoneum). There are definite and potentially serious physiological effects of the pressurized CO_2 within the abdomen.[3,4] Capnoperitoneum exposes the patient to the rare but life

threatening risk of gas embolism[5] and creates the need for a sealed operating system to prevent gas leakage and loss of operating space. Cardiovascular function may be altered by entrapment of blood in the lower limbs and ventilation pressures may need to be increased in order to maintain oxygenation of the arterial blood.[6]

Gasless, isopneumic, or apneumic laparoscopy is a relatively new technique first described in 1991[7,8] which involves lifting the patient's abdominal wall with a mechanical device instead of gas insufflation. Without the effects of pressurized CO_2 in the abdomen and the resultant high level of arterial PCO_2, gasless laparoscopy provides a significant improvement in hemodynamics and pulmonary ventilation [6,9,10] as well as being theoretically air embolism free when compared to capnoperitoneum. Additionally, a complication of traumatic diaphragmatic repair with CO_2 pneumoperitoneum would be a clinical picture similar to that of a tension pneumothorax.[11] Other advantages of the gasless laparoscopic technique include: standard surgical instruments can be utilized,[12] suturing and knot tying are easier,[13] and continuous suction can be used without a loss of exposure.[12]

One-lung ventilation (OLV) provides a large surgical field for conventional thoracic and thoracoscopic surgery. By collapsing one lung lobe, the surgeon has a large working space and access to the thoracic organs. OLV has not been routinely performed in veterinary medicine and there is limited information about the cardiopulmonary effects. [14,15] Review of the literature revealed no studies of the cardiopulmonary response of OLV and two-lung ventilation (TLV) during

thoracoscopic and gasless laparoscopic incision repair in human or veterinary medicine.

The purpose of our study was to determine the cardiopulmonary effects of video-assisted thoracoscopy and gasless laparoscopy for the repair of a diaphragmatic incision in the dog. A gasless laparoscopic technique using an abdominal wall lifting device was compared to a thoracoscopic technique utilizing one-lung ventilation. The feasibility and physiologic effects of the two techniques were compared.

Materials and Methods

Animals

This study was approved by the Committee on Animal Care at Iowa State University. All dogs were housed in approved facilities managed by the Laboratory Animal Resources.

Fifteen young, female dogs (4 beagles, 3 keeshounds, and 8 mixed) weighing 8-14 kg were randomly assigned to three groups: control (CNT, n=5), thoracoscopic diaphragmatic incision repair (TDIR, n=5), and gasless laparoscopic diaphragmatic incision repair (GLDIR, n=5). All dogs were found to be healthy by physical examination, complete blood count, serum chemistry profile and thoracic radiography.

Instrumentation

The dogs were premedicated intramuscularly with butorphanol 0.2 mg/kg (Torbugesic, Fort Dodge Inc, Fort Dodge, IA) fifteen minutes before anesthesia was

induced intravenously with 5% thiopental sodium (10 mg/kg) (Pentothal, Abbott Laboratories, North Chicago, IL) to allow airway intubation. Left bronchial intubation was performed using bronchoscopy in CNT and TDIR dogs. A guide consisting of a 120-cm length of polyethylene tubing with a flexible wire fixed within the lumen was inserted through the epiglottis and guided by bronchoscopy into the left bronchus. A double-lumen 9 fr tube (Rusch, Rusch Inc., Duluth, GA) was then inserted over the previously placed guide wire until the tip was located in the left bronchus. Dogs in the GLDIR group received endotracheal intubation. Anesthesia was maintained with 1.5-2% isoflurane (Isoflo, Abbott Laboratories, North Chicago, IL) in oxygen (1 LPM) using a semiclosed circle breathing circuit. Body temperature was maintained using a circulating warm water blanket and heat lamps. All dogs were placed in dorsal recumbency, clipped, and prepared for surgery.

A 20-gauge, 5-cm or 22-gauge, 3-cm teflon catheter (Angiocath, Deseret Medical Inc, Sandy, UT) was placed percutaneously in the dorsal pedal artery for arterial blood gas samples and measurement of systemic arterial pressures. The pressure transducer was zero referenced at the level of the right atrium.

An introducer (Arrow, Arrow international Inc, Reading, PA and Check-Flo, Cook Veterinary Products Inc, Bloominton, IN) and 7.5 fr 110-cm thermodilution catheter (Edwards Swan-Ganz, thermodilution catheter; Baxter Healthcare Co, Irvine, CA and Hands-Off, Arrow International Inc, Reading, PA) were placed percutaneously in the right jugular vein and advanced until the distal port of the catheter was in the pulmonary artery. Correct placement was verified by observing

the characteristic pulmonary artery waveforms on a monitor. The proximal and distal ports of the catheter were attached to strain gauge pressure transducers (zero referenced at the level of the right atrium) to measure central venous pressure (CVP), mean pulmonary arterial pressure (MPAP), and pulmonary capillary wedge pressure (PCWP).

Cardiac output (CO) was determined by thermodilution (COM-2, Baxter Healthcare Co, Irvine, CA). Five milliliters of zero degree Celsius 5% dextrose were used as the injectate administered through the proximal infusion port of the thermodilution catheter. Three rapidly sequenced injections were averaged to determine a mean CO for each recording time. Injections were performed during the expiratory phase of the ventilatory cycle to minimize the effect of positive intrathoracic pressure. Core temperature was recorded and heart rate (HR) was continuously monitored using the lead II electrocardiogram (EKG).

A polyvinyl catheter for measuring airway pressure (AWP) was placed in the endotracheal tube lumen and connected to a pressure transducer that was zero referenced at the level of the trachea. Airflow (AF) was measured using a pneumotach (Statham, Hato Rey, Puerto Rico). The pressure transducers, EKG and pneumotach were connected to a multiple channel computerized data acquisition system (AcqKnowledge III for MP100, Biopac Systems Inc, Goleta, CA).

After instrumentation, the dogs were placed on a time-cycled ventilator (Ventimeter, Air Shields Inc, Hatboro, PA) and allowed to stabilize for thirty minutes. The intermittent positive pressure ventilation (IPPV) was set to maintain a peak

airway pressure below 25 cm H_2O. Arterial blood gas samples were analyzed during the procedure and the tidal volume and respiratory rate were varied with the goal of maintaining a $PaCO_2$ of 40 ± 5 mm Hg.

The pressure transducers and pneumotach were calibrated before starting each experiment and a zero baseline was established before data collection throughout the experiment.

Experimental procedure

The experiment included data collection on days 1 and 2. On day 1, after instrumentation and thirty minutes of stabilization, the experiment consisted of five periods: pretreatment (15 min), break 1 (B1), treatment (90 min), break 2 (B2) and post-treatment (30 min). The baseline values were collected during the pretreatment period. During break 1 (B1), pneumothorax and one-lung ventilation (OLV) were performed on CNT and TDIR dogs, whereas pneumothorax and insertion of the abdominal lifting device were performed on GLDIR dogs. Pneumothorax was created using a bovine teat cannula inserted through an intercostal space at the level of the costochondral junction. The pneumothorax cannula was sutured to the chest wall. During the treatment period, CNT and TDIR dogs were randomly assigned to have either right or left lung collapse. One-lung ventilation was initiated by clamping one barrel of the double lumen tube consequently blocking the airflow to one of the lungs. Successful OLV was verified using the thoracoscope. If necessary, the endobronchial tube was repositioned to achieve one-lung collapse

and one-lung ventilation. During the 90-minute treatment period, data was collected every fifteen-minutes. Treatment group summary:

- CNT group –Thoracoscopy and OLV (right lung ventilation, n=2; left lung ventilation, n=3)
- TDIR group –Thoracoscopy, OLV (right lung ventilation, n=2; left lung ventilation, n=3) and diaphragmatic incision with repair
- GLDIR group – Gasless laparoscopy, Two-lung ventilation (TLV) and diaphragmatic incision with repair

During break 2 (B 2) the chest wall was sutured, negative intra-thoracic pressure reestablished, and collapsed lungs reinflated. The post-treatment period consisted of collection points at 15-minute intervals.

On day 2, a twenty-four hour arterial blood gas sample was collected from each dog while it was breathing room air. Manual restraint and local anesthesia were used.

Data collected on day 1 included blood gas analysis of arterial and mixed venous samples collected from the dorsal pedal artery and pulmonary artery, respectively. HR, CO, mean arterial pressure (MAP), MPAP, PCWP, CVP, respiratory rate (RR), AF and AWP were continuously monitored and data were collected at specified time intervals. Calculated data included cardiac index (CI), % shunt and minute volume (MV).

The diaphragmatic incision repair by thoracoscopy and gasless laparoscopy were described in a separate publication.

Statistical Analysis

The group differences from baseline were compared by using a one-way ANOVA for repeated measurements. The treatment and post-treatment means were compared with baseline means within each group using the paired t-test. In SAS, GLM procedure was used for the repeated measurement analyses and LSMEANS was used for the t-tests. Analysis of variance for repeated measurements and a 2-way analysis of variance at each time point were performed to compare groups. Comparison of right lung ventilation and left lung ventilation for CNT and TDIR groups were made based on changes from baseline. Generally, a significance level of 0.05 was used; however, Bonferroni's adjustment of the significance level to P = 0.05 / 6 was used in comparison of right and left lung ventilation. Bonferroni's adjustment was used to validate the 95% confidence interval for repeated measurements made on the same dogs. The new significance level was noted wherever applicable.

Results

General conditions

Fifteen dogs, five in each group, weighing 11.4 ± 0.5 kg (mean ± SE) were studied. The CNT and TDIR dogs had OLV during the treatment period while the GLDIR dogs had TLV. The duration of the treatment period was 90 min in 14 dogs and 120 min in one GLDIR dog due to the length of the diaphragmatic incision. There were two breaks, B1 and B2, one before and one after lung collapse. They were variable in length for the CNT, TDIR and GLDIR groups (B1 = 54 ± 6, 62 ± 5

and 71 ± 9 (mean ± SE) min, respectively; B2 = 44 ± 1, 48 ± 6 and 33 ± 5 min, respectively). There was no significant difference among the groups in the length of the B1 periods or B2 periods.

Blood loss was subjectively the least in the CNT group, but the diaphragmatic incision caused mild to moderate blood loss in the TDIR and GLDIR groups. After the day 1 experiment, one TDIR dog was autotransfused with blood withdrawn from the chest. No other surgical complications occurred during perioperation and postoperation.

General findings

From the statistical analysis, the baseline values of all measured and calculated variables were not significantly different between groups. In addition, between group comparisons of all measured and calculated data collected during the treatment period were not significantly different. The results of analysis within groups showed some significant differences from the baseline. In analysis of right and left lung ventilation, only the PaO_2 values with the left lung collapse during the initial treatment period were significantly different from those with the right lung collapse.

Hemodynamic data (Table 1)

The HR increased significantly from baseline during the treatment period of CNT ($P < 0.01$) and TDIR groups ($P < 0.01$) and approached baseline values by the 30 min sample of the post-treatment period in the CNT group. The HR also increased from baseline in the GLDIR group during the treatment period but was not

Table 1. Measured and calculated cardiovascular data (mean ± SE) from CONTROL, TDIR and GLDIR Groups (n=5)

Period	Baseline	B1	Treatment						B2	Post-treatment	
Time (min)	0		15	30	45	60	75	90		15	30
HEART RATE (bpm)											
Control	84 ± 8		114 ± 10**	115 ± 9**	112 ± 9**	111 ± 8**	110 ± 10**	114 ± 10**		102 ± 9*	98 ± 9*
TDIR	89 ± 14		121 ± 15*	118 ± 13**	117 ± 13**	121 ± 14*	123 ± 16*	123 ± 16*		124 ± 18**	124 ± 18*
GLDIR	82 ± 9		111 ± 19	116 ± 17	118 ± 17	120 ± 17	120 ± 16	120 ± 16		116 ± 13*	114 ± 10*
CARDIAC OUTPUT (l/min)											
Control	1.33 ± 0.2		1.98 ± 0.3*	1.93 ± 0.3	1.93 ± 0.3*	1.93 ± 0.3*	1.96 ± 0.3*	1.98 ± 0.2*		1.97 ± 0.3*	1.87 ± 0.3*
TDIR	1.36 ± 0.2		1.58 ± 0.1	1.69 ± 0.2	1.72 ± 0.2	1.84 ± 0.1	1.89 ± 0.1	1.93 ± 0.1		1.65 ± 0.2	1.61 ± 0.2
GLDIR	1.61 ± 0.2		1.46 ± 0.2	1.67 ± 0.2	1.76 ± 0.2	1.60 ± 0.2	1.69 ± 0.4	1.73 ± 0.3		1.59 ± 0.3	1.83 ± 0.3
CARDIAC INDEX (ml/min/kg)											
Control	126 ± 20		189 ± 20**	204 ± 30*	221 ± 50	237 ± 60	257 ± 80	273 ± 90		286 ± 110	294 ± 130
TDIR	129 ± 20		147 ± 10	156 ± 20	160 ± 20	172 ± 20	178 ± 20	184 ± 30		150 ± 10	147 ± 20
GLDIR	152 ± 10		135 ± 10	154 ± 20	164 ± 20	149 ± 20	156 ± 30	161 ± 20		148 ± 30	171 ± 40
MAP (mm Hg)											
Control	64.9 ± 3.8		83.2 ± 7.0*	77.5 ± 6.2	79.1 ± 4.8	72.0 ± 5.7	73.6 ± 6.5	72.6 ± 5.9		68.7 ± 4.6	68.2 ± 4.6
TDIR	62.2 ± 8.4		83.1 ± 7.2	69.0 ± 5.6	65.5 ± 4.7	71.9 ± 2.5	75.0 ± 3.0	73.5 ± 6.4		65.1 ± 5.4	62.2 ± 3.1
GLDIR	68.0 ± 7.1		72.4 ± 5.8	74.1 ± 6.0	72.8 ± 5.8	73.1 ± 4.1	69.0 ± 3.5	69.6 ± 2.2		65.0 ± 5.4	68.6 ± 3.4
MPAP (mm Hg)											
Control	12.8 ± 1.2		18.5 ± 1.6**	18.8 ± 1.7**	18.4 ± 1.6**	18.0 ±1.5**	18.2 ± 1.8*	18.5 ± 1.6**		15.5 ± 2.0	15.4 ± 1.6
TDIR	12.1 ± 0.8		16.9 ± 0.9**	17.3 ± 1.3**	16.8 ± 1.3**	17.2 ± 0.9*	18.2 ± 0.9*	18.2 ± 1.5*		11.8 ± 0.8	12.8 ± 1.1
GLDIR	12.0 ± 0.9		14.5 ± 1.4	16.5 ± 1.0*	15.8 ± 1.2*	16.7 ± 1.3*	15.7 ± 1.2	15.7 ± 0.8		13.2 ± 1.3	12.3 ± 1.5

** Significant difference ($P < 0.01$) from baseline

* Significant difference ($P < 0.05$) from baseline

B1 (Break period 1= mean ± SE) in control, TDIR and GLDIR groups was 54 ± 6, 62 ± 5 and 71 ± 9 min respectively.

B2 (Break period 2= mean ± SE) in control, TDIR and GLDIR groups was 44 ± 1, 48 ± 6 and 33 ± 5 min respectively

Abbreviation: MAP, mean arterial pressure; MPAP, mean pulmonary arterial pressure

statistically significant. The HR remained significantly increased from baseline values during the post-treatment period in the TDIR and GLDIR groups. CO and CI increased significantly from the baseline in the CNT group and a similar but smaller increase which was not statistically significant occurred in the TDIR group. CO and CI during the post-treatment period remained elevated in the CNT group but decreased slightly in the TDIR group. CO and CI changed slightly from the baseline values during the treatment and post-treatment periods in the GLDIR group. MAP increased slightly during the treatment period and decreased to the baseline values during the post-treatment period of all groups. MPAP was significantly increased from the baseline values during the treatment period in all groups. MPAP during the post-treatment period decreased to values that were close to the baseline in all groups, but to a lesser extent in the CNT group.

Respiratory and blood gas data (Table 2)

During the treatment and post-treatment periods, minute ventilation (MV) was not significantly different from the baseline values in all groups except at the 90 min sample of the treatment period and 15 min sample of the post-treatment period in the TGDIR group. AWP increased significantly in the CNT and in the TDIR groups during the treatment period (Fig 1). During the post-treatment period, the AWP decreased towards baseline values in all groups, but was still significantly different from the baseline in the CNT and TDIR groups.

During the treatment period, the % shunt increased significantly from the baseline in CNT, TDIR and GLDIR groups (Fig 2). The % shunt values during the

Table 2. Measured and calculated respiratory and blood gas data (mean ± SE) from CONTROL, TDIR and GLDIR Groups (n=5)

Period	Baseline	B1	Treatment						B2	Post-treatment	
Time (min)	0		15	30	45	60	75	90		15	30
MINUTE VENTILATION (l/min)											
Control	2.86 ± 0.2		2.64 ± 0.5	2.85 ± 0.4	2.85 ± 0.4	2.73 ± 0.4	2.71 ± 0.4	2.66 ± 0.4		2.67 ± 0.1	2.68 ± 0.1
TDIR	2.53 ± 0.1		2.80 ± 0.3	2.66 ± 0.3	2.61 ± 0.3	2.56 ± 0.3	2.30 ± 0.3	2.11 ± 0.2*		2.13 ± 0.2*	2.47 ± 0.1
GLDIR	2.97 ± 0.5		2.73 ± 0.5	2.25 ± 0.4	2.11 ± 0.3	2.39 ± 0.3	2.57 ± 0.3	2.41 ± 0.3		2.66 ± 0.2	2.44 ± 0.3
AIRWAY PRESSURE (cm H_2O)											
Control	11.4 ± 1.3		19.0 ± 2.8*	20.5 ± 2.2**	20.5 ± 2.5*	20.0 ± 2.1**	19.6 ± 2.5**	20.0 ± 2.5**		16.3 ± 2.3*	15.8 ± 2.3*
TDIR	10.8 ± 1.5		18.6 ± 2.0*	18.2 ± 1.9*	17.6 ± 1.7*	17.7 ± 1.9**	16.5 ± 2.0*	18.0 ± 1.5**		14.6 ± 1.8**	13.1 ± 1.1
GLDIR	9.5 ± 1.9		11.8 ± 1.9	12.0 ± 1.0	11.9 ± 1.0	13.7 ± 0.9	14.4 ± 1.2	14.3 ± 1.0		14.5 ± 1.4	13.2 ± 1.6
SHUNT (%)											
Control	11.7 ± 1.2		35.5 ± 4.4**	31.7 ± 3.8**	31.9 ± 3.8**	30.3 ± 3.8**	30.5 ± 3.8**	30.8 ± 3.9**		16.6 ± 1.9	17.2 ± 1.7*
TDIR	14.1 ± 2.2		37.7 ± 3.1**	38.8 ± 3.7**	39.0 ± 5.2*	40.1 ± 4.6**	38.4 ± 5.1*	39.6 ± 5.6*		18.7 ± 2.1	18.9 ± 1.9
GLDIR	16.8 ± 2.1		25.2 ± 4.5*	31.2 ± 7.6	30.1 ± 3.1**	30.0 ± 5.2*	28.9 ± 4.7*	25.9 ± 4.6*		23.2 ± 3.0	22.5 ± 1.9
PaO_2 (mm Hg)											
Control	496 ± 13		152 ± 37**	182 ± 39**	184 ± 39**	203 ± 45**	209 ± 45**	215 ± 47**		475 ± 17	471 ± 12
TDIR	502 ± 25		158 ± 39**	142 ± 41**	140 ± 40**	128 ± 39**	151 ± 30**	160 ± 31**		422 ± 22*	422 ± 18**
GLDIR	500 ± 10		327 ± 62*	315 ± 63*	291 ± 52*	299 ± 77*	308 ± 70*	323 ± 76		335 ± 70	370 ± 51*
$PaCO_2$ (mm Hg)											
Control	38.4 ± 1.9		43.1 ± 3.2	40.5 ± 3.5	41.3 ± 4.0	41.4 ± 3.8	42.7 ± 4.0	43.4 ± 4.0		42.7 ± 2.2	42.8 ± 2.5
TDIR	35.3 ± 1.3		35.3 ± 2.0	37.0 ± 3.1	38.5 ± 3.0	39.5 ± 3.9	40.7 ± 4.0	43.9 ± 4.1		39.2 ± 0.7	40.3 ± 1.0
GLDIR	35.6 ± 0.8		39.5 ± 3.6	42.5 ± 2.5	45.1 ± 1.7*	45.4 ± 2.7*	44.8 ± 4.4	43.7 ± 2.8		40.3 ± 1.3**	40.8 ± 1.0**
ARTERIAL pH											
Control	7.39 ± .03		7.36 ± .02	7.37 ± .02	7.36 ± .02	7.36 ± .02	7.35 ± .02	7.34 ± .02		7.34 ± .01	7.35 ± .01
TDIR	7.39 ± .02		7.37 ± .02	7.36 ± .03	7.34 ± .02	7.33 ± .03	7.32 ± .03	7.29 ± .03*		7.34 ± .01	7.33 ± .02
GLDIR	7.38 ± .01		7.34 ± .03	7.30 ± .02*	7.28 ± .02**	7.28 ± .03*	7.28 ± .04	7.29 ± .03*		7.32 ± .02**	7.32 ± .02**
PvO_2 (mm Hg)											
Control	54.5 ± 4.6		49.2 ± 1.6	48.5 ± 2.0	49.6 ± 2.8	49.7 ± 3.1	51.2 ± 2.9	51.9 ± 3.4		64.2 ± 2.1	65.1 ± 2.1
TDIR	56.7 ± 4.8		50.0 ± 4.2	44.6 ± 3.9	45.0 ± 3.7	44.6 ± 4.2	47.3 ± 3.0	49.4 ± 1.8		59.6 ± 3.8	59.3 ± 3.8
GLDIR	64.9 ± 3.4		53.2 ± 2.7	66.2 ± 10.6	61.0 ± 6.7	62.5 ± 8.0	59.2 ± 6.9	57.4 ± 7.4		57.7 ± 9.1	53.5 ± 14.7

** Significant difference ($P < 0.01$) from baseline

* Significant difference ($P < 0.05$) from baseline

B1 (Break period 1= mean ± SE) in control, TDIR and GLDIR groups was 54 ± 6, 62 ± 5 and 71 ± 9 min respectively.

B2 (Break period 2= mean ± SE) in control, TDIR and GLDIR groups was 44 ± 1, 48 ± 6 and 33 ± 5 min respectively

Abbreviation: PaO_2, arterial O_2 tension; $PaCO_2$, arterial CO_2 tension; PvO_2, mixed venous O_2 tension

Figure 1. Airway pressure (mean ± SE) in the CNT, TDIR and GLDIR groups

B - Baseline (0), T - treatment (90 min) and PT - post-treatment (30 min) periods

*, ** Significant difference ($P < 0.05, 0.01$) from the baseline. No data collected during break period 1 and 2 (B1, B2)

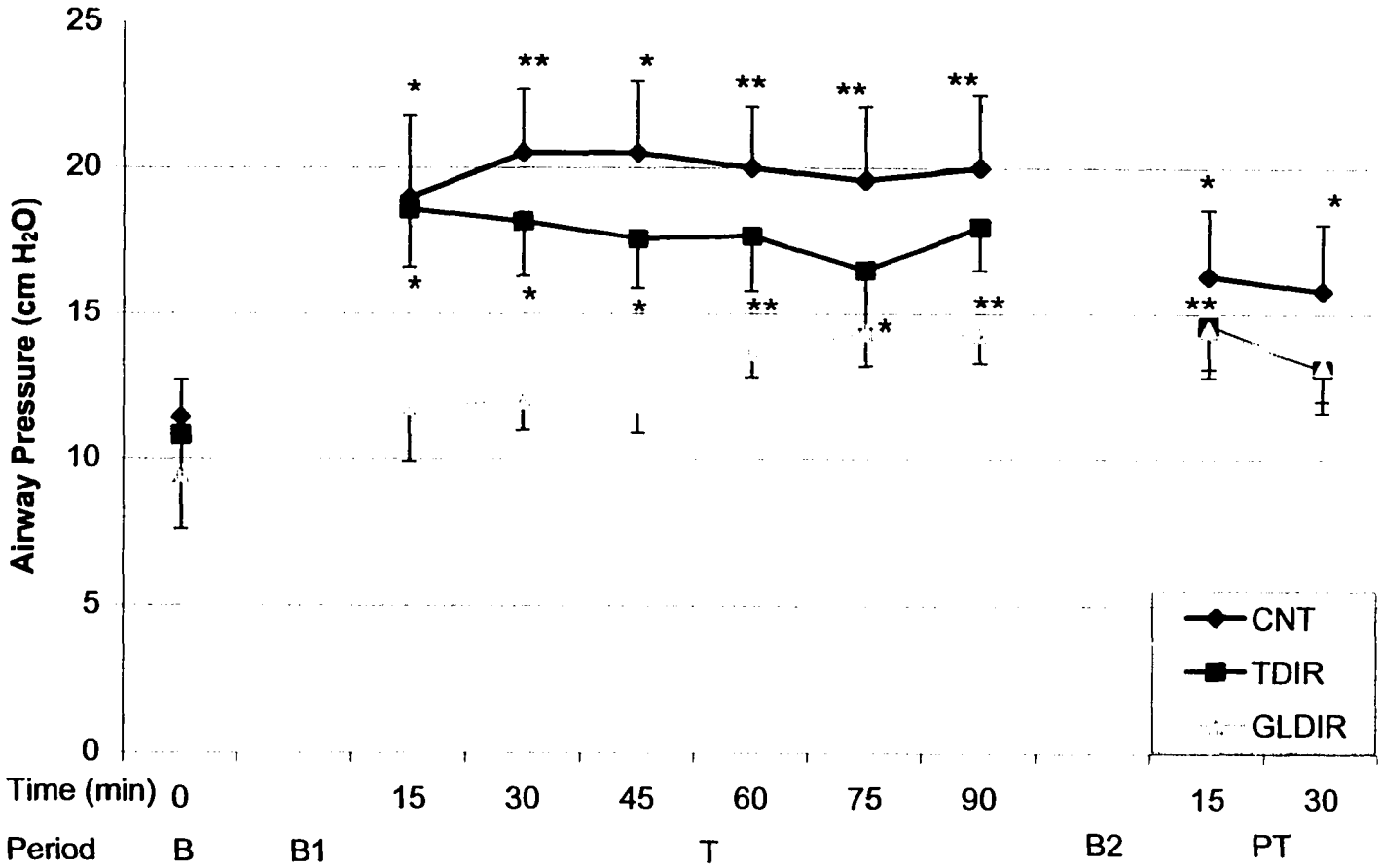
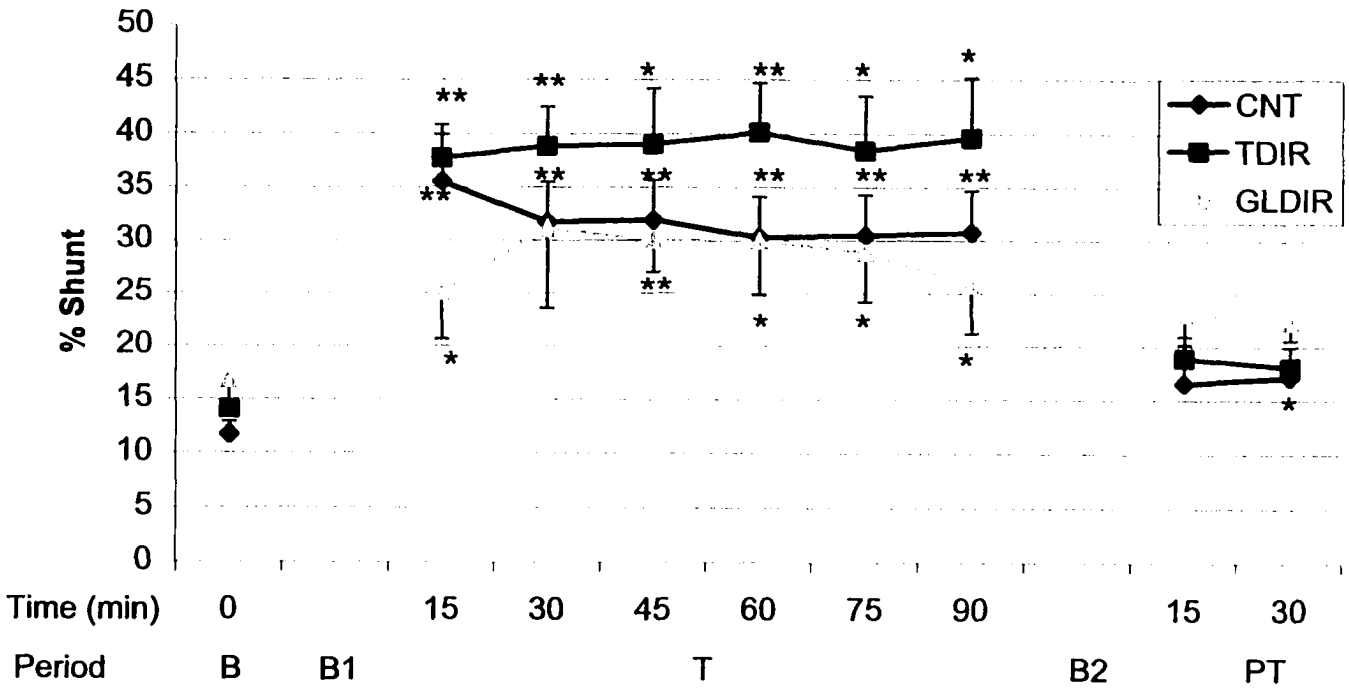

25
20
15
10
5
0
Airway Pressure (cm H2O)
Time (min) 0 15 30 45 60 75 90 15 30
Period B B1 T B2 PT
CNT
TDIR
GLDIR

Figure 2. % Shunt (mean ± SE) of the CNT, TDIR and GLDIR groups

B - Baseline (0), T - treatment (90 min) and PT - post-treatment (30 min) periods

*, ** Significant difference ($P < 0.05, 0.01$) from the baseline. No data collected during break period 1 and 2 (B1, B2)


50
45
40
35
30
25
20
15
10
5
0
% Shunt
CNT
TDIR
GLDIR
Time (min)
0
15
30
45
60
75
90
15
30
Period
B
B1
T
B2
PT

post-treatment period of all groups decreased to values that were close to the baseline and not significantly different except at the 30 min sample time in the CNT group. PaO_2 decreased significantly during the treatment period in the CNT, TDIR, and GLDIR groups (Fig 3). The PaO_2 increased during the post-treatment period in all groups, but the PaO_2 values of the TDIR and GLDIR groups were still significantly lower than the baseline values. One dog with a right lung collapse in the TDIR group developed severe hypoxemia, the PaO_2 ranged from 51 to 69 mm Hg during the entire treatment period. Another dog with right lung collapse in the same group experienced a transient hypoxemia (PaO_2 = 76 mm Hg) at the 60 min sample time in the treatment period. None of the dogs in the CNT or TDIR groups with left lung collapse (n=4) had a PaO_2 below 100 mm Hg.

The PaO_2 from dogs with right lung collapse were compared to those with left lung collapse. The PaO_2 values during the treatment period with the right lung collapsed were significantly lower at the 15 min ($P < .01$), 30 min ($P < .05$) and 45 min ($P < .05$) sample times using a two-way ANOVA. However, when the data was examined with the Bonferroni's adjustment (a more conservative test of significant difference) the PaO_2 values at the 15 min sample time with the right lung collapsed were the only values that were significantly less than those with the left lung collapsed (Fig 4).

During the treatment and post-treatment periods, the $PaCO_2$ did not change significantly from baseline. At the 45 and 60 min sample times during the treatment period, the $PaCO_2$ values of the GLDIR group were increased significantly from

Figure 3. Arterial oxygen tension (PaO_2) (mean ± SE) of the CNT, TDIR and GLDIR groups

B - Baseline (0), T - treatment (90 min) and PT - post-treatment (30 min) periods

*, ** Significant difference ($P < 0.05, 0.01$) from the baseline. No data collected during break period 1 and 2 (B1, B2)

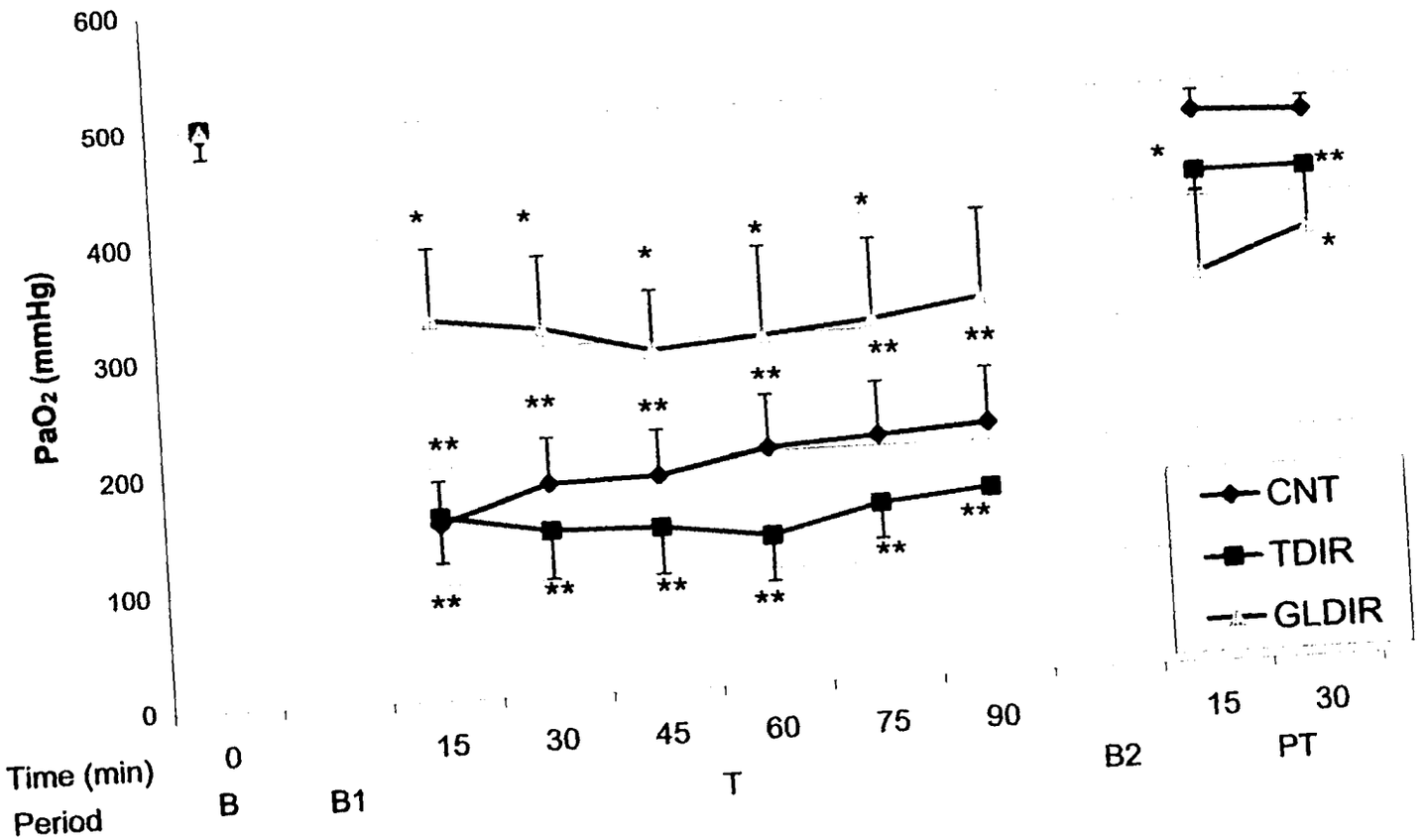

600
500
400
300
200
100
0
PaO2 (mmHg)
Time (min)
Period
0
B
B1
15
30
45
60
75
90
T
B2
15
30
PT
CNT
TDIR
GLDIR

Figure 4. PaO_2 values (mean ± SE) with left (Lt) lung collapse were significantly (†, $P < .05$; ††, $P < .01$) greater than with right (Rt) lung collapse at 15, 30 and 45 min in the treatment period (T) but the Bonferroni's adjustment showed statistical significance (‡, $P < .01$) only at the15 min sample.

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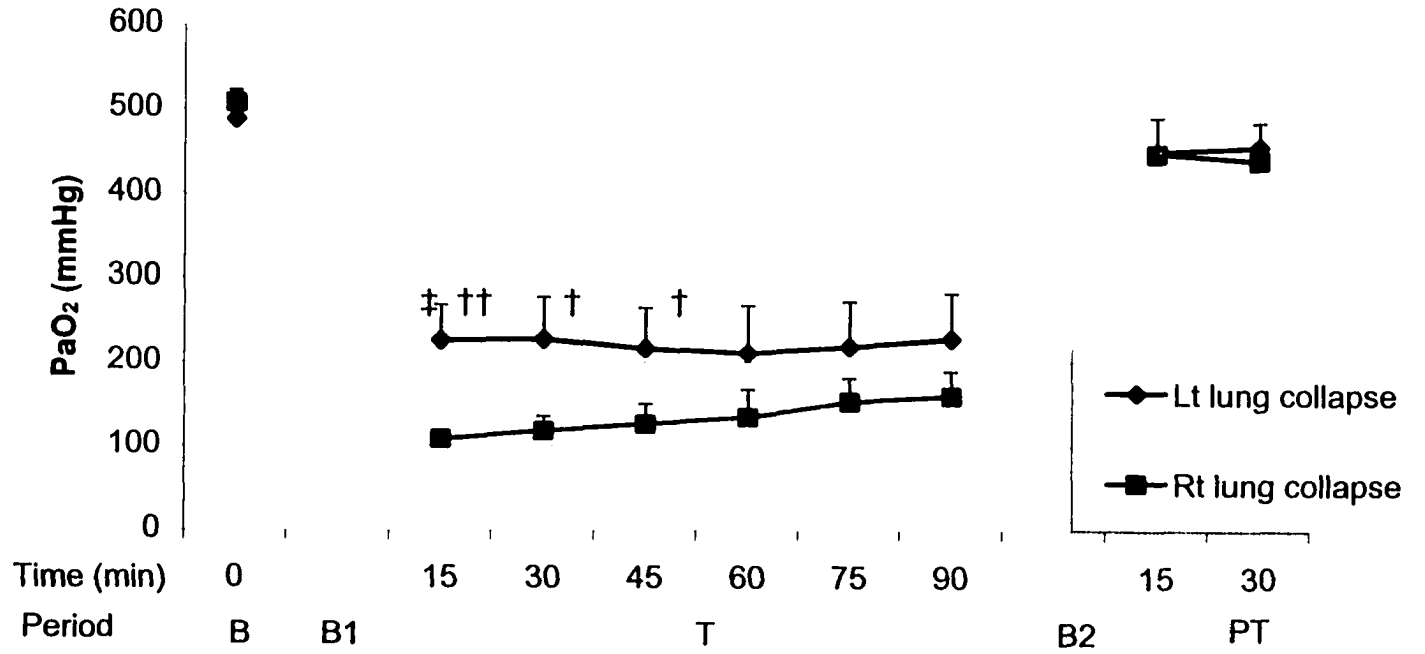
600
500
400
300
200
100
0
PaO2 (mmHg)
‡
††
†
†
Lt lung collapse
Rt lung collapse
Time (min)
0
15
30
45
60
75
90
15
30
Period
B
B1
T
B2
PT

baseline. Arterial pH decreased slightly during the treatment and post-treatment periods in all groups.

The arterial pH in the GLDIR group was significantly less than baseline values during those sample times of the treatment and post-treatment periods when the $PaCO_2$ values were increased. The PvO_2 decreased and increased from baseline values during the treatment and post-treatment periods, respectively, in all groups but was not statistically significant.

Other variables that were not significantly different from the baseline values during the treatment and post-treatment periods of all groups included systolic and diastolic arterial pressure, systolic pulmonary arterial pressure, CVP, PCWP, systemic vascular resistance (SVR), pulmonary vascular resistance (PVR), RR, tidal volume (TV), oxygen delivery (OD), oxygen consumption (OC), oxygen utilization (OU), AF and body temperature.

The results of the arterial blood gas samples on day 2 were compared among the three groups and found not to be significantly different. The means of PaO_2 and $PaCO_2$ in the CNT, TDIR and GLDIR groups were 84.2, 33.7; 82.4, 30.9 and 87.2, 33.6 mm Hg, respectively.

Discussion

The cardiopulmonary response of healthy dogs to thoracoscopy (with or without a diaphragmatic incision and repair) was not significantly different from gasless laparoscopy. The lack of significant difference of any variables between the three groups may be due to the small number of dogs in each group and the

combination of the right or left lung ventilation in the same group. The treatments of the three groups did cause significant cardiopulmonary change from baseline (intermittent positive pressure ventilation with a closed chest). The changes in HR, CO and MAP during the treatment periods in the CNT and TDIR groups may have resulted from sympathetic nervous system activation due to surgery and one-lung collapse, whereas those changes in the GLDIR group may have resulted from the surgical manipulations with two-lung ventilation. The significantly increased MPAP in the CNT and TDIR groups may be due to hypoxic pulmonary vasoconstriction (HPV)[16-18] and sympathetic nervous system activation due to surgery. The increased MPAP in the GLDIR group may be due to the pneumothorax and partial lung collapse with reduced functional residual capacity (FRC) and sympathetic nervous system activation. HPV is a protective pulmonary mechanism in mammals. When the alveolar oxygen tension is decreased, local vasoconstriction of small pulmonary arteries is induced. HPV results in the dual response of increased pulmonary perfusion pressure (PPP) and blood flow diversion from hypoxic regions to normoxic regions of the lung. The expected increase in pulmonary shunt with alveolar hypoxia is reduced and the arterial oxygen tension increases with HPV.[16] The degree of HPV in a particular lung segment is influenced by multiple factors including alveolar PO_2, PvO_2, CO and PPP. Anesthetic agents also have direct and indirect effects on the normoxic and hypoxic lung regions altering HPV.[19,20] Inhalational anesthetics such as isoflurane anesthesia will inhibit HPV by direct action.[18,19] The exact mechanism of inhibition is unknown, but cyclooxgenase inhibition has been shown to potentiate

the magnitude of HPV in conscious and isoflurane-anesthetized dogs.[18] Thus, one possible mechanism by which isoflurane anesthesia may attenuate HPV would involve enhancement of the vasodilator efficacy of cyclooxygenase metabolites.[18] The indirect effect of inhalational anesthetics on HPV was clarified by Marshall and Marshall who reported that a reduction in CO will decrease the PvO_2 (if oxygen consumption remains unchanged) which in turn would intensify HPV.[20]

The increased peak airway pressure with IPPV during the treatment period in the CNT and TDIR groups may have resulted from an increase in airway resistance concomitant with switching from TLV to OLV.[21] The decreased PaO_2 and increased percent shunt in CNT and TDIR groups were significantly different from the baseline during OLV because of the increase in ventilation-perfusion mismatch within the lungs. The attenuating effect of isoflurane anesthesia on hypoxic pulmonary vasoconstriction may have increased the hypoxic potential of OLV. The decreased PaO_2 and increased % shunt in the GLDIR group probably resulted from a ventilation-perfusion mismatch secondary to the decrease in FRC that occurred with pneumothorax. When the PaO_2 data from dogs in the CNT and TDIR groups was pooled according to right (n=6) and left lung (n=4) collapse it was found that the right lung collapse group showed a trend of lower PaO_2 values than the left lung collapse group. This result is similar to a study in humans.[22] Since the dog's right lung is larger than the left lung, a right lung collapse with isoflurane attenuation of HPV could result in a greater decrease in PaO_2 and increase in % shunt. Also, collapse of the larger right lung would cause a greater increase in MPAP and PPP

which indirectly attenuates HPV and increases pulmonary blood flow to the hypoxic lung which could result in an increase in physiologic shunt.[23,24]

Traumatized animals with diaphragmatic hernia may have pulmonary contusions and ventilation-perfusion mismatch before anesthesia. The consequence of producing a right lung collapse in an actual trauma case may cause more severe hypoxemia when compared with a left lung collapse. There are several techniques to improve the PaO_2 level during one-lung ventilation that may help reduce the patient's risk of hypoxemia.[25-28]

In this study, the partial pressure of arterial carbon dioxide ($PaCO_2$) was controlled during the experiment and minute ventilation was altered in order to maintain the $PaCO_2$ at 40 ± 5 mm Hg. The end-tidal carbon dioxide concentration ($PEtCO_2$), determined from gas samples from the distal airway during the treatment period with either TLV or OLV did not correlate well with the $PaCO_2$ levels (data not shown). A recent study concluded that capnometry in thoracotomy dogs was not a reliable indicator for the adequacy of ventilation.[29] The reason for the difference in $PaCO_2$ and $PEtCO_2$ values with thoracotomy and TLV or OLV may be the increase of ventilation / perfusion mismatch associated with atelectatic lungs.[29]

The results in this study indicated that the changes in cardiopulmonary parameters were less in the GLDIR group, although not statistically different from the CNT and TDIR groups. In addition, during thoracoscopy, right lung collapse with left lung ventilation may predispose to an increased risk of hypoxemia when compared to left lung collapse with right lung ventilation.

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Appendix

Formulas used for calculation of cardiopulmonary variables

$$CI\ (ml/min/kg) = [CO\ (L/min) \div body\ weight\ (Kg)] \times 10^3$$

$$MV\ (L/min) = TV\ (L/breath) \times RR\ (breaths/min)$$

$$Q_s/Q_t\ (\%) = [CcO_2\ (ml/dl) - CaO_2\ (ml/dl) \div CcO_2\ (ml/dl) - CvO_2\ (ml/dl)] \times 100$$

CO = cardiac output; CI = cardiac index; Q_{ps}/Q_t = physiologic shunt; CcO_2 = pulmonary end capillary oxygen content; CaO_2 = arterial oxygen content; CvO_2 = mixed venous oxygen content; MV = minute ventilation; TV = tidal volume; RR = respiratory rate.

References

1 Smith RS, Fry WR, Tsoi EK, et al: Preliminary report on videothoracoscopy in the evaluation and treatment of thoracic injury. Am J Surg 166:690-3; discussion 693-5,1993

2 Ffrantzides CT and Carlson MA: Laparoscopic repair of a penetrating injury to the diaphragm: A case report. J Laparoendosc Surg 4:153-6, 1994

3 Ho HS, Gunther RA and Wolfe BM: Intraperitoneal carbon dioxide insufflation and cardiopulmonary functions. Arch Surg 127:928-933, 1992

4 Mark DW and Murr PC: Laparoscopic insufflation of the abdomen depresses cardiopulmonary function. Surg Endosc 7:12-16, 1993

5 Lantz PE and Smith JD: Fatal carbon dioxide embolism complicating attempted laparoscopic cholecystectomy – Case report and literature review. J Forensic Sci 39:1468-80, 1994

6 Martin IG and McMahon MJ: Gasless Laparoscopy. J R Coll Surg Edinb 41:72-74, 1996

7 Kitano S, Tomikawa M, Iso Y, et al: A safe and simple method to maintain a clear field of vision during laparoscopic cholecystectomy. Surg Endosc 6:197-8, 1992

8 Gazayerli MM: The Gazayerli endoscopic retractor model 1. Surg Laparosc Endosc 1:98-100, 1991

9 Koivusalo AM, Kellokumpu I, Scheinin M, et al: A comparison of gasless mechanical and conventional carbon dioxide pneumoperitoneum methods for laparoscopic cholecystectomy. Anesth Analg 86:153-8, 1998

10 Couture P, Boudreault D, Girard F, et al: Haemodynamic effects of mechanical peritoneal retraction during laparoscopic cholecystectomy. Can J Anaesth 44 (5 Pt 1) :467-72, 1997

11 Power M, McCoy D and Cunningham AJ: Laparoscopic-assisted repair of a traumatic ruptured diaphragm. Anesth Analg 78:1187-9, 1994

12 Paolucci V, Gutt CN, Schaeff B, et al: Gasless laparoscopy in abdominal surgery. Surg Endosc 9:497-500, 1995

13 Wang Q, Deng S and Huang Y: Application of gasless laparoscopic device in laparoscopic surgery. Chung Hua Wai Ko Tsa Chih 33:15-8, 1995

14 Canwell S, Duke T, Walker D, et al: One-lung versus two-lung ventilation in the dog: Comparison of cardiopulmonary parameters. Proc 30th Annu Meet Am Coll Vet Anesth, 1996

15 Garcia F, Prandi D, Pena T, et al: Examination of the thoracic cavity and lung lobectomy by means of thoracoscopy in dogs. Can Vet J 39:285-291,1998

16 Glasser SA, Domino KB, Lindgren L, et al: Pulmonary blood pressure and flow during atelectasis in the dog. Anesthesiology 58:225-31, 1983

17 Malmkvist G, Fletcher R, Nordstrom L, et al: Effects of lung surgery and one-lung ventilation on pulmonary arterial pressure, venous admixture and immediate postoperative lung function. Br J Anaesth 63:696-701, 1989

18 Lennon PF and Murray PA: Attenuated hypoxic pulmonary vasoconstriction during isoflurane anesthesia is abolished by cyclooxygenase inhibition in chronically instrumented dogs. Anesthesiology 84:404-414, 1996

19 Domino KB, Borowec L, Alexander CM et al: Influence of isoflurane on hypoxic pulmonary vasoconstriction in dogs. Anesthesiology 64:423-429, 1986

20 Nunn JK: Nunn's Applied Respiratory Physiology (ed 4). Oxford, England, Butterworth-Heinemann, 1994, pp 414

21 Barnas GM and Sprung J: Lung mechanical behavior during one-lung ventilation. J Cardiothorac Vas Anesth 1:604-7, 1997

22 Katz Y, Zisman E, Isserles SA et al: Left, but not right, one-lung ventilation causes hypoxemia during endoscopic transthoracic sympathectomy. J Cardiothorac Vas Anesth 10:207-9, 1996

23 Marshall BE and Marshall C: Continuity of response to hypoxic pulmonary vasoconstriction. J Appl Physiol 49:189-196,1980

24 Marshall BE and Marshall C: A model for hypoxic constriction of the pulmonary circulation. J Appl Physiol 64 69-77, 1988

25 Moutafis M, Liu N, Dalibon N, et al: The effects of inhaled nitric oxide and its combination with intravenous almintrine on PaO_2 during one-lung ventilation in patients undergoing thoracoscopic procedures. Anesth Analg 85:1130-5, 1997

26 Inomata S, Nishikawa T, Saito S, et al: "Best" PEEP during one-lung ventilation. Br J Anaesth 78:754-6, 1997

27 Dikmen Y, Aukac B and Eroleay H: Unilateral high frequency jet ventilation during one-lung ventilation. European J Anaesth 14:239-243, 1997

28 Reid CW, Slinger PD and Lenis S: A comparison of the effects of propofol-alfentanil versus isoflurane anesthesia on arterial oxygenation during one-lung ventilation. J Cardiothorac Vas Anesth 10:860-3, 1996

29 Wagner AE, Gaynor JS, Dunlop CI, et al: Monitoring adequacy of ventilation by capnometry during thoracotomy in dogs. JAVMA 212:377-9, 1998

CHAPTER THREE THORACOSCOPIC AND GASLESS LAPAROSCOPIC DIAPHRAGMATIC INCISION REPAIR IN DOGS

A paper to be submitted for publication in Veterinary Surgery

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Objective---The objectives of the study were to develop and compare two video-assisted surgical techniques for repair of a diaphragmatic incision: 1) gasless laparoscopy using an abdominal wall lifting device, and 2) thoracoscopy with one-lung ventilation (OLV).

Animals--- Fifteen healthy young female dogs weighing 11.4 ± 0.5 kg (mean ± SE) were assigned to three groups: control (CNT, n=5), thoracoscopic diaphragmatic incision repair (TDIR, n=5) and gasless laparoscopic diaphragmatic incision repair (GLDIR, n=5).

Design---Randomized complete block design

Methods---All dogs were anesthetized and positioned in dorsal recumbency. Control (CNT) dogs received OLV and thoracoscopy to confirm OLV during the treatment period. TDIR dogs received OLV and a thoracoscopic diaphragmatic incision (6-8 cm) and repair. One left and two right thoracoscopic approaches were utilized for the repair of the left and right diaphragmatic incisions. The GLDIR dogs received two-lung ventilation (TLV) and a gasless laparoscopic diaphragmatic

incision and repair. The GDIR dogs had right, left (6-8 cm) and transdiaphragmatic incisions (10-12 cm) in the ventral diaphragm. A simple continuous suture pattern with extracorporeal knot tying was utilized for all repairs.

Results---Thoracoscopic and gasless laparoscopic diaphragmatic incision repairs were successfully performed and all dogs recovered with no major complication. Surgical time for the right thoracoscopic diaphragmatic incision repairs, (n=3; 45, 47 and 60 min) was shorter than that for the left thoracoscopic diaphragmatic incision repairs (n=2, 80 and 82 min). In the GLDIR group, the surgical time was similar (45 and 47 min) for the right and left diaphragmatic incision repairs. Incisions involving both right and left sides of the diaphragm in three dogs had surgical times of 75, 90 and 120 min.

Conclusion---This study describes the use of thoracoscopy and gasless laparoscopy to repair diaphragmatic incisions. These techniques could potentially have clinical application that would produce less post-operative pain and shorter recuperation times for diaphragmatic hernia repair in clinical patients.

Introduction

In human medicine, laparoscopic and thoracoscopic surgery has been gaining popularity since 1988 with the help of video-camera systems and the development of laparoscopic cholecystectomy.[1] As generally accepted, its merits are the provision of a minimally invasive procedure and short recuperation time. As a result, numerous surgical procedures and instruments have been developed. But in veterinary medicine only a few laparoscopic and thoracoscopic surgical

procedures have been described. Hence, opportunities exist for the development of new laparoscopic and thoracoscopic surgical procedures that are minimally invasive and have short recovery times for animal patients.

Traumatic diaphragmatic hernia is a common injury in small animals and a laparotomy, thoracotomy or a combination of both techniques is performed to repair the hernia. Repair of traumatic diaphragmatic hernia has been successfully performed in humans using video-assisted thoracoscopy[2] and laparoscopy with CO_2 pneumoperitoneum.[3] A gasless laparoscopic technique for traumatic diaphragmatic hernia has not been reported.

In human and veterinary medicine, the majority of laparoscopic surgical procedures have been carried out utilizing carbon dioxide (CO_2) pneumoperitoneum or capnoperitoneum. But, there are potentially serious physiological effects from the pressurized CO_2 gas within the abdomen.[4,5] The most serious of these effects is the rare but life threatening risk of gas embolism.[6] Cardiac function may be altered by entrapment of blood in the lower limbs and ventilatory pressures may need to be increased to maintain oxygenation of arterial blood.[7] An important complication of traumatic diaphragmatic repair with CO_2 pneumoperitoneum is an increase in intrapleural pressure and lung collapse producing a clinical situation similar to a tension pneumothorax.[8,9] Capnoperitoneum also creates the need for a sealed operating system to prevent gas leakage and loss of operating space.

Gasless, isopneumic or apneumic laparoscopy was first described in 1991,[10,11] and involved lifting the patient's abdominal wall with a mechanical device

instead of gas insufflation. Without the effect of pressurized carbon dioxide gas in the abdomen, gasless laparoscopy provided hemodynamic and respiratory function stability as well as being theoretically air embolism free when compared to capnoperitoneum.[5,12,13] Further, with gasless laparoscopy, standard surgical instruments can be used,[14] it is easier for suturing and knot tying, [15] and continuous suction can be used without a loss of exposure.[14]

Thoracoscopy, like laparoscopy, requires that operating space be provided for instrument manipulation and visualization. One method for providing this space in the thoracic cavity is to collapse one lung lobe and ventilate the patient with the remain lung. One-lung ventilation (OLV) provides an adequate surgical field for conventional thoracic and thoracoscopic surgery. By collapsing one lung lobe, the surgeon has a large working space and access to the thoracic organs. One-lung ventilation has not been routinely performed in veterinary medicine and there is limited information about the cardiopulmonary effects. [16,17]

The purpose of this study was to develop and compare two video-assisted surgical techniques for repair of diaphragmatic incisions: 1) gasless laparoscopy using an abdominal wall lifting device, and 2) thoracoscopy with OLV. The cardiopulmonary effects of one-lung ventilation and two-lung ventilation during thoracoscopic and gasless laparoscopic diaphragmatic incision repair in the dog were measured and are being reported in a separate publication.

Materials and Methods

Animals

This study was approved by the Committee on Animal Care of Iowa State University. All dogs were housed in approved facilities managed by the Laboratory Animal Resources.

Fifteen adult, female dogs were randomly assigned in an equal number to three groups: control (CNT), thoracoscopic diaphragmatic incision and repair (TDIR) and gasless laparoscopic diaphragmatic incision and repair (GLDIR). All groups were similar in age, breed and mean weight (11.4 ± 0.51 kg). The dogs were found to be healthy by physical examination, complete blood count, serum chemistry profile and thoracic radiography.

Anesthesia and One-lung ventilation

The dogs were intramuscularly premedicated with butorphanol 0.2 mg/kg (Torbugesic, Fort Dodge Inc, Fort Dodge, IA) fifteen minutes before anesthesia was intravascularly induced using 5% thiopental sodium (Pentothal, Abbott laboratories, North Chicago, IL) to allow airway intubation. Endobronchial intubation was performed using bronchoscopy in CNT and TDIR dogs. A 120-cm long guide composed of a flexible wire fixed within a 4-mm diameter polyethylene tube was inserted with bronchoscopic assistance into the left bronchus. Then, the endobronchial barrel of a double-lumen 9 fr tube (Rusch, Rusch Inc., Duluth, GA) was inserted over the guide tubing until the tip of the barrel was positioned in the left bronchus. Dogs of the GLDIR group received endotracheal intubation. Anesthesia

was maintained with 1.5-2% isoflurane (Isoflo, Abbott Laboratories, North Chicago, IL) in 100% oxygen at a flowrate of 1-2 LPM with a semiclosed circle breathing circuit. Instrumentation for collecting physiologic parameters is described in another publication.

Experimental design

All dogs were positioned in dorsal recumbency and the thorax of CNT and TDIR dogs and the thorax and abdomen of GLDIR dogs were prepared for aseptic surgery.

Control (CNT) dogs had OLV and thoracoscopy during the treatment period while TDIR dogs received OLV and a thoracoscopic diaphragmatic incision and repair. The GLDIR dogs received two-lung ventilation (TLV) and gasless laparoscopic diaphragmatic incision and repair. All dogs were given a pneumothorax before thoracoscopic or laparoscopic approaches. The surgical time started when the diaphragm was incised and ended when the incision was completely sutured.

Equipment

The video-assisted laparoscopy or thoracoscopy was performed with a 10 mm, 10° telescope (Richard Wolf, Richard Wolf Co, Vermon Hill, IL) attached to a digital camera (Dyonics, Dyonics Inc, Andover, MA). The light port was connected via a fiberoptic cable to a metal halide light source (Autobrite, Dyonics Inc, Andover, MA). The laparoscopic instruments used included: needle holder, grasping forceps, babcock forceps, tissue retractor, electrocautery and suction probe (Ethicon Inc. Somerville, NJ) and scissors (Take-apart, Karl Storz Inc, Goleta, CA). The scope

and surgical instruments were introduced into the abdomen through 12-mm trocar-cannula units (Endopath, Ethicon Inc., Somerville, NJ) which were equipped with a spring-loaded safety shield.

Nylon suture with a long straight cutting needle (Ethilon KS, 2/0, 75 cm, Ethicon Inc, Somerville, NJ) was modified for suturing the diaphragm by shortening the length of the needle to 2 cm.

Thoracoscopy

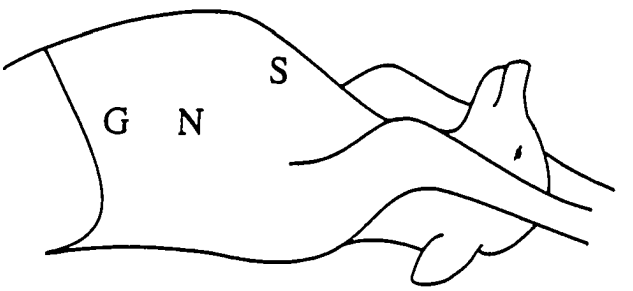
After pneumothorax was produced, a 1.5-cm skin incision was made over the fourth intercostal space at the level of the costochondral junction to accommodate the tip of the trocar cannula unit which was angled caudally and inserted into the substernal space. This portal location was between the heart and sternum when the scope was inserted. The heart, hemithorax and mediastinum could be visualized. A window was created through the mediastinum by dissecting with a 2-mm grasping forceps passed through the instrument channel of the scope. The mediastinal window was used to confirm OLV by passing the scope through the window into the opposite side of the chest.

Thoracoscopic approach

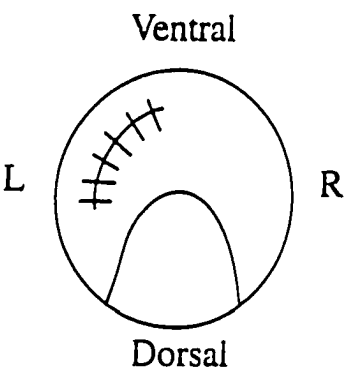
Right and left thoracoscopic approaches utilized three portals. The scope was inserted at port (S) as described above. For the left thoracoscopic approach, the portals for the needle holder (N) and grasping forceps (G) were located at one-third to one-half of the distance from the sternum to the vertebral column in the 5^{th} or 6^{th} and 7^{th} intercostal spaces, respectively (Fig 1A). Two different right thoracoscopic

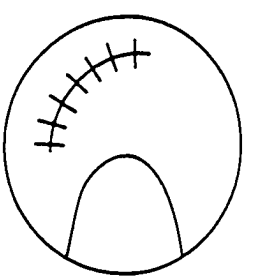
Figure 1 A, Diagram of the left thoracoscopic approach used in 2 dogs in which S, G and N were the locations for the entry of the telescope, grasping forceps and needle holder, respectively. B, the location of the incisions and repair of the diaphragm of the TDIR dogs.

A



B





approaches were used and are shown in Fig 2A and 2B. In the first approach, Fig 2A, the G port was located adjacent to the sternum in the 6th intercostal space, whereas the N port was about one-third to one-half of the distance from the sternum to the vertebral column in the same intercostal space. The second approach (Fig 2B) was similar to the left thoracoscopic approach, but the positions of the N and G ports were reversed for the right-handed surgeons.

Curved incisions in the pars costalis and sternalis of the diaphragm were made in TDIR dogs (Fig 1B, 2C). The length of the diaphragmatic incisions was approximately 6-8 cm and abdominal organs did not enter the thorax of most dogs. Two dogs received a left diaphragmatic incision and a left thoracoscopic approach for repair as shown in Fig 1A, the other three dogs in the TDIR group received a right diaphragmatic incision and one of the two approaches shown in Fig 2A, B for repair.

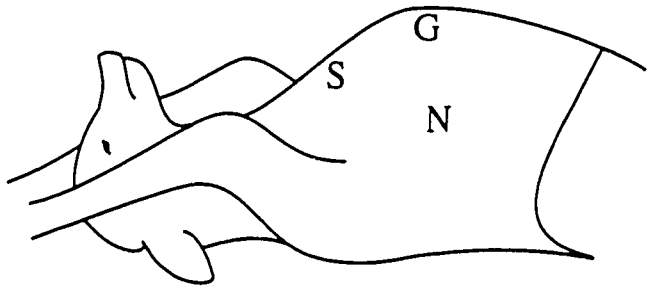
Gasless laparoscopic approach

The cranial abdominal wall was lifted away from the visceral organs, creating a working space without CO_2 pneumoperitoneum, with a device which consisted of two horizontally projecting arms that were connected to two vertical bars and a transabdominal rod (Fig 3).

To insert the transabdominal pin for gasless laparoscopy, the abdominal wall was lifted using a towel clamp percutaneously inserting into the rectus abdominis about 5 cm cranial to the umbilicus. While the abdominal wall was elevated a trocar cannula, the S port, was inserted on the midline at the umbilicus into the abdominal

Figure 2. A and B, Diagrams of the two right thoracoscopic diaphragmatic approaches used in 3 dogs in which S, G and N were the locations for the telescope, grasping forceps and needle holder, respectively. C, the location of the incisions and repair of the diaphragm in the three TDIR dogs.

A



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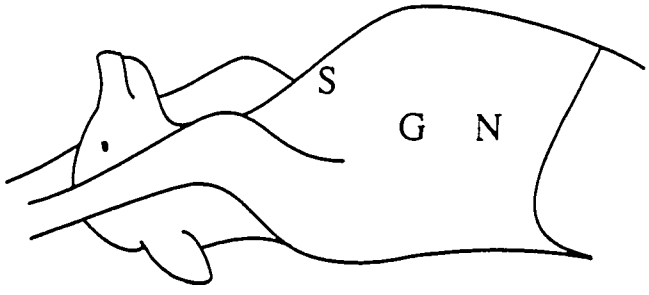

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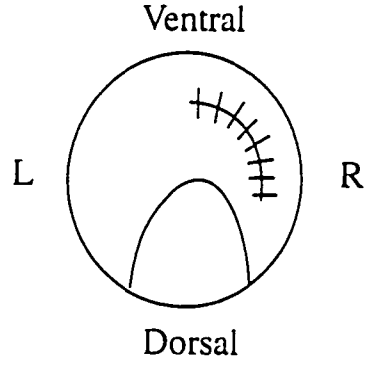
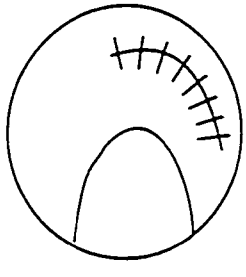




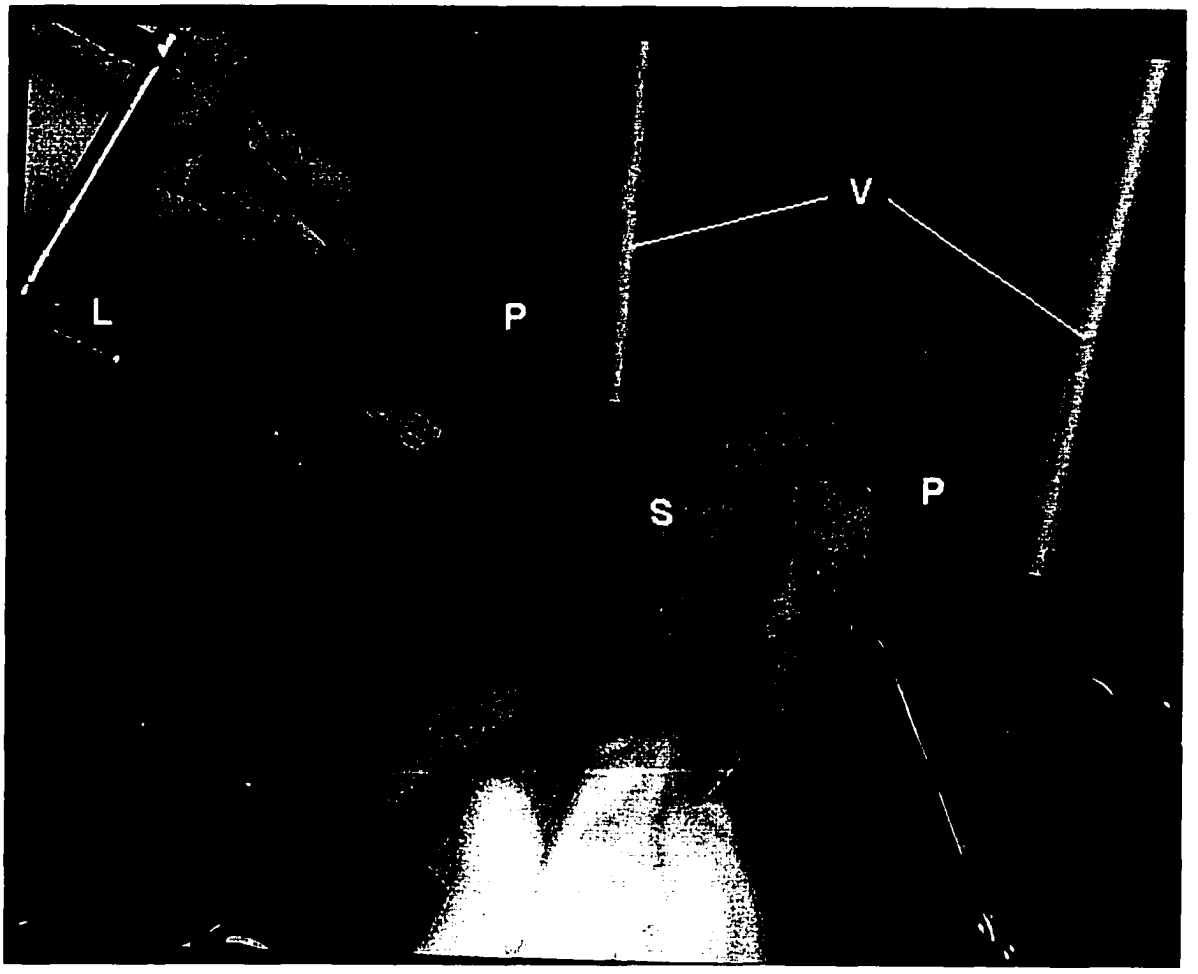


Figure 3. Gasless laparoscopy for creating and repairing a diaphragmatic incision. The abdominal wall and the cranial part of the falciform ligament were lifted away from the abdominal organs using a transabdominal pin (P) and supporting vertical bars (V). Several interrupted sutures (S) were placed around the falciform ligament under laparoscopic (L) guidance.

cavity. A 3 mm 35 cm long stainless steel rod was carefully passed into the abdomen through this port and the proximal end was directed craniolaterally towards one side of the abdominal wall behind the costal arch. An incision was made over the protruding rod through the skin and underlying musculature in order to expose the pin. The proximal end of the rod was pulled through the abdominal wall until the distal end was within the abdominal cavity. A scope was then inserted into the abdomen through the midline (S) port and used to direct the distal end of the rod beneath the cranial part of the falciform ligament and against the opposite abdominal wall at a symmetrical location. Again an incision was made over the protruding rod resulting in a trans-abdominal lifting rod. The ends of the rod were connected to two vertical bars that lifted the cranial abdominal wall and the falciform ligament. The N and G ports were inserted into the lifted area (Fig 4A).

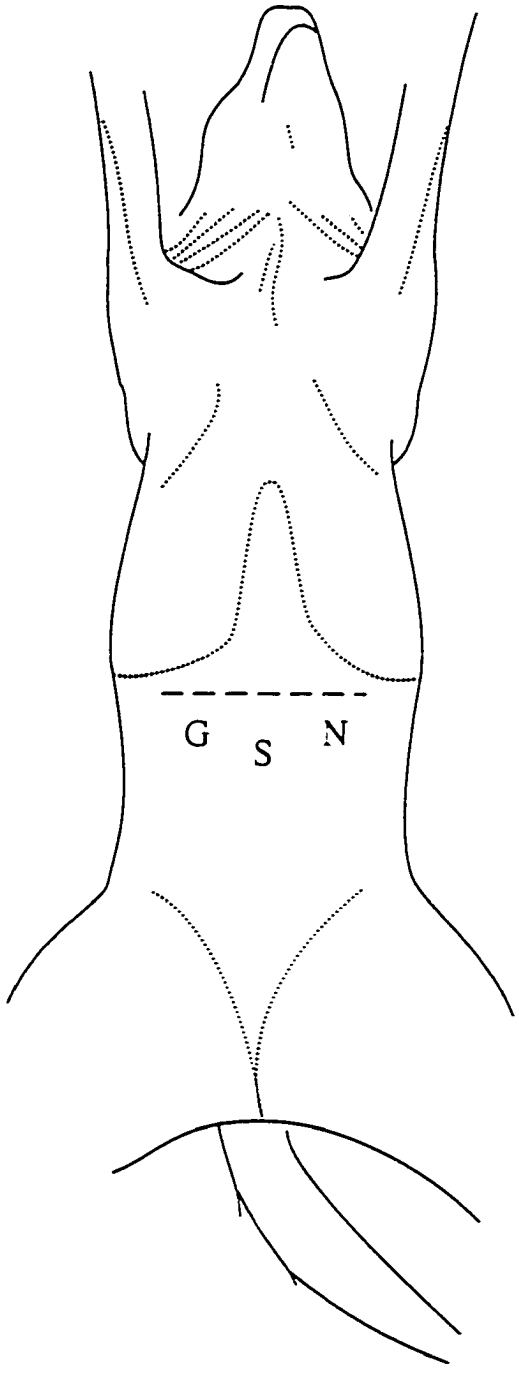
Curved incisions 6-12 cm long were made in the ventral part of the pars costalis and pars sternalis of the diaphragm in the GLDIR dogs (Fig 4B). One dog had a right diaphragm incision, one had a left diaphragm incision and the three other dogs had incisions involving both sides of the diaphragms (Fig 4B). All diaphragmatic incisions were laparoscopically repaired utilizing the abdominal lift device and the approach shown in Fig 4A.

Suturing technique

A simple continuous suture pattern was used to close all the diaphragmatic incisions. Preliminary studies revealed that the long length of suture needed for a

Figure 4. A, diagram of the gasless laparoscopic diaphragmatic approach. The dashed line indicates the location where the transabdominal rod was inserted across the abdominal wall. S, G and N are the locations of the telescope, grasping forceps and needle holder, respectively. B, a diagram showing the location of the incisions and repair performed on the diaphragm of the GLDIR dogs.

A



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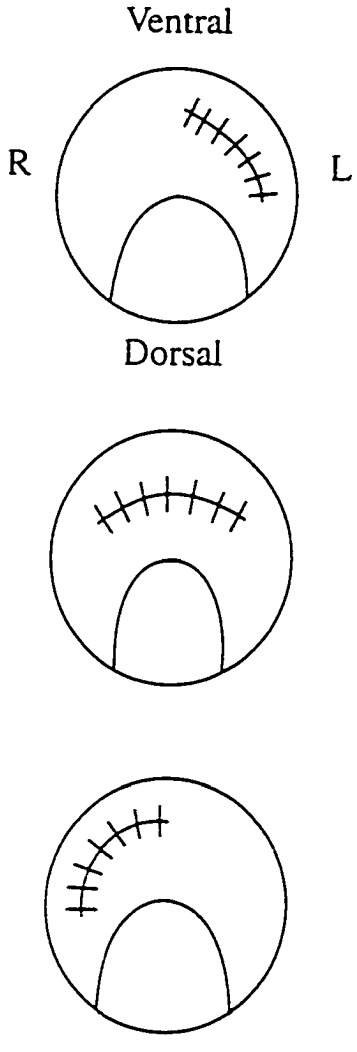

continuous suture pattern frequently became tangled and knotted within the abdominal cavity. This problem was eliminated by looping the suture material out the instrument port while the needle was being placed for each stitch in the diaphragm. Suturing for incision closure always started at the bottom (dorsal aspect) and ended at the top (ventral aspect). An extra-corporeal knot tying technique[18] was performed using either a 10-mm laparoscopic or regular babcock forceps.

All the wounds in the abdominal wall were closed with a simple interrupted suture pattern using 2/0 chromic catgut in the muscular and subcutaneus layers and 3/0 nylon in the skin.

Results

Thoracoscopic and gasless laparoscopic diaphragmatic incision repairs were successfully performed and all dogs recovered with no major complication. Surgical times for the right thoracoscopic diaphragmatic incision repairs (n=3; 45, 47 and 60 min) were shorter than that for the left thoracoscopic diaphragmatic incision repairs (n=2, 80 and 82 min). In the GLDIR group, the surgical time was similar (45 and 47 min) for the right and left gasless laparoscopic diaphragmatic incision repairs. Incisions involving both right and left sides of the diaphragm in three dogs had surgical times of 75, 90 and 120 min. The dog requiring 120 min for surgery received the longest incision and had liver herniation into the thorax that required an additional instrument port behind the xiphoid cartilage to help replace the liver.

Discussion

The success of laparoscopic or thoracoscopic diaphragmatic hernia repair will depend upon a combination of factors including suturing technique, anatomical location of the tear, surgical field or working space, visualizaton, skill of the surgeon and the patient's cardiopulmonary status.

Diaphragmatic suturing using a short (2 cm) straight needle with monofilament suture (2/0 nylon) and a simple continuous suture pattern with extracorporeal knot tying were determined by preliminary studies to be the preferred method for diaphragmatic closure during thoracoscopy and gasless laparoscopy. The advantages of the suturing technique used in the present study included elimination of suture material tangling inside the abdominal and thoracic cavity, less confusion due to the two-dimension view, shorter surgical time and reduced cost. The suturing techniques used for the repair of diaphragmatic rupture in humans included a simple interrupted suture pattern,[19] unique type of continuous suture,[20] staples[8] and a mesh or patch with clips.[21,22] Extracorporeal knot tying is a simple and easy technique compared to the intracorporeal technique. However, extracorporeal knot tying may create more tissue tension during the procedure and the first throw may loosen while the second throw is being applied.

Different surgical fields (working space) were produced by the thoracoscopic and gasless laparoscopic approaches. The thoracoscopic approach produced a surgical field anterior to the hemidiaphragm and between the heart and lateral thoracic wall. The diaphragmatic incisions located in the ventral part of the right or

left pars costalis and pars sternalis were feasible to repair. But, the one incision that extended beyond the midline of the diaphragm needed additional portals for instruments and careful attention was needed to avoid injury to the working lung on the other side. With the gasless laparoscopic technique, the distance between the diaphragm and the scope was shorter compared with that in the chest. In most circumstances, gasless laparoscopy provided a good surgical field and access to the pars sternalis, part of the tendinous diaphragm and the ventral part of both pars costalis. During laparoscopy the falciform ligament impeded the surgical view of the diaphragm. The transabdominal pin was purposely placed to elevate the falciform and improve visualization. But in one dog (Fig 3) a few interrupted sutures were also placed percutaneously around a very large falciform ligament to help hold it against the ventral abdominal wall.

The rigid rib cage provided less flexibility for portal movement and the location of instrument ports was very important in the thoracoscopic diaphragmatic incision repair. In contrast, the instrument ports moved more freely during suturing with gasless laparoscopy. The left thoracoscopic repairs were more difficult to perform when compared with the right for the right-handed surgeons. Consequently, the surgical time was different between the left versus right thoracoscopic approaches (80, 82 versus 45, 47 and 60 min, respectively).

The right, left and trans-diaphragmatic incisions of the ventral diaphragm were completely repaired by using the same gasless laparoscopic approach. The surgical time did not show a difference between the right versus left ventral

diaphragmatic incision repairs (45 versus 47 min). But, it was technically more difficult to suture on the midline during closure of the trans-diaphragmatic incisions with both approaches.

The metal halide light source provided adequate illumination and the camera system provided images with good resolution and natural color. The temperature difference between the dog's body and scope caused the scope to fog. The distal lens of the scope was simply wiped off with a clean gauze sponge moisten with sterile saline. The use of an antifog solution, laparoscopic heater, or placement of the scope tip in sterile warm water has been suggested to solve the problem. [23]

The surgical techniques provided visualization of both body cavities to, at least, a limited degree. The gasless laparoscospic approach provided the ability to explore the thoracic cavity by passing the scope through the diaphragmatic incision. But, the gasless laparoscopic technique allowed visualization of only the cranial abdominal cavity. Intrathoracic visualization was judged to be better with either thoracoscopy or gasless laparoscopy than conventional thoracotomy or laparotomy.

GLDIR was utilized in this study because it would provide better hemodynamic and respiratory function than laparoscopy with CO_2 pneumoperitoneum. In addition, a gas seal was not required and loss of the surgical exposure during continuous suction was not a problem with the gasless technique. Some conventional rather than laparoscopic surgical instruments were utilized in this procedure, thus minimizing the need for the purchase of laparoscopic instruments. The main disadvantages of the gasless technique in humans were

decreased surgical exposure and increased technical difficulty when compared with CO_2 pneumoperitoneum. The gasless technique provides only regional abdominal wall lifting, whereas CO_2 pneumoperitoneum lifts the whole abdominal wall. But, having only regional surgical exposure may optimize accomplishing some laparoscopic surgical procedures. New lifting devices and gasless laparoscopic instruments have been developed which may help solve the problem. [24]

Video-assisted thoracic surgery in humans has been performed with an alternative technique using low (6-8 mm Hg) pressure CO_2 insufflation of the thoracic cavity to facilitate lung collapse. The resulting pneumothorax may predispose to cardiopulmonary instability and air embolism that could be life threatening. In the present study, thoracoscopic diaphragmatic incision repair was performed without insufflating CO_2. In order to obtain adequate visualization, the thoracoscopy was performed with one-lung ventilation which may lead to hypoxemia. Clinically, animals with traumatic diaphragmatic hernia may have a decrease in pulmonary function due to the trauma and develop more severe hypoxemia than the animals in this study. Arterial oxygen partial pressure measurements during this study indicate that a right lung collapse may have a higher risk of hypoxemia when compared with a left lung collapse. The cardiopulmonary responses to one-lung ventilation and thoracoscopy and gasless laparoscopy during this study are reported in detail elsewhere.

In conclusion, this study has described the use of thoracoscopy and gasless laparoscopy to repair diaphragmatic incisions. These techniques could potentially

have clinical application that would provide reduced pain and shorter recuperation times in diaphragmatic hernia repair for clinical patients.

Acknowledgement

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References

1 MacFadyen BV and Ponsky JL: Laparoscopy for the general surgeon Surg Cli North Am 72:(Preface), 1992

2 Smith RS, Fry WR, Tsoi EK, et al: Preliminary report on videothoracoscopy in the evaluation and treatment of thoracic injury. Am J Surg 166:690-3; discussion 693-5,1993

3 Frantzides CT and Carlson MA: Laparoscopic repair of a penetrating injury to the diaphragm: A case report. J Laparoendosc Surg 4:153-6, 1994

4 Ho HS, Gunther RA and Wolfe BM: Intraperitoneal carbon dioxide insufflation and cardiopulmonary functions. Arch Surg 127:928-933, 1992

5 Mark DW and Murr PC: Laparoscopic insufflation of the abdomen depresses cardiopulmonary function. Surg Endosc 7:12-16, 1993

6 Lantz PE and Smith JD: Fatal carbon dioxide embolism complicating attempted laparoscopic cholecystectomy – Case report and literature review. J Forensic Sci 39:1468-80, 1994

7 Martin IG and McMahon MJ: Gasless Laparoscopy. J R Coll Surg Edinb 41:72-74, 1996

8 Power M, McCoy D and Cunningham AJ: Laparoscopic-assisted repair of a traumatic ruptured diaphragm. Anesth Analg 78:1187-9, 1994

9 Penden CJ and Prys-Roberts C: Capnothorax: implications for the anaesthetist. Anaesthesia 48:664-6, 1993

10 Kitano S, Tomikawa M, Iso Y, et al: A safe and simple method to maintain a clear field of vision during laparoscopic cholecystectomy. Surg Endosc 6:197-8, 1992

11 Gazayerli MM: The Gazayerli endoscopic retractor model 1. Surg Laparosc Endosc 1:98-100, 1991

12 Koivusalo AM, Kellokumpu I, Scheinin M, et al: A comparison of gasless mechanical and conventional carbon dioxide pneumoperitoneum methods for laparoscopic cholecystectomy. Anesth Analg 86:153-8, 1998

13 Couture P, Boudreault D, Girard F, et al: Haemodynamic effects of mechanical peritoneal reaction during laparoscopic cholecystectomy. Can J Anaesth 44 (5 Pt 1) :467-72, 1997

14 Paolucci V, Gutt CN, Schaeff B, et al: Gasless laparoscopy in abdominal surgery. Surg Endosc 9:497-500, 1995

15 Wang Q, Deng S and Huang Y: Application of gasless laparoscopic device in laparoscopic surgery. Chung Hua Wai Ko Tsa Chih 33:15-8, 1995

16 Canwell S, Duke T, Walker D, et al: One-lung versus two-lung ventilation in the dog: Comparison of cardiopulmonary parameters. Proc 30th Annu Meet Am Coll Vet Anesth, 1996

17 Garcia F, Prandi D, Pena T, et al: Examination of the thoracic cavity and lung lobectomy by means of thoracoscopy in dogs. Can Vet J 39:285-291,1998

18 Topel HC: Extracorporeal knot tying-endoscopic babcock clamp in Endoscopic Suturing and Knot Tying Ethicon Co, pp 22-25

19 Van der Zee DC and Bax NM: Laparoscopic repair of congenital diaphragmatic hernia in a 6-month-old child. Surg Endosc 9: 1001-3, 1995

20 Kuster, GG, Kine LE and Garzo G: Diaphragmatic hernia through the foramen of Morgagni laparoscopic repair case report. J Laparosc Surg 2:93-100, 1992

21 Campos LI and Sipes EK: Laparoscopic repair of diaphragmatic hernia. J Laparos Surg 1:369-373, 1991

22 Huntington TR: Laparoscopic Transabdominal preperitoneal repair of a hernia of Morgagni. J Laparoendosc Surg 6:131-3, 1996

23 Jones BD: Laparoscopy. Vet Cli North Am (Sm Ani Prac) 20:1243-1263,1990

24 Gutt C, Voepel H, Held S, et al: Instruments for gasless laparoscopic surgery. Zentralbl Chir 121:578-83, 1996

CHAPTER FOUR GENERAL CONCLUSION

To my knowledge this is the first study comparing the cardiopulmonary responses to diaphragmatic incision repair by either the thoracoscopic or gasless laparoscopic approach in dogs.

Fifteen healthy young female dogs weighing 11.4 ± 0.5 kg (mean ± SE) were assigned into three groups: control (CNT, n=5), thoracoscopic diaphragmatic incision repair (TDIR, n=5) and gasless laparoscopic diaphragmatic incision repair (GLDIR, n=5). On day 1, all dogs were anesthetized, positioned in dorsal recumbency, instrumented, and ventilated to maintain the $PaCO_2$ level at 40 ± 5 mm Hg. Data collections were performed at 15 minute intervals during pretreatment (15 min), treatment (90 min) and post-treatment periods (30 min). The data collection included cardiopulmonary variables and arterial and venous blood gas samples. During the treatment period, the CNT dogs received a pneumothorax, thoracoscopy and one-lung ventilation, [left (n=3) or right (n=2) lung ventilation]. The TDIR dogs received the same procedure and number of left and right lung ventilation as the CNT dogs plus a diaphragmatic incision and repair. The GLDIR dogs received pneumothorax, two-lung ventilation (TLV), abdominal wall lifting and a diaphragmatic incision and repair. On day 2, an arterial blood gas sample was collected at 24 hours after the experiment in all dogs.

Results from this study demonstrated that the cardiopulmonary response of healthy dogs to thoracoscopy (with or without a diaphragmatic incision and repair) was not significantly different from gasless laparoscopy. The treatments of the three

groups did cause significant cardiopulmonary change from baseline (intermittent positive pressure ventilation with a closed chest). In the CNT and TDIR groups, heart rate (HR), cardiac output (CO) (only CNT), mean pulmonary pressure (MPAP), airway pressure (AWP) and % shunt increased significantly and PaO_2 decreased significantly from the baseline during the treatment period. In the GLDIR group, MPAP and % shunt increased significantly while PaO_2 decreased significantly from the baseline, but to a lesser extent in the GLDIR than in the CNT and TDIR groups during the treatment period. The PaO_2 values with the right lung collapsed (CNT, TDIR; n = 6) were significantly lower than those with the left lung collapsed (CNT, TDIR; n =4) at the 15 min ($P < .01$), 30 min ($P < .05$) and 45 min ($P < .05$) sample times during the treatment period. However, when the data was examined with the Bonferroni's adjustment ($P = 0.05 / 6$) PaO_2 values only at the 15 min sample time with right lung collapse were significantly less than those with a left lung collapse.

In conclusion, the results in this study indicated that the adverse changes in cardiopulmonary response were less in the GLDIR group, although not statistically different from the CNT and TDIR groups. In addition, during thoracoscopy, right lung collapse with left lung ventilation may predispose to an increased risk of hypoxemia when compared to left lung collapse with right lung ventilation.

The second part of the study, described in chapter Three, explains and compares two video-assisted surgical techniques for repair of diaphragmatic incisions: 1) gasless laparoscopy using an abdominal wall lifting device with two-lung ventilation (TLV), and 2) thoracoscopy with one-lung ventilation (OLV). This

study was performed concurrently with the first study and the animals and experimental design have been described above.

All dogs were anesthetized and positioned in dorsal recumbency. Control (CNT) dogs received OLV and thoracoscopy to confirm OLV during the treatment period. TDIR dogs received OLV and a thoracoscopic diaphragmatic incision (6-8 cm) and repair. One left and two right thoracoscopic approaches were utilized for the repairs. The GLDIR dogs received two-lung ventilation (TLV) and gasless laparoscopic diaphragmatic incision and repair. Repair of the right, left (6-8 cm) and transdiaphragmatic incisions (10-12 cm) of the ventral diaphragm were performed. A simple continuous suture pattern with extracorporeal knot tying was used for all repairs.

The diaphragmatic incisions were successfully repaired in all dogs with no major complications. Surgical times for the right thoracoscopic diaphragmatic incision repairs (n=3; 45, 47 and 60 min) were shorter than those for the left thoracoscopic diaphragmatic incision repairs (n=2, 80 and 82 min). In the GLDIR group, the surgical time was similar (45 and 47 min) for the right and left incision repairs. Incisions involving both right and left sides of the diaphragm in three dogs had surgical times of 75, 90 and 120 min.

In conclusion, this study has described the use of thoracoscopy and gasless laparoscopy to repair diaphragmatic incisions. These techniques could potentially have clinical application that would reduce post-operative pain and shorten recuperation times in diaphragmatic hernia repair for clinical patients.

APPENDIX A: ADDITIONAL DATA

Table 1. Measured and calculated cardiovascular data (mean ± SE) from CONTROL, TDIR and GLDIR Groups (n=5)

Period	Baseline	B1	Treatment					B2	Post-treatment	
Time (min)	0	15	30	45	60	75	90		15	30
HEART RATE (bpm)										
Control	84 ± 8	114 ± 10**	115 ± 9**	112 ± 9**	111 ± 8**	110 ± 10**	114 ± 10**		102 ± 9*	98 ± 9*
TDIR	89 ± 14	121 ± 15*	118 ± 13**	117 ± 13**	121 ± 14*	123 ± 16*	123 ± 16*		124 ± 18**	124 ± 18*
GLDIR	82 ± 9	111 ± 19	116 ± 17	118 ± 17	120 ± 17	120 ± 16	120 ± 16		116 ± 13*	114 ± 10*
CARDIAC OUTPUT (l/min)										
Control	1.33 ± 0.2	1.98 ± 0.3*	1.93 ± 0.3	1.93 ± 0.3*	1.93 ± 0.3*	1.96 ± 0.3*	1.98 ± 0.2*		1.97 ± 0.3*	1.87 ± 0.3*
TDIR	1.36 ± 0.2	1.58 ± 0.1	1.69 ± 0.2	1.72 ± 0.2	1.84 ± 0.1	1.89 ± 0.1	1.93 ± 0.1		1.65 ± 0.2	1.61 ± 0.2
GLDIR	1.61 ± 0.2	1.46 ± 0.2	1.67 ± 0.2	1.76 ± 0.2	1.60 ± 0.2	1.69 ± 0.4	1.73 ± 0.3		1.59 ± 0.3	1.83 ± 0.3
CARDIAC INDEX (ml/min/kg)										
Control	126 ± 20	189 ± 20**	204 ± 30*	221 ± 50	237 ± 60	257 ± 80	273 ± 90		286 ± 110	294 ± 130
TDIR	129 ± 20	147 ± 10	156 ± 20	160 ± 20	172 ± 20	178 ± 20	184 ± 30		150 ± 10	147 ± 20
GLDIR	152 ± 10	135 ± 10	154 ± 20	164 ± 20	149 ± 20	156 ± 30	161 ± 20		148 ± 30	171 ± 40
MAP (mm Hg)										
Control	64.9 ± 3.8	83.2 ± 7.0*	77.5 ± 6.2	79.1 ± 4.8	72.0 ± 5.7	73.6 ± 6.5	72.6 ± 5.9		68.7 ± 4.6	68.2 ± 4.6
TDIR	62.2 ± 8.4	83.1 ± 7.2	69.0 ± 5.6	65.5 ± 4.7	71.9 ± 2.5	75.0 ± 3.0	73.5 ± 6.4		65.1 ± 5.4	62.2 ± 3.1
GLDIR	68.0 ± 7.1	72.4 ± 5.8	74.1 ± 6.0	72.8 ± 5.8	73.1 ± 4.1	69.0 ± 3.5	69.6 ± 2.2		65.0 ± 5.4	68.6 ± 3.4
SAP (mm Hg)										
Control	99 ± 7	124 ± 13	117 ± 14	117 ± 12	110 ± 12	109 ± 14	112 ± 11		109 ± 10	108 ± 9
TDIR	90 ± 11	108 ± 9	95 ± 11	89 ± 11	102 ± 7	102 ± 8	105 ± 8		93 ± 9	89 ± 9
GLDIR	108 ± 14	109 ± 14	110 ± 14	113 ± 14	112 ± 11	107 ± 10	111 ± 9		102 ± 11	109 ± 9
DAP (mm Hg)										
Control	53.1 ± 2.9	68.9 ± 5.4*	63.7 ± 4.0	63.1 ± 2.0	58.4 ± 4.2	60.3 ± 4.7	58.7 ± 4.7		55.1 ± 3.4	55.0 ± 4.1
TDIR	50.2 ± 7.8	71.0 ± 7.7	56.1 ± 4.6	52.8 ± 3.3	56.9 ± 2.2	59.5 ± 3.8	55.9 ± 4.8		51.9 ± 5.4	49.8 ± 2.6
GLDIR	53.0 ± 5.8	58.5 ± 4.1	59.8 ± 4.1	57.4 ± 4.4	57.4 ± 3.0	53.6 ± 3.0	53.2 ± 1.7		49.9 ± 4.2	52.2 ± 3.2

** Significant difference ($P < 0.01$) from baseline, * Significant difference ($P < 0.05$) from baseline

B1 (Break period 1= mean ± SE) in control, TDIR and GLDIR group was 54 ± 6, 62 ± 5 and 71 ± 9 min respectively.

B2 (Break period 2= mean ± SE) in control, TDIR and GLDIR group was 44 ± 1, 48 ± 6 and 33 ± 5 min respectively.

Abbreviation: MAP, mean arterial pressure; MPAP, mean pulmonary arterial pressure; SAP, systolic arterial pressure; DAP, diastolic arterial pressure; PAP, pulmonary arterial pressure; SPAP, systolic pulmonary arterial pressure; DPAP, diastolic pulmonary arterial pressure; CVP, central venous pressure; PCWP, pulmonary capillary wedge pressure; SVR, systemic vascular resistance; PVR, pulmonary vascular resistance.

Table 1. (con't)

Period	Baseline	B1	Treatment					B2	Post-treatment	
Time (min)	0	15	30	45	60	75	90		15	30
MPAP (mm Hg)										
Control	12.8 ± 1.2	18.5 ± 1.6**	18.8 ± 1.7**	18.4 ± 1.6**	18.0 ±1.5**	18.2 ± 1.8*	18.5 ± 1.6**		15.5 ± 2.0	15.4 ± 1.6
TDIR	12.1 ± 0.8	16.9 ± 0.9**	17.3 ± 1.3**	16.8 ± 1.3**	17.2 ± 0.9*	18.2 ± 0.9*	18.2 ± 1.5*		11.8 ± 0.8	12.8 ± 1.1
GLDIR	12.0 ± 0.9	14.5 ± 1.4	16.5 ± 1.0*	15.8 ± 1.2*	16.7 ± 1.3*	15.7 ± 1.2	15.7 ± 0.8		13.2 ± 1.3	12.3 ± 1.5
SPAP (mm Hg)										
Control	19.9 ± 1.9	25.8 ± 2.6	27.1 ± 2.6*	26.3 ± 2.4*	25.0 ± 2.5	25.7 ± 3.1	25.5 ± 2.5		22.3 ± 3.0	22.5 ± 2.5
TDIR	19.8 ± 1.5	24.3 ± 1.5*	24.8 ± 2.7	24.5 ± 1.9	26.9 ± 2.9	29.4 ± 3.5	29.6 ± 5.1		18.4 ± 1.1	19.1 ± 2.5
GLDIR	17.9 ± 1.6	20.4 ± 2.6	25.3 ± 3.6	24.2 ± 3.7	26.4 ± 3.6	23.1 ± 2.2	24.4 ± 2.8		20.2 ± 2.4	19.7 ± 2.4
DPAP (mm Hg)										
Control	8.3 ± 1.0	13.3 ± 1.5**	13.5 ± 1.7**	13.0 ± 1.5**	12.9±1.5**	13.0 ± 1.6**	13.5 ± 1.5**		10.5 ± 1.6	10.2 ± 1.5
TDIR	7.4 ± 1.1	11.3 ± 1.7**	11.3 ± 1.1**	11.2 ± 1.4*	9.9 ± 1.5*	10.9 ± 0.9*	10.5 ± 1.1*		7.1 ± 1.3	7.8 ± 1.2
GLDIR	7.4 ± 1.1	9.7 ± 1.0	10.5 ± 0.9*	10.0 ± 1.1	9.5 ± 1.4	10.3 ± 0.9	10.0 ± 0.6		8.2 ± 1.0	7.5 ± 1.1
CVP (mm Hg)										
Control	5.7 ± 0.4	6.8 ± 0.4*	6.4 ± 0.4	7.1 ± 0.6*	7.0 ± 0.6*	7.3 ± 0.6**	7.2 ± 0.8*		5.3 ± 0.8	5.9 ± 0.7
TDIR	5.3 ± 1.0	5.9 ± 0.9	5.8 ± 1.1	6.3 ± 1.3	6.4 ± 0.8	6.6 ± 0.5	6.7 ± 0.5		4.3 ± 0.8	4.6 ± 0.9
GLDIR	5.0 ± 0.5	6.2 ± 0.6	6.4 ± 0.4	6.2 ± 0.3	6.4 ± 0.4	6.3 ± 0.3	5.3 ± 0.9		2.8 ± 1.1	1.8 ± 0.5*
PCWP (mm Hg)										
Control	6.2 ± 0.6	7.5 ± 0.6	7.2 ± 0.6	7.9 ± 0.5	8.3 ± 1.0	8.3 ± 0.4*	7.3 ± 0.5		5.8 ± 0.7	6.2 ± 0.7
TDIR	7.0 ± 1.9	9.7 ± 1.3	9.5 ± 1.4	9.9 ± 1.8*	9.8 ± 1.3	10.3 ± 1.6*	7.7 ± 1.6		7.3 ± 1.8	7.2 ± 1.1
GLDIR	7.1 ± 0.8	8.4 ± 0.8	8.8 ± 0.7	9.4 ± 1.0	8.3 ± 0.4	8.5 ± 0.5	7.8 ± 0.2		6.7 ± 1.0	6.4 ± 0.3
SVR • 10^3 (dyn-s-cm^{-5})										
Control	3.7 ± 0.4	3.3 ± 0.5	3.1 ± 0.4*	3.2 ± 0.4*	2.9 ± 0.4*	2.9 ± 0.4*	2.3 ± 0.3*		2.8 ± 0.4*	2.8 ± 0.3*
TDIR	3.4 ± 0.3	4.0 ± 0.4	3.0 ± 0.2	2.8 ± 0.3	2.9 ± 0.1	2.9 ± 0.2	2.8 ± 0.3		3.2 ± 0.7	3.1 ± 0.5
GLDIR	3.1 ± 0.1	3.7 ± 0.2	3.4 ± 0.2	3.1 ± 0.2	3.5 ± 0.4	3.4 ± 0.5	3.3 ± 0.5		3.7 ± 0.7	3.4 ± 0.6
PVR (dyn-s-cm^{-5})										
Control	390 ± 38	439 ± 29	494 ± 48	447 ± 40	411 ± 86	395 ± 39	443 ± 33		355 ± 40	364 ± 45
TDIR	336 ± 83	380 ± 87	395 ± 83	280 ± 73	322 ± 111	349 ± 100	399 ± 64		212 ± 84	249 ± 55
GLDIR	237 ± 31	363 ±104	396 ± 80	336 ± 117	456 ± 111	408 ± 112	401± 72		379 ± 73	266 ± 40

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Table 2. Measured and calculated respiratory data (means ± SE) from CONTROL, TDIR and GLDIR Group (n=5)

Period	Baseline	B1	Treatment						B2	Post-treatment	
Time (min)	0		15	30	45	60	75	90		15	30
RESPIRATORY RATE (bpm)											
Control	11.6 ± 0.6		13.3 ± 0.8	13.3 ± 0.7	12.8 ± 0.6	12.8 ± 0.6	12.8 ± 0.6	12.8 ± 0.6		11.7 ± 1.1	11.7 ± 1.1
TDIR	11.1 ± 0.5		11.6 ± 0.8	11.6 ± 0.9	11.6 ± 0.8	11.6 ± 0.9	11.6 ± 0.9	11.6 ± 0.9		11.6 ± 0.9	11.6 ± 0.9
GLDIR	12.0 ± 0.4		11.1 ± 0.9	11.1 ± 0.9	11.0 ± 0.9	11.0 ± 0.9	11.0 ± 0.9	11.0 ± 0.9		11.5 ± 0.5	11.2 ± 0.5
TIDAL VOLUME (ml)											
Control	250 ± 23		202 ± 41	218 ± 34	227 ± 34	217 ± 35	215 ± 34	212 ± 35		235 ± 21	236 ± 20
TDIR	230 ± 17		245 ± 31	233 ± 31	230 ± 31	225 ± 31	205 ± 34	189 ± 28		192 ± 28	217 ± 18
GLDIR	247 ± 43		229 ± 45*	214 ± 45*	202 ± 40**	225 ± 35	239 ± 34	227 ± 35		235 ± 21	218 ± 30
SPECIFIC TIDAL VOLUME (ml/kg)											
Control	20.3 ± 1.5		16.1 ± 2.7	17.6 ± 2.3	18.4 ± 2.4	17.5 ± 2.4	17.4 ± 2.4	17.0 ± 2.4		19.1 ± 1.4	19.1 ± 1.3
TDIR	21.1 ± 1.4		22.9 ± 3.5	21.6 ± 3.3	21.2 ± 3.1	20.7 ± 2.8	18.6 ± 2.5	16.9 ± 1.9		17.2 ± 1.8	19.7 ± 1.0
GLDIR	21.9 ± 2.2		20.3 ± 2.7*	18.8 ± 2.8*	17.9 ± 2.4**	20.1 ± 2.1	21.3 ± 1.5	20.3 ± 1.9		21.5 ± 1.1	19.5 ± 1.1
MINUTE VENTILATION (l/min)											
Control	2.86 ± 0.2		2.64 ± 0.5	2.85 ± 0.4	2.85 ± 0.4	2.73 ± 0.4	2.71 ± 0.4	2.66 ± 0.4		2.67 ± 0.1	2.68 ± 0.1
TDIR	2.53 ± 0.1		2.80 ± 0.3	2.66 ± 0.3	2.61 ± 0.3	2.56 ± 0.3	2.30 ± 0.3	2.11 ± 0.2*		2.13 ± 0.2*	2.47 ± 0.1
GLDIR	2.97 ± 0.5		2.73 ± 0.5	2.25 ± 0.4	2.11 ± 0.3	2.39 ± 0.3	2.57 ± 0.3	2.41 ± 0.3		2.66 ± 0.2	2.44 ± 0.3
SHUNT(%)											
Control	11.7 ± 1.2		35.5 ± 4.4**	31.7 ± 3.8**	31.9 ± 3.8**	30.3 ± 3.8**	30.5 ± 3.8**	30.8 ± 3.9**		16.6 ± 1.9	17.2 ± 1.7*
TDIR	14.1 ± 2.2		37.7 ± 3.1**	38.8 ± 3.7**	39.0 ± 5.2*	40.1 ± 4.6**	38.4 ± 5.1*	39.6 ± 5.6*		18.7 ± 2.1	18.9 ± 1.9
GLDIR	16.8 ± 2.1		25.2 ± 4.5*	31.2 ± 7.6	30.1 ± 3.1**	30.0 ± 5.2*	28.9 ± 4.7*	25.9 ± 4.6*		23.2 ± 3.0	22.5 ± 1.9
LUNG COMPLIANCE (ml/cm H_2O)											
Control	39.9 ± 5.9		11.5 ± 2.9*	11.3 ± 2.4*	12.3 ± 3.1*	11.7 ± 2.7*	11.8 ± 2.5*	11.4 ± 2.6**		22.1 ± 4.3*	22.3 ± 3.5*
TDIR	43.6 ± 7.6		13.5 ± 1.6*	13.1 ± 1.9*	13.5 ± 2.1*	13.6 ± 2.6*	13.9 ± 3.6*	11.1 ± 2.0*		19.6 ± 3.3*	27.3 ± 3.4
GLDIR	54.8 ± 12.4		23.9 ± 7.8	18.9 ± 4.9	17.0 ± 3.0	16.9 ± 2.9	17.0 ± 2.6	16.1 ± 2.6		23.8 ± 6.4	22.6 ± 4.9

** Significant difference ($P < 0.01$) from baseline, * Significant difference ($P < 0.05$) from baseline

B1 (Break period 1= mean ± SE) in control, TDIR and GLDIR group was 54 ± 6, 62 ± 5 and 71 ± 9 min respectively.

B2 (Break period 2= mean ± SE) in control, TDIR and GLDIR group was 44 ± 1, 48 ± 6 and 33 ± 5 min respectively.

Table 2. (con't)

Period	Baseline	B1	Treatment					B2	Post-treatment	
Time (min)	0	15	30	45	60	75	90		15	30
O_2 DELIVERY (ml/min)										
Control	321± 37	448 ± 50	441 ± 62	443 ± 64	442 ± 57*	451 ± 63	455 ± 47*		472 ± 70*	449 ± 57*
TDIR	305 ± 39	334 ± 17	354 ± 42	362 ± 48	382 ± 43	396 ± 23	402 ± 19		370 ± 47	363 ± 53
GLDIR	359 ± 34	320 ± 50	365 ± 65	385 ± 64	349 ± 64	371 ± 92	379 ± 71		348 ± 75	400 ± 81
O_2 CONSUMPTION (ml/min)										
Control	58.5 ± 8	70.3 ± 6*	70.2 ± 6	69.2 ± 6	71.8 ± 4*	70.1 ± 6	69.5 ± 5		62.0 ± 6	57.9 ± 5
TDIR	49.5 ± 8	51.5 ± 7	58.2 ± 6	60.2 ± 7	67.1 ± 9	65.3 ± 10	60.9 ± 6		59.4 ± 7	61.3 ± 8*
GLDIR	48.4 ± 8	49.0 ± 8	47.6 ± 11	49.9 ± 5	46.8 ± 8	50.6 ± 10	55.8 ± 6		51.1 ± 6	55.6 ± 7
O_2 UTILIZATION										
Control	0.19 ± .03	0.16 ± .02	0.17 ± .02	0.17 ± .03	0.17 ± .02	0.16 ± .02	0.16 ± .02		0.14 ± .01	0.13 ± .02
TDIR	0.17 ± .02	0.16 ± .03	0.18 ± .04	0.18 ± .04	0.19 ± .04	0.17 ± .03	0.15 ± .02		0.17 ± .03	0.19 ± .04
GLDIR	0.13 ± .02	0.16 ± .03	0.14 ± .04	0.15 ± .03	0.14 ± .03	0.15 ± .03	0.16 ± .03		0.18 ± .04	0.16 ± .03
AIRFLOW (l/min)										
Control	17.6 ± 1.8	14.1 ± 3.1	15.2 ± 2.6	15.9 ± 2.6	15.2 ± 2.6	15.1 ± 2.6	14.8 ± 2.7		16.5 ± 1.6	16.5 ± 1.5
TDIR	16.2 ± 1.5	17.3 ± 2.3	16.4 ± 2.3	16.2 ± 2.4	15.9 ± 2.4	14.4 ± 2.8	13.2 ± 2.2		13.4 ± 2.2	15.2 ± 1.5
GLDIR	17.6 ± 3.3	16.3 ± 3.4*	15.2 ± 3.4	14.3 ± 3.0*	15.9 ± 2.5	17.0 ± 2.5	16.1 ± 2.6		16.6 ± 1.6	15.4 ± 2.2
AIRWAY PRESSURE (cm H_2O)										
Control	11.4 ± 1.3	19.0 ± 2.8*	20.5 ± 2.2**	20.5 ± 2.5*	20.0 ± 2.1**	19.6 ± 2.5**	20.0 ± 2.5**		16.3 ± 2.3*	15.8 ± 2.3*
TDIR	10.8 ± 1.5	18.6 ± 2.0*	18.2 ± 1.9*	17.6 ± 1.7*	17.7 ± 1.9**	16.5 ± 2.0*	18.0 ± 1.5**		14.6 ± 1.8**	13.1 ± 1.1
GLDIR	9.5 ± 1.9	11.8 ± 1.9	12.0 ± 1.0	11.9 ± 1.0	13.7 ± 0.9	14.4 ± 1.2	14.3 ± 1.0		14.5 ± 1.4	13.2 ± 1.6
BODY TEMP (degree Celsius)										
Control	35.8 ± 0.6	35.6 ± 1.2	35.5 ± 1.2	35.5 ± 1.1	35.5 ± 1.1	35.6 ± 1.1	35.5 ± 1.1		35.7 ± 1.0	35.7 ± 0.9
TDIR	35.2 ± 1.2	34.7 ± 1.1*	34.6 ± 1.0*	34.5 ± 1.0*	34.6 ± 0.9	34.4 ± 0.9	34.5 ± 0.9		35.2 ± 1.0	35.4 ± 1.1
GLDIR	34.8 ± 1.2	34.5 ± 1.2	34.6 ± 1.1	34.7 ± 1.2	34.6 ± 1.1	34.5 ± 1.2	34.5 ± 1.2		34.4 ± 1.1	34.4 ± 1.1

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Table 3. Arterial and venous blood gas data (mean ± SE) from CONTROL, TDIR and GLDIR Groups

Period	Baseline	B1	Treatment					B2	Post-treatment	
Time (min)	0	15	30	45	60	75	90		15	30
PaO_2 (mm Hg)										
Control	496 ± 13	152 ± 37**	182 ± 39**	184 ± 39**	203 ± 45**	209 ± 45**	215 ± 47**		475 ± 17	471 ± 12
TDIR	502 ± 25	158 ± 39**	142 ± 41**	140 ± 40**	128 ± 39**	151 ± 30**	160 ± 31**		422 ± 22*	422 ± 18**
GLDIR	500 ± 10	327 ± 62*	315 ± 63*	291 ± 52*	299 ± 77*	308 ± 70*	323 ± 76		335 ± 70	370 ± 51*
$PaCO_2$ (mm Hg)										
Control	38.4 ± 1.9	43.1 ± 3.2	40.5 ± 3.5	41.3 ± 4.0	41.4 ± 3.8	42.7 ± 4.0	43.4 ± 4.0		42.7 ± 2.2	42.8 ± 2.5
TDIR	35.3 ± 1.3	35.3 ± 2.0	37.0 ± 3.1	38.5 ± 3.0	39.5 ± 3.9	40.7 ± 4.0	43.9 ± 4.1		39.2 ± 0.7	40.3 ± 1.0
GLDIR	35.6 ± 0.8	39.5 ± 3.6	42.5 ± 2.5	45.1 ± 1.7*	45.4 ± 2.7*	44.8 ± 4.4	43.7 ± 2.8		40.3 ± 1.3**	40.8 ± 1.0**
ARTERIAL pH										
Control	7.39 ± .03	7.36 ± .02	7.37 ± .02	7.36 ± .02	7.36 ± .02	7.35 ± .02	7.34 ± .02		7.34 ± .01	7.35 ± .01
TDIR	7.39 ± .02	7.37 ± .02	7.36 ± .03	7.34 ±.02	7.33 ± .03	7.32 ± .03	7.29 ± .03*		7.34 ± .01	7.33 ± .02
GLDIR	7.38 ± .01	7.34 ± .03	7.30 ± .02*	7.28 ± .02**	7.28 ± .03*	7.28 ± .04	7.29 ± .03*		7.32 ± .02**	7.32 ± .02**
PvO_2 (mm Hg)										
Control	54.5 ± 4.6	49.2 ± 1.6	48.5 ± 2.0	49.6 ± 2.8	49.7 ± 3.1	51.2 ± 2.9	51.9 ± 3.4		64.2 ± 2.1	65.1 ± 2.1
TDIR	56.7 ± 4.8	50.0 ± 4.2	44.6 ± 3.9	45.0 ± 3.7	44.6 ± 4.2	47.3 ± 3.0	49.4 ± 1.8		59.6 ± 3.8	59.3 ± 3.8
GLDIR	64.9 ± 3.4	53.2 ± 2.7	66.2 ± 10.6	61.0 ± 6.7	62.5 ± 8.0	59.2 ± 6.9	57.4 ± 7.4		57.7 ± 9.1	53.5 ± 14.7
$PvCO_2$ (mm Hg)										
Control	46.5 ± 2.7	48.0 ± 2.7	45.6 ± 3.0	47.3 ± 3.8	46.4 ± 3.7	47.7 ± 3.5	48.8 ± 3.8		48.9 ± 2.4	49.3 ± 2.2
TDIR	42.5 ± 2.0	40.2 ± 1.9	40.7 ± 3.0	42.7 ± 2.6	44.4 ± 3.4	45.1 ± 3.8	48.3 ± 3.6		45.8 ± 0.7	47.5 ± 1.9
GLDIR	42.6 ± 1.4	44.2 ± 3.2	47.3 ± 2.3	50.1 ± 1.7	51.7 ± 2.3*	50.5 ± 3.4	50.0 ± 2.4		47.8 ± 1.4**	47.1 ± 1.8*
VENOUS pH										
Control	7.35 ± .03	7.32 ± .02	7.34 ± .02	7.33 ± .02	7.33 ± .02	7.32 ± .02	7.34 ± .02		7.34 ± .01	7.35 ± .01
TDIR	7.34 ± .02	7.34 ± .02	7.34 ± .03	7.31 ± .02	7.30 ± .03	7.30 ± .03	7.26 ± .03*		7.30 ± .01	7.29 ± .02
GLDIR	7.34 ± .02	7.31 ± .03	7.28 ± .02	7.26 ± .02	7.25 ± .03*	7.26 ± .03	7.26 ± .03*		7.28 ± .02*	7.28 ± .02*

** Significant difference ($P< 0.01$) from baseline, * Significant difference ($P< 0.05$) from baseline

B1 (Break period 1= mean ± SE) in control, TDIR and GLDIR group was 54 ± 6, 62 ± 5 and 71 ± 9 min respectively.

B2 (Break period 2= mean ± SE) in control, TDIR and GLDIR group was 44 ± 1, 48 ± 6 and 33 ± 5 min respectively.

Abbreviation: PaO_2, arterial oxygen tension; $PaCO_2$, arterial carbon dioxide tension; PvO_2, mixed venous oxygen tension; $PvCO_2$,mixed venous carbon dioxide tension.

APPENDIX B: PHYSIOLOGIC FORMULAS

Formulas used for calculation of cardiopulmonary and oxygenation variables

CI (ml/min/kg) = [CO (L/min) ÷ body weight (kg)] × 10^3

SVR (dynes-s-cm $^{-5}$) = 80 [MAP (mm Hg) – CVP (mm Hg)] ÷CO (L/min)

PVR (dynes-s-cm $^{-5}$) = 80 [MPAP (mm Hg) – PCWP (mm Hg)] ÷CO (L/min)

(80 = factor determined by converting mm Hg to dynes/cm^2 and l/min to cm^3/sec;

1 mm Hg = 1333 dynes/cm^2)

MV (L/min) = [TV (ml/breath) × RR (breaths/min)] ÷10^3

Q_{ps}/Q_t (%) = $[CcO_2$ (ml/dl) – CaO_2 (ml/dl)] ÷ [$CcO_2 - CvO_2$] ×100

CcO_2 (ml/dl) = Hb (gm/dl) ×1.36 (% O_2 $Saturation_c$ ÷100) + 0.003 ($P_B - P_{H2O}$)

= (Hb × 1.36 × 1) + 0.003 (740 – 47)

CaO_2 (ml/dl) = Hb (gm/dl) × 1.36 (%O_2 $Saturation_a$ ÷100) + 0.003 × PaO_2

CvO_2 (ml/dl) = Hb (gm/dl) × 1.36 (%O_2 $Saturation_v$ ÷100) + 0.003 × PvO_2

1 gram of Hb can combine with 1.36 ml of O_2; 0.003 = solubility coefficient of O_2 (defined as 0.003 ml O_2/ 100 blood / mm Hg PO_2); P_B = 740 mm Hg when 100 % O_2 utilized and at Ames altitude)

OD (ml/min) = CO (L/min) × CaO_2 (ml/dl) × 10

OC (ml/min) = CO (L/min) × [CaO_2 (ml/dl) – CvO_2(ml/dl)] ×10

OU (ratio) = OC ÷ OD

LC_{oc} (ml/cm H_2O) = ΔV (ml) ÷ [AWP_{bi} (cm H_2O) – AWP_{ei} (cm H_2O)]

LC_{cc} (ml/cm H_2O) = ΔV(ml) ÷ [(AWP_{bi} (cm H_2O) – EP_{bi} (cm H_2O)) – ($AWP_{ei} - EP_{ei}$)]

ΔV (ml) = [AF (L/min) – a] ÷ b

AF received from an integral area under the curve of an inspiration phase, a = intercept and b = slope of a linear regression equation between airflow and volume received from calibration curves.

CI = cardiac index; CO = cardiac output; SVR = systemic vascular resistance; MAP = mean arterial pressure; CVP = central venous pressure; PVR = pulmonary vascular resistance; MPAP = mean pulmonary arterial pressure; PCWP = pulmonary capillary wedge pressure; MV = minute ventilation; TV = tidal volume; RR = respiratory rate; Q_{ps}/Q_t = physiologic shunt; CcO_2 = pulmonary end capillary oxygen content; CaO_2 = arterial oxygen content; CvO_2 = mixed venous oxygen content; Hb = venous hemoglobin; % O_2 Saturation$_c$, % O_2 Saturation$_a$, %O_2 Saturation$_v$ = percent saturation oxygen of capillary, arterial and mixed venous blood, respectively; P_B = barometric pressure; P_{H2O} = vapor pressure; PaO_2 = partial pressure arterial oxygen; PvO_2 = partial pressure mixed venous oxygen; OD = oxygen delivery; OC = oxygen consumption; OU = oxygen utilization ratio; LC_{oc} = lung compliance during open chest; ΔV = air volume difference between the beginning and end of an inspiration phase; AWP_{bi} = airway pressure at the beginning of an inspiration; AWP_{ei} = airway pressure at the end of an inspiration; LC_{cc} = lung compliance during closed chest; AF = airflow; EP_{bi} = esophageal pressure at the beginning of an inspiration; EP_{ei} = esophageal pressure at the end of an inspiration;

PO_2 (partial pressure oxygen), PCO_2 (partial pressure carbon dioxide) and pH were adjusted to 37 ° C by using the blood gas correction normogram for

temperature shown in Nunn JK: Nunn's Applied Respiratory Physiology (ed 4). Oxford, England, Butterworth-Heinemann, 1994, pp 570-572 (Appendix E)

APPENDIX C: SURGICAL PICTURES

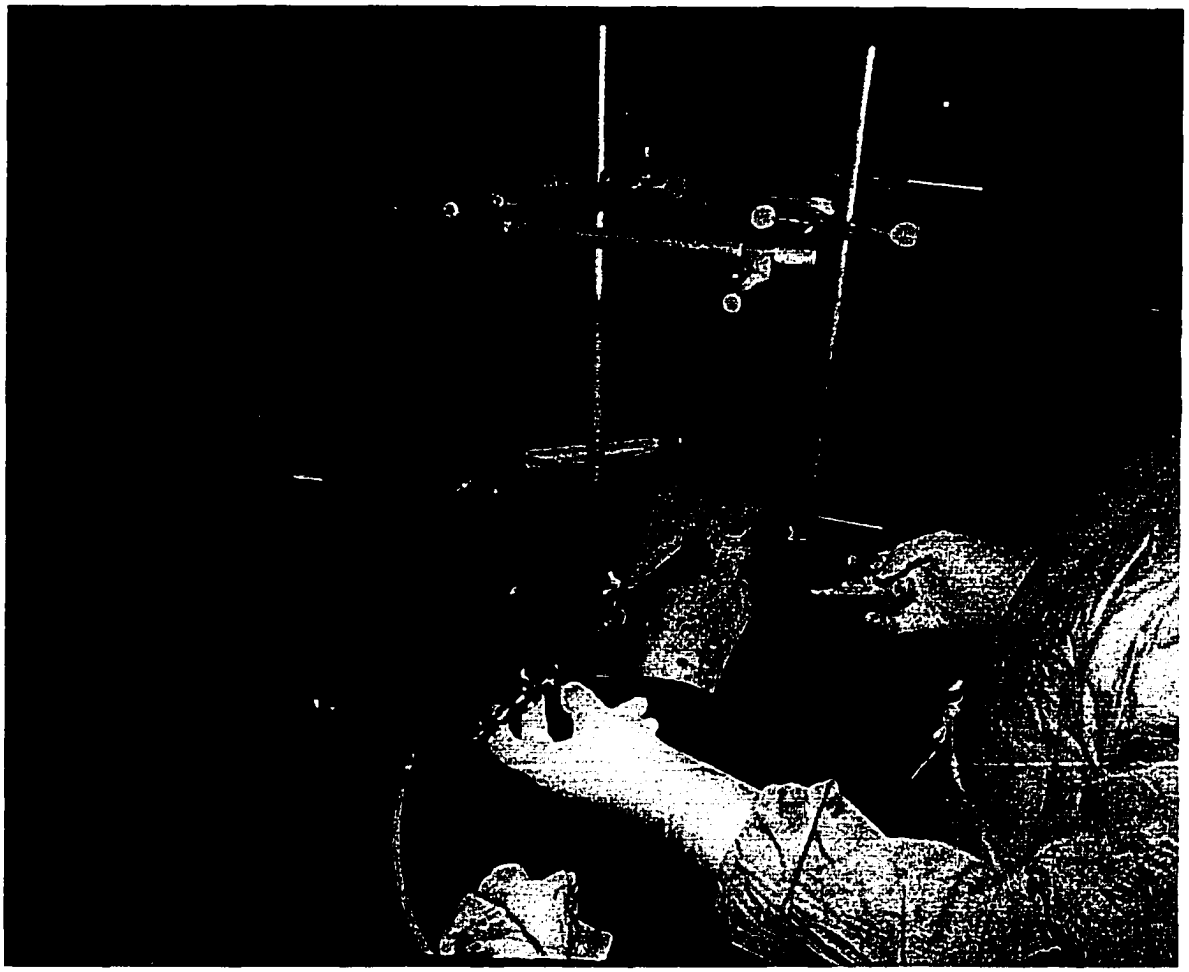

Figure 1. The dog's abdominal wall of the GDIR group and the cranial part of the falciform ligament were lifted using the transabdominal pin and abdominal distention device.

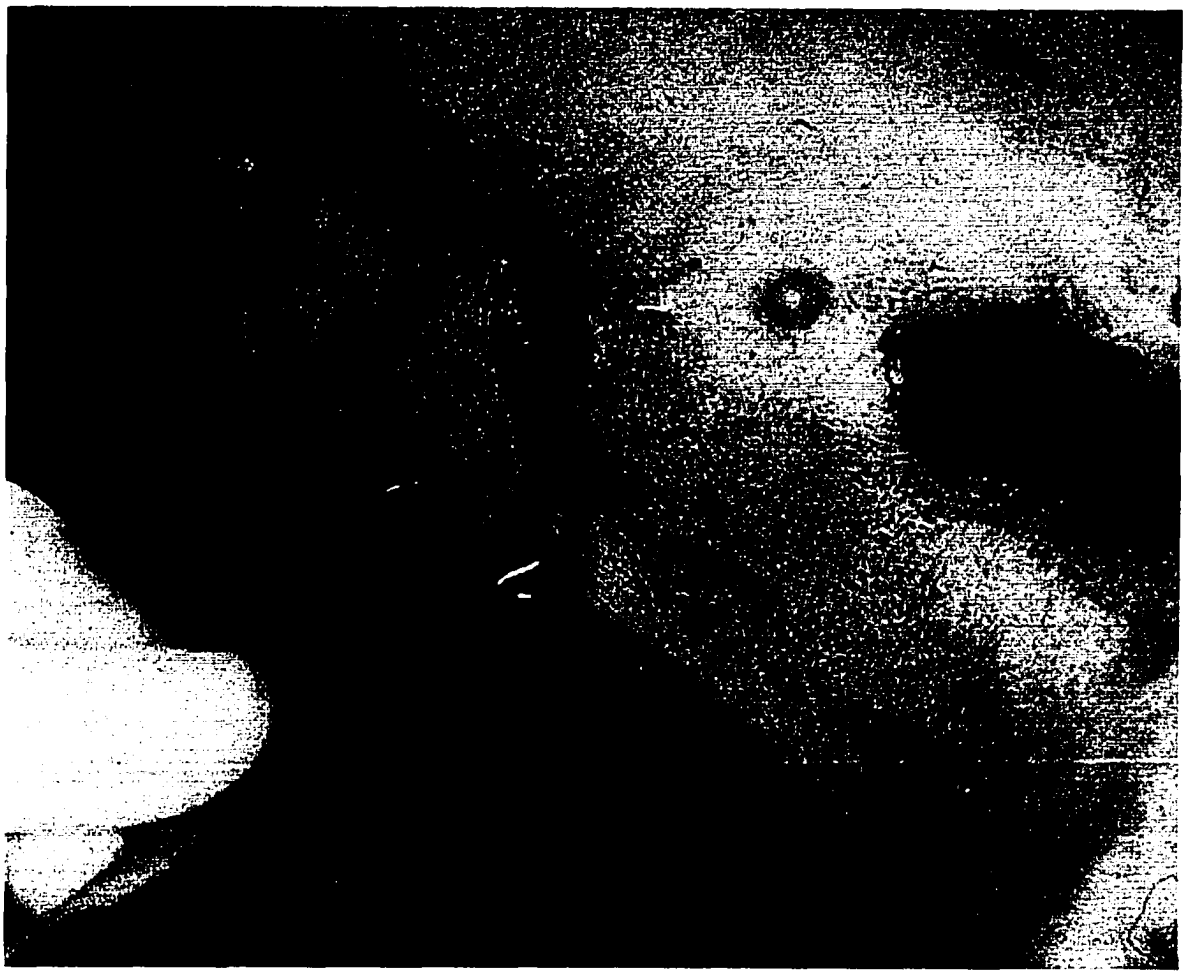

Figure 2. A pair of regular instead of a laparoscopic Babcock forceps was used for extracorporeal knot tying in a TDIR dog.

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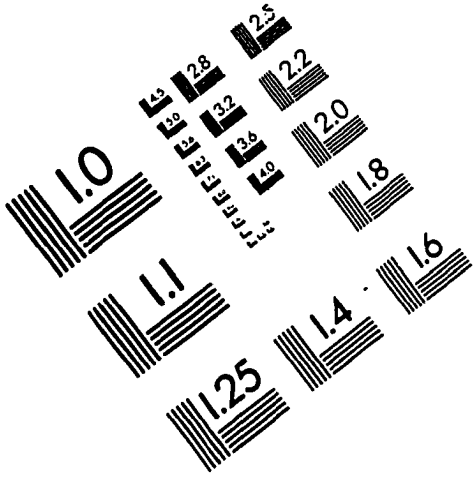
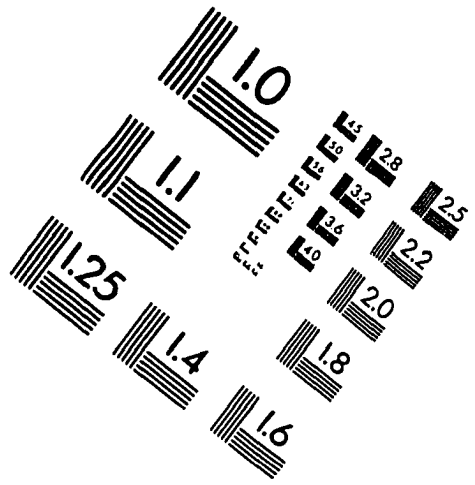
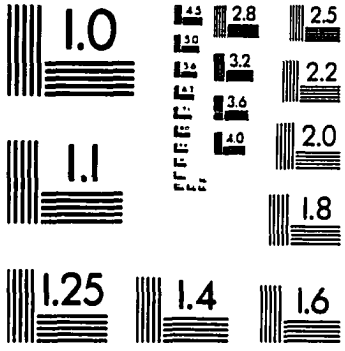
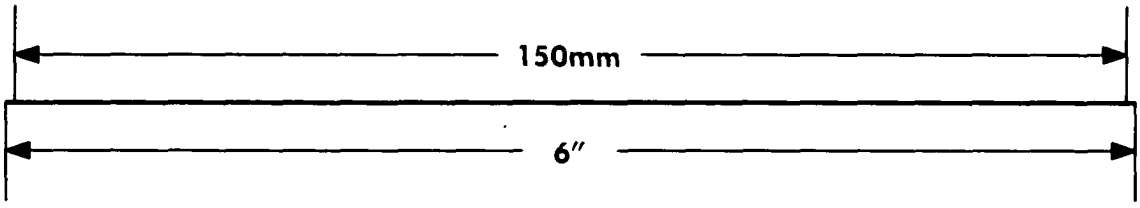
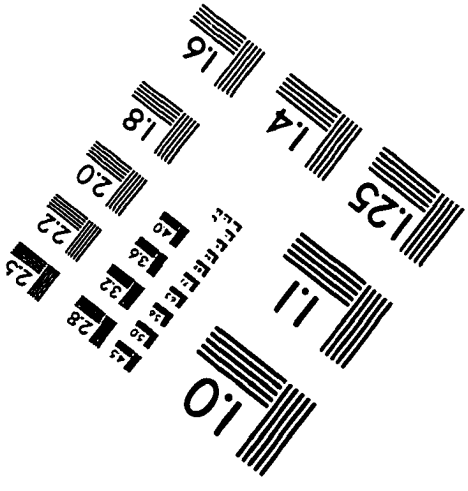
IMAGE EVALUATION TEST TARGET (QA-3)

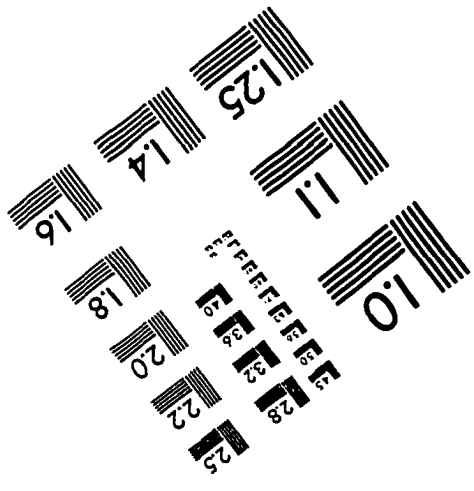












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