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REVIEW

Recent advances in soft tissue minimally invasive surgery

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Advancements in soft tissue minimally invasive surgery have been rapid and comprehensive since its inception in human medicine approximately 25 years ago. From its origins in traditional laparoscopy, followed rapidly by video-assisted thoracoscopic surgery, minimally invasive surgery in human medicine has evolved through a number of different platforms that now include single-port approach devices, robotic surgery as well as natural orifice transluminal endosurgery. Whilst some of these remain beyond the reach of veterinary medicine for now, largely because of technical challenges and the prohibitive costs of some single-use disposable components, veterinary minimally invasive surgery is advancing rapidly allowing our small animal patients to benefit from some of the many documented advantages that a minimally invasive approach affords the patient.

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INTRODUCTION

The first reports of laparoscopic interventions in the veterinary literature emerged as early as the mid-1980s when some early workers elected to use what was then an emerging technology in human medicine to assess whether it would lend itself to use in veterinary patients (Wildt & Lawler 1985). Since then a number of very useful and simple laparoscopic and laparoscopic-assisted procedures such as the laparoscopic-assisted ovariohysterectomy (Austin et al. 2003, Devitt *et al.* 2005, Mayhew *et al.* 2007), ovariectomy (Van Goethem *et al.* 2003, Van Nimwegen *et al.* 2005, Van Nimwegen & Kirpensteijn 2007, Dupre *et al.* 2009, Culp *et al.* 2009, Case *et al.* 2011), cryptorchidectomy (Miller *et al.* 2004, Mayhew 2009a), gastropexy (Rawlings *et al.* 2001, 2002a) and cystotomy (Rawlings *et al.* 2003, Pinel *et al.* 2013) as well as laparoscopic organ biopsy (Rawlings *et al.* 2002b, Mayhew 2009b) emerged and have been widely adopted at many centres. In North America and Europe these procedures are now being used widely and a recent survey of diplomates and residents of the American College of Veterinary Surgeons (ACVS) documented that 86% of small animal diplomates and 98% of residents had performed minimally invasive surgery (MIS) procedures and that 52% of all diplomates of the ACVS had completed at least one training course in MIS (includes orthopaedic MIS courses) since finishing their residency training (Bleedorn *et al.* 2013).

The use of MIS in veterinary general practice is increasing partly driven by the fact that many routine surgical procedures such as elective neutering, gastropexy and cystotomy amongst others, lend themselves so well to an MIS approach. In more recent years further investigation of more complex interventions has also taken place in some centres with the development of procedures such as adrenalectomy (Jiménez Peláez *et al.* 2008, Naan *et al.* 2013, Mayhew *et al.* 2013a) ureteronephrectomy (Mayhew *et al.* 2013b) and cholecystectomy (Mayhew *et al.* 2008). These procedures have been reported in small numbers and the learning curve has not been well-defined. Case selection criteria are also not well-defined for these interventions and further work is required to further develop this knowledge.

Thoracoscopic, or video-assisted thoracoscopic surgery (VATS) is in an earlier phase of development in veterinary medicine and this slower development mirrors its development in human medicine where minimally invasive thoracic interventions only started to emerge in the early 1990s (Mack *et al.* 1992). With surgical intervention in the thorax remaining a non-routine care procedure and the often complex and expensive collaborations required between surgeons, criticalists and anaesthetists in management of these cases, the learning curve for veterinarians has likely been hampered by inadequate case numbers and the technical challenges involved. A number of VATS procedures have, however, now been documented and other interventions are being introduced regularly. The first of these to gain widespread acceptance was the VATS pericardial window (PW) and subphrenic pericardiectomy (Jackson *et al.* 1999, Walsh *et al.* 1999, Dupre *et al.* 2001). Since then others have suggested refinements to the techniques (Mayhew *et al.* 2009) or evaluated outcomes more critically (Case *et al.* 2013a). More recently results of VATS lung lobectomy (Lansdowne *et al.* 2005, Mayhew *et al.* 2013c) and minimally invasive approaches to chylothorax (Radlinsky *et al.* 2002, Allman *et al.* 2010, Sakals *et al.* 2011, Mayhew *et al.* 2012a) have been documented from more than one centre. Other interventions in small numbers of cases using VATS techniques include patent ductus arteriosus ligation (Borenstein *et al.* 2004), cranial mediastinal mass resection (Mayhew & Friedberg 2008), auricular mass resection (Ployart *et al.* 2013), ligation of persistent right aortic arch (Isakow *et al.* 2000, MacPhail *et al.* 2001), tracheobronchial lymph node resection (Steffey *et al.* 2012) and treatment of bullous emphysema (Brissot *et al.* 2003).

The challenge for veterinarians interested in the field of MIS is now to move beyond the initial descriptions of these techniques and provide evidence for their use by evaluation of short- and long-term outcomes when compared to traditional open approaches.

Evidence base for MIS in veterinary surgery

In the human field, a large amount of research effort has been invested into the establishment of the evidence base for MIS procedures. While a variety of introductory publications describing different author's early experience with a given procedure have been published in the veterinary literature, only a small number of reports have focused on comparing MIS to traditional surgical approaches using populations of either research animals or comparable clinical populations with naturally occurring disease. Reliable outcome measures are a challenge in veterinary medicine but most investigations have employed either definable outcomes such as surgical time and complication rates or parameters of post-surgical pain or stress such as serum cortisol and glucose measurement as well as a variety of visual analogue pain scales (Devitt *et al.* 2005, Walsh *et al.* 1999). In one of the earliest studies to compare a population of healthy animals undergoing either open or laparoscopic ovariohysterectomy, the MIS group was found to have lower pain scores for 24 hours post-operatively, whereas indirect measures of surgical stress, cortisol and glucose, were significantly increased in the open group up to 2 and 6 hours, respectively compared to baseline, which was not the case for the MIS group (Devitt *et al.* 2005). Surgical time has been compared between open and MIS approaches in a number of studies. Surgical time needs to be interpreted with caution in these studies as many represent the early part of a centre's learning curve in comparison to that of an open procedure that the surgeon is presumably, in most cases, experienced with. However, several studies have documented longer surgical times associated with an MIS procedure compared to the traditional open procedure (Culp *et al.* 2009, Mayhew *et al.* 2013c, Arulpragasam *et al.* 2013). Other studies have evaluated the return to normal function using an objective measure of activity. Accelerometry has been validated for use in both dogs and cats and was used to compare open to laparoscopic OVE in a cohort of small dogs (Culp *et al.* 2009). A detectable difference was found between groups with activity counts in the 48 hours post-operatively being 25 and 62% below baseline activity in the laparoscopic and open groups, respectively (Culp *et al.* 2009). In another study using accelerometry devices a laparoscopic-assisted gastropexy was compared to a "next generation" technique performed entirely laparoscopically using intracorporeal suturing (Mayhew & Brown 2009). Accelerometry revealed activity counts that were 44% and 11 to 19% decreased compared to pre-operatively in the laparoscopic-assisted and total laparoscopic groups, respectively in the 7 days post-operatively; a difference that was statistically significant and was attributed to the avoidance of the deep paramedian incision performed for the "assisted" technique. The duration of this effect appeared to be somewhere in the region of 4 to 5 days post-operatively.

More recently, other studies have concentrated not only on improvements in post-operative discomfort but in the effect on morbidity of the MIS approaches. In a study comparing surgical site infection (SSI) rates between open and minimally invasive surgery, on univariate analysis surgical approach (MIS *versus* open) was found to have a beneficial effect on SSI rate post-operatively (Mayhew *et al.* 2012b). The SSI rate for the open group was 5.5% compared to an SSI rate of 1.7% in the MIS group. However, it should be noted that on multivariate analysis, this difference was at least in part driven by other potential confounders. Further studies will be required to confirm this hypothesis.

In thoracic surgery, few studies have been pursued evaluating the difference between open and MIS approaches. One study evaluated the difference between an open and a VATS approach in a canine pericardiectomy model (Walsh *et al.* 1999). In this report the VATS approach was associated with lower post-operative pain scores in the post-operative period as well as higher blood glucose and cortisol concentrations in the thoracotomy group. Rescue analgesics were used with greater frequency in the thoracotomy group and fewer complications were observed in the VATS group (Walsh *et al.* 1999). A recent clinical study has documented the results of VATS lung lobectomy in 22 canine patients with primary lung lobe tumours compared to a population that underwent thoracotomy for the same reason (Mayhew *et al.* 2013c). The VATS approach was feasible and not associated with significantly greater morbidity but there was no apparent advantages in the length of hospital stay, ICU time or indwelling thoracic drain time, all of which have been documented in humans after VATS lobectomy (Villamizar *et al.* 2009, Rueth *et al.* 2010). In this study no attempt was made to evaluate post-operative pain, discomfort or activity between groups. In addition, outcome measures were not indexed to any clinical benchmarks and significant confounders caused by the decisions of different managing clinicians may have influenced outcomes. Future studies are required in this area to investigate in a prospective fashion the effects of these interventions *versus* their traditional open counterparts.

Recent advancements in laparoscopic surgery

With experience gained from performance of some of the simpler laparoscopic procedures, veterinary surgeons have been able to conquer some of the challenges associated with laparoscopic instrumentation, the development of hand-eye coordination and depth perception which has allowed a number of more advanced laparoscopic procedures to be developed. These include adrenalectomy, cholecystectomy and ureteronephrectomy. Several other procedures have been re-evaluated resulting in the publication of modified or "second-generation" techniques. The following is a discussion of a select group of more advanced techniques currently being performed at a limited number of centres.

Laparoscopic gastropexy

Since the first description of the classical laparoscopic-assisted gastropexy in 2001 (Rawlings *et al.* 2001) which today remains the most widely performed minimally invasive gastropexy, several second-generation gastropexy techniques aimed at refining the procedure in a variety of ways have been published. Two techniques aimed at converting the "assisted" technique into a totally laparoscopic technique have been described although neither has gained widespread adoption. The practical use of a technique employing the endoGIA stapling device to create a gastropexy between two tissue tunnels undermined beneath the transversus abdominis and the seromuscular layer of the stomach was likely hindered by the significant expense associated with the use of surgical staplers (Hardie *et al.* 1996). This technique was also associated with a significant incidence of gastric perforation which occurred in 2 of 14 dogs in the study population. The technique previously mentioned that employed intracorporeal suturing to create a gastropexy was aimed at avoiding the full-thickness paramedian incision in the bodywall used in the laparoscopic-assisted incision (Mayhew & Brown 2009). While shown to be associated with improved return to normal function post-operatively compared to laparoscopic-assisted gastropexy it was associated with longer surgical time. Intracorporeal-suturing is a technique new to most veterinary surgeons and can be challenging. This technique also requires special instrumentation (laparoscopic needle-holders) and can be associated with difficulty maintaining tension during suturing of the gastropexy site and knot-tying (Mayhew & Brown 2009). Recently the use of new barbed suture (V-Loc, Covidien Inc.; Quill, Angiotech Pharmaceuticals Inc.) was described both in a biomechanical study using a canine cadaver gastropexy model (Imhoff & Monnet 2013) as well as in two clinical canine case series (Runge & Holt 2013, Spah *et al.* 2013). This suture obviates the need for intracorporeal knot-tying and aids in tension maintenance during the process of suturing the gastropexy (Fig 1). This may eliminate some of the challenges encountered in the previous technique using non-barbed suture material. Another laparoscopic-sutured gastropexy has been described where sutures were passed across the body wall from an extra-corporeal location and employed cauterisation of the peritoneal surface over the gastropexy site to encourage adhesion formation (Mathon *et al.* 2009). Necropsy evidence at 10 weeks demonstrated the formation of a reliable gastropexy in all seven dogs despite the lack of a surgical incision through the serosal surfaces of the tranversus abdominis or seromuscular layer of the stomach.

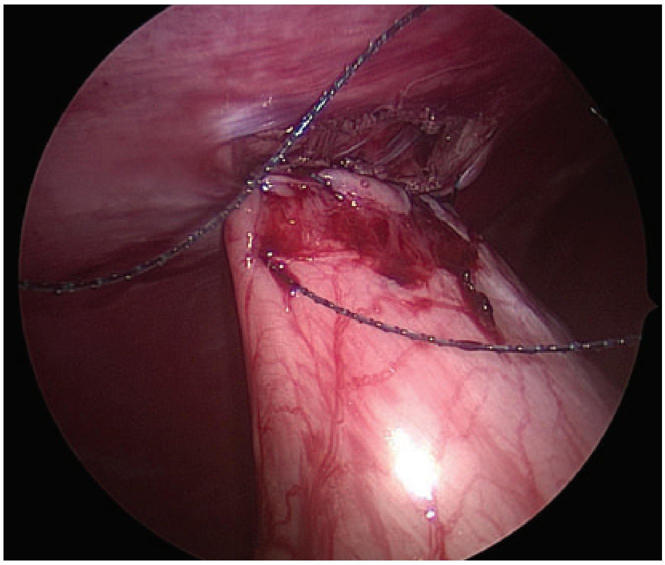

FIG 1. An intracorporeally sutured gastropexy is being performed using barbed suture (V-Loc, Covidien Inc.) that aids in maintenance of tension during suturing.

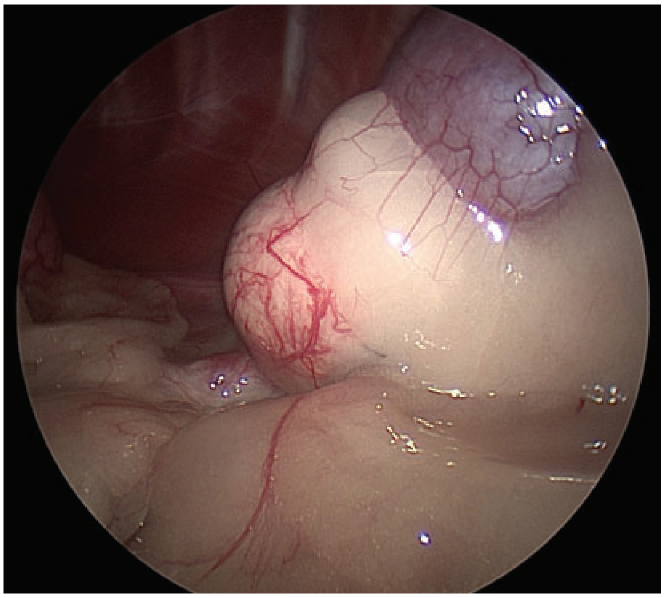

FIG 2. Laparoscopic view of an adrenal mass prior to attempted dissection. The kidney can be seen caudal to the mass.

Laparoscopic adrenalectomy

Laparoscopic adrenalectomy (LA) was developed in humans during the early 1990's as a useful technique for removal of smaller functional or non-functional benign adrenal masses (Fig 2). Studies in humans have demonstrated significant improvements in surgical morbidity associated with LA compared to open adrenalectomy and the technique has been refined over the years. In veterinary medicine the first description of LA was published in 2005. Results of this cohort of seven cushingoid dogs with adrenocortical carcinoma was very encouraging with minimal operative morbidity and no conversions reported for both right- and left-sided lesions although two dogs died in the perioperative period from suspected thromboembolic disease (Jiménez Peláez *et al.* 2008). In this study, the principal technical challenge encountered was capsular rupture with consequent leakage of necrotic centres from the tumours that were aspirated. More recently, LA has been reported in sternal recumbency using cushions to elevate the thoracic and pelvic area in order to displace organs away from the area of the adrenal gland by gravitational force. The authors of this report of predominantly left-sided lesions had similarly excellent results with no major intraoperative complications, no conversions and eight of nine dogs being discharged from the hospital within 72 hours (Naan *et al.* 2013). The authors suggested that this positioning affords superior visualisation provided by organs falling away from the surgical site although comparison to another position was not performed. Another cohort of clinical cases of LA was reported recently and included 20 canine and three feline right- and left-sided lesions comprising both cortical masses as well as phaeochromocytomas (Mayhew *et al.* 2013a). In this case series capsular rupture occurred in three right-sided lesions but all animals were discharged from the hospital and only one cat required conversion to an open technique. Feline LA has also been described in one cat with a left-sided aldosterone-secreting tumour, which lived for more than four years post-operatively with no evidence of recurrence (Smith *et al.* 2012). Surgical challenges particular to cats include the difficulty in dissection of the tumor from the sometimes very large perirenal fat pads (Fig 3) and the extreme friability of the abdominal wall in cushingoid animals that can make CO_2 leakage and maintenance of a pneumoperitoneum very challenging (Mayhew *et al.* 2013a).

Studies are underway to compare morbidity between open and laparoscopic adrenalectomy and continued refinements to this technique will no doubt be the subject of further studies in the future. Further study is also needed into the ideal case selection criteria for LA. Indications for LA from the author's group include tumours up to 4 to 5 cm that have been shown using advanced imaging (preferably dual-phase computed tomography) not to be invasive into the local vasculature or surrounding organs.

Laparoscopic cholecystectomy

While laparoscopic cholecystectomy (LC) was the first advanced laparoscopic procedure to gain mainstream acceptance in human medicine it has received little attention in small animal patients probably due to the infrequent nature of surgical disease of the gallbladder in small animals. LC has been described in a cohort of six dogs suffering from gall bladder mucocoele in which the procedure was completed without significant intraoperative complications or conversion although surgical time was prolonged (range: 95 to 165 minutes) in those cases (Mayhew *et al.* 2008). Common bile duct ligation is one of the most time-consuming parts of the procedure and was performed primarily using extra-corporeally tied ligatures which are quite laborious and time-consuming to place. The author has since completed a small number of additional cases using intracorporeally sutured common bile duct ligation which was subjectively more efficient but further research is required to optimise the technique of LC in the future. Case selection for LC is critical. Gall bladder mucocoele represents the most common pathology treatable with LC but common bile duct obstruction must be ruled out using pre-operative biochemical evaluation of the patient along with the results of diagnostic imaging. If the clinical presentation is consistent with an obstructive component then an open approach is favoured by this author, to allow flushing of the common bile duct through a duodenotomy incision and catheterisation of the major duodenal papilla. Similarly, if a significant bile peritonitis is present an open coeliotomy is favoured to ensure that thorough lavage of the abdomen can be performed and all sites of potential rupture within the extra-hepatic biliary tract can be evaluated.

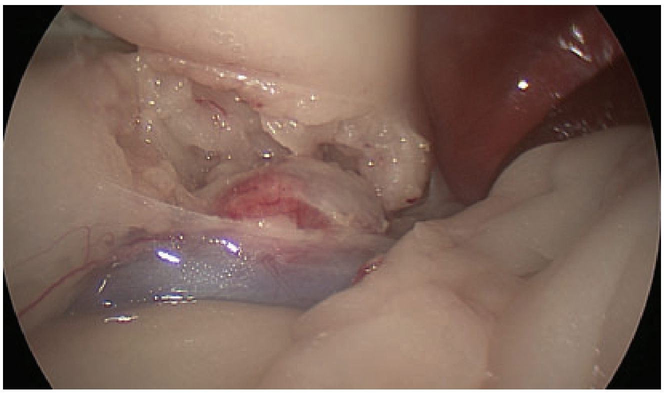

FIG 3. A right-sided adrenal tumour is shown in a cat. Note the abundance of periadrenal fat that can make the dissection more tedious and the close approximation of the mass to the wall of the caudal vena cava. Extreme care is required during dissection of the plane between the mass and the vena cava.

Laparoscopic ureteronephrectomy

Performed frequently in humans principally for management of renal cancers and for live donor nephrectomy for renal transplantation this procedure has only recently been reported in a cohort of canine clinical cases (Mayhew *et al.* 2013b). Renal neoplasia is an infrequent diagnosis in small animals and late diagnosis is a common problem. When a large mass is present with or without perirenal lymphadenopathy, laparoscopic resection can be a challenge. Despite quite large lesions being resected laparoscopically in humans care should be taken early in the learning curve as complications can arise. In the study mentioned predominantly benign lesions were resected and complications were encountered including retroperitoneal and capsular haemorrhage. In one case conversion to an open approach was performed as a massive hydroureter was present and access to the ureterovesicular junction for final ureteral ligation was judged to be too challenging. Ideal case selection has yet to be well-defined but current recommendations are that modestly sized lesions, ideally confined to the renal capsule, without massive hydroureter are the best cases to attempt early in the learning curve.

Recent advances in video-assisted thoracoscopic surgery (VATS)

The development of VATS in veterinary medicine has been slower most likely because of the challenges involved in operating close to vital thoracic structures, the requirement for some cases to be performed using specialised anaesthetic techniques such as one-lung ventilation (OLV) and the challenges of limited working space in the thorax of many of our smaller patients. Despite these challenges a number of interventions have been described in small case series and a smaller number still have been documented in case series from multiple centres. The most frequently performed VATS interventions will be discussed here in more detail including thoracoscopic pericardiectomy, lung lobectomy and management of idiopathic chylothorax (IC).

VATS pericardiectomy

One of the first interventions to be performed using a VATS approach was a PW technique that was described principally for palliation of idiopathic (IPE) and neoplasia-associated pericardial effusion (Fig 4). This technique has been described by several authors now both in experimental dogs (Walsh *et al.* 1999) as well as populations of clinical canine cases (Jackson *et al.* 1999, Case *et al.* 2013a) and is generally a very successful and relatively simple technique. Despite the Jackson *et al.* (1999) description of using one-lung ventilation for PW formation most authors now agree that a PW can be created in most dogs without the use of OLV. More recently the ability of a PW, performed using a VATS approach, to provide effective long-term palliation of IPE compared to an open subphrenic pericardiectomy, has been questioned. (Case *et al.* 2013a). Further study into this question is necessary but this author is likely to recommend subtotal pericardiectomy be considered in dogs with IPE in the future. Subphrenic pericardiectomy can be performed using a VATS technique and this has been demonstrated in an experimental study using alternating OLV (Mayhew *et al.* 2009) as well as without OLV in a group of clinical cases (Dupre *et al.* 2001). The VATS technique for subphrenic pericardiectomy is somewhat more challenging and time-consuming than creation of a VATS PW.

VATS lung lobectomy

Lung lobectomy can be completed using either a VATS-assisted technique (Fig 5) where the lesion is exteriorised through a small intercostal "assist" incision using "open" thoracoabdominal surgical staplers (Laksito *et al.* 2010) or using an entirely VATS approach where the lung lobes are stapled intra-thoracically (Fig 6) and endoscopic stapling systems are used (Garcia *et al.* 1998, Lansdowne *et al.* 2005, Mayhew *et al.* 2013c). The learning curve for the VATS technique is probably somewhat more challenging than for the VATS-assisted technique and OLV is generally required. One of the main challenges in VATS lobectomy is institution of and safe monitoring of OLV and failure of OLV represents the most common cause of conversion to open lobectomy in these cases (Lansdowne *et al.* 2005, Mayhew *et al.* 2013c). An assisted technique is less challenging but may not allow access to the very base of the pulmonary hilus in all dogs. It may also be challenging to resect some of the larger lesions. Appropriate selection in VATS cases is key as a high conversion rate is likely if attempts are made to resect lesions that are too large or too close to the hilus early in the learning curve (Lansdowne *et al.* 2005). In the author's institution lesions up to approximately 8 cm are operated in dogs more than 30 kg. In dogs 10 to 30 kg lesions up to approximately 5 cm are approached using a VATS approach although this

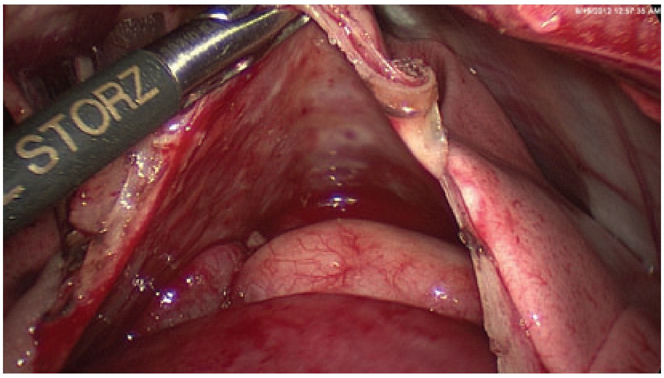

FIG 4. A large pericardial window has been created thoracoscopically for palliation of pericardial effusion in this dog with a heart-based mass that is visible medial to the right auricular appendage.

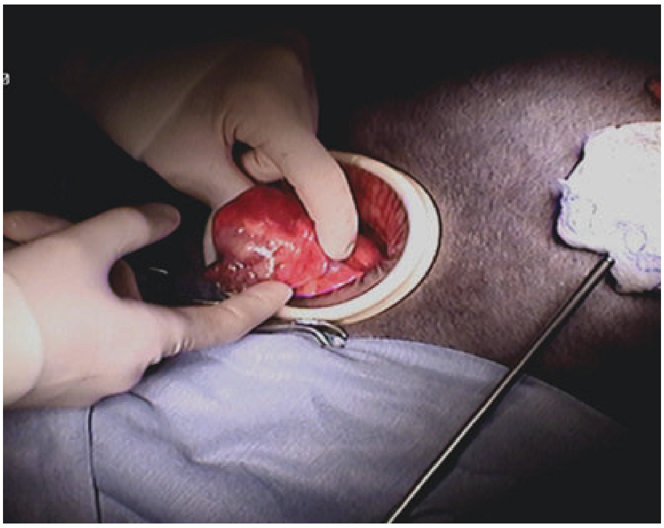

FIG 5. In this VATS-assisted lung lobectomy the end of a lung lobe can be seen being exteriorised from the thorax through a wound retractor device in preparation for being resected using stapling equipment extra-thoracically. (Photo courtesy of Dr Jeffrey Runge).

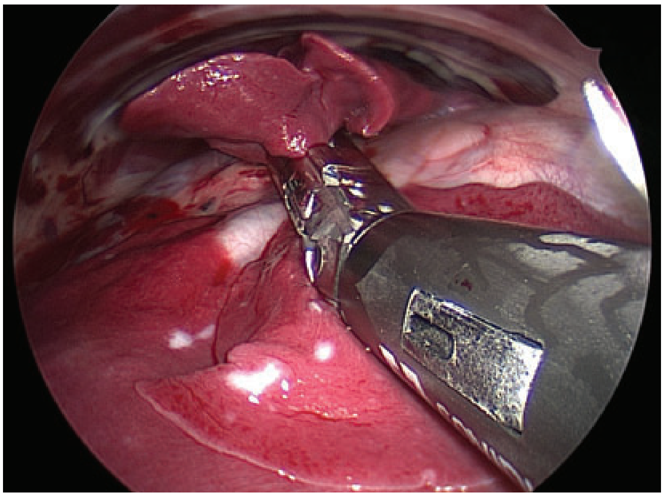

FIG 6. A right cranial lung lobe resection is being performed. The EndoGIA stapler (Covidien Inc.) is in position ready to be discharged across the lobe hilus.

relationship has not been well-defined (Mayhew *et al.* 2013c). Smaller dogs and cats (<10kg) are more challenging and resection in these patients using a VATS technique has not yet been described. VATS lung lobectomy for resection of non-neoplastic lesions is less well characterised. One report of VATS lobectomy for treatment of three dogs with spontaneous pneumothorax due to bullous emphysema has been published (Brissot *et al.* 2003). Treatment was successful in these three cases. The author's experience with cases of spontaneous pneumothorax has been mixed and owners should be warned that a higher rate of recurrence might have to be expected in these cases due to the possibility of smaller lesions in inaccessible parts of the thorax being missed. Recurrence rates after VATS treatment of spontaneous pneumothorax in humans has been shown to be higher than when an open thoracotomy approach is used (Macduff *et al.* 2010).

Minimally invasive management of idiopathic chylothorax

Management of idiopathic chylothorax (IC) has long been controversial with a large number of different techniques described for surgical management of the condition. The combination of thoracic duct ligation and subphrenic pericardiectomy has been described in cohorts of dogs and cats using open surgical techniques (Fossum *et al.* 2004, Carobbi *et al.* 2008) and has now been described using a VATS technique (Figs 7 and 8) both in healthy dogs (Radlinsky *et al.* 2002) and those with IC (Allman *et al.* 2010, Mayhew *et al.* 2012a). Results from these studies only report the outcomes of the VATS approach in 13 dogs with IC but results compare very favourably with the results obtained with this combination of therapies using an open thoracic approach. Recently a report of two cats with IC treated with a VATS approach was published with resolution of signs seen in both cases (Haimel *et al.* 2012). Cisterna chyli ablation has emerged as an additional procedure favoured by some surgeons and in one prospective randomised study was shown to have improved results compared to a control group treated with thoracic duct ligation and pericardiectomy using an open surgical approach (McAnulty 2011). The minimally invasive approach to cisterna chlyi ablation has been described in healthy research dogs (Sakals *et al.* 2011) but results of the procedure have not yet been published in a population of clinical cases.

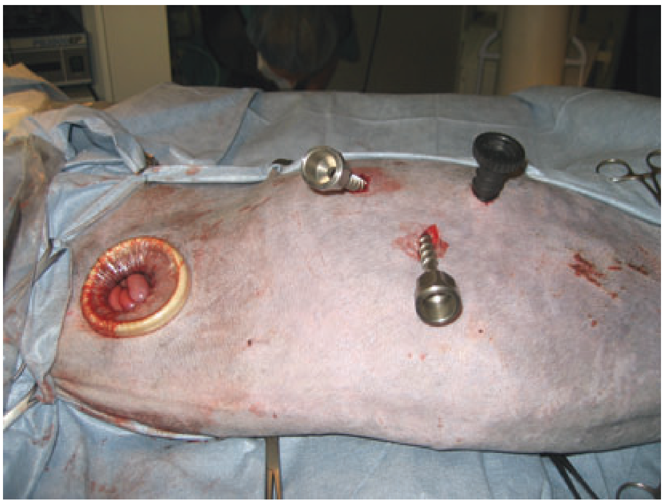

FIG 7. Patient positioning and portal placement for thoracoscopic thoracic duct ligation. The small "assist" incision has been created for access to the abdominal lymph nodes for injection of methylene blue dye. This procedure can also be performed in sternal recumbency.

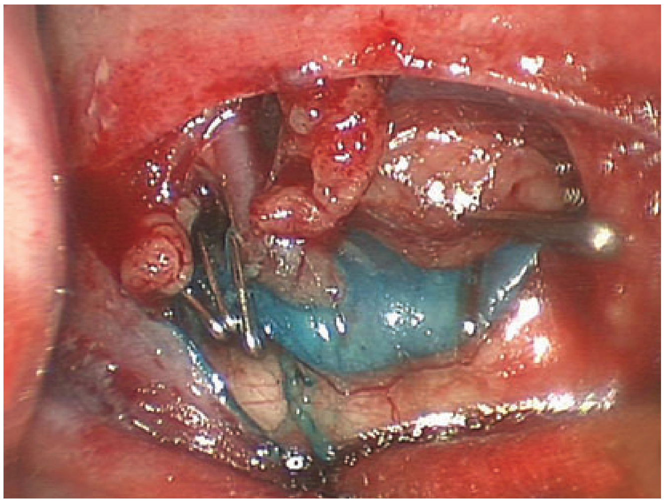

FIG 8. This dog presented with multiple thoracic duct branches that are highlighted with methylene blue dye. Haemoclips can be seen in place to seal the thoracic duct branches.

Advanced minimally invasive surgical platforms

In human medicine the first laparoscopic and thoracoscopic procedures developed in the late 1980s and early 1990s have now gone through many refinements and newer surgical platforms have emerged that may or may not stand the test of time. Whether they are adopted widely is influenced by a variety of factors including evidence base, technical difficulty, expense and extraneous factors such as the influence of reimbursement policies of medical insurance companies. Some of these newer innovations in MIS include single port surgery, minilaparoscopy and needlescopic surgery, natural orifice transluminal endoscopic surgery (NOTES) and procedures performed using surgical robots.

Robotic surgery is performed using a series of robotic arms that are positioned over the patient and control the telescope and instruments through cannulae placed into the body cavity in question. The surgeon is positioned at a console remote from the patient and controls the instruments using hand and foot controls. Advantages of this technique include finer control over the instrumentation and improved access to parts of the body that may be a challenge using traditional laparoscopic instrumentation. Despite robotic surgery growing in popularity greatly in recent years (367,000 robotic procedures were performed in the USA in 2011) the additional cost of the devices and the disposables, as well as the additional surgical time required to set up the console, are causing a more critical analysis of outcomes to be performed. In one large study of hysterectomy in women published recently, the cost of a robotic hysterectomy was almost a third greater than a laparoscopic hysterectomy and outcomes were almost identical (Wright *et al.* 2013). Much of

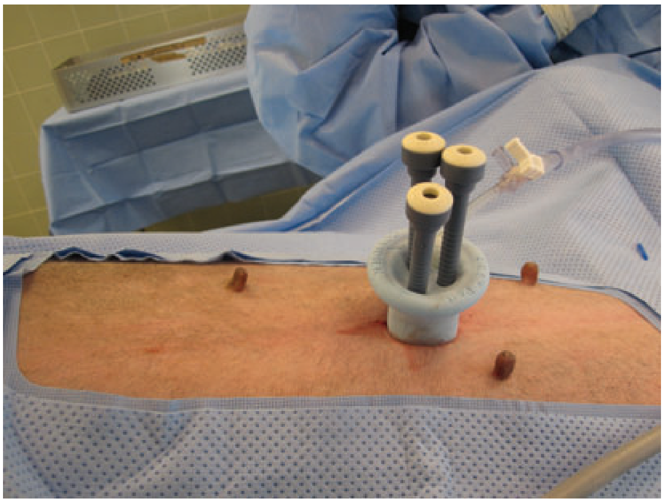

FIG 9. The single incision laparoscopic surgery (SILSÔ, port; Covidien Inc.) port can be seen in position in this dog. Either three 5 mm cannulae (as shown) can be placed through the device or two 5 mm and one 5 to 12 mm cannulae can be used in combination.

this technology is patent protected and so costs are expected to decrease when competition in the marketplace increases over the next 5 years as patent protection is lost on many of the components. This may allow this technology to be explored further in the veterinary field in future years.

The NOTES technique was conceived as an access platform that would allow abdominal procedures to be performed through either the stomach, colon or female genital tract. Using small incisions made in these organs and the passage of flexible endoscopes, procedures can be completed with no external incisions at all. NOTES procedures in veterinary medicine have been pioneered at Purdue University and the investigations have shown that this approach is possible for a variety of veterinary procedures (Freeman *et al.* 2011). The procedure may still face many challenges to widespread veterinary adoption given the technically challenging nature of the procedure and the requirement for surgeons to develop flexible endoscopic skills, which is more challenging than operating with rigid telescopes.

In part due to the technically challenging nature and proportionally greater expense of robotic surgery and NOTES, single port MIS techniques have grown greatly in popularity recently. Single port surgery uses either an operating laparoscope or one of several currently available single port devices that are available on the human market. Operating laparoscopes are telescopes that incorporate an operating channel that allows passage of one laparoscopic instrument within the working channel. Ovariectomy has been described using the operating laparoscope (Dupre *et al.* 2009, Case *et al.* 2011) although because of the inherent limitation of having only one instrument and the lack of triangulation created, more advanced procedures are likely to be challenging using this device. More recently a variety of human single-port devices that allow multiple instrument passage simultaneously have been adapted for veterinary use. These include the SILS device (Fig 9, Covidien Inc.), the Triport (Olympus America Inc.), the Endocone (Karl Storz Inc.) and the Gelpoint (Applied Medical Inc.) amongst others (Runge 2012). These devices were originally designed for placement in the umbilicus producing little or no scarring due to the recessed nature of the incision in humans. A considerable amount of triangulation is still possible with some of these devices due to either their malleable nature (e.g. SILS) or the ability to place instrumentation at differing locations (e.g. Gelpoint) according to the surgeon's personal preference. The number of ports available varies from 3 to 5 depending on the particular device and they can be single-use disposable as in the case of the SILS and Triport or resterilisable as in the case of the Endocone. Disadvantages to single-port approaches exist in that some triangulation is lost and the disposable single-use varieties are expensive if not reused. This loss of triangulation has been partly overcome by the design of prebent or articulating instruments that allow some distance to be placed between the instrument tips so that they do not impinge on each other too much and these have been used in veterinary patients (Runge & Mayhew 2013). However, articulating instruments are more expensive and many interventions can be performed using regular straight laparoscopic instrumentation. Recent evidence suggests that minimising port numbers may help to decrease pain compared to multi-port approaches (Case *et al.* 2011). Currently several procedures have been described using single-port approaches in veterinary medicine including ovariectomy (Manassero *et al.* 2012) ovariectomy in combination with gastropexy (Runge & Mayhew 2013), cryptorchidectomy (Runge & Holt 2012), intestinal biopsy and resection (Case & Ellison 2013b) and splenectomy (Khalaj *et al.* 2012). In the future it is very likely that many more procedures will be described using these single port devices. A recent publication showed that the SILS port can be reliably sterilised using ethylene oxide and may be safe for reuse in small animal patients. (Coisman *et al.* 2013).

In conclusion, veterinary medicine is seeing a rapid acceleration in the development of minimally invasive soft tissue surgical interventions both in the realm of general practice and specialty practice. Much research remains to be done in establishing which procedures will lend themselves well to an MIS approach and in which cases a traditional open approach might remain the wiser choice. It is an exciting concept to be able to offer our small animal patients many of the advantages that have been realised in humans undergoing minimally invasive approaches for a variety of procedures.

Conflict of interest

None of the authors of this article has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

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