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The role of endoscopy in bovine internal medicine – A review of current indication fields

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ABSTRACT

Endoscopy in bovine internal medicine has come a long way from the first profound research papers in the 1980s to its present-day use. This paper reviews the progress in the 2000s and identifies the main application fields for diagnostic and therapeutic use. Inclusion criteria for scientific papers and reports encompassed focus on endoscopic examination techniques in cattle in the field of internal medicine and publication in a peer reviewed journal (case report/review/original research paper/short communication). Only papers written in English or German language were considered. Studies on laparoscopy, theloscopy, and bronchoscopy show that endoscopic approaches often enable more rapid and accurate diagnosis and treatment options for single diseased animals as well as on a herd level. Oesophagoscopy, rumenoscopy, cystoscopy and thoracoscopy have also been increasingly studied and proven to be safe and effective tools with some limitations in diagnosing and/or treating various diseases in cattle. Scientific approaches explored the epidural space in cattle and comparison of different endoscope systems lead to recommendations for sinuscopy. Yet, this narrative literature review clearly shows that unlike in human medicine, where endoscopy as a minimally invasive technique is used for countless routine procedures every day, there is still some catching up to do in bovine medicine even though the potential of endoscopy in this field has been documented.

Introduction

As a minimally invasive technique, endoscopy is applied for both diagnostic and therapeutic approaches. The big advantage of this technique over other imaging techniques is that pathological findings and organ motions can be viewed directly on site as a closeup and in real time, which facilitates confirmation of a diagnosis and even a more precise prognosis. The diagnostic character is based on direct visualisation and on the opportunity to collect biopsy material, perform a diagnostic puncture or a lavage under visual control.

The technological progress in veterinary medicine in general and the growing consciousness for animal health on an individual level render the benefits of endoscopy increasingly relevant in bovine internal medicine. This review aims to identify the main progress in the 2000s.

Endoscopy in internal bovine medicine – a literature review

This review conforms to the Scale for the Assessment of Narrative Review Articles (SANRA) guidelines (Baethge et al., 2019). The PubMed, Scopus, Web of Science and Google Scholar databases were searched for papers published within the last 23 years (January 2000 till May 2023) containing the main keywords ("endoscopy/endoscopic" OR "laparoscopy/laparoscopic" OR "oesophagoscopy" OR "rhinoscopy" OR "tracheoscopy" OR "bronchoscopy" OR "sinuscopy" OR "epiduroscopy" OR "theloscopy" OR "videoendoscopy" OR "theloresectoscopy") AND ("bovine" OR "cattle" OR "calf" OR "calves" OR "dairy" OR "cow") in the title. Identified papers were reviewed in detail to determine their eligibility for inclusion. Inclusion criteria encompassed publication in a peer reviewed journal (case report/review/original research paper/-short communication) and focus on endoscopic techniques in cattle in the field of internal medicine. Only papers written in English or German language were considered. Exclusion criteria comprised conference papers, interim reports, letters, chapters in textbooks, and papers outside the scope of bovine internal medicine. The eligible papers were assigned to different topics, dependent on the body region examined. According to the scientific focus of the respective paper, letters (A-D) were assigned to each publication (Supplementary Tables S1 - S7): novel endoscopic examination technique presenting physiological and pathological

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findings (A), diagnostic and therapeutic values of different endoscopic examination techniques with the help of case reports (B), use of endoscopy to clarify scientific questions in the frame of internal diseases (C), and evaluation of endoscopic techniques with respect to animal health or comparing these with other current diagnostic approaches (D). We acknowledge the limitation that search method and inclusion criteria for this review rely on authors' experiences and thus may involve subjective selection bias.

Scientific papers related to the use of endoscopic examinations in cattle in the field of internal medicine

Ninety-nine scientific papers met the inclusion criteria. These were published between January 2000 and May 2023. No papers were published in 2003 and 2010, in the remaining years minimum 1 and maximum 8 papers (Fig. 1). Considering the spectrum of endoscopic examination techniques (Fig. 1) laparoscopy was reported most frequently ($n = 37$), followed by theloscopy ($n = 19$), bronchoscopy ($n = 17$), and papers on endoscopy of the upper digestive tract (oesophagus, rumen/reticulum) ($n = 16$). The thorax and the urinary tract were reported less frequently (thorax: $n = 4$, urinary tract: $n = 4$). There is one scientific paper describing epiduroscopy and sinuscopy, respectively. One of the 99 papers included (Vijayakumar et al., 2018) was assigned to two different endoscopic examination topics (upper digestive and respiratory tract).

Scientific papers concerning the laparoscopic approach were published regularly over the period covered, while papers about theloscopy were more frequently published between 2000 and 2006. Bronchoscopy is described in papers predominantly published from 2006 onwards. Scientific papers about endoscopic examination of the upper digestive tract mainly were published as case reports since 2011.

Regarding the countries of affiliation of the first author (Fig. 2) publications originated from Germany ($n = 15$), Austria ($n = 14$), and Canada ($n = 12$) were published most frequently in the early 2000s. Since 2015 authors from India ($n = 18$) and Brasil ($n = 11$) published more frequently, mostly about experiences with laparoscopy, theloscopy and endoscopy of the upper respiratory and digestive tract (Fig. 2).

Concerning the publication type (Supplementary Tables S1 - S7), predominantly original research papers were published ($n = 76$), followed by case reports ($n = 17$), short communications ($n = 5$) and reviews ($n = 1$).

Laparoscopy

For laparoscopy a total of 37 papers matched the criteria of this literature research (Table 1, Supplementary Table S1). In the early 2000s several studies were published on the basic principles of diagnostic laparoscopy and laparoscopically gathered physiological and pathological findings (König et al., 2000a, 2000b; Franz et al., 2000; Boure, 2005, Karvountzis, 2020). It has been shown that in the standing animal solely the dorsolateral parts of the abdominal cavity can be examined laparoscopically. For the ventral parts cattle must be placed in dorsal recumbency, performing a ventral approach (Franz et al., 2000; Babkine and Desrochers, 2005; Silva et al., 2021). Diagnostic laparoscopy additionally offers the option to obtain biopsy material under visible control. Laparoscopically performed biopsy of the liver, kidney (Chiesa et al., 2009a; b), and intestine (Klein et al., 2002) was described in standing as well as in animals in dorsal recumbency. The authors of these studies not only described the laparoscopic biopsy technique in healthy animals as feasible and safe but moreover this technique allows instant monitoring for potential hemorrhage after the biopsy.

Papers on therapeutic laparoscopy in bovines mainly address the repositioning of left displaced abomasum ($n = 22$). Two-step abomasopexy and 1-step abomasopexy techniques have been described. The 2-step abomasopexy by Janowitz (1998) was the basis for several other procedures developed. In the standing animal the toggle pin suture is placed into the dislocated abomasum and deflated under laparoscopic guidance via the left paralumbar area. In a second step the cow is placed in dorsal recumbency and under laparoscopic control from the ventral right paramedian area the suture is retrieved using a grasping forceps. Then the abomasum is pulled towards the abdominal wall (the sutures are tied over a roll of gauze stent) (Janowitz, 1998; Newmann et al., 2008). Advantages of this technique described are the visualisation of the lateral and ventral-cranial part of the abdomen, and a short surgery time, what suggested this technique appropriate for the use under field conditions (Seeger and Doll, 2007; Jorritsma et al., 2008; Van Leeuwen et al., 2009; Freick et al., 2013; Fiore et al., 2018). Disadvantage is, that the cow must be positioned in dorsal recumbency by manpower using ropes or with the help of a hydraulic chute. Additionally, this can lead to a stress situation for the animal as shown by Tschoner et al. (2020), who evaluated plasma concentration of cortisol and substance P in 28 cows with left displaced abomasum treated by 2-step technique according to Janowitz (1998). Before surgery all cows received Procain-Penicillin and Ketoprofen and 14 cows were treated with xylazine before laparoscopy. The other animals received placebo, remained nonsedated and served as control group. Blood samples were taken before and several times within 24 hours after surgery. Concentration of substance P, a neurotransmitter associated with inflammatory processes and pain didn`t differ between the groups but plasma concentration of the stress marker cortisol showed lower values in animals of the xylazine group at

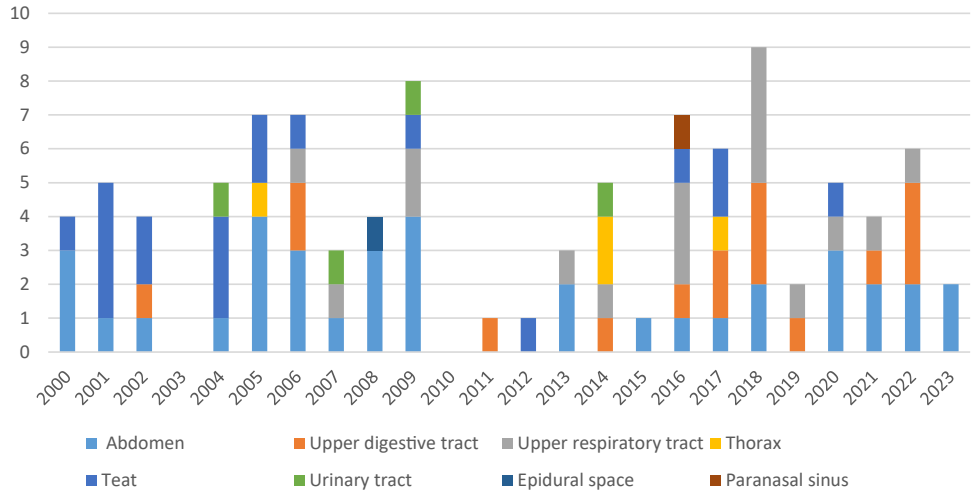

Fig. 1. Numbers of publications between 2000 and 2023 on endoscopic examinations of different organs or body cavities in cattle.

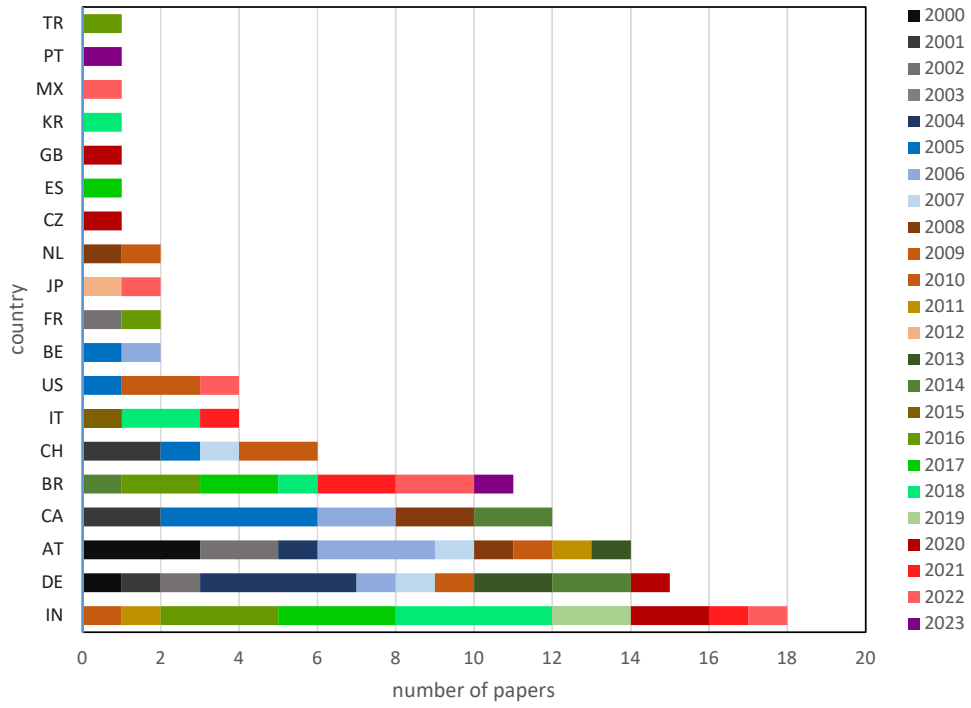

Fig. 2. Numbers of publications between 2000 and 2023 on endoscopic examination techniques in dependence of first author`s affiliation (current ISO 3166 country codes are used: AT, Austria; BE, Belgium; BR, Brazil; CA, Canada; CH, Switzerland; CZ, Czech Republic; DE, Germany; ES, Spain; FR, France; GB, Great Britain; IN, India; IT, Italy; JP, Japan; KR, Korea; MX, Mexico; NL, The Netherlands; PT, Portugal; TR, Turkey; US, United States of America).

Table 1
Papers about bovine laparoscopy with different topics (n = 37).

Topic of paper	Number of papers
Technique, physiological and /or pathological findings	27
Case report on endoscopic diagnostic and therapeutic potential	2
Use of endoscopy to clarify special scientific questions	0
Evaluation of laparoscopic approach	8

all time points, being significantly lower at the time before lateral recumbency. Tschoner et al. (2020) concluded that the administration of xylazine resulted in lower stress levels for cattle and thus recommend xylazine administration before laparoscopic abomasopexy to improve animals' well-being during and after surgery.

A 1-step abomasopexy technique in the standing animal was developed to simplify this minimally invasive procedure for use in the field (Barisani, 2004; Christiansen, 2004). The abomasal toggle pin suture placement, deflation, and abomasal fixation is performed via the left paralumbar area in the standing cow and requires a so called "spieker" for fixation. As disadvantages limited visualisation of the abdominal cavity (cranial-ventral abdominal cavity not visible) as well as risk of fixing the greater omentum in the suture or even puncturing the abomasum during suture placement is documented (Newmann et al., 2008; Van Leeuwen et al., 2009). Perotta et al. (2017) reported on experiences with the 1-step technique on 21 Holstein Friesian cows with left displaced abomasum under field conditions. Surgical complications described were ruminal, abomasal, and splenic perforation as well as difficulties in leading the spieker ventrally. However, the authors evaluated this technique as feasible in the field. Freick et al. (2013) evaluated the 1-step technique in a retrospective study on 487 Holstein Friesian cows with left (n = 454) and right (n = 33) displaced abomasum, originating from one single dairy farm. All cows with left displacement have been successfully treated by laparoscopic approach. 84% of the cows with right displaced abomasum were operated successfully. The authors stated that right displaced abomasum could only be repositioned if there was no torsion. Nessmann et al. (2013) reported a modified Christiansen technique for laparoscopic treatment of the left displaced abomasum in 55 cows under field conditions to be feasible due to a short duration of surgery and the fact, that after 6–16 months still 81% of the treated cows were on the farm.

Iso et al. (2022) evaluated the 1-step laparoscopic abomasopexy in the standing animal as feasible for use in pregnant cows (days 259–274 of gestation) with left abomasal displacement. They performed this technique in 15 cows successfully using 2 portal sites. No postoperative complications raised, and all cows had a normal delivery.

A 1-step technique also can be performed in animals in dorsal recumbency (Newmann et al., 2005; Babkine et al., 2006; Mulon et al., 2006; Tolasi et al., 2015). Newmann et al. (2005) presented a 1-step technique performed via right paramedian area in 4 cows with left displaced abomasum, combining laparoscopic approach and the blind roll-and-tack procedure (Grymer and Sterner, 1982). Advantages such as visualising abomasal toggle suture placement with less surgery time, fewer incisions and less equipment are mentioned. The authors also state, that this technique is feasible to be performed in the field. Mulon et al. (2006) demonstrated a modified ventral laparoscopic abomasopexy technique and evaluated the outcome in 18 dairy cattle with displaced abomasum (left abomasal displacement: n = 17, right abomasal displacement: n = 1) in a retrospective study. All cows were successful treated. There was no evidence of clinical recurrence of abomasal displacement for a mean follow-up of 15.5 months. In contrast to Newmann et al. (2005) a suture material swaged on a curved needle, a laparoscopic needle driver, and a grasping forceps were used for abomasal fixation. The pexy sutures are passed through the abomasal wall without penetration of the mucosa, buried subcutaneously and do not require removal. Babkine et al. (2006) also presented a 1-step laparoscopic abomasopexy in 10 dorsal recumbent healthy, dry Holstein Friesian cows using 3 portal sites in the paramedian right area between umbilicus and xyphoid. The abomasopexy according to Mulon et al. (2006) proved to be safe and quick. A repeat laparoscopy 3 months later showed adhesion formation at the abomasopexy site, which were not continuous in all cases. Mulon et al. (2006) discuss that this

technique can be used even for preventive fixation of the abomasum. In our opinion a benefit of this suggestion needs to be further investigated in the frame of animal welfare.

A modified 1-step laparoscopic abomasopexy technique was presented by Correa et al. (2018). The authors examined 6 adult healthy cattle in dorsal recumbency using 4 portal sites. Abomasopexy was performed using suture threads connected to special surgical staples that were fixed in the greater abomasal curvature. Additionally, to stimulate abomasal adhesion to the abdominal wall cauterization of the abomasal serosa was performed. Adhesion formation was controlled 30 days after first surgery and showed lineal adhesion in four cows. The authors declared this technique not being applicable to perform under field conditions.

The effects of laparoscopic reposition of the displaced abomasum on animal health were investigated in controlled clinical studies in comparison to conventional laparotomy (Seeger et al., 2006; Roy et al., 2008; Wittek et al., 2009; Haloun et al., 2020; Giesteira et al., 2023). The results revealed beneficial effects on recovery, postoperative feed intake, milk yield, and abomasal emptying rate.

Seeger et al. (2006) treated 60 cows with left displaced abomasum by 2-step laparoscopic approach and 60 cows by omentopexy via laparotomy in the right paralumbar fossa. The surgical success rate was 98,3% in the laparoscopic group. Severe adhesions between abomasum and left ventral abdominal wall were responsible for failing repositioning of the abomasum in one cow. All cows with laparotomy were successfully operated. The time of surgery for the laparoscopic procedure was significantly shorter compared to laparotomy. The daily energy intake as well as the daily milk yield increased significantly 4 days after surgery in the cows of each group but more rapid in the laparoscopic group.

Roy et al. (2008) compared the 2-step laparoscopic technique in 152 cows with conventional right flank omentopexy performed in 101 cows. The authors described the laparoscopic technique as feasible and easy to learn. A shorter surgery time and a more rapid return to pre-surgery feed intake of the respective cows were defined as main advantages of laparoscopy. The milk yield (day 1–60 after surgery) increased rapidly in both groups and showed no significant differences between groups.

Wittek et al. (2009) assessed a significant faster abomasal emptying rate in cattle treated with 2-step laparoscopic technique (n = 15) when compared to laparotomy (n = 15) since animals treated by laparoscopy showed an increased rumen contraction rate after surgery. Additionally, the authors observed no differences in postoperative milk yield until 3 days after surgery between groups.

A recent study reported that cows with left displaced abomasum treated by 1-step laparoscopy (n = 63) according to Christiansen (2004) and cows treated by laparotomy (n = 63) showed a similar milk yield 30 d after surgery, and cows of the laparoscopic group had a significantly shorter surgical recovery time (Giesteira et al., 2023).

Serum biochemical parameters were evaluated in a retrospective study by Haloun et al. (2020) to assess if there is a difference over time (30 days) in cows with left displaced abomasum treated by 2-step abomasopexy technique (n = 44) and treated by right flank laparotomy (n = 9). Blood samples were taken once before and two times after surgery (day 10 and 30). Most parameters tested acted comparable over time between groups but there was a significant difference for the inflammation induced plasma protein haptoglobin at day 10, showing a distinct lower serum concentration in the laparoscopy group. In a study of Seeger et al. (2006) the results of tested blood parameters (before and 5 days post-surgery) were comparable between the groups, but values for serum total bilirubin and glutamate dehydrogenase returned significantly faster to reference ranges in cows treated with laparoscopy.

The decision to choose a certain kind of laparoscopic abomasopexy technique seems to be surgeon dependent. In general, it can be stated that more research is required on recurrence rate including adhesion formation and evaluation of advantages and disadvantages of the respective technique. The studies available now are difficult to compare, due to the study protocols. Nevertheless, the results shown in the papers available justify the use of laparoscopic procedures for reposition of the left and even right displaced abomasum. Obstacles identified for laparoscopic approaches were adhesions between abdominal organs or between abomasum and abdominal wall (Seeger et al., 2006; Roy et al., 2008). Although not examined in their study Seeger et al. (2006) advise to keep the period of dorsal recumbency as short as possible to minimize possible cardiopulmonary compromise. The authors refer to investigations showing that dorsal recumbency leads to considerable cardiopulmonary effects (Klein and Fisher, 1988; Wagner et al., 1990). Additionally, Seeger et al. (2006) suggested that the use of antibiotics can be omitted when the risk of external contamination is effectively controlled. Based on our own experience postoperative infection complications are rear due to the minimally invasive character of this surgical intervention and thus antimicrobial prophylaxis is not required in most cases. This is also of economic importance for the owner (no milk loss due to withdrawal) besides the high importance for public health (antimicrobial resistance) and good veterinary practice. Only in cases when concomitant diseases are diagnosed (e.g.: mastitis, metritis, ketosis, claw diseases) the use of antibiotics is recommended. Newmann et al. (2008) recommend postoperative antibiotic treatment in cases when body temperature remains > 39.5 °C after 24 hours. In a study that focused on detection of peritoneal inflammatory indicators, laparoscopic abomasopexy was evaluated as beneficial over right and left flank laparotomy with omentopexy (Wittek et al., 2012). To the authors knowledge the effect of administration of analgesics (non-Steroidal anti-inflammatory drugs - NSAIDs) has not been examined so far in context with laparoscopic procedures in cattle. Its use is varying in the abomasopexy studies published. Some authors disclaim NSAID use because of associating the minimally invasive technique with less pain (Seeger et al., 2006; Fiore et al., 2018; Giesteira et al., 2023). We and other authors recommend preoperative administration of NSAIDs for prevention of the onset of nociception (Anderson and Muir, 2005; Tschoner et al., 2020).

Basic studies, providing information regarding physiological and pathological laparoscopic findings are available on umbilical structures in calves (Boure et al., 2001; Robert et al., 2016; De Oliveira Monteiro et al., 2021; Silva et al., 2023). For closure of ventral abdominal wall defects or resection of the apex of the urinary bladder and umbilical structures cadaver studies on bovine fetuses and calves have been published (Boure et al., 2001; De Oliveira Monteiro et al., 2021; Silva et al., 2023). The latter technique has been already successfully performed in anaesthetized calves positioned in dorsal recumbency (Boure et al., 2001). In this context two laparoscopic suture patterns for repair of a ruptured urinary bladder were compared in clinically normal calves with the result that a one-layer bladder closure is suggested (Boure et al., 2001). A lateral approach for resection of umbilical vein and urachus by laparoscopic technique was successfully demonstrated by De Oliveira Monteiro et al. (2021) in a cadaver study.

In contrast to the laparoscopically performed reposition of the displaced abomasum, endoscopic repair of navel diseases has not reached a routine status yet. Studies investigating the effect on animal health are not available. Currently the clinical relevance of this technique seems to be low. Of course, the price of instruments must also be considered and might be encountered as a disadvantage by bovine practitioners not performing many endoscopic surgeries per year. As described in the context of the displaced abomasum (Roy et al., 2008) the cost of the instruments would be recovered after approximately 100 laparoscopy-guided procedures.

From a scientific point of view studies on cattle nutrition and feeding are very important in bovine medicine and therefore not uncommon. Cannulation of organs such as rumen and abomasum often is required for repeated sampling. A study by Gurgel et al. (2022) in cadavers of bovine fetuses showed a feasible laparoscopic cannulation technique for minimally invasive abomasal content collection.

Theloscopy

For teat endoscopy a total of 19 papers matched the criteria of this literature research (Table 2, Supplementary Table S2).

Scientific papers on theloscopy published from 2000 up to 2010 were mostly dedicated to the description of the technique in cattle and the physiological and pathological endoscopic findings (Riedl et al., 2004a, 2004b; Geishauser et al., 2005; Rathod et al., 2009). It has been shown that theloscopy can be performed through either the teat canal or the lateral teat wall. Endoscopy via teat canal allows visualisation of the teat canal and the teat cistern. The lateral access enables examination of the teat cistern, and the inner opening of the teat canal (Fürstenberg`s rosette) (Querengässer and Geishauser, 2001; Geishauser and Querengässer, 2001; Zulauf and Steiner, 2001).

Vangroenweghe et al. (2006) examined 4 cows in their first and 4 cows in their second lactation. By using the teat canal approach even lactiferous ducts could be visualised. During the procedure the mammary quarter was rinsed with normal saline to get an optimum view on the mucosal surface. Tissue biopsies were gained from different locations using a flexible biopsy forceps. Antibiotic treatment was performed in some cows via application into the teat cistern others did not receive antibiotics. The authors showed that theloscopy had no negative impact on milk flow and udder health. In addition, no benefit of antibiotic treatment was observed. Quarter milk production and somatic cell count did not differ among groups.

The main indication field for theloscopy turned out to be treatment of distal teat stenosis under visual control (Zulauf and Steiner, 2001; Fremont et al., 2002; Bleul et al., 2005). Mucosal detachment can be removed using cutting instruments or by coagulating the mucosal lesion using the theloresectoscope (Zulauf and Steiner, 2001; Sendag et al., 2016; Walvekar et al., 2017; Udayakumari et al., 2020). Several studies comparing theloscopy/theloresectoscopy with thelotomy demonstrated advantages from minimally invasive surgical techniques regarding udder health, milk flow, and somatic cell count (Geishauser and Querengässer, 2001; Hirsbrunner et al., 2001; Querengässer and Geishauser, 2001; Zulauf and Steiner, 2001; Fremont et al., 2002; Kiosis et al., 2002). Benefits are a shorter hospitalization time, and a lower risk of recurrence of teat stenosis or developing mastitis (Hirsbrunner et al., 2001; Fremont et al., 2002; Udayakumari et al., 2020).

Teat tissue changes can be diagnosed performing endoscopy. A report on five cows with toxic mastitis displayed hemorrhages of the mucosa of the teat cistern of various grades and good matching of the endoscopical and histological findings (Condino et al., 2012). Theloscopy also revealed that teat cannulas, frequently used for postoperative treatment of distal teat stenosis, can lead to severe mucosal damage (Bleul et al., 2000). Especially using cotton-lined teat dilators generated inflammatory reaction, and therefore are a risk factor for development of mastitis (Mösenfechtel et al., 2004).

The combination of ultrasonography and theloscopy for diagnostic purposes is also presented (Condino et al., 2012; Miranda et al., 2017). These authors state that theloscopy in contrast to ultrasonography facilitates the determination of extent of mucosal changes in teat tissue.

Publication frequency on theloscopy decreased since 2010. This phenomenon can be linked to lower incidence of teat stenosis due to changing housing systems in Western countries as well as to the fact that the first papers were published from authors with affiliation to European countries and Canada, where this technique is fully established now. This would be in coherence with the observation that in the last years mainly authors from India, and Turkey, shared their experiences with diagnostic and therapeutic theloscopy (Rathod et al., 2009; Sendag et al., 2016; Walvekar et al., 2017; Udayakumari et al., 2020).

Table 2
Papers about bovine theloscopy with different topics (n = 19).

Topic of paper	Number of papers
Technique, physiological and /or pathological findings	11
Case report on theloscopic diagnostic and therapeutic potential	1
Use of theloscopy to clarify special scientific questions	3
Evaluation of theloscopic approach	4

Endoscopic examination of the upper respiratory tract

For endoscopy of the upper respiratory tract a total of 17 papers matched the criteria of this literature research (Table 3, Supplementary Table S3).

For this examination technique flexible gastroscopes are used. They require adequate length to examine the upper respiratory tract from the nasal meatus up to the mainstem bronchi (Franz and Baumgartner, 2006; Anderson and St Jean, 2008; Franz, 2013; Batista et al., 2016). Usually, the animal is restrained in the standing position (Franz, 2013; Masoodi et al., 2016; Venkatesakumar et al., 2020). Performing local anaesthesia of the ventral nasal meatus is recommended by using lidocaine which allows easier insertion of the endoscope into the trachea and is described to be a safe topical anaesthetic in cattle (Dadak et al., 2009). Biometric parameters of the upper respiratory tract such as the naso-epiglottic, naso-tracheal, naso-apical bronchus, naso-carinal distance were investigated and described for healthy adult crossbred cattle (Masoodi et al., 2016).

Hoyos-Jaramillo et al. (2022) compared the clinical protection of vaccinated and non-vaccinated calves experimentally infected with BVDV2 and BHV1 with the help of endoscopy. Calves of the non-vaccinated group showed distinct signs of inflammation at different regions of the upper respiratory tract.

In general, clinical signs such as stridores, pathological nasal discharge, swelling in the retropharyngeal area, coughing, dyspnoea are described as indications for endoscopy of the upper respiratory tract (Franz, 2013). Pharyngeal diseases are diagnosed by using endoscopy alone or in combination with other imaging techniques such as ultrasonography or radiography. The endoscopic diagnosis of retropharyngeal abscess, nasal neoplasia, laryngeal cyst, nasal abscess, nasal schistosomiasis and tracheal collapse are described in several papers (Franz and Baumgartner, 2006, 2007; Lejeune et al., 2009; Shalini et al., 2016; Ro et al., 2018; Faillace et al., 2018; Sasikala and Vijayakumar, 2018; Vijayakumar et al., 2018; Devi et al., 2019; Yogeshpriya et al., 2021). Aside from visual inspection, biopsy under endoscopic control led to exact diagnosis (nasal schistosomiasis, squamous cell carcinoma, chondrosarcoma) (Franz and Baumgartner, 2007; Yogeshpriya et al., 2021). Nevertheless, it seems that the use of endoscopy of the upper respiratory tract especially among veterinarians in the field is not very common. As some authors stated the reason may be rooted in highly priced instruments (Yogeshpriya et al., 2021).

Another indication of bronchoscopy is the bronchoalveolar lavage (BAL), which is performed either in lung diseased animals (Venkatesakumar et al., 2020) or as sampling technique for the lower respiratory tract in experimental animal models (Prohl et al., 2014). Dependent on indication various procedure protocols are available either in the standing animal or in lateral recumbency with or without sedation (Prohl et al., 2014; Venkatesakumar et al., 2020). Due to high incidence of bovine respiratory disease in calves, an early and accurate diagnosis is important with respect to animal welfare and profitability (Ollivett et al., 2015; Pravettoni et al., 2021). Although no

Table 3
Papers about bovine endoscopy of the upper respiratory tract with different topics (n = 17).

Topic of paper	Number of papers
Technique, physiological and /or pathological findings	5
Case report on theloscopic diagnostic and therapeutic potential	9
Use of theloscopy to clarify special scientific questions	1
Evaluation of theloscopic approach	2

evidence-based studies are published, endoscopically performed BAL can probably lead to a more precise detection of causative agents in cases of enzootic bronchopneumonia, as BAL fluid can be gained from the tracheal bronchus, leading to the right cranial lung lobe that is primilary affected (Prohl et al., 2014; Pardon and Buczinski, 2020; Ollivett et al., 2015; Venkatesakumar et al., 2020).

Endoscopic examination of the upper digestive tract

For endoscopy of the upper digestive tract (oesophagus and forestomachs) a total of 16 papers matched the criteria of this literature research (Table 4, Supplementary Table S4).

Several case descriptions showed the potential of oesophagoscopy for diagnosis of oesophageal foreign bodies, megaoesophagus, oesophageal diverticulum, rupture, oesophageal obstruction and stricture, inflammation, and neoplasia (Franz and Baumgartner, 2002; Vijayakumar et al., 2011; Gomez et al., 2014; Krishnaraj et al., 2016; Sasikala et al., 2017a; Vijayakumar et al., 2018; Trovatelli et al., 2021; Venkatesakumar et al., 2022). The affected animals often exhibit specific clinical signs, such as regurgitation, salivation, recurrent tympany, or swelling in the neck region.

The potential as a diagnostic tool for detection of infectious diseases such as MCF (Malignant Catarrhal Fever) or BVD (Bovine Virus Diarrhoea) in cattle was demonstrated by evaluation of the oesophageal mucous membrane for typical signs of inflammation and biopsy for detection of BVDV Ag by PCR technique in persistently and transiently infected animals (Franz and Baumgartner, 2002; Franz et al., 2006b).

Two endoscopic techniques were presented in 2006 describing the physiological anatomical endoscopic appearance of the reticulum and rumen in healthy milk fed calves and in calves starting to ruminate using a flexible endoscope. While one technique was performed via oral route, the other one was performed via temporal ruminal fistula (Franz et al., 2006a). Feed was withheld for 12 hours before examination procedure. In all ruminating calves the rumen had to be flushed before endoscopy to gain optimal view of the rumen and reticulum. The oral approach was limited by not being able to visualise the reticular groove and the reticulum.

Rumenoscopy in calves never became a routine diagnostic technique but showed to have potential when using it to obtain serial samples of the ruminal mucosa. Ramos-Zayas et al. (2022) presented an oral endoscopic biopsy procedure of the rumen wall of the dorsal sac of the rumen in healthy sedated calves with an average weight of 72.3 +/- 14.8 kg. Before the procedure the calves underwent a 12-h fasting period. The authors presented a safe and quick biopsy technique and performed rumen papillae measurement (width, height). Dos Santos et al. (2022) performed a rumenoscopy-guided percutaneous rumenostomy in an experimental model in cadavers of bovine fetuses about 8 months of age.

Although rumenoscopy has been described as feasible technique in calves, this technique is suggested to have limitations in adult cattle, since a huge amount of rumen fluid prevents visualisation of the mucosal surface especially of the ventral parts of rumen and reticulum (Franz, 2011; Ramos-Zayas et al., 2022). Nevertheless, a report described a successful diagnostic use of rumenoscopy in an adult cow, showing clinical signs such as anorexia and recurrent tympany. The authors detected endoscopically several polyethylene bags in the rumen, which finally were removed by rumenotomy (Sasikala et al., 2018b). It was the same group that tried to find further diagnostic potential of endoscopy of the forestomachs in healthy adult cattle (Sasikala et al., 2017b; Sasikala et al., 2019). It was necessary to fasten the animals for almost 48 hours before examination with free access to water, just administering dextrose normal saline intravenously. Endoscopy was performed via oronasal route using a flexible endoscope. The reticulum could be visualized and biopsy of the mucosa was performed successfully (Sasikala et al., 2017b). The technique of endoscopic biopsy of the reticulum and rumen was also demonstrated in adult cattle with ruminal acidosis by Sasikala et al. (2018a). The patients were not sedated and not fastened. Biopsy of the reticular and ruminal mucosa was only successful when flushing the reticulum/rumen before using an orogastric tube and removing a huge amount of ruminal fluid using a rehydration pump. Histopathological changes of the specimen revealed vacuolar degeneration of the squamous epithelium in reticulum and rumen.

In our opinion fastening of the animal for a longer time and flushing the rumen followed by suction of the ruminal content must be assessed under the aspect of animal welfare and therefore should be avoided.

Table 4
Papers about bovine endoscopy of the upper digestive tract including oesophagus, rumen, and reticulum with different topics (n = 16).

Topic of paper	Number of papers
Technique, physiological and /or pathological findings	7
Case report on endoscopic diagnostic and therapeutic potential	7
Use of endoscopy to clarify special scientific questions	2
Evaluation of endoscopic approach	0

Cystoscopy

For cystoscopy a total of 4 papers matched the criteria of this literature research (Table 5, Supplementary Table S5).

Endoscopy of the urinary tract allows visualisation of the urethra, the urinary bladder and the ureteral openings and is performed using rigid or flexible endoscopes (Franz et al., 2004; Braun et al., 2007, 2009; Pavelski et al., 2014). By visual inspection of the surface of the mucous membrane different types of cystitis can be diagnosed (catarrhalic cystitis, haemorrhagic cystitis, fibrinous-purulent cystitis) (Franz et al., 2004). The endoscopic assessment of mucosal lesions was also demonstrated in cows with bovine enzootic haematuria, which ranged from reddening over ecchymotic haemorrhages to visualisation of a tumour (Pavelski et al., 2014). Two case reports demonstrate the potential of cystoscopy in cows for diagnosing rupture of the urinary bladder or urachal rupture (Braun et al., 2007; 2009). In a two-year-old Brown Swiss cow a patent urachus was responsible for failing to visualise the apex of the urinary bladder endoscopically, the flexible endoscope (diameter 0.9 cm) could be advanced into the tube-like urachus. Final diagnosis was given in combination with physical examination, ultrasonography of the abdomen and interpretation of blood laboratory work (azotemia) (Braun et al., 2009). In another adult cow a bladder rupture due to necrotizing cystitis following dystocia was diagnosed (Braun et al., 2007). The fact that the cranial pole of the bladder could not be identified endoscopically led to the assumption that it was ruptured at this site what was confirmed at postmortem examination.

Thoracoscopy

For bovine thoracoscopy a total of 4 papers matched the criteria of this literature research (Table 6, Supplementary Table S6).

In 2005, a case report presented the therapeutic potential of thoracoscopy for the first time in an adult pregnant cow to reduce clinical signs following heart failure due to pericardial lymphoma (Van Biervliet et al., 2005). Thoracoscopic pericardiotomy was performed in the standing animal supplied with intranasal oxygen throughout the procedure and local anaesthesia at the trocaration sites at the right thoracic

Table 5
Papers about bovine cystoscopy with different topics (n = 4).

Topic of paper	Number of papers
Technique, physiological and /or pathological findings	1
Case report on cystoscopic diagnostic and therapeutic potential	2
Use of cystoscopy to clarify special scientific questions	1
Evaluation of cystoscopic approach	0

Table 6
Papers about bovine thoracoscopy with different topics (n = 4).

Topic of paper	Number of papers
Technique, physiological and /or pathological findings	1
Case report on thoracoscopic diagnostic and therapeutic potential	1
Use of thoracoscopy to clarify special scientific questions	0
Evaluation of thoracoscopic approach	2

wall. Serosanguineous pleural fluid was removed, and pericardial fluid was drained after applying topical lidocaine and performing a "T"-shaped incision in the pericardium. One month after the procedure the cow was still doing well but developing abortion 3 weeks after discharge from hospital (Van Biervliet et al., 2005).

Almost 10 years later thoracoscopy was described in detail by Scharner et al. (2014) in standing healthy adult cattle. After local anaesthesia at the portal sites, a pneumothorax was created by trocaration of the pleural space. A rigid endoscope was inserted, and the visible anatomical structures identified. Thoracoscopy was successfully performed in all cows, which were monitored for 10 days after surgery, showing no pathological changes.

Shortly thereafter the first study was published evaluating the effect of thoracoscopy on the cardiovascular system and lung function (Michaux et al., 2014). The authors performed thoracoscopy in healthy, sedated adult cattle in standing position. Cardiovascular and pulmonary variables were assessed before, during and after the thoracoscopy. Only a mild increase of heart and respiratory rate and a moderate decrease of arterial oxygen saturation and PaO_2 were detected (Michaux et al., 2014).

Perez-Villalobos et al. (2017) published results of thoracoscopy in 17 calves affected with lung diseases in different study settings (hospital and feedlots, different endoscopic instruments and approaches). Two clinically healthy calves served as control. The procedure was performed in the standing animal, in two calves in recumbent position. Sedation was necessary in four calves due to temperamental behaviour. Meloxicam was administered parenteral, lidocaine and adrenalin at the trocaration sites. In the diseased calves, the authors visualised small lung abscesses, emphysema, edema, and lung adhesions. The only complications observed were subcutaneous emphysema and a pleural laceration in one calf in recumbent position. The authors state that thoracoscopy is a safe technique also under field conditions. All calves showed an increase of body weight during one month after surgery. The authors recommend performing thoracoscopy in standing animals using flexible endoscopic equipment, which is in contrast to the study of Scharner et al. (2014).

In all studies dealing with thoracoscopy the authors emphasized the importance of accurate diagnosis of lung diseases especially in the feedlot industry. While they describe the diagnostic potential of endoscopic techniques it must be considered that other non-invasive techniques should be prioritised due to animal welfare. Thus, studies evaluating diagnostic accuracy of ultrasonography versus endoscopy for assessment of lung diseases are missing, ultrasonography is non- invasive and has a great diagnostic potential (Buczinski et al., 2014; Ollivett and Buczinski, 2016; Timsit et al., 2016; Cramer and Ollivett, 2019; Pravettoni et al., 2021). Especially for on-farm assessment the use of ultrasonography in lung-diseased calves is recommended (Ollivett et al., 2015; Pravettoni et al., 2021) due to early and accurate diagnosis and prognosis.

Epiduroscopy and sinuscopy

For bovine epiduroscopy and sinuscopy a total of 2 papers matched the criteria of this literature research (Table 7, Supplementary Table S7).

A single scientific paper (Franz et al., 2008) was published on endoscopic examination of the epidural space in six healthy adult cattle. The study provided detailed description of anatomy and endoscopic physiological findings of the epidural space in standing cattle using a flexible endoscope (length:75 cm, diameter: 2.3 mm). To our opinion it is not only of scientific interest to gain insight into the anatomic structures of the epidural space in this species, epiduroscopy can also help to evaluate possible epidural tissue reaction to epidurally applied anaesthetics, as shown in other animal species (King et al., 1984; Kytta et al., 1986).

Table 7
Papers about bovine epiduroscopy (n = 1) and bovine sinuscopy (n = 1) with different topics.

Topic of paper	Number of papers
Technique, physiological and /or pathological findings	2
Case report on thoracoscopic diagnostic and therapeutic potential	0
Use of thoracoscopy to clarify special scientific questions	0
Evaluation of thoracoscopic approach	0

One paper provides information on endoscopic examination of the frontal and maxillary sinus in cows with sinusitis after trepanation (Basso et al., 2016). In horses, sinuscopy is widely used for inspection of the sinuses, to collect samples and perform biopsies (Perkins et al., 2009). Experience with a specific technique in one species can help to better explore its application in other animal species. Basso et al. (2016) hence compared different endoscopes and recommend using a rigid and angulated (30°) arthroscope with a diameter of 4 mm in cattle.

Conclusions

The potential of diagnostic and therapeutic endoscopic interventions in bovine internal medicine has been documented in the last couple decades. The benefits of this minimally invasive technique include quicker diagnosis and prognosis as well as shorter recovery time, less tissue injury, less post-operative pain, and lower risk of post-treatment infections. The latter allows reduction of antibiotic medication, what should not be undervalued, neither economically nor with respect to animal welfare and to public health and antimicrobial resistance. Flexible and rigid endoscopic systems certainly will be improved continuously to allow easier performance of existing procedures. Not all innovations to come will help improve procedures for large animals as well but all should be constantly monitored and evaluated to help improve bovine internal medicine and bovine health.

CRediT authorship contribution statement

Sonja Franz: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Agnes Maria Dadak:** Writing – review & editing, Writing – original draft, Visualization, Formal analysis. **Lisa Hofer:** Investigation.

Conflict of interest statement

None of the authors has any other financial or personal relationships that could inappropriately influence or bias the content of the paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.tvjl.2024.106093.

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