

# Minimally invasive repair of congenital inguinal hernias in nine foals using an automated laparoscopic suturing device and barbed suture

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## Summary

**Background:** Laparoscopic herniorrhaphy using staples or smooth suture has been shown to be safe and effective for the surgical treatment of congenital inguinal hernia in colts and gives the possibility to spare the testicles. An automated laparoscopic suturing device combined with barbed suture reduces the technical challenges of laparoscopic suturing.

**Objectives:** The objective of the study was to describe the application of the Endo Stitch™ automated suturing device in combination with V-Loc™ unidirectional barbed suture for laparoscopic herniorrhaphy in foals with congenital inguinal hernia, share experiences and provide long-term follow-up regarding the outcome.

**Study design:** Retrospective case series.

**Methods:** Medical records of all foals that had laparoscopic herniorrhaphy using the Endo Stitch™ combined with V-Loc™ unidirectional barbed suture at two equine referral hospitals between May 2015 and July 2022 were reviewed. Long-term follow-up was conducted by telephone interviews with the owners using a standardised questionnaire.

**Results:** Nine foals aged 0.5–13 weeks suffering from unilateral (seven cases) or bilateral (two cases) indirect inguinal hernia underwent unilateral (two cases) or bilateral (seven cases) laparoscopic herniorrhaphy using the described technique. In two animals, the testicles were spared, five animals were bilaterally castrated, and two were unilaterally castrated at the time of herniorrhaphy. No major intraoperative complications occurred. Postoperatively, foals were bright and alert and none of them had significant complications attributable to the surgery. Median long-term follow-up was 8 months. No re-herniation was observed in any of the cases at any time postoperatively.

**Main limitations:** Retrospective study design and follow-up period of less than 6 months in three cases.

**Conclusions:** Laparoscopic herniorrhaphy using the Endo Stitch™ laparoscopic suturing device and V-Loc™ barbed suture is technically less demanding than previously described laparoscopic techniques and effective in preventing re-herniation in foals suffering from congenital inguinal hernia. A fast and uncomplicated postoperative recovery can be expected.

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## INTRODUCTION

Congenital inguinal herniation is a presumably hereditary condition in newborn colts, where abdominal content protrudes into the inguinal canal and the scrotum (Schumacher, 2018). Usually, the herniated tissue is a portion of ileum or distal jejunum (Schumacher, 2018; Tóth & Schumacher, 2018) but inguinal herniation of the large colon has been described (Mariën et al., 2001). If the herniated content passes through the vaginal ring and comes to lie within the vaginal process, the inguinal hernia is classified as indirect and this is the most common presentation in affected foals (Freeman, 2018; Schumacher, 2018). A so-called 'ruptured inguinal hernia' is present if the vaginal process tears and the herniated intestines come to lie within the subcutaneous tissues (Schumacher, 2018; Tóth & Schumacher, 2018). This condition is differentiated from the less common event of an *inguinal rupture*, sometimes also referred to as *direct inguinal hernia* (Schumacher, 2018). In this case, the small intestine and occasionally the testicle leave the abdominal cavity through a rent in the peritoneum and transverse fascia adjacent to the vaginal ring and come to lie outside the intact vaginal process in the inguinal and scrotal subcutaneous space (Freeman, 2018; Schumacher, 2018; Tóth & Schumacher, 2018).

Congenital inguinal herniation can occur unilaterally or bilaterally and, typically, scrotal or inguinal swelling is the only noticeable clinical sign. Indirect congenital inguinal hernias are most often reducible and nonstrangulating and, therefore, do not cause of abdominal discomfort (Mariën, 2001; Schumacher, 2018). Nevertheless, foals with nonreducible or with ruptured inguinal hernias can show depression and colic of variable degrees (Gracia-Calvo et al., 2014; Mariën, 2001). Indirect reducible congenital inguinal hernias often resolve spontaneously by the age of 3–6 months and this progression can be assisted by repeated manual reduction of the hernia or by applying a truss after manual reduction (Mariën, 2001; Schumacher, 2018). Surgical management is indicated in ruptured inguinal hernias and inguinal ruptures, if the hernia is nonreducible, if the hernia fails to resolve or if the hernia is exceptionally large (Mariën et al., 2001; Schumacher, 2018).

When taking an open approach, the superficial inguinal ring is exposed, the hernia reduced, the vaginal tunic ligated, and the testicle removed. The external inguinal ring may be sutured as an adjunctive measure to prevent re-herniation (Mariën et al., 2001; Schumacher, 2018). Minimally invasive laparoscopic approaches to repair congenital inguinal hernias by closing the vaginal rings have been introduced and investigated by several authors (Caron & Brakenhoff, 2008; Klohnen & Wilson, 1996; Mariën, 2001). These laparoscopic techniques are reported to be safe and effective with the inherent advantages of a minimally invasive approach such as decreased incisional site morbidity, high level of postoperative comfort, rapid return to normal activity and excellent cosmetic outcome (Caron & Brakenhoff, 2008; Klohnen & Wilson, 1996; Mariën et al., 2001). Furthermore, the herniated intestine and the umbilical structures can be assessed visually. If wished so, laparoscopic herniorrhaphy allows to spare the testicles and unaltered masculine development (Mariën, 2001). Laparoscopic closure of the vaginal rings is either

achieved using intra-corporeal staples or by direct intra-corporeal suturing. The latter incorporates a larger volume of tissue compared to a stapled closure, and it is therefore speculated that this results in a more secure seal of the vaginal ring (Caron & Brakenhoff, 2008). Intra-corporeal suturing, however, is technically demanding and requires considerable practice to be carried out efficiently.

The use of automated suturing devices facilitates and accelerates laparoscopic suturing (Adams et al., 1995; Hart et al., 2013; Nguyen et al., 2000; Pattaras et al., 2001), but knot tying remains challenging. The use of barbed suture materials can eliminate the need for intra-corporeal knot tying in laparoscopic procedures and, thus, effectively reduce the technical difficulties and duration of these procedures (Gardella et al., 2018; Greenberg & Goldman, 2013; Huhn, 2016). In barbed sutures, helically arranged barbs on the suture surface anchor the suture in the surrounding tissue's collagen matrix, so that the suture holds tension on its own. This provides even tension distribution along the apposed tissues without constricting them, therefore reducing the risk for ischaemic necrosis and related dehiscence (Gingras et al., 2012; Ingle et al., 2013; Ruff, 2013). Furthermore, the surface area of adhesion between tissues is increased, which favours the healing process (Albanese et al., 2016) and the amount of suture material in the patient can be reduced (Giusto, Caramello, et al., 2019). After their initial introduction in human medicine for cosmetic procedures and cutaneous closure (Murtha et al., 2006; Ruff, 2013), barbed sutures gained wider acceptance in various surgical fields (Lin et al., 2016) and they proved to be especially beneficial for different laparoscopic procedures, including the urogenital (Einarsson et al., 2010; Gardella et al., 2018; Massoud et al., 2013) and gastrointestinal (Tsukada et al., 2016; Velotti et al., 2022) fields. In equine surgery, the use of barbed sutures has been investigated *ex vivo* as well as in clinical cases for different open and laparoscopic applications (Adler et al., 2020; Albanese et al., 2016; Corsalini et al., 2016; Gandini et al., 2017; Gialletti et al., 2021; Giusto, Caramello, et al., 2019; Kamus et al., 2022; Major et al., 2017; Nelson & Hassel, 2014; Ruzickova et al., 2016; Sinovich et al., 2020). Ragle and colleagues first described laparoscopic vaginal ring closure with an automated suturing instrument and barbed suture in an adult gelding with an acquired inguinal hernia (Ragle et al., 2013). The authors concluded that this simple and effective method should be considered as a treatment option for inguinal herniation in horses. Recently, barbed suture, although not used in combination with an automated suturing device, was also successfully applied for laparoscopic herniorrhaphy in a male sheep (Jakobek et al., 2021). The aim of the present report is to describe the application of an automated suturing instrument in combination with a unidirectional barbed suture for laparoscopic herniorrhaphy in foals with congenital inguinal hernia and to provide a long-term follow-up regarding the outcome.

## MATERIALS AND METHODS

Medical records of all foals with congenital inguinal hernia treated surgically at two equine referral hospitals, Fethard Equine Hospital,

Ireland and the Equine Clinic Bern at the Swiss Institute of Equine Medicine, Switzerland, between May 2015 and July 2022 were reviewed. Cases were included if vaginal ring closure was performed laparoscopically using an automated laparoscopic suturing device (Endo Stitch™, Medtronic (Schweiz) AG) in combination with a custom-made unidirectional barbed suture (V-Loc™ 180 Absorbable Reload for Endo Stitch™ suturing device, Medtronic (Schweiz) AG). Data specifically retrieved from the medical records comprised age, breed, side of herniation, reducibility of the hernia, presence of colic, precedent conservative management, intraoperative findings, as well as any note of intra- and postoperative complications, including possible re-herniation.

Long-term follow-up was obtained from owners by telephone interviews or email using a standardised questionnaire. In a structured interview, owners were asked about the general condition of the foal during convalescence, healing of the laparoscopic portal sites, if signs of colic occurred and if re-herniation was observed. Furthermore, in all colts that were not castrated as part of the laparoscopic herniorrhaphy, it was inquired whether the colt had been castrated in the meantime and (if so), if complications were encountered with the castration procedure.

## Preparation for surgery

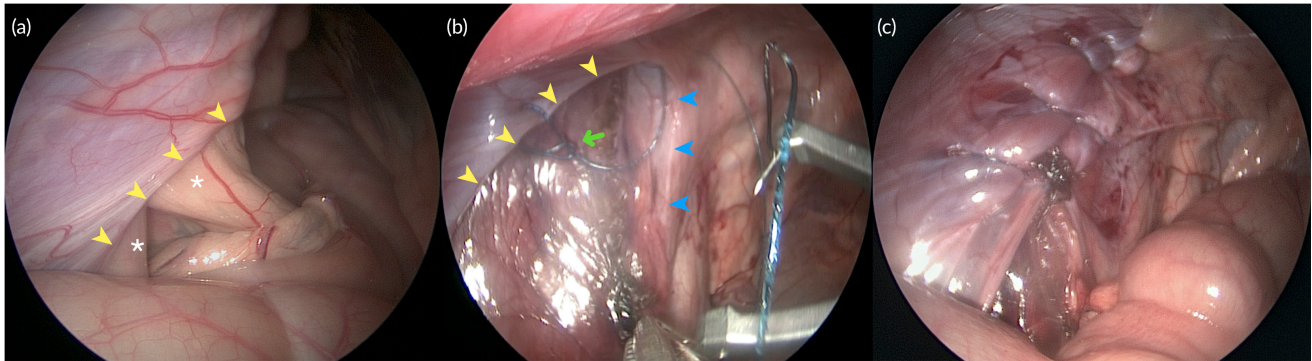
Foals were allowed to nurse before surgery. All subjects received nonsteroidal anti-inflammatory drugs (NSAIDs) (flunixin meglumine 1.1 mg kg<sup>-1</sup> bwt IV or phenylbutazone 4.4 mg kg<sup>-1</sup> bwt IV), prophylactic antimicrobials (benzylpenicillin 30,000 IU kg<sup>-1</sup> bwt IV in combination with gentamicin sulfate 6.5 mg kg<sup>-1</sup> bwt IV or amikacin 20 mg kg<sup>-1</sup> bwt IV; or oxytetracycline 6.6 mg kg<sup>-1</sup> bwt IV) and 3000 IU tetanus serum (Equilis® Tetanus Serum, MSD Animal Health GmbH) prior to anaesthesia. Before induction of general anaesthesia, foals were sedated with xylazine 0.3–1 mg kg<sup>-1</sup> bwt IV, according to age and individual response. Analgesia was provided with butorphanol 0.02 mg kg<sup>-1</sup> bwt IV or levo-methadone 0.05 mg kg<sup>-1</sup> bwt IV at the discretion of the anaesthetist. General anaesthesia was induced with a mixture of 3 mg kg<sup>-1</sup> bwt ketamine hydrochloride IV and 0.05 mg kg<sup>-1</sup> bwt diazepam IV. Maintenance of general anaesthesia was achieved with isoflurane (end-tidal concentration 1.2%–1.5%) vaporised in 100% oxygen and delivered via a circle system. The trachea was intubated and lungs were ventilated to maintain normo-capnoea (end-tidal CO<sub>2</sub> 35–45 mmHg). The foals were positioned in dorsal recumbency on the operating table. One surgeon suspended the hindlimbs on a horizontal bar to allow for elevation of the caudal part of the foal later during surgery. Vital parameters (heart rate, respiratory rate, arterial blood pressure, blood oxygen saturation), as well as inspired/expired gas (fraction of inspired oxygen, end-tidal CO<sub>2</sub>, end-tidal isoflurane), were continuously monitored. A urinary catheter was placed, and the caudal ventral abdomen was clipped, aseptically prepared and draped.

## Surgical procedure

A 1.5 cm skin incision was made approximately 3 cm cranial to the umbilicus. Using a number 11 blade, a small stab incision was made through the linea alba, and a blunt test cannula was advanced into the peritoneal cavity and used to insufflate CO<sub>2</sub> or ambient air to produce abdominal distension. Once the pressure of 10–15 mmHg was reached, the test cannula was withdrawn and the incision in the linea alba was elongated to fit a trocar-cannula unit, which was then inserted in the distended abdomen. The trocar was removed and a 10 mm, 57 cm, rigid 30° angle laparoscope (Karl Storz SE & Co. KG) or 10 mm, 47 cm, rigid 0° laparoscope (Richard Wolf GmbH), depending on the surgeon's preference, was introduced through the cannula. The operating table was tilted 30°, or the caudal part of the foal was elevated by lifting the bar suspending the hindlimbs, to have the foal in Trendelenburg position, thus displacing the viscera cranially. Subsequently, the vaginal rings were inspected (Figure 1a) and paramedian instrument portals were created similarly as described previously (Mariën et al., 2001). Briefly, the instrument portals, one on each side, were created slightly caudal to the umbilicus, equidistant in the paramedian plane between the superficial inguinal ring and umbilicus. A spinal needle was used to confirm appropriate location of these portals. A small incision was made at these sites and a trocar-cannula unit was inserted in these portals under direct laparoscopic observation. If not already spontaneously reduced in Trendelenburg position, herniated intestines were retracted into the abdomen using atraumatic laparoscopic forceps.

Depending on the owner's preference, the testicles were spared, or foals were castrated. For laparoscopic castration, the atraumatic forceps were placed in the contralateral instrument portal, passed underneath the median ligament of the bladder, and traction was applied on the mesorchium to pull the testis through the vaginal ring into the abdominal cavity. The testis was then grasped with the laparoscopic forceps and held in position so that the ligament of the tail of the epididymis could be transected using an electrothermal bipolar vessel-sealing device (Liga Sure™, Medtronic [Schweiz] AG) inserted through the remaining ipsilateral instrument portal. Thereafter, the mesorchium with the testicular vasculature and the ductus deferens with its mesoductus were sealed and transected with the Liga Sure™. The testicle was then temporarily deposited in the caudal aspect of the peritoneal cavity.

For closure of the vaginal ring, the Endo Stitch™ suturing device was loaded with a 20 cm USP 2-0 or 0 (surgeon's preference) polyglyconate absorbable unidirectional barbed suture (V-Loc™) and introduced in the abdomen through the contralateral instrument portal. Suturing was started at the caudal border of the vaginal ring if the gonadal structures had been removed, or just cranial to the vascular structures contained within the mesorchium, if the foal was not to be castrated. First, a generous bite of the caudal edge of the internal abdominal oblique muscle, forming the cranial border of the internal inguinal ring, was taken. The suture was then anchored by passing the needle through the looped end and pulling it tight. With



**FIGURE 1** Illustration of different stages of the surgical procedure in an 8-week-old Swiss Warmblood foal: (a) Laparoscopic inspection shows an enlarged left vaginal ring (yellow arrowheads) with small intestinal loops (white asterisks) passing through the vaginal ring into the inguinal canal. (b) After the small intestinal loops have been retracted into the abdomen and the testicle has been removed, suturing of the vaginal ring starts at its caudal aspect. A first tissue bite is taken at the cranial border of the vaginal ring (yellow arrowheads) with the Endo Stitch™ laparoscopic suturing device loaded with the V-Loc™ barbed suture. The suture is passed through its looped end (green arrow) to anchor it. The next tissue bite is taken at the caudal border of the vaginal ring (blue arrowheads). (c) Completed suture closure of the left vaginal ring.

the second bite, the caudal portion of the vaginal ring was grasped (Figure 1b). A simple continuous suture pattern was run from caudal to cranial, apposing the two borders of the vaginal ring. When arriving at the cranial end of the vaginal ring, the suture was held under moderate tension and cut with laparoscopic suture scissors, leaving a tag of approximately 1–2 cm length (Figure 1c). The same procedure was repeated on the contralateral side, if both vaginal rings were closed.

In foals that were castrated, the testicles were removed from the abdominal cavity following vaginal ring closure. To do so, a laparoscopic forceps was inserted in the ipsilateral paramedian portal, the testicle was grasped, and the forceps withdrawn until the testicle was wedged against the opening of the cannula. The portal was then carefully enlarged with Metzenbaum scissors (if needed) until testicle, cannula and forceps could be withdrawn from the abdomen. Finally, the abdomen was deflated, and all portals sutured in two layers (i.e. linea alba or external rectus sheath and skin) using absorbable suture material and the surgical sites were covered with an adhesive dressing (Snögg Animal Polster, Animal Health [Farm and Stable GmbH and Co.]). Foals were recovered from general anaesthesia hand-assisted and were allowed to nurse within the first hour after recovery.

## Postoperative care

All subjects received systemic NSAIDs and antimicrobials in the postoperative period. The choice of agents used, and the duration of postoperative medication were at the discretion of the responsible surgeon. Additionally, gastroprotectants (sucralfate 20 mg kg<sup>-1</sup> bwt PO) were administered. Foals underwent a daily clinical examination for the duration of their hospitalisation and special attention was paid to control for any scrotal swelling and the laparoscopic portals. Adhesive dressings were left in place until they detached

by themselves and were not replaced. Owners were instructed to keep the mare and foal in a stable with access to a small paddock for a total duration of 4 weeks following surgery. After that, regular turnout could be resumed.

## Statistical analysis

Numerical variables were presented as median and interquartile range (IQR) based on normality testing (Shapiro–Wilk test) using R version 4.1.1 (R Core Team, R Foundation for Statistical Computing).

## RESULTS

### Clinical presentation

Nine foals underwent laparoscopic herniorrhaphy using the Endo Stitch™ in combination with a unidirectional barbed suture between May 2015 and July 2022. Two Franches Montagnes, one Irish Sport Horse, one Lusitano, one Swiss Warmblood and four Thoroughbreds were included. Inguinal herniation was noticed at or shortly after birth in all cases. Inguinal hernia was unilateral in seven and bilateral in two cases. Four of the unilateral hernias were right-sided and three were left-sided. All inguinal hernias were nonpainful on palpation and reducible. Ultrasonography was inconsistently performed prior to surgery. One foal (Case 2) showed several episodes of colic immediately after inguinal hernia first occurred, but colic resolved after repeated manual reduction and application of a truss. Another foal (Case 6) was reported to sporadically show signs of mild colic at home. In this case, the size of the bilateral hernia was fluctuating. Conservative management by repeated manual reduction and/or application of a truss failed to resolve the condition where attempted. Owners of the foals presented in this case series elected to

TABLE 1 Case details and surgical procedures performed.

Case no.	Clinic	Breed	Age at surgery (weeks)	Hernia: Right (R), left (L), bilateral (B)	Reducible (yes/no)	Conservative management prior to surgery: Repeat manual reduction (M), Truss (T), None (N)		Herniorrhaphy: Right (R), Left (L), Bilateral (B)	Castration: Right hemi-castration (R), Left hemi-castration (L), bilateral castration (B), not castrated (N)	Follow-up (months)
1	ISME	LUS	4	L	Yes	M		B	N	93
2	ISME	FM	1	L	Yes	M/T		B	R	8
3	FEH	TB	5-8 <sup>a</sup>	B	Yes	M/T		B	B	3
4	FEH	TB	13	R	Yes	NA		R	R	4
5	ISME	FM	0.5	R	Yes	N		B	B	22
6	ISME	SW	8	B	Yes	N		B	B	21
7	FEH	TB	10	R	Yes	NA		B	B	5
8	FEH	ISH	10	R	Yes	M/T		B	B	17
9	FEH	TB	12	L	Yes	M		L	N	7

Abbreviations: FEH, Fethard Equine Hospital; FM, Franches Montagnes (light breed of draught horses, indigenous to Switzerland); ISH, Irish Sport Horse; ISME, Swiss Institute of Equine Medicine; LUS, Lusitano; NA, not available; SW, Swiss Warmblood; TB, Thoroughbred.

<sup>a</sup>Estimated.

pursue surgical treatment because they were unwilling to continue with the conservative management, because they observed one or more episodes of colic, or because the hernia seemed overly large or was fluctuating in size. The exact age at surgery was not available for Case 3 but was estimated to be somewhere between 5 and 8 weeks based on the drug dosages used, which were calculated based on bodyweight. In the remaining eight foals, age at presentation ranged from 0.5 to 13 weeks (median 9, IQR 7). Clinical examination findings relevant to the cases are summarised in Table 1.

## Surgical procedure

All inguinal hernias were indirect and nonruptured. In all cases in which the hernia had not reduced spontaneously with dorsal recumbency prior to laparoscopic exploration, small intestine was found to be herniated. Retraction of small intestine into the abdomen was generally easy. No adhesions and no devitalised bowel were detected. The umbilical remnants were assessed as being unremarkable in all foals. In 7/9 cases, both vaginal rings were reduced during surgery. In Case 4, only the enlarged vaginal ring related to the hernia was sutured. On the contralateral side, no hernia was present, and the vaginal ring did not appear enlarged. The surgeon was unable to retract the left testis back into the abdomen. Because this foal was having respiratory difficulty under anaesthesia, the surgeon decided not to prolong anaesthetic time and so, herniorrhaphy and castration was carried out unilaterally only. In Case 9, herniorrhaphy was performed unilaterally because the vaginal ring contralateral to the side of herniation was assessed as not being enlarged. The latter observation was supported by the intraoperative finding that the descended testis of that side could not be retracted into the abdomen when placing gentle traction on the spermatic cord. This foal was not castrated. Bilateral castration was performed in 5/9 cases. In these cases, the testicles were readily retracted into the abdomen through the vaginal ring. Unilateral castration was performed in 2/9 cases. This included Case 4, where the surgery was discontinued because the foal experienced respiratory difficulty under anaesthesia. In Case 2, the right testicle was found intra-abdominally and was therefore removed. Two foals (Cases 1 and 9) were not castrated. In Case 9, on the side of the hernia, an assistant grasped the descended testicle from outside the surgical field to maintain it in the scrotum during herniorrhaphy. Recovery from anaesthesia was uneventful in all cases. An overview of the surgical procedures is presented in Table 1.

## Intraoperative complications

In 6/9 cases, no intraoperative complications occurred. Case 4 showed respiratory problems during general anaesthesia but recovered uneventfully from anaesthesia. In Case 6, the foal slid cranially during the surgical procedure, because of inadequate fixation on the operating table. This foal needed to be repositioned to complete the

procedure. Also in Case 6, there was loss of abdominal distension through the laparoscopic cannula because of a broken valve at the beginning of laparoscopy. In Case 8, moderate bleeding from the body wall occurred upon portal creation, which abated when the trocar was placed.

### Early postoperative period (<4 weeks)

The postoperative hospitalisation period ranged from 2 to 4 days (median 2, IQR 1). Postoperative antimicrobials were administered for 1–11 days (median 2, IQR 7) and NSAIDs for 2–5 days (median 3, IQR 2), respectively. Postoperatively, all foals were bright and alert and without fever. Only mild scrotal swelling was observed, and no re-herniation occurred in any of the cases at any time postoperatively. The owner of Case 6 observed sporadic episodes where the foal was in dorsal recumbency upon return from the clinic. According to the owner, the same foal also developed a painful swelling at one of the portal sites. However, the foal appeared otherwise healthy, and this resolved spontaneously without further intervention. Other than that, no signs of colic or problems with the portals were observed or reported for any other operated foal in the early postoperative period. The owner of Case 3 had the impression that the foal had a stiff gait of the hind legs in the first days following hospitalisation.

### Long-term follow-up and outcome (> 4 weeks)

Owners were contacted by telephone or email and interviewed using a standardised questionnaire. Five equids were still with the same owner at the time of the interview (Cases 1, 5, 6, 8 and 9). The remaining four had been sold 3–8 months after surgery and, thereafter, lost to follow-up. The follow-up ranged from 3 to 93 months (median 8, IQR 16). All owners reported a fast recovery and that normal pasture turnout was resumed 4 weeks after hospital discharge. Case 2 was re-admitted to the hospital twice because of mild to moderate colic signs, 1 and 2 months postoperatively. In this foal, equine gastric ulcer syndrome was diagnosed at the second presentation. On both occasions, colic resolved with conservative treatment, including NSAIDs on the second presentation (metamizole 40 mg kg<sup>-1</sup> bwt IV once), oral fluid and mineral oil administration on both presentations and gastro-protective therapy (omeprazole 4.4 mg kg<sup>-1</sup> bwt PO SID and sucralfate 20 mg kg<sup>-1</sup> bwt PO BID) on the second presentation. Until lost to follow-up at the age of 8 months, no further colic episodes were observed. Recurrence of inguinal herniation did not occur in any case. Case 1 was castrated at the age of 5 years at a different clinic. At this stage, only the right testicle was descended into the scrotum. An attempt to bilaterally castrate the horse via an inguinal approach was made. Because the left testicle was not found in the inguinal canal, only the descended right testicle was removed. Standing laparoscopy was performed 2 weeks later. The left testicle was found to be located abdominally and was subsequently removed laparoscopically.

The attending surgeon was not aware that the horse had been subjected to an inguinal herniorrhaphy as a foal. When asked about the appearance of the vaginal ring at the time of the laparoscopic castration, the veterinarian stated that it looked unremarkable. The castration history in the two unilaterally castrated foals (Cases 2 and 4) remains unknown, because these foals were sold as hemi-castrates and were thereafter lost to follow-up. Case 9 was 10 months old at the time of follow-up and had not been castrated at that time. All owners were satisfied with the outcome of the procedure.

## DISCUSSION

The objective of this report was to describe the application of an automated suturing instrument in combination with a unidirectional barbed suture for laparoscopic herniorrhaphy in foals with congenital inguinal hernia and to report the intra- and postoperative complications and the outcome. The results of this case series indicate that this technique is efficient in preventing hernia recurrence and well tolerated with a low risk for intra- and postoperative complications.

Various laparoscopic techniques to close the vaginal ring, thereby preventing inguinal herniation, have been described. Laparoscopic herniorrhaphy may be performed in foals with congenital inguinal hernia or in stallions or geldings after resolution of an acquired inguinal hernia to prevent recurrence. In foals, this allows to spare the testicles and unaltered masculine development (Mariën, 2001). In adult stallions that should stay intact, the surgeon's goal is to effectively prevent hernia recurrence while maintaining adequate blood supply to the testis and physiological cremaster muscle function (Ragle et al., 2013; Schumacher, 2018). Laparoscopic methods to close the vaginal ring are considered more certain to achieve this goal compared to an external inguinal ring closure (Freeman, 2018; Ragle et al., 2013; Schumacher, 2018). Previously described laparoscopic herniorrhaphy techniques in foals include vaginal ring closure under general anaesthesia with intra-corporeal staples or interrupted sutures and with or without concurrent laparoscopic castration (Caron & Brakenhoff, 2008; Klohnen & Wilson, 1996; Mariën et al., 2001). In adult horses, laparoscopic herniorrhaphy may be performed under general anaesthesia (Fischer et al., 1995; Klohnen & Wilson, 1996; Rossignol et al., 2007) or in the standing horse (Mariën, 2001; Ragle et al., 2013; Rossignol et al., 2014; Wilderjans et al., 2012; Wilderjans & Meulyzer, 2021). In adult horses, a variety of techniques and implants have been proposed to accomplish closure of the vaginal rings, including nonabsorbable mesh implants positioned in combination with a peritoneal flap (Fischer et al., 1995), cylindrical polypropylene mesh insertion into the inguinal canal (Mariën, 2001), peritoneal flap transposition (Rossignol et al., 2007; Wilderjans et al., 2012), cyanoacrylate gluing (Rossignol et al., 2014), direct suturing with regular or barbed sutures (Caron & Brakenhoff, 2008; Ragle et al., 2013), and most recently, a tacked intraperitoneal slitted mesh technique (Wilderjans & Meulyzer, 2021).

Although the vaginal rings have been successfully closed in foals using staples (Klohnen & Wilson, 1996; Mariën et al., 2001), it has

been suggested that suture closure is more secure, because suture bites can be placed individually and incorporate as much tissue as needed in contrast to the fixed dimensions of staple instruments (Caron & Brakenhoff, 2008). On the other hand, intra-corporeal laparoscopic suturing is technically demanding and requires considerable training to be applied efficiently, with square knot formation and maintenance of suture tension during continuous pattern suturing being the most challenging aspects (Fransson & Huhn, 2015). The use of barbed suture in minimally invasive surgery alleviates or evades these difficulties. First, knot tying is not required when using barbed sutures. Second, barbed sutures do not loosen or slide backwards and therefore tissue apposition is maintained without continuous traction on the leading suture strand (Fransson & Huhn, 2015; Gardella et al., 2018; Huhn, 2016). With the introduction of barbed suture specifically designed for the use with the Endo Stitch™ automated laparoscopic suturing device, the benefits of these two were combined to create an efficient instrument to facilitate and accelerate laparoscopic suturing (Hart & Sobolewski, 2013; Omotosho et al., 2011; Ruzickova et al., 2016). Because of the proposed benefits of barbed suture in combination with the Endo Stitch™ automated laparoscopic suturing device, we started to use them for laparoscopic herniorrhaphy in foals.

Although we did not measure the operating time and we do not have a control group where conventional laparoscopic suturing was applied, all participating surgeons found suturing of the vaginal ring using barbed suture combined with the EndoStitch™ automated suturing device technically less challenging and more time efficient. This is in agreement with others, who have reported similar experiences with the use of barbed sutures in open and in laparoscopic procedures (Adler et al., 2020; Einarsson et al., 2011; Giusto, Iussich, et al., 2019; Nelson & Hassel, 2014; Omotosho et al., 2011). Timesaving mainly arises from the absence of knot tying and the self-anchoring properties of the suture, which makes suturing more ergonomic (Adler et al., 2020; Giusto, Iussich, et al., 2019). An automated suturing device can further accelerate and facilitate laparoscopic suturing (Adams et al., 1995; Nguyen et al., 2000; Ragle et al., 2013; Ruzickova et al., 2016), but when using smooth suture, knot strength might be reduced in comparison with conventional laparoscopic suturing because of the tendency not to tie complete alternate square knots (Pattaras et al., 2001). These concerns are overcome when using barbed suture, where knot tying is not necessary.

Intraoperative complications directly associated with the surgical procedure were rare. To prevent body wall haemorrhage caused by laceration of larger blood vessels during paramedian instrument portal placement, one technique particularly useful in foals is to visualise larger blood vessels by illuminating the body wall with the laparoscope from the inside while the lights in the surgery room are switched off.

Effectiveness of the vaginal ring closure was evidenced by the absence of hernia recurrence, indicating that the closure was not inferior to other herniorrhaphy procedures in foals in regard to the holding strength of the repair. Although the short needle length of the V-Loc™ barbed suture and the jaw dimensions of the Endo Stitch™

device limit the depth of the tissue bites (Pattaras et al., 2001), this was not considered disadvantageous for the herein-described procedure. In foals, sufficient amounts of tissue were grasped from both edges of the vaginal rings to provide a seemingly robust continuous seal. This is in accordance with the reports by Ragle and colleagues, who were the first to describe the application of a unidirectional barbed suture in combination with an automated suturing instrument for the purpose of vaginal ring closure in an adult horse (Ragle et al., 2013). When re-evaluating the surgery sites laparoscopically 6 weeks after vaginal ring closure, complete healing of the suture lines and continued reduction in the ring size was observed bilaterally, and the horse was without hernia recurrence 20 months postoperatively (Ragle et al., 2013).

The performance and strength of barbed suture was evaluated for various applications in numerous *ex vivo* and *in vivo* experimental studies (Albanese et al., 2016; Arbaugh et al., 2013; Demyttenaere et al., 2009; Giusto, Caramello, et al., 2019; Giusto, Iussich, et al., 2019; Major et al., 2017; Nelson & Hassel, 2014; Omotosho et al., 2011; Ruzickova et al., 2016; Sinovich et al., 2020). These studies supported the effectiveness and strength of barbed suture. Where barbed suture performed inferior to conventional suture, load at failure was well above loads expected in live animals (Nelson & Hassel, 2014; Sinovich et al., 2020). Reports about the use of barbed sutures in equine laparoscopic procedures in clinical cases are not abundant but promising. For example, laparoscopic nephrosplenic space ablation using barbed suture has been successfully employed (Gandini et al., 2017; Gialletti et al., 2021) and was evaluated advantageous over mesh ablation (Gialletti et al., 2021). Corsalini and colleagues used unidirectional barbed suture for laparoscopic uteropexy in three mares (Corsalini et al., 2016). They concluded that the use of barbed suture was easy and practical and that it was effective in maintaining the uterus suspended dorsally as confirmed by rectal palpation 4–6 months postoperatively. Furthermore, barbed suture was recently used in three horses to close a dorsally located diaphragmatic defect through a thoracoscopic approach (Kamus et al., 2022).

As reported by others (Caron & Brakenhoff, 2008; Klohnen & Wilson, 1996; Mariën et al., 2001), recovery after laparoscopic herniorrhaphy was quick and postoperative complications were rare and mild. Case 2 was re-admitted to the clinic because of colic twice within 2 months after herniorrhaphy. While it remained elusive whether gastric ulcer syndrome was the sole reason for the colic episodes, adhesion formation in the area of the vaginal ring cannot be excluded. Abdominal adhesion formation after the use of barbed suture in laparoscopic procedures has been reported in human patients (Köhler et al., 2015). Paying meticulous attention on avoiding free barbed suture ends protruding from tissues was therefore recommended (Köhler et al., 2015). Nevertheless, if proper technique is applied, the amount of exposed foreign material within the abdomen can possibly even be reduced with barbed suture, as no bulky knots are present (Giusto, Caramello, et al., 2019; Sinovich et al., 2020). Several studies in different species found no significant differences between barbed and conventional sutures

regarding the incidence or magnitude of abdominal adhesion formation (Einarsson et al., 2011; Giusto, Iussich, et al., 2019; Omotosho et al., 2011). Furthermore, the benefit of taking a minimally invasive laparoscopic approach may outweigh the risk associated with the suture material when compared to an open herniorrhaphy approach, where manipulation of any prolapsed small intestines may lead to a higher risk for abdominal adhesion formation.

In one horse (Case 1), castrated at the age of 5 years, the left testicle was located abdominally and subsequently removed in a standing laparoscopic procedure. This horse has had a left-sided congenital inguinal hernia and had been subjected to a bilateral vaginal ring closure without castration at the age of 1 month. It can only be speculated, that at the time of laparoscopic vaginal ring closure, the surgeons may have missed that the left testicle and epididymis were either retained or drawn back into the abdomen during retraction of herniated intestine from the inguinal canal.

Sparing the testicles was highlighted as a key element of laparoscopic herniorrhaphy by one author (Mariën et al., 2001). However, little is known about the effects of neonatal castration on normal masculine development in horses. In the present retrospective study, one or both testes were spared in 4/9 individuals. In 5/9 colts, owners wished to castrate the foals at the time of herniorrhaphy to avoid the need of a future surgical procedure. As it was recommended before (Mariën et al., 2001; Schumacher & Perkins, 2010), we advise against breeding with males that suffered from a congenital inguinal hernia, because of the possible heritability of the condition. Although the limited data from our study does not allow robust conclusions to be drawn regarding the development of early castrated foals, recent data suggest that castration at 3 days of age does not interfere with morphological or behavioural development (Cognie et al., 2022).

Only three foals in this case series were originally intended to stay intact. Therefore, the other six foals would have been candidates for a traditional open inguinal approach. The latter involves twisting and ligation of the vaginal tunic with subsequent castration and, if deemed necessary, the additional closure of the external inguinal ring. After having operated the first two foals with a testicle-sparing technique, we continued to recommend the minimally invasive, laparoscopic technique also in cases for which owners requested castration. Arguably, this recommendation is driven by the minimally invasive nature of the laparoscopic procedure and technical simplicity of intracorporal suturing with the help of the automated laparoscopic suturing device and barbed sutures. Likewise, other investigators have described the advantages over an open inguinal approach as omitting inguinal dissection and potentially decreasing postoperative morbidity (Caron & Brakenhoff, 2008; Klohnen & Wilson, 1996) thus allowing for rapid return to normal pasturing. Another rationale in favour of the laparoscopic approach is that the vaginal ring is the first structure traversed by herniated bowel and that its laparoscopic closure might be advantageous over external inguinal ring closure (Caron & Brakenhoff, 2008), which not entirely eliminates the risks of herniation into the inguinal canal (Jakobek et al., 2021).

In the foals subjected to castration, retraction of extra-abdominally located testes into the abdomen was readily performed, with the

exception of one foal (Case 4). This is not surprising in the subject that was operated in the first week of life (Case 5), given that the vaginal rings are described to be incompletely contracted within the first weeks after birth (Bergin et al., 1970). Moreover, in older foals, abnormally large vaginal rings are usually present on the side of herniation (Schumacher & Perkins, 2010) and they are potentially dilated by the herniated content. However, under physiological conditions, the vaginal rings typically contract to a size small enough to preclude passage of the testis from either side within a few weeks after birth (Bergin et al., 1970). This explains why the testis contralateral to the hernia in Cases 4 and 9 (both about 3 months old at the time of surgery) was not readily displaced into the abdomen through traction on the spermatic cord. Nevertheless, retraction of the testis into the abdomen was easy on the contralateral side to the hernia in two foals at 10 weeks of age (Cases 7 and 8) and this might be attributable to an increased size of the vaginal ring on the unaffected side in these individuals. In cases where retraction of the testicle into the abdomen is not possible, surgical enlargement of the vaginal ring may be considered.

Disadvantages of laparoscopic herniorrhaphy are the need for specialised, expensive equipment and the need for expertise in laparoscopic surgery. Furthermore, Trendelenburg position during anaesthesia may predispose to development of peri-anaesthetic hypoxemia (Binetti et al., 2018).

Important limitations of this case series are its retrospective nature and a low case number. In all but one case, follow-up was not available up to full maturity (median follow-up 8 months). Therefore, although unlikely, hernia recurrence during a longer postoperative period cannot be ruled-out entirely. More importantly, this precluded identification of any unintended consequences of the herniorrhaphy procedure on later castration for Cases 2, 4 and 9. These were not at all or only hemi-castrated as part of the laparoscopic inguinal hernia repair. Such consequences may be cryptorchid testicular structures, as observed in Case 1, or adhesion formation resulting from the vaginal ring closure.

Foals in this case series were operated at a relatively young age (median 9 weeks), although reducible indirect inguinal hernias that cause no abdominal distress can resolve spontaneously up to the age of 6 months (Schumacher, 2018; Tóth & Schumacher, 2018). One may therefore argue that, in the cases presented here, conservative management could have been successful. Nevertheless, the occurrence of a previous episode of colic and fluctuating size or large size of the hernia were factors that led to the recommendation to pursue surgery in some of our cases. Furthermore, conservative management can be laborious for the owners and this is why in other cases, owners elected to have their foals operated after unsuccessful conservative management for a certain period.

## CONCLUSION

We conclude that laparoscopic herniorrhaphy using the EndoS-titch™ automated laparoscopic suturing device combined with V-Loc™ unidirectional barbed suture is technically less demanding



than previously described laparoscopic techniques and effective in preventing re-herniation. In cases where owners wish to spare the animal's testicles to allow for unhampered masculine growth, the testes can be left in situ while the vaginal rings are effectively reduced. Nevertheless, if preferred, bilateral laparoscopic castration is readily performed at the time of herniorrhaphy. A fast and uncomplicated postoperative recovery can be expected in operated foals.

## AUTHOR CONTRIBUTIONS

T. Maurer and T.M. McEntee collected and analysed the retrospective data, performed the follow-up interviews and prepared a first draft of the manuscript. I. Petruccione prepared the anaesthesia part of the manuscript. C. Koch, T. O'Brien, M. Coleridge, T. Maurer and T.M. McEntee prepared the final version of the manuscript. All surgeries were performed by the co-authors, and all authors approved the final version of the manuscript.

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## CONFLICT OF INTEREST STATEMENT

No conflicts of interest have been declared.

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None.

## ETHICS STATEMENT

Retrospective study of archived medical records. Verbal or written informed client consent was given for use in retrospective studies.

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