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ORIGINAL RESEARCH

Development of a laparoscopic technique for inguinal hernioplasty in standing horses

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ABSTRACT

Background: Most previously described techniques for laparoscopic inguinal hernioplasty (IH) in horses require advanced laparoscopic skills. Our objective was to describe a new laparoscopic IH technique using a surgical anchoring system.

Methods: Standing laparoscopic IH was performed unilaterally in eight experimental stallions, using the contralateral inguinal canal (IC) as a control. A polyether ether ketone harpoon was anchored in the craniolateral aspect of the vaginal ring, and an extracorporeal knot was used to fix the device. Clinical evaluation, including testicular palpation and lameness examination, was conducted before and for 4 weeks after surgery. Repeat laparoscopy was performed 28 days later.

Results: Standing laparoscopic IH was performed in all horses with a surgical time of 38 ± 12.85 minutes. In two animals, a small peritoneal tear occurred that did not require repair. No other complications were recorded. On repeat laparoscopy, all devices were in place, and the IC remained partially closed in all horses.

Limitations: The procedure was performed on normal experimental horses and has not been employed on horses that have had an inguinal hernia.

Conclusions: This new standing laparoscopic hernioplasty technique provides another potential method for simple partial closure of the IC in stallions at risk of or with history of inguinal herniation.

KEYWORDS
hernioplasty, horse, inguinal hernia, laparoscopy, PEEK harpoon

INTRODUCTION

Inguinal hernioplasty (IH) can be performed in horses to prevent herniation while preserving the testicle.[1,2] Several laparoscopic techniques have been described for this procedure, including transabdominal retroperitoneal mesh insertion,[3] cylindrical mesh insertion within the inguinal canal (IC),[4] peritoneal flap,[5,6] vaginal ring (VR) suture,[7,8] cyanoacrylate glue injection into the IC[9] and using a tacked intraperitoneal slitted mesh (TISM).[10] Most of these techniques require advanced laparoscopic skills.

Various surgical anchoring systems are commercially available. Polyether ether ketone (PEEK) is a non-absorbable biopolymer with an excellent biocompatibility. In human medicine, anchoring systems using this biomaterial have already been applied in different surgical fields,[11] where surgical PEEK harpoons are fixed without need for complex laparoscopic procedures.[12]

Our hypothesis is that a modified PEEK anchoring device can provide partial occlusion of the IC in standing equine laparoscopic hernioplasty preserving the testicle. Therefore, the objective of this study was to develop a standing laparoscopic technique for IH using a modified PEEK anchoring device.

MATERIALS AND METHODS

Animals

Eight stallions (five Spanish Pure Breed [PRE] and three crossbred) without signs or history of inguinal hernia or testicular abnormalities were used. The number of animals was based on previous studies describing the development of IH laparoscopic techniques in the standing horse.[4,9] The age and bodyweight of the animals were 2–20 years and 400–440 kg, respectively (Supporting Information S1). Preoperative clinical examinations were within normal limits.

The care and use of animals complied with the Spanish Policy for Animal Protection RD 53/2013, which meets the European Union Directive 2010/63 on the protection of animals used for experimental and other scientific purposes. The eight animals used in the prospective study recovered successfully from the experimental procedure, and there was no reason to apply humane endpoints. All animals, after an accommodation period of 2 weeks, were kept in boxes in the Veterinary Teaching Hospital of the University of Zaragoza and paddocks of the facilities of the Animal Research Service of the University of Zaragoza, with free access to water and fed ad libitum grass hay.

Study design

One IC of each horse was randomly (coin flipping method) selected to undergo unilateral laparoscopic IH, and the contralateral IC and testicle were used as controls. The first four authors and the last one were aware of the side treated in each animal during the conduct of the experiment, the evaluation of the results and the analysis of the data.

Preoperative and serial postoperative clinical examination and lameness assessments were performed. Twenty-eight days after IH, laparoscopy was repeated to visualise the device placement and the appearance of the internal inguinal ring (IR).

Development of the anchoring device

The anchoring device was based on a PEEK harpoon used in human medicine for laparoscopic sacrocolpopexias.[12] After incorporating the necessary adjustments, the definitive device set consisted of a PEEK harpoon (DIMA, Calatayud, Spain) with a 150 cm long, size 2, threaded non-absorbable monofilament suture (DIMA) of polyvinylidene fluoride (PVDF). The harpoon had a length of 9.5 mm and a maximum width of 9 mm. It was anchored into the lateral wall (parietal part of IR) through the peritoneal flap, which formed the axial lip (visceral part) of the IR. The other component of the system was a PEEK 'button' (DIMA) which was threaded through the suture and fixed with an extracorporeal knot to ensure IC partial closure (Figure 1). For the placement of the harpoon, specific stainless-steel laparoscopic instruments were designed, including a 51.5 cm applicator

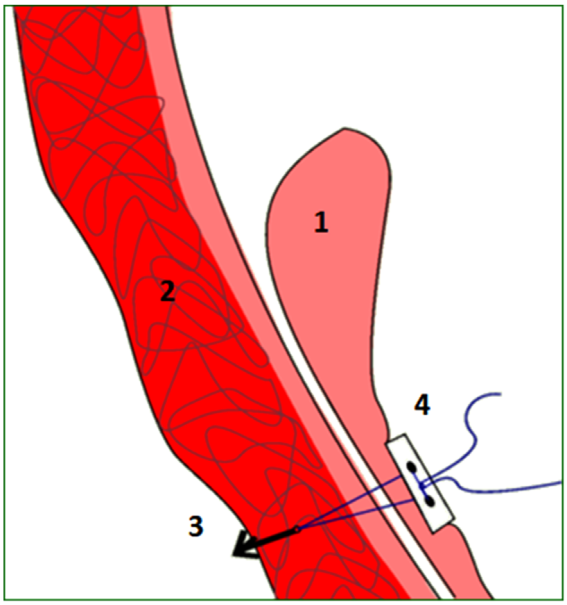

FIGURE 1 Illustration of a cross-section of the inguinal canal showing the basis of the closure system. (1) Visceral part of the vaginal ring; (2) parietal part of vaginal ring and musculature of abdominal wall; (3) harpoon anchored; (4) the button and threaded suture allowing obliteration of the inguinal canal

(DIMA) with a protective 10 mm × 44.5 cm sheath (DIMA) and a 5 mm × 80 cm laparoscopic knot pusher (DIMA). The different components of the system are shown in Figure 2.

Perioperative and anaesthetic protocols

Food was withheld for 18 hours, and water was withheld for 3 hours prior to surgery. The animals were previously tranquilised with acepromazine maleate (Equipromazina, Labiana Life Science, Tarrasa, Barcelona, Spain; 0.04 mg/kg bodyweight [bwt] intravenously [IV]). A 12-gauge catheter (Braunüle MT, BBraun Medical, Rubí, Barcelona, Spain) was placed in the jugular vein. Horses were sedated with a combination of detomidine hydrochloride (Domosedan, Orion Pharma Corporation, Madrid, Spain; 13 μg/kg bwt IV) and butorphanol tartrate (Torbugesic, Zoetis Spain, Alcobendas, Madrid, Spain; 0.02 mg/kg bwt IV). A urinary catheter was placed for the duration of surgery to facilitate bladder decompression. Sedation was maintained by continuous rate infusion of detomidine (Domosedan; 6 μg/kg bwt/hour IV) and spaced boluses of butorphanol (Torbugesic; 0.02 mg/kg IV). Local analgesia was provided by infiltration with 20 ml of 2% lidocaine solution (Anesvet, Laboratorios Ovejero, León, Spain) at the portal sites. Shortly before surgery, sulfadoxine-trimethoprim (Borgal, Virbac, Esplugas de Llobregat, Barcelona, Spain; 30 mg/kg bwt intramuscularly, once daily) and flunixin-meglumine (Finadyne, Schering Plough, Madrid, Spain; 1.1 mg/kg bwt IV, twice daily) were administered. Micronised aluminium (Aluspray, Vetoquinol Especialidades Veterinarias, Alcobendas, Madrid, Spain) was sprayed over the surgical wounds. The medication was continued for 3 days. Horses were box rested for 4 weeks, with

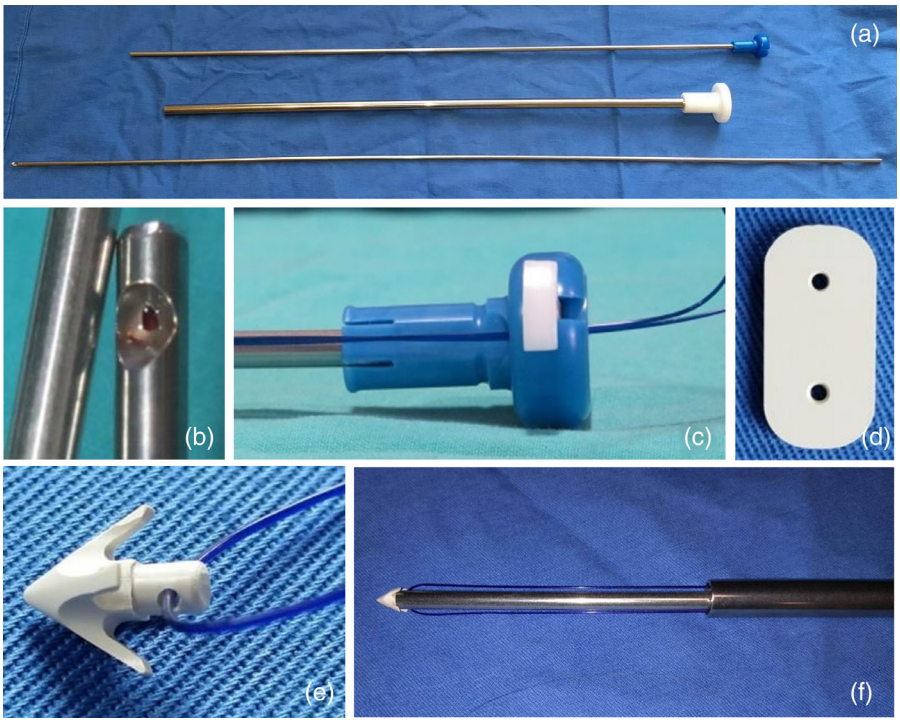

FIGURE 2 Different components of the surgical anchoring system. (a) Stainless-steel devices used for the application: applicator (top), its protective sheath (middle) and knot pusher (bottom). (b) Detail of the tip of the knot pusher. (c) Detail of the end of the applicator with a system to fix the two ends of the suture. (d) Polyether ether ketone (PEEK) 'button'. (e) PEEK harpoon with a threaded non-absorbable monofilament suture of polyvinylidene fluoride. (f) PEEK harpoon mounted in the applicator; when the applicator is completely pushed in, it protrudes 6.5 cm beyond the tip of the sheath

hand walking (two times 10 min/day) introduced in the third and fourth weeks.

Surgical technique

All horses were restrained in stocks with their heads supported on a padded stand. The abdominal flank was clipped and aseptically prepared for laparoscopic surgery. Laparoscopic access was performed on the left or right side, without prior abdominal insufflation, using an 11 mm and 15 cm long helicoidal optic cannula (Endotip, Karl Storz, Tuttlingen, Germany). For the laparoscope portal, a 1.5 cm skin incision was made midway between the last rib and the tuber coxae, dorsal to the palpable crus of the internal oblique abdominal muscle. The trocarless cannula was introduced into the abdomen with a rigid 58 cm 0° laparoscope inside. Through this cannula, CO_2 was introduced with an automatic insufflator until an intra-abdominal pressure of 12–15 mmHg was reached. Two additional trocars and cannulas (Versastep, Covidien, Dublin, Ireland) were inserted under laparoscopic observation to be used as instrument portals: the second portal (11 or 12 mm) was placed 12–15 cm ventral and 3 cm caudal to the first portal, and the third portal (11 or 5 mm) was placed 8–10 cm ventral to the first portal and 5–8 cm caudal to the second portal.

Once the harpoon was placed on the applicator within its protective sheath, it was introduced through the second portal and was directed to the IR (Figure 3a) in the craniolateral aspect of the VR, 1 cm below the dorsal edge of the visceral part of the VR (Figure 3b) and as close as possible to the spermatic cord. In the first four horses, before anchoring the harpoon, 5–10 ml of 2% lidocaine solution was injected in the parietal and visceral parts of the IR and slight craniolateral traction was applied to the visceral part of the VR with laparoscopic forceps inserted in the third portal. In the remaining four horses, this procedure was not performed, and the spermatic cord was retracted caudomedially with the laparoscopic forceps. For the anchoring manoeuvre, the protective sheath was slightly withdrawn, and the applicator with the harpoon was exteriorised. The applicator device was pressed against the lip of visceral part of the VR and punctured it, crossing the IC and reaching the parietal part of the IR in the abdominal wall. When the applicator was completely pushed in, it protruded 6 cm from the internal tip of the sheath (Figure 2f), and the mounted harpoon reached 6.5 cm from this internal tip.

When the harpoon was anchored, the protective sheath and the applicator were removed from the abdomen (Figure 3c), with the PVDF threaded suture exiting through the second portal. Before fixing the device, the suture was attached with mosquito forceps to a manual dynamometer to check the resistance to the tensile force of the anchor system. In all horses, a tensile force was exerted until it reached 10 N.

Subsequently, the suture was threaded through the button and was introduced by the same portal and directed against the IC (Figure 3d) with a laparoscopic knot pusher device (Figure 3e). Four extracorporeal half hitches were done to form a knot for fixing

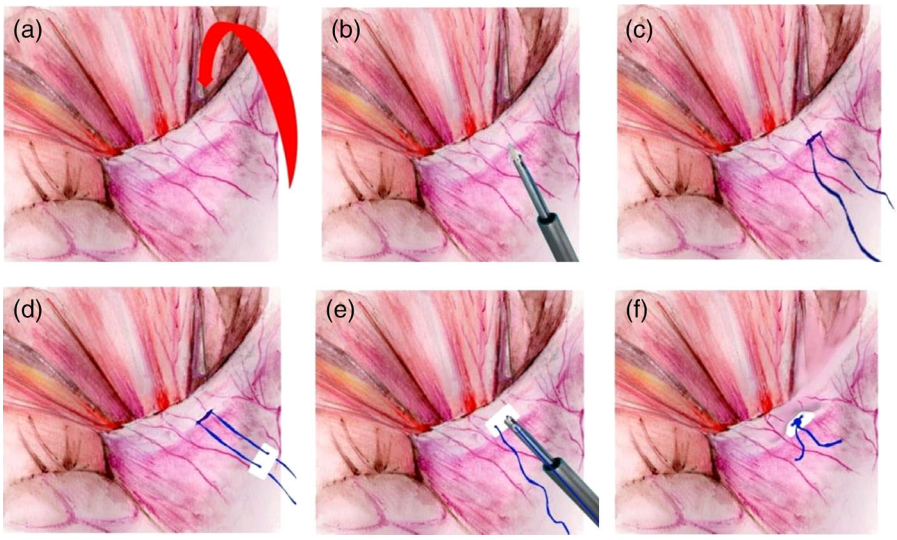

FIGURE 3 Illustrations of the steps of the standing laparoscopic inguinal hernioplasty procedure using a harpoon. (a) Left inguinal region with a red arrow illustrating opening of the inguinal canal. (b) The harpoon mounted on the applicator within its protective sheath, directed to the craniolateral aspect of the vaginal ring, 1 cm below its dorsal edge. (c) Harpoon anchored into the musculature of the parietal part of vaginal ring and the two ends of the polyvinylidene fluoride threaded suture exiting through the visceral part of vaginal ring. (d) The button being directed by the sutures against the vaginal ring. (e) A laparoscopic knot pusher device helps to direct the button and extracorporeal knot against the vaginal ring. (f) The remaining suture was cut and removed

the device. Each half hitch was extracorporeally performed and subsequently pushed with a laparoscopic knot pusher to hold the button. The remaining suture was cut and removed (Figure 3f). The appearance of the internal IR and the degree of opening of the VR were laparoscopically inspected without making an objective measurement. Videos of the procedure are provided in the Supporting Information (S2 and S3). Portals were closed with a simple continuous pattern using 2-0 polyglyconate (subcutis) and surgical staples (skin). The time from first skin incision to first subcutaneous suture placement was recorded.

Postoperative clinical assessment

Horses were subjected to a daily basic clinical examination during the 28 days of the study. Both testicles were examined by inspection and palpation on days 0 (pre-laparoscopy), 1, 2, 3, 7, 21 and 28. In addition, lameness examination was performed on days 0 (pre-laparoscopy) and 27.

Repeat laparoscopy

Twenty-eight days after the initial procedure, all horses were subjected to a repeat laparoscopy to evaluate the pelvic cavity and the inguinal region, placing only the single laparoscopic portal as described earlier, on each side of the abdomen.

RESULTS

Surgical procedure

IH was successfully performed on the right in two horses and on the left in six horses. The procedure was considered easy to perform. All the anchoring devices withstood a tensile force of 10 N. The average surgical time, including the time taken to check the tensile force with the dynamometer, was 38 ± 12.85 minutes, with a range of 20–56 minutes (Table 1).

In all horses, the degree of obliteration of IC was adequate, according to subjective evaluation (Figure 4a,b). In one horse, the harpoon was placed too far from the mesorchium and it was necessary to anchor a second device to ensure IC obliteration. Due to unexpected movement of another horse, the harpoon was inappropriately placed and only partially embedded in the visceral flap of the VR without reaching the abdominal wall. This harpoon was carefully removed with the aid of laparoscopic forceps, combining gentle twisting and traction. The animal showed no signs of pain during the removal, despite the lack of local anaesthesia. After recovering this harpoon, it was loaded again in the applicator device and could be reused. In both animals, a small peritoneal tear occurred (Figure 4d) that did not require repair (Figure 4e). No additional intra-operative complications were found during the procedure.

Outcome

No abnormalities were observed on physical examination, lameness evaluation or testicular examination within 28 days after surgery. The surgical incisions healed without complications.

During the repeat laparoscopic procedure, none of the devices had failed, and the IC remained partially occluded in all horses (Figure 4c). However, in two horses, the degree of VR opening was slightly larger than that observed immediately after placement of the anchoring device (Supporting Information S4).

In all cases, a slight localised peritoneal reaction covering the device was observed (Figure 4c). This

TABLE 1 Summary of the inguinal hernioplasty surgeries, showing surgical times and complication incidences

Horse	Site	Surgery time (min)	Traction of VR	Surgical complication	Quantity of employed harpoons	Quantity of harpoons remain implanted	Opening of VR in repeated laparoscopy after put harpoon	Testicular cord pushed caudomedially
1	Left	56	Yes	Additional harpoon necessary	2	2	Similar	No
2	Left	42	Yes	No	1	1	Increased	No
3	Right	35	Yes	No	1	1	Increased	No
4	Left	35	Yes	No	1	1	Similar	No
5	Left	48	No	No	1	1	Similar	Yes
6	Left	46	No	First harpoon mislocated and removed	2	1	Similar	Yes
7	Right	22	No	No	1	1	Similar	Yes
8	Left	20	No	No	1	1	Similar	Yes

Note: The horse number shows the chronologic order of intervention.
Abbreviation: VR, vaginal ring.

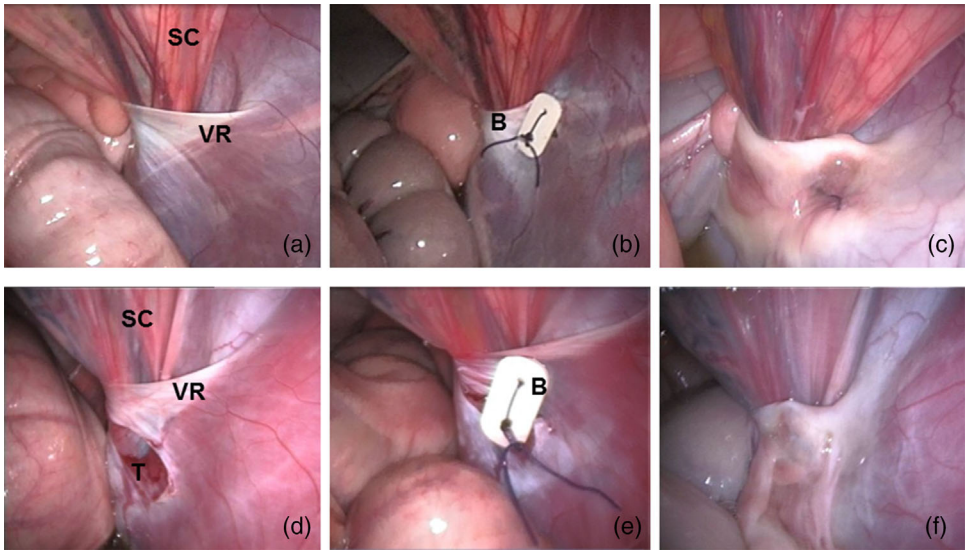

FIGURE 4 Laparoscopic images of horse 4 (a-c) and horse 6 (d-f) at various stages during the study. Left column (a and d): vaginal ring before anchoring of definitive harpoon for inguinal hernioplasty. Middle column (b and e): immediately after completing the hernioplasty. Right column (c and f): repeated laparoscopy 28 days after the procedure. The inguinal canal of horse 4 was adequately obliterated at the repeated laparoscopy but showed a slight peritoneal reaction that covers the button. Horse 6 had a small tear in peritoneum caused by a failed attempt at harpoon anchoring and showed a slight peritoneal reaction covering the button, similar to other horses without small peritoneal defects during the procedure. B, polyether ether ketone button; SC, spermatic cord; T, small tear in peritoneum after removal of a misplaced harpoon; VR, craniolateral aspect of the vaginal ring

reaction was similar in all animals, including those two cases with slight peritoneal tears. No abdominal adhesions were observed in any case (Figure 4f).

DISCUSSION

Testicular preservation after inguinal herniation and prevention of re-herniation is the goal when treating breeding stallions.[4,6,9] Some breeds, including PRE horses, are predisposed to inguinal herniation.[13] Prophylactic obliteration of the IC may be beneficial in these horses. Several laparoscopic testis-sparing IH techniques have been described.[14] However, most of them require placement of intracorporeal knots and complex dissections. This complexity increases when the laparoscopy is performed in the standing horse.[5–7] In this study, a new technique was developed for standing closure of the IC. In other laparoscopic techniques, IC closure can require advanced surgical skills and prolonged surgical times or the use of glue that can leak, slide or migrate into the IC.[9] This new technique could provide a simplified approach for partial closure of the IC. Nevertheless, it is important to

consider that performing this procedure requires specific consumables as well as the laparoscopic instruments that have been designed for placing the harpoon.

A considerable part of the surgical time was dedicated to tying the extracorporeal knots. Part of the capnoperitoneum was lost due to sutures protruding from the laparoscopic cannula during this part of the procedure. To avoid this, the entrance of the cannula was closed with a finger. However, it was usually necessary at this moment to wait until sufficient intra-abdominal pressure was recovered. The technique could be improved by using Roeder's or modified Roeder's knots. This could reduce time and avoid some of the capnoperitoneal leakage, and in addition, they are safer knots[15] that would improve anchorage security.

A key point in the effectiveness of IH laparoscopy is based on the amount of tissue involved in the closure. Thus, some authors emphasise that the chosen system should include the VR, the internal oblique muscle and the cremaster muscle with its fascia, emphasising that involvement of a generous volume of tissue at the closure confers greater security.[7] Therefore, the amount of tissue involved in the hernioplasty technique is directly related to the resistance of the partial closure of the IC. Accordingly, the use of staples in the adult horse for IH is not recommended because they do not withstand the muscle tension in the IR during movement.[5] Accordingly, in our study all the harpoons withstood a minimum tensile force of 10 N and remained properly placed after 28 days. However, it is possible that the estimated harpoon pull force was not accurately measured due to the direction of suture pull, even though the suture pull was in alignment with the cannula. Nevertheless, it may not be necessary for the applicator device to protrude so far from its protective sheath (more than 6 cm) in order to reach the abdominal wall. It may even be dangerous if the entire length of the harpoon penetrates as structures in the hindlimb and important vessels could be reached.

An important aspect to consider in order to avoid re-herniation is that the spermatic cord should be positioned firmly against the caudomedial border of the IC, as herniation could occur caudomedially towards the mesorchium.[6] To achieve this goal, a slight craniolateral traction over the visceral aspect of the VR was applied before anchoring the harpoon in the first four horses. However, this manoeuvre was abandoned in the following four horses due to the possibility of creating tears in the peritoneum with the laparoscopic forceps. Therefore, in the subsequent four horses, the technique was modified by pulling the spermatic cord caudomedially with atraumatic forceps through the third portal. Thus, the spermatic cord was confined against the caudomedial edge of the IC before anchoring the harpoon on its craniolateral aspect.

There were two horses in which, upon repeated laparoscopy, the VR appeared more open than it was immediately after placement of the anchoring device. In these cases, slight craniolateral traction was exerted on the VR when the harpoon was placed. We hypothesise that this could have been caused by elongation of tissues being held under traction by the device; however, dehiscence was not observed in any case. Another possible explanation is that the single knots may have partially slipped out. This would be another important reason to consider modifying the technique by employing other safer sliding knots, such as laparoscopic self-locking knots. Nevertheless, we consider that the degree of openness of the VR is not the key point to avoid inguinal re-herniation. Even though the VR is the first structure to be crossed by the herniated intestine, the speculative opinion of some authors is that the strangulation actually occurs in the neck formed by the IC, 2–3 cm distal to the VR.[16] Therefore, it would be more important to achieve an adequate obliteration of the IC rather than a VR closure. The goal of this new technique is IC obliteration, achieved by a 'sandwich' pressuring over the IC with the harpoon–button system, 1 cm below the edge of the VR. Additionally, the presence of sutures and the slight postoperative peritoneal reaction contribute to the obliteration of the IC even though the VR remained not fully closed. For all these reasons, in this procedure, the harpoon was specifically placed about 1 cm below the dorsal edge of the VR, as close as possible to the spermatic cord. This would not completely avoid the possibility of herniation on the caudomedial side of the VR.[6] Therefore, ideally, the harpoon should be applied while preventing the possible relaxation of the VR by pushing the spermatic cord caudally. However, it is important to note that the spermatic cord could be affected if the device is placed more ventrally.

The method chosen to randomise the side of intervention was to flip a coin every day, just before surgery. It was not anticipated that this randomisation method could create a big difference between the number of cases operated on the left (n=6) or on the right (n=2) side, which might have interfered with the observation of possible complications associated with one specific side. However, we found no specific difficulties in performing this technique on one side or another. In addition, the use of the Endotip optical trocar allowed direct access on the right side, decreasing accidental puncture of the cecum.[17]

Using healthy animals with normal-sized IR and no history of inguinal herniation was a limitation of our study. Studies with healthy animals have been frequently used in other experimental designs in order to test the safety and usefulness of a technique prior to its clinical use.[5] However, in previously herniated horses, the ring can be distorted and enlarged. In these cases, it may be necessary to place a second harpoon more craniolaterally to close the enlarged part of the VR. The results of this preliminary study suggest that the procedure is safe and may be useful, but further assessment of testicular function and long-term studies on clinical cases are warranted.

In summary, we report a new laparoscopic technique for IH that appears to be a simple and safe

procedure to partially close the IC in standing horses without need for advanced laparoscopic skills. This procedure was not tested in patients with abnormal IR, and testicular function was not assessed; thus, further research is needed to evaluate its efficacy for hernia prevention and its effect on reproductive ability in clinical cases.

AUTHOR CONTRIBUTIONS

Arantza Vitoria and Francisco José Vázquez Bringas contributed to the study design and execution, data collection, analysis, interpretation, manuscript preparation and final approval of the manuscript. Antonio Romero contributed to the study design and execution, manuscript preparation and final approval of the manuscript. Sara Fuente and Laura Barrachina contributed to study execution, data collection, data analysis, manuscript preparation and final approval of the manuscript. Ignacio de Blas and Lydia Gil contributed to data analysis, manuscript preparation, critical revision of the article for important intellectual content and final approval of the manuscript.

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CONFLICT OF INTEREST

The authors declare no financial or other conflict of interest related to this report.

DATA AVAILABILITY STATEMENT

The original data presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

All procedures performed in this study were carried out under Project Licence PI42/14 and approved by the Advisory Ethics Committee for Animal Experimentation from the Universidad de Zaragoza.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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