ESCOLA UNIVERSITÁRIA VASCO DA GAMA

MESTRADO INTEGRADO EM MEDICINA VETERINÁRIA

Incisional Complications after Colic Surgery in Horses

Inês Almeida Santos

Coimbra, outubro de 2021

ESCOLA UNIVERSITÁRIA VASCO DA GAMA

MESTRADO INTEGRADO EM MEDICINA VETERINÁRIA

Incisional Complications after Colic Surgery in Horses

Coimbra, outubro de 2021

Inês Almeida Santos

Aluna do Mestrado integrado em Medicina Veterinária

Constituição do Júri

Presidente do Júri: Prof. Doutora Sofia Ferreira Anastácio

Arguente: Prof. Doutor Tiago de Melo Silva Ramos Pereira

Orientador: Prof. Doutora Rosa Lino Neto

Orientador Interno

Prof. Doutora Ana Rita Caseiro Santos

Coorientador Interno

Doutor Ricardo Brás Campos

Orientadores Externos

Doutora Judit Viu Mella

(Hospital Veterinario Sierra de Madrid)

Doutor Marco de Bruijn

(Dierenkliniek Wolvega)

Doutor Peter Wiemer

(Lingehoeve Diergeneeskunde)

Thesis of the Curricular Internship of the Study Cycle Leading to the Master's Degree in Veterinary Medicine of EUVG

Acknowledgements

A sincere thank you to my Internal Supervisor and Co-supervisor, Prof. Dr. Ana Rita Santos and Dr. Ricardo Campos, for all the help in the process of writing this work.

A special thanks to all the people overseas that welcomed me even before we met, that taught me, and cared about me and made these past months the great journey and amazing learning experience it was. External Supervisors Dr. Judit Viu Mella, Dr. Marco de Bruijn and Dr. Peter Wiemer. Naming all the staff from Lingehoeve, Sierra and Wolvega would make another whole thesis, so I will leave a big thank you to all the people that belong to each of their respective teams.

To all the internship colleagues which are now friends, with whom I have worked closely, thanks for all the patience and help, for the good times and especially for the friendly words at the end of the rough days.

To my friends that have been always there for me and to the ones I made during this wonderful course, without you it would not had been the same.

Last, but most important, to my family, for this opportunity and unconditional support at all times, for making my dreams come true.

General Table of Contents

List of Figures

List of Abbreviations

cm	Centimetre
ºC	Degree Celsius
e.g.	*exempli gratia*
h	Hour
i.e.	*id est*
µL	Microlitre
mm	Millimetre
m.	*Musculus*
p.	Page
PaO_2	Partial pressure of oxygen
%	Percentage
SSI	Surgical site infection
™	Trademark

Incisional Complications after Colic Surgery in Horses

Inês Santos[a], Ricardo Campos[a], Ana Rita Santos[a,b]

[a] Departamento de Medicina Veterinária, Escola Universitária Vasco da Gama (EUVG), Av. José R. Sousa Fernandes 197, Campus Universitário, Lordemão, 3020-210, Coimbra, Portugal (ines.a.s.88@gmail.com)

Department of Veterinary Sciences, Vasco da Gama University School (EUVG), Av. José R. Sousa Fernandes 197, Campus Universitário, Lordemão, 3020-210, Coimbra, Portugal (ines.a.s.88@gmail.com)

[b] Centro de Investigação Vasco da Gama (CIVG), Av. José R. Sousa Fernandes 197, Campus Universitário, Lordemão, 3020-210, Coimbra, Portugal

Center for Investigation Vasco da Gama (CIVG), Av. José R. Sousa Fernandes 197, Campus Universitário, Lordemão, 3020-210, Coimbra, Portugal

Abstract

In Equine Medicine, one of the most common emergency problems encountered refers to colic syndrome and surgical resolution is a possible therapeutic approach.

Despite many recent advances in surgical and postoperative management, complications following ventral midline celiotomy often occur. Amongst these, incisional complications include dehiscence, incisional infection, incisional drainage, and hernia formation. A variety of factors must be analysed and considered in the clinical decision process, and adequate preventive measures are recommended to reduce the risk of the events.

The present review focuses on incisional complications, as they present the most common postsurgical complications encountered, detailing on its pathogenesis, pre-, intra-, and postoperative management, diagnosis, therapeutics, and prognosis.

Key Words

colic, dehiscence, drainage, hernia, incision, infection, *linea alba*

1. Introduction

In Equine Medicine, one of the most common emergency problems encountered refers to colic syndrome. The colic syndrome denotes a series of clinical signs associated with painful events in the abdomen, that may originate from either the gastrointestinal tract, its most common source and defined by some authors as ‘’alimentary or true colic’’, or other abdominal organic systems, such as the reproductive, urinary or muscular systems, often termed as ‘’false colic’’ (Edwards, 2013).

This syndrome can present through a variety of physiological and behavioural signs, that may reflect the severity of pain the horse is experiencing, which can be defined as mild, moderate, or severe (Edwards, 2013).

Colic is always a serious medical and economical issue in the equine industry worldwide, and it is amongst the most common causes of death in this species (Hines, 2018).

The therapeutics implemented in each colic situation depends on a variety of factors and may rely on a non-surgical/medical approach, combining selected drugs and adjuvant therapies, or a surgical correction of the organic anomaly. The colic surgery decision involves a series of considerations, including the prognosis for survival, but also the assessment of possible post-operative complications (Edwards, 2013)..

There are several postoperative complications that can occur and that will increase cost of treatment, hospital admission time, morbidity and mortality, and delay the return to previous or expected level of performance (Edwards, 2013).

Despite many recent advances in surgical and postoperative management, complications following ventral midline celiotomy often occur. Incisional complications include dehiscence, incisional infection, incisional drainage, and hernia formation (Hassel, 2017)**.** Some of the postoperative complications may occur as early as in the period of anaesthetic recovery, while others may not occur until weeks or months after discharge from the hospital (Edwards, 2013)**.** Hence, it is necessary to consider all the different moments before, during and after the surgery, and implement preventative measures that aim at an increase of positive outcomes and decrease the occurrence and severity of complications.

2. Medical *versus* Surgical Colic

Colic diagnosis is a challenge, given the unspecific character of the observed signs, and the veterinarian must rely on the history, physical examination, and complementary diagnostic procedures to be able to determine the probable or definitive cause of abdominal pain, formulate possible treatment plans and associated prognosis and communicate the different options for an adequately informed decision (Marshall & Blikslager, 2019). Additional challenges are faced due to often limited availability or financial

disposition for the application of complementary diagnostic procedures, as well as for the possible treatment options.

Patient characterization can aid the diagnostic process. There are specific gastrointestinal diseases that are more commonly described in certain breed, gender and/or age**.** During examination, the horse's temperament is of great importance when evaluating behavioural sings, since stoic horses can pose even greater challenge because, instead of exhibiting physical pain, they can simply appear depressed (Desrochers & White II, 2017)**.**

Following a thorough clinical assessment, approximately 90% of the horses exhibiting colic are eligible to be treated medically (Edwards, 2013). Nevertheless, pathologies causing colic can be life threating, as the horse's health condition can rapidly deteriorate, so it is considered an emergency and must always be approached as so (Marshall & Blikslager, 2019).

Surgical intervention is indicated when the exact cause of pain is identified, and surgery is necessary to correct the problem, or when there is no definitive diagnosis, but there is evident and immediate risk for the horse's life or when analgesia is not able to control the pain experienced. In these scenarios, an exploratory laparotomy is the last diagnostic or therapeutic procedure to resort (Edwards, 2013)**.**

There are some general indications for the need of surgery that include (White II, 2017):

- the presence of uncontrollable and/or severe pain;
- gastric reflux;
- absence of intestinal sounds on abdominal auscultation;
- some findings on rectal palpation, like distended small intestine and distended and displaced large colon;
- increased protein concentration with red blood cells and degenerate neutrophils in a peritoneal fluid sample.

Other signs are generally contraindicators for surgery, such as (White II, 2017)**:**

- depression;
- lack of pain;
- temperature above 39,2° C;
- neutrophilia or neutropenia (<3000/µL);
- presence of progressive intestinal sounds.

All of the clinical information is carefully interpreted, and the decision to continue medical treatment, perform an exploratory celiotomy or perform euthanasia can be made (Marshall & Blikslager, 2019).

If surgical procedure is to be forwarded, the owner must also have perceived all the complications that can possibly occur and must be well aware that if their horse's condition is too advanced, intraoperative euthanasia will be an outcome likely to occur.

Euthanasia is a valid decision and is often taken in consideration of the owner's financial disposition, or under a bad prognosis or the veterinarian decision that there is no possible treatment for the horse's advanced deteriorated health condition.

The survival rate of horses that undergo colic surgery is about 70%**.** Mortality and morbidity factors, *i.e.* the postoperative related complications, may occur as early as the period of anaesthetic recovery, while others may not occur until weeks or months after discharge from the hospital, with the majority occurring during the first week after surgery (Edwards, 2013)**.**

Complications have been identified in 40% of horses undergoing colic surgery (Wilson *et al*., 1995). The described complications associated with the postoperative colic patient are (Southwood, 2021)**:**

- persistence of pain/colic;
- pyrexia;
- incisional complications;
- postoperative reflux;
- postoperative ileus;
- diarrhoea;
- intravenous catheter-associated complications;
- hemoperitoneum;
- enterotomy and enterectomy associated complications;
- septic peritonitis;
- postoperative intraperitoneal adhesions;
- metabolic complications;
- endotoxemia/systemic inflammatory response syndrome and shock;
- laminitis.

The present review focuses on one of the most common postsurgical complications encountered, related to the surgical incision, detailing on its pathogenesis, pre-, intra-, and postoperative management, diagnosis, therapeutics, and prognosis.

3. Incisional complications

Particularizing the incisional complications, these include:

- incisional drainage or infection (Figure1);
- excessive peri-incisional oedema (Figure 2);
- suture dehiscence (Figure 3);
- abdominal wall herniation (Figure 4).

Some surgeons prefer to use the term “incisional drainage” or “incisional complication” rather than infection, unless there is growth on bacterial culture (Ingle-Fehr *et al*., 1997, Isgren *et al*., 2017). SSI can also be defined as the presence of purulent discharge associated with swelling, heat and pain around the skin incision (with wound drainage defined as the presence of serous or serosanguinous discharge from the wound associated with local oedema, but without heat or pain)(Mair & Smith, 2005b). One author classified incisional infection as drainage of fluid from the surgical site beyond the initial 48h after surgery (Gazzerro *et al*., 2015).

Although drainage and infection from the surgical site can have many definitions, a lot of times they are assessed has if they are the same problem. It is also assumed that any incisional drainage would be detrimental to healing and indicative of local inflammation and/or infection (Ingle-Fehr *et al*., 1997).

Surgical site infection (SSI) or incisional infection has been reported to occur from 3% (Tnibar *et al*., 2013) up to 25% of horses that underwent colic surgery (Mair & Smith, 2005a, Ingle-Fehr *et al*., 1997, Torfs *et al*., 2010, Isgren *et al*., 2017, Anderson *et al*., 2015, Colbath *et al*., 2014, Coomer *et al*., 2007).

Figure 1: Ventral midline incision depicting incisional drainage (adapted from Complications in Equine Surgery (p. 329), by Rubio Martinez, Luis M., Hendrickson, Dean A.. 2021, Hoboken, NJ: Wiley-Blackwell. Copyright [2021] by New Bolton Center. Reprinted with permission.)

Figure 2: Ventral midline incision with excessive per-incisional oedema (in Complications in Equine Surgery (p. 322), by Rubio Martinez, Luis M., Hendrickson, Dean A.. 2021, Hoboken, NJ: Wiley-Blackwell. Copyright [2021] by New Bolton Center. Reprinted with permission.)

Abdominal wall hernia formation occurs in up to 3-16% of horses after colic surgery and is most common in horses that present postoperative wound drainage or infection (Mair & Smith, 2005c).

Complications can lead to patient discomfort and increased costs, so knowing the predisposing factors can help in reducing the complication rates (Mair & Smith, 2005a).

Figure 3: Ventral midline incision presenting dehiscence of the abdominal wall suture (in The Equine Acute Abdomen (p. 628) by Blikslager, Anthony T., White, N. A., Moore, James N., Mair, Tim S., 2017, Hoboken, NJ: Wiley. Copyright [2017]. Reprinted with permission.)

Figure 4: Ventral midline abdominal wall herniation (in The Equine Acute Abdomen (p. 631) by Blikslager, Anthony T., White, N. A., Moore, James N., Mair, Tim S., 2017, Hoboken, NJ: Wiley. Copyright [2017] by Nat White. Reprinted with permission.)

Intrinsic factors, like breed, gender, age, body weight and concomitant diseases, which cannot be controlled before the surgical procedure, should also be addressed to predict the likelihood of complications to occur. These factors may also impact on the therapeutic decision. As an example, the horse's advanced age can be perceived as a detrimental prognostic factor and have great preponderance weight on the owner's decision to proceed to surgery. However, a study showed that geriatric or mature horses have similar occurrences of short-term complications and short-term outcomes associated with complications after colic surgery (Gazzerro *et al*., 2015). Severe disease and excessive subcutaneous fat are other factors beyond the control of the surgeon, and that may contribute to incisional complications (Wilson *et al*., 1995). A superior body weight is also associated with a higher SSI rate (Isgren *et al*., 2017).

Other extrinsic factors may also affect patients outcome, as described in a study where horses had a higher incidence of SSI in the summer and winter months, compared with spring and autumn (Isgren *et al*., 2017).

3.1. Anatomy of the *linea alba*

The abdominal wall is composed of four muscles interspersed on three muscular layers, with different fibre orientation. The external and internal oblique muscles have extensive aponeurosis, which form the external leaf of the sheath of the *musculus (m.) rectus abdominis*, that fuses at the ventral midline, inserting in the *linea alba*. The abdominal tendon has insertion along the *linea alba*. The internal leaf of the sheath of the *m. rectus abdominis* is formed by the aponeurosis of the *m. transversus abdominis*. The *m. rectus abdominis* locates at the ventral part of the abdomen and, unlike the other abdominal muscles, does not form an aponeurosis, rather lying within the sheath formed by the aponeurosis of these (Liebich *et al*., 2020).

The *linea alba* is described has a ventro median union, where the bilateral parts of the mesoderm unite during development. It has an umbilical opening, the *anulus umbilicalis*, for the urachus and umbilical vessels in the foetus, which becomes the scar-like umbilicus after birth. The *linea alba* is therefore a tendinous cord, which extends between the xiphoid cartilage and the cranial border of the pelvis, where it inserts to the *tendo praepubicus*. It is bordered by the *m. rectus abdominis*, which pursues a sagittal course within the abdominal floor on both sides of it and is marked by *intersectiones tendineae*. The *linea alba* reinforces the ventral abdominal wall together with the deep fascia of the trunk, with which it unites in the midline. In large animals the ventral part of the deep fascia of the trunk is interwoven by a mesh of elastic fibres. Due to the yellow colour of these fibres, this part of the deep fascia is also called the yellow abdominal tunic (*tunica flava abdominis*)(Liebich *et al*., 2020).

3.2. Pathogenesis

Surgical site complications can occur isolated or can coexist and predispose to mutual occurrence.

In the case of SSI, the probability of its occurrence is a complex relationship between microbial, host and wound characteristics, presence of foreign material, and devitalized tissue (Stewart & Richardson, 2019). The foreign material can account for the suture material itself that, along with different skin edges apposition efficiency. The use of surgical staples is suggested to allow greater early postoperative contamination, possibly due to the apposition of skin edges and thus sealing of the wound being less effective, when compared with sutures, which allows for earlier postoperative contamination (Torfs *et al*., 2010).

The aetiology and pathogenesis for SSI is not yet clear, and is hypothesised to derive from underlying tissue injury (inevitable), bacterial contamination, antimicrobial drug resistance, and overwhelmed or impaired host immune response (Southwood, 2021)**.** Increase in the probability of SSI is also associated with problems secondary to the colic surgery, such as postoperative colic (Isgren *et al*., 2017, Anderson *et al*., 2015, Darnaud *et al*., 2016), repeat laparotomy (Mair & Smith, 2005b, Darnaud *et al*., 2016, Torfs *et al*., 2010), intraperitoneal contamination, septic peritonitis, and thrombophlebitis (Mair & Smith, 2005b).

Infection also contributes to delayed wound healing, and it is described as the primary reason for dehiscence, resulting in the separation of the skin and subcutaneous tissue so that the body wall is visible (Gazzerro *et al*., 2015). Partial dehiscence of the *linea alba* leads to hernia formation, whereas total dehiscence leads to eventration (Marshall & Blikslager, 2019).

Further, SSI or incisional drainage, excessive oedema, postoperative colic, leukopenia are, in turn, risk factors for body wall herniation (Gibson *et al*., 1989, Dunkel, 2015, Southwood, 2021).

It is during anaesthetic recovery after laparotomy that acute total dehiscence is more likely to occur (Marshall & Blikslager, 2019).

3.3. Preoperative Management

After the decision to follow a diagnostic and/or therapeutic surgical approach, a period of preparatory actions will take place, extending to the moment the surgeon incises the skin. Horses most often undergo colic surgery in an emergency setting with compromised clinical status, so a good preparation is key to make the process rapid and effective, involving multidisciplinary teams. Edwards (2013) states that *"Colic surgery is a team effort, and the chances of success are greatest when the optimum number of people and back-up facilities are available"* (Edwards, 2013).

The preparatory steps for surgical procedure (under general anaesthesia) involve a complete preanaesthetic assessment, which is recommended to include a complete physical examination and complementary laboratory assessment (such as haematology, serum biochemistry, and peritoneal fluid evaluation, if necessary), if not performed previously or if clinical status of the patient is deteriorating rapidly. The general health status of the patient is a well-known factor for adequate inflammatory and healing responses, hence affecting the outcome of any surgical intervention (Rötting, 2017).

In any instance of sedation or anaesthesia, especially when recumbency will occur, food and water withdrawal are recommended. However, because of its emergency character, the colic surgery patient will most likely not be subjected to any intake restriction before the procedure. It is also common practice to leave a nasogastric tube inserted pre and intraoperatively, to minimize the risk of gastric rupture and of aspiration of gastric contents when in presence of gastric reflux, when the horse is positioned in dorsal recumbency on the surgical table (Rötting, 2017).

Prophylactic antibiotics are administered as a part of the preoperative tasks. Usually, first-line broad-spectrum antibiotics, such as potassium penicilin combined with gentamicin are used. This step is critical for infection prevention, and their administration should occur within one hour until the beginning of surgery. It is recommended to administer a second dose if the procedure extends beyond 2 half lives of the drug or if there is significant blood loss perioperatively (Southwood, 2021).

Further, preliminary steps for the asepsis of the surgical step are taken. Cleanliness of the surgical environment is a basic standard and must be promoted through grooming/cleaning of the horse and hoof picking before entering surgical theatre (Rötting, 2017) or even before entering the induction box.

After induction and positioning in dorsal recumbency, the horse's feet and sternum are at a higher vertical point than the abdomen, and the fall of hair and debris can possibly contaminate the surgical field, so it is necessary for these regions to be cleaned (hoovered) and covered. The hooves can have their shoes be left in place, but the distal limbs should be covered with tape and/or rectal sleeves (Rötting, 2017) or other materials such as normal examination gloves or disposable shoe covers.

In male horses, the penis can be kept within the prepuce, packed with gauze, and the prepuce closed with suture material or towel clamps, or exteriorized. A urinary catheter can be inserted, so debris and urine do not interfere and contaminate the surgical field. One disadvantage of urinary catheterization is the additional time under general anaesthesia it may require (Rötting, 2017), unless the team is working fast and effective, and multiple tasks are being carried at the same time.

The trichotomy of the surgical field is essential and should be initiated from cranial, starting at the xiphoid process of the sternum region, to caudal, until the prepuce or mammary glandules, and laterally at the level of the flank skin folds (Rötting, 2017). The hair clipping with a 0,25 mm blade is preferred to shaving with a razor blade, as there is evidence that the latter damages the surface of the skin, predisposing to incisional infection. The skin is then disinfected, most commonly using alcohol, and chlorhexidine or iodine formulations. After disinfection, approximately 20% of the original bacterial flora of the skin will remain in the deeper layers of the skin, making it possible for skin surface recolonization after 30 to 60 minutes. Care must be taken to ensure the unidirectional centrifugal assepsis procedure (Rötting, 2017).

Finally, the placement of sterile drapes constitutes a crucial moment for the surgical field asepsis. The ideal surgical field draping is sterile and impermeable to water and bacteria. It should also be smooth to avoid irritation to the bowel placed on the drape (Rötting, 2017).

Jointly, the described measures aim to prevent and/or minimize the incidence of postoperative complications.

3.4. Surgical management and intraoperative risk factors

The greatest period of risk for SSI, and therefore for other SSI associated complications, is from the time of the incision until the time of closure (*i.e.* the duration of surgery)(Stewart & Richardson, 2019).

The ventral midline celiotomy, also referred as laparotomy, is the most frequently used approach to the abdomen. An incision is made through the skin and subcutaneous tissues, from the umbilicus region, with the possibility of extending it about 30 to 40 cm cranially (Marshall & Blikslager, 2019). There are increased risks in the event of repeat celiotomy, which have been associated with higher probability of

suffering SSI (Mair & Smith, 2005b, Darnaud *et al*., 2016) and hernia formation, as 32% horses undergoing repeated celiotomy developed the later (Dunkel *et al*., 2015).

The haemorrhage provoked by incising the skin and subcutaneous tissue, is controlled to allow the *linea alba* to be seen. The *linea alba* starts to be incised in the umbilicus region, where it is thickest, about 2 or 3 cm to allow insertion of the surgeon's thumb or a forceps between the *linea alba* and the abdominal viscera, and proceed with extending the incision, taking attention to the fact that the *linea alba* gets thinner with the distance from the umbilicus. The peritoneum is opened with the surgeon's fingers, and thus access to the abdominal contents is achieved (Marshall & Blikslager, 2019).

The incisional size is also regarded as a risk factor for complications. Although the incision can be extended up to approximately 40 cm, an incision larger than 27 cm, extending until the cranial aspect of the *linea alba* (where it is thinner and narrower), has been associated with increased tension on the tissues, which are likely to compromise wound healing. So, horses that have an incision smaller than 27 centimetres, which remained within the fenestration of the drape and possibly within the thicker portion of the *linea alba*, have inferior incidence of SSI (Darnaud *et al*., 2016). Extension of the incision to the xiphoid cartilage can also result in difficulty with closure, failure of the body wall to heal, peritoneal-cutaneous fistula and ultimately to acute evisceration (Sanders *et al*., 1977).

SSI has also been associated with large colon lesions, potentially associated with trauma to the body wall and incision due to large colon manipulation (Phillips & Walmsley, 1993), outside of the body cavity, posing stress and pressure to the incisional edges.

While it seems logical that SSI would be greater following a clean/contaminated procedure, most studies report no association between SSI incidence and an enterotomy or enterectomy being performed (Anderson *et al*., 2015, Colbath *et al*., 2014, Coomer *et al*., 2007, Phillips & Walmsley, 1993, Ingle-Fehr *et al*., 1997). However, one study demonstrated that the distance between the procedure and the incision is, in turn, a factor to consider: lower SSI rate is observed when procedures are executed distant to the incision, like a pelvic flexure enterotomy, small intestinal resection, or no enterotomy/enterectomy is performed at all (Darnaud *et al*., 2016).

After surgical correction of the gastrointestinal pathology, the suturing of the abdominal incision is another critical step. Wound closure is performed layer-by-layer, and closure of the *linea alba* is the most critical layer in providing strength to the abdominal wall (Cook, 2017)**.** In the closure of any incision, the surgeon must select the adequate type, size, and pattern of suture, and be attentive to tissue bite size and knot security (Rötting, 2017).

A study has showed that if closure is performed by an unexperienced surgeon, there is increased chance of tissue damage, and therefore of SSI occurrence (Torfs *et al*., 2010). Closure of the peritoneum is also not recommended because it appears to increase the incidence of adhesions, especially in the presence of faecal contamination (Cook, 2017), but lavage of the *linea alba* with saline solution prior to skin closure

appears protective, probably due to the physical removal of blood cloths and gross contamination. This step should be considered standard in ventral midline celiotomy closure (Torfs *et al*., 2010).

Adams & Fessler (2000) described that before suturing the *linea alba*, the subcutaneous fat and fascia should be dissected so it would allow closure of the linea alba without strangulation of adjacent fat, which has little suture-holding ability (Adams & Fessler, 2000). This method is, however, contradictory. This approach was later associated with a higher occurrence of SSI (Mair & Smith, 2005b) but, more recently, the subcutaneous dissection was associated with a lower risk of the event, in an univariable analysis. This finding might be surprising because subcutaneous dissection increases dead space and enhances bleeding at the surgical site. Nevertheless, it was not a significant risk factor in the multivariate analysis, showing that, despite its rationale, it might not be a determinant factor (Torfs *et al*., 2010).

Different suture materials and patterns have been studied and it was demonstrated that:

- chromic gut is a risk factor to SSI, and therefore also for body wall hernia formation (Gibson *et al*., 1989);
- the use of staples for skin closure is associated with higher incidence of SSI (Torfs *et al*., 2010);
- the use of an antibacterial coated suture material does not decrease SSI (Bischofberger *et al*., 2010);
- 2-layer (body wall and skin suture) *versus* 3-layer (body wall, subcutaneous tissue and skin suture) closure might not impact on SSI, although the 2-layer provokes less suppuration (Coomer *et al*., 2007);
- 3-layer closure is shown to be protective for SSI (Isgren *et al*., 2017);
- the use of a modified subcuticular suture pattern decreases SSI (Colbath *et al*., 2014).

The most appropriate suture material should be as strong as the tissue to suture, however there is a sparsity of sutures stronger than the equine *linea alba*, and most *linea alba*-suture constructs studied failed at the suture knot in earlier studies (Magee & Galuppo, 1999, Hassan *et al*., 2006, Trostle *et al*., 1994, Fierheller & Wilson, 2005, Anderson *et al*., 2013). A recent study showed that most cases of acute abdominal dehiscence were actually due to the failure of the body wall adjacent to an intact suture line (Hann *et al*., 2021), and not the suture itself.

After closure of the *linea alba*, and before the closure of the upper layers, the application of medical grade honey gel has been recently shown safe and effective in reducing SSI. This evidence suggests this could be an additional step included in the surgical routine, in order to maximize prevention of complications (Gustafsson *et al*., 2020).

Alongside the surgical procedure itself, anaesthetic monitoring and maintenance also play a role in postsurgical complications. Reducing the anaesthetic time and establishing strategies to prevent and manage hypoxaemia, since it was shown that intraoperative low PaO_2 contributes to the development of SSI following colic surgery, because it can lead to devitalization of tissues (Costa-Farré *et al*., 2014).

Protecting the wound from contamination during anaesthetic recovery from surgery and in the early postoperative period should also be considered important (Ingle-Fehr *et al*., 1997). Placement of a sterile towel or a polyhexamethylene biguanide–impregnated protective dressing secured with sutures over the incision site is associated with significantly lower incisional infection following colic surgery, compared with horses that had sterile gauze placed over the wound secured with an iodine-impregnated adhesive drape (Mair & Smith, 2005b). Application of a stent bandage was previously associated with a higher rate of wound complications (Mair & Smith, 2005b), but more recently, it was reported to significantly reduce the likelihood of incisional infections (Tnibar *et al*., 2013) as did the use of an abdominal bandage during the immediate postoperative period (Smith *et al*., 2007).

If a horse with incisional infection requires a repeated laparotomy, other approaches can be taken, like a paramedian one**.** If the infected incision is reopened, and body wall integrity is compromised, the incision can be closed with stainless steel wire with hard rubber tubing stents (Southwood, 2015)**.**

3.5. Postoperative management

Postoperative care of a colic patient often includes control of pain, fluid therapy, antimicrobial prophylaxis (started preoperatively), and feeding management (Southwood, 2015), amongst other measures.

Studies have shown that antimicrobial prophylaxis administered for 72h is effective in preventing incisional infections (Durward-Akhurst *et al*., 2013), and that even a 24h treatment could suffice, as more recent studies suggest that there is no evidence of more prolonged administration to be more efficient (Darnaud *et al*., 2016).

The immediate postoperative colic patient should be in an intensive care unit, with constant observation in the early postoperative period, when pain, attitude and appetite, colic signs, abdominal distension and sounds, faecal production and water consumption and urination should be monitored (Southwood, 2015).

Following the initial period, daily monitoring is to be maintained, and staples or non-absorbable suture materials are removed within 10 to 14 days after surgery (Southwood, 2015). Ponies usually heal faster, so their incision may not be so predisposed to suffering complications (Provost, 2019). The patient should be prescribed to rest after such intervention, for a minimum of 8 weeks (Southwood, 2021), allowing for adequate tissue healing and abdominal wall strength regain. The horse should be strictly confined to a stall for a minimum of 4 weeks, beginning short walks on short lead in the 4 weeks subsequently and, after those, other 4 weeks of allowance into a pasture and/or light exercise. After this time, it is expected that the horse is able return to the previous use (Southwood, 2015).

3.6. Diagnosis of complications

The physical examination of the postoperative colic patient should include, among other aspects, the monitoring of the incision by routine visualization and palpation of the area with gloved hands. Physical examination can locate areas moist or soft, or active drainage (Southwood, 2021). For assessment of the incision, one must be attentive for oedema or cellulitis, pain on palpation and drainage, which are indicative for infection**.** Drainage of serosanguinous fluid during the initial 24-36 hour after surgery is not concerning and is not necessarily associated with infection. Also, fever is not always present when there is incisional infection (Southwood, 2015), however, when there is excessive peri-incisional oedema, heat and pain during palpation of the incision area, it is very likely that there is an incisional infection, and a fever associated (Southwood, 2021).

Ultrasonography can be used to further assess the incisional status and detect variations in tissue characterisation. It can identify fluid accumulations and can encounter complications in the healing of ventral midline incisions. Through serial examinations it is possible to monitor the healing of the incision (Wilson *et al*., 1989).

A study showed that SSI typically occurs from 2 to 21 days within the surgery, with the majority happening at day 12 (Darnaud *et al*., 2016). The horse's owner or caregiver may therefore be the one noticing an incisional discharge, because it usually happens at day 12 post-surgery, when the patient has likely already been discharged (Southwood, 2021).It is good practice to, when an incisional discharge is present, after the initial 48h, to collect (aseptically) a sample and submit it to bacterial culture and sensitivity tests, in order to achieve the appropriate antimicrobial drug therapy regimen. *Escherichia coli, Enterococcus* spp. and other *Enterobacteriaceae* are the most common infecting microorganisms, and tend to be drug resistant, thus highlighting the importance of performing antibiotic susceptibility tests (Southwood, 2021). A study tested the most commonly used antimicrobial drugs in the most common isolated bacteria, and showed that 92% were resistant to penicillin and 18% were resistant to gentamicin (Isgren *et al*., 2017). This sets to rethink the risk-benefit balance of the most commonly employed prophylactic protocols.

Diagnosis of a body wall hernia is made on physical examination and may only be evident weeks to months after surgery. These are often perceived by the owner or caregiver as well. However, if they are small they most often remain unnoticed and may only be diagnosed if a repeat celiotomy becomes necessary (Southwood, 2021).

Dehiscence, with evisceration, rarely occurs but when they do, the diagnosis is confirmed through the observation of the eviscerated contents (Southwood, 2021)(Figure 5).

Figure 5: Eviscerated omentum through a partial incisional dehiscence (in Complications in Equine Surgery (p. 327), by Rubio Martinez, Luis M., Hendrickson, Dean A.. 2021, Hoboken, NJ: Wiley-Blackwell. Copyright [2021] by New Bolton Center. Reprinted with permission.)

3.7. Therapeutics

Drainage is likely to occur until sutures are absorbed, that occurs up to 3 months after surgery. This duration is unlikely to be decreased by the administration of antimicrobial therapy, and the bacteria causing SSI are often resistant to commonly used antimicrobials. SSI is primarily treated by establishing drainage by removing staples or skin sutures and keeping the incision clean with saline solution, and then maintaining it dry. Sterile instruments like Kelly haemostats can be used to open the skin carefully. If the skin is apposed with continuous absorbable suture pattern, drainage may be achieved without removing the suture. After 7 to 10 days, when the skin should be healed, the sutures can be removed to allow drainage, without provoking entire dehiscence of the skin. By removing the suture material, the skin heals by 'second intention', usually without considerable consequences (Southwood, 2021). In any event, the incisional wound shall be managed carefully, as advocated by Provost: ''*All traumatic open wounds should be handled as if they are infected, as should any incision from which there is purulent drainage.''* (Provost, 2019).

It may occur that the skin and subcutaneous tissue dehiscent, which may cause concerns with abdominal support capacity and possible herniation. If total dehiscence is imminent, abdominal support should be given, and the horse shall be anesthetized for further repair (Marshall & Blikslager, 2019). Small body wall defects can be managed conservatively with confinement and abdominal support. The *linea alba* may be able to be re-sutured, whereas in cases where the body wall is infected or damaged, debridement and placement of support wires may be required (Canada *et al*., 2015). The technique involves the passing of monofilament 18 to 22-gauge stainless-steel wire with a large cutting needle, in a through-and-through interrupted vertical-mattress pattern, with suture bites placed 5 cm from the edge of the wound and 2,5 cm apart. Plastic tubes are incorporated on the wire, to avoid cutting through the skin. The wire is tightened and secured, and the cut ends are guarded inside the tubing (Figure 6). Skin and subcutaneous layers are left unsutured to allow drainage (Marshall & Blikslager, 2019).

Maggot debridement therapy, alongside surgical debridement, can also be used to provide a better healing in cases of dehiscence, and even in cases with coexistence of multidrug resistance infection (Lepage *et al*., 2012).

Negative pressure wound therapy has been used with success to treat dehiscent infected abdominal incisions, it stimulates rapid formation of granulation tissue, reduces size of the wound and effectively removes fluid (and bacterial load) from the wound (Theoret, 2017).

Figure 6: 22-gauge stainless-steel wire suture with tubing applied to the body wall after incisional dehiscence (in The Equine Acute Abdomen (p. 629) by Blikslager, Anthony T., White, N. A., Moore, James N., Mair, Tim S., 2017, Hoboken, NJ: Wiley. Copyright [2017]. Reprinted with permission.)

Abdominal bandage may be beneficial to keep the compromised incision site clean, but it requires to be changed 1 to 3 times a day, depending on the amount of drainage from SSI or peritoneal cavity. The

Figure 7: Pressure necrosis of the withers due to an improperly placed and padded hernia belt (in Complications in Equine Surgery (p. 331), by Rubio Martinez, Luis M., Hendrickson, Dean A.. 2021, Hoboken, NJ: Wiley-Blackwell. Copyright [2021] by New Bolton Center. Reprinted with permission.)

bandage must remain dry, to avoid severe damage to the skin (maceration).

Complementary support can be given to prevent herniation events by an abdominal support bandage or hernia belt, alongside with strict exercise restriction and stable confinement. An hernia belt may also decrease the duration and volume of drainage by providing stability for healing (Southwood, 2021). These devices must be carefully placed and padded, especially on the withers, to prevent pressure sore and necrosis (Canada *et al*., 2015)(Figure 7).

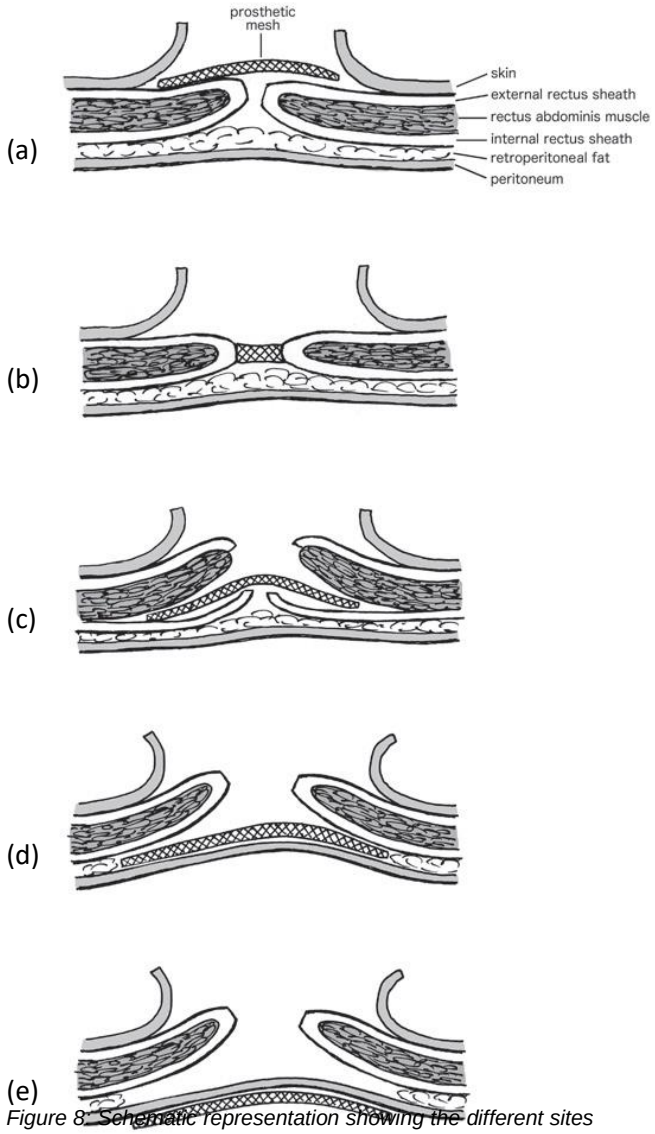

Figure 8: Schematic representation showing the different sites where a mesh can be applied to repair an incisional hernia (adapted from Equine Surgery (p.648) by Auer, Jörg A., Stick, John A., Kümmerle, Jan M., Prange, Timo, 2019, St. Louis, Missouri: Elsevier Inc.. Copyright [2019] by Elsevier Inc.)

Hernia repair can currently be achieved through five different techniques: primary closure without the use of prosthetic mesh, prothestic mesh onlay with primary closure, prosthetic mesh inlay, prosthetic mesh sublay with primary closure or with fascial overlay, and laparoscopic repair with intraperitoneal mesh underlay. Thus, mesh placement is designated in the following ways: onlay (Figure 8a), inlay (Figure 8b), retrorectus sublay (Figure 8c), preperitoneal sublay (Figure 8d) and underlay (Figure 8e).

It is further important to decrease the bodyweight in overweight horses, and to diminish the volume of intestinal contents prior to the repair procedure, contributing to increased chances of success (Marshall & Blikslager, 2019).

3.8. Prognosis

The incisional complications can be classified as *minor* or *major*. *Minor* complications are not immediately life-threatening, and include peri-incisional oedema, drainage, incisional abscess, suture sinus and superficial dehiscence. Partial and complete

dehiscence were considered to be *major* incisional complications (Wilson *et al*., 1995), and constitute indication for performing a repeated laparotomy (Marshall & Blikslager, 2019).

Although manageable, SSI requires prolonged treatment and contributes to increased chance of herniation (Phillips & Walmsley, 1993, Ingle-Fehr *et al*., 1997, Mair & Smith, 2005c), resulting in delayed return to athletic activity (Davis *et al*., 2013).

Acute body wall dehiscence with evisceration is uncommon but potentially fatal (Southwood, 2021). Even in a case of total dehiscence, where eventration can be managed with stainless-steel wire, the patient remains at risk for incisional hernia (Marshall & Blikslager, 2019). Stallions and pregnant or in the early post-partum period mares are more susceptible to acute abdominal dehiscence due to the increased intra-abdominal pressure. This increase in stallions is explained by the vocalisation behaviour, and in mares by the weight of carrying the foetus, and the foal's nursing period. Mares in the post-partum period may also have their body wall weakened. Other non-gender related risk factors include coughing and ascites. In these patients, abdominal wall support should be given early as prevention (Hann *et al*., 2021).

Cosmetic non-incarcerated hernias of the ventral body wall do not always require surgical correction, although they are usually repaired if cosmesis is an important outcome (Southwood, 2021). If abdominal organs herniate and are or become at risk of incarceration or evisceration, additional measures must be considered, including the need for a surgical approach. However, to these authors knowledge, there are no reports of incarceration of intestine within an incisional hernia (Marshall & Blikslager, 2019). Besides the cosmetic criteria, it is also essential to address that the abdominal hernia should not affect the athletic activity of a horse in the clinical decision process (Immonen *et al*., 2017)(Figure 9).

Figure 9: Abdominal hernia (red arrow) not affecting the athletic activity of a horse (in Complications in Equine Surgery (p. 332), by Rubio Martinez, Luis M., Hendrickson, Dean A.. 2021, Hoboken, NJ: Wiley-Blackwell. Copyright [2021] by Janelle Gunther. Reprinted with permission.)

Primary hernia closure results in a good cosmetic outcome in 84% of horses. In one study, outcome following primary closure did not differ to that when additional support of the repair was provided with mesh placement. Indeed, in cases in which a mesh was used, a longer duration of surgery and

hospitalization were registered, and were more likely to develop postoperative complications while having a longer duration of convalescence prior to return to use (Whitfield-Cargile *et al*., 2011).

The postsurgical recovery time ranges up to 2 months, during which the horse should be confined to a stall or small paddock, and hand walked several times a day, whilst using abdominal support (Marshall & Blikslager, 2019).

Core abdominal rehabilitation exercises (*e.g.* carrot exercises), for 4 weeks, beginning 4 weeks after surgery if there are no incisional complications, or 4 weeks following resolution of any incisional complications, are safe and may accelerate convalescence and improve return to performance (Holcombe *et al*., 2019).

The use of abdominal support is also advised. One of the advantages of using an abdominal bandage, like the CM™ Hernia Belt (Figure 10) in the management/treatment for hernia is that the horse can initiate an exercise program, while having the abdominal support in place (Marshall & Blikslager, 2019).

Figure 10: Abdominal support using CM™ Hernia Belt (in Complications in Equine Surgery (p. 331), by Rubio Martinez, Luis M., Hendrickson, Dean A.. 2021, Hoboken, NJ: Wiley-Blackwell. Copyright [2021] by New Bolton Center. Reprinted with permission.)

4. Future directions

Future clinical and experimental research trend are directed towards the development of new methodologies to increase the efficacy in the prophylaxis for incisional complications and establishing the pathogenesis for SSI. There are general factors that are being explored to positively influence wound healing such as topical therapy, stem cells, innovative pharmaceuticals, local anaesthetics and anti-inflammatory drugs (Provost, 2019), that might have possible applications before the closure of the incision, and thus modulate the most critical period for SSI to establish.

SSI and hernia formation are common complications of abdominal surgery in human patients as well so, depending on the concept of One Health for global and shared research, achievements directed

towards human medicine issues can be addressed in a translational perspective and inspire advances in the veterinary field of clinics and research:

- prophylactic mesh reinforcement of the abdominal wall after a laparotomy has been studied in humans, and its use as a prophylaxis measure is associated with lower incidence of incisional hernia formation after laparotomy. Although increasing the operating time, baring a slightly higher rate of seroma, and occasional wound pain after surgery, it was demonstrated to be a safe and effective procedure to prevent incisional hernia formation (Wang *et al*., 2017);
- commonly used antiseptic agents such as povidone iodine and chlorhexidine gluconate applied to irrigation fluids for incision lavage before suturing have demonstrated their efficacy in reducing SSI risk, while antibiotic agents applied in irrigation fluids have had no benefit reported. The effective volume of fluid and its delivery method (gravity, power or pulse irrigation) have yet to be determined (Edmiston *et al*., 2018);
- a device that protects the incision edges while continuously performing lavage intraoperatively has been shown to achieve good results in reducing bacterial contamination of the incision (Mueller *et al*., 2017).

Other methods for colic treatment have been explored, such as reducing the size of tympanized large intestines. This procedure could allow for the ventral midline incision to remain within the 27 cm, if a laparotomy would be required, and further contribute to decrease the risk of SSI. Besides using percutaneous decompression, Scotti *et al.*, described a method for performing transrectal decompression, and showed its safety and effectiveness in treating large intestine tympany (Scotti *et al*., 2013).

For prevention of abdominal wall dehiscence, it was advised by Hann *et al.*, that further studies should be carried regarding the tension applied in the sutures for the closure of the ventral midline incision because, in human patients, dehiscence was attributed to abdominal wall sutures being too tight or not widely enough placed (Hann *et al*., 2021).

These and other factor are yet to be addressed in veterinary surgery, in general, and particularly in the equine field, that poses greater challenges for the size and weight of the species, as well as for the high performance demanded in most animals.

5. Conclusion

Incisional complications are a subject of great relevance in the spectrum of complications that can subsequent colic surgery.

A variety of factors must be analysed and considered in the clinical decision process, and adequate preventive measures have proven effective in the risk management of the issue and are recommended to be implemented as gold standard routine procedures.

Surgical teams must be aware of the basilar Halstead principles and effort to maintain up to date on the most recent advances and recommendations to employ the most suitable methods and techniques throughout the surgical process and be willing to continuously improve and innovate. They should also be provided with the most efficient equipment, and investment in prevention on clinical facilities is rapidly paid off by minimizing costs with treatments, while globally improving the quality of veterinary care provided.

Finally, the translational perspective of the application of human medicine measures and techniques in equine medicine (and other veterinary fields) should be stimulated. Joint efforts for the advancement of knowledge on the topic would weigh positively in terms of economics, but mostly in favour of the animal's health and well-being and the development of veterinary medicine up to higher standards.

6. References

Adams, S. B., & Fessler, J. F. (2000). Ventral Midline Celiotomy and Abdominal Exploration. In S. B. Adams & J. F. Fessler (Eds.), *Atlas of Equine Surgery* (1st ed., pp. 87–92). W.B. Saunders Company.

Anderson, S. L., Bracamonte, J. L., Hendrick, S., Carmalt, J. L., & Wilson, D. G. (2013). Ex Vivo Comparison of 7 Polydioxanone, 2 Polyglactin 910 for Closure of Ventral Median Celiotomy in Horses. *Veterinary Surgery*, *42*(4), 463–467. https://doi.org/10.1111/j.1532-950X.2013.12002.x

Anderson, S. L., Devick, I., Bracamonte, J. L., Hendrick, S., Barber, S. M., Carmalt, J. L., & Wilson, D. G. (2015). Occurrence of Incisional Complications After Closure of Equine Celiotomies With USP 7 Polydioxanone. *Veterinary Surgery*, *44*(4), 521–526. https://doi.org/10.1111/j.1532-950X.2014.12275.x

Bischofberger, A. S., Brauer, T., Gugelchuk, G., & Klohnen, A. (2010). Difference in incisional complications following exploratory celiotomies using antibacterial-coated suture material for subcutaneous closure: Prospective randomised study in 100 horses. *Equine Veterinary Journal*, *42*(4), 304–309. https://doi.org/10.1111/j.2042-3306.2009.00020.x

Canada, N. C., Beard, W. L., Guyan, M. E., & White, B. J. (2015). Comparison of sub-bandage pressures achieved by 3 abdominal bandaging techniques in horses. *Equine Veterinary Journal*, *47*(5), 599–602. https://doi.org/10.1111/evj.12329

Colbath, A. C., Patipa, L., Berghaus, R. D., & Parks, A. H. (2014). The influence of suture pattern on

the incidence of incisional drainage following exploratory laparotomy. *Equine Veterinary Journal*, *46*(2), 156–160. https://doi.org/10.1111/evj.12091

Cook, V. L. (2017). Abdominal Closure. In *The Equine Acute Abdomen* (3rd ed., pp. 604–609). John Wiley & Sons, Inc.

Coomer, R. P. C., Mair, T. S., Edwards, G. B., & Proudman, C. J. (2007). Do subcutaneous sutures increase risk of laparotomy wound suppuration? *Equine Veterinary Journal*, *39*(5), 396–399. https://doi.org/10.2746/042516407X195123

Costa-Farré, C., Prades, M., Ribera, T., Valero, O., & Taurà, P. (2014). Does intraoperative low arterial partial pressure of oxygen increase the risk of surgical site infection following emergency exploratory laparotomy in horses? *Veterinary Journal*, *200*(1), 175–180. https://doi.org/10.1016/j.tvjl.2014.01.029

Darnaud, S. J. M., Southwood, L. L., Aceto, H. W., Stefanovski, D., Tomassone, L., & Zarucco, L. (2016). Are horse age and incision length associated with surgical site infection following equine colic surgery? *Veterinary Journal*, *217*, 3–7. https://doi.org/10.1016/j.tvjl.2016.09.004

Davis, W., Fogle, C. A., Gerard, M. P., Levine, J. F., & Blikslager, A. T. (2013). Return to use and performance following exploratory celiotomy for colic in horses: 195 cases (2003-2010). *Equine Veterinary Journal*, *45*(2), 224–228. https://doi.org/10.1111/j.2042-3306.2012.00615.x

Desrochers, A., & White II, N. A. (2017). Diagnostic Approach to Colic. In *The Equine Acute Abdomen* (3rd ed., pp. 223–262). John Wiley & Sons, Inc.

Dunkel, B., Mair, T., Marr, C. M., Carnwath, J., & Bolt, D. M. (2015). Indications, complications, and outcome of horses undergoing repeated celiotomy within 14 days after the first colic surgery: 95 cases (2005–2013). *Journal of the American Veterinary Medical Association*, *246*(5), 540–546.

Durward-Akhurst, S. A., Mair, T. S., Boston, R., & Dunkel, B. (2013). A comparison of two antimicrobial regimens on the prevalence of incisional infections after colic surgery. *Veterinary Record*, *172*(11), 287. https://doi.org/10.1136/vr.101186

Edmiston, C. E., Spencer, M., & Leaper, D. (2018). Antiseptic irrigation as an effective interventional strategy for reducing the risk of surgical site infections. *Surgical Infections*, *19*(8), 774–780. https://doi.org/10.1089/sur.2018.156

Edwards, G. B. (2013). Gastroenterology 1. Colic. In T. Mair, S. Love, J. Schumacher, R. Smith, & G. Frazer (Eds.), *Equine Medicine, Surgery and Reproduction* (2nd ed., pp. 21–47). Saunders Elsevier.

Fierheller, E. E., & Wilson, D. G. (2005). An in vitro biomechanical comparison of the breaking strength and stiffness of polydioxanone (sizes 2, 7) and polyglactin 910 (sizes 3, 6) in the equine linea alba. *Veterinary Surgery*, *34*(1), 18–23. https://doi.org/10.1111/j.1532-950x.2005.00004.x

Gazzerro, D. M., Southwood, L. L., & Lindborg, S. (2015). Short-term complications after colic surgery in geriatric versus mature non-geriatric horses. *Veterinary Surgery*, *44*(2), 256–264. https://doi.org/10.1111/j.1532-950X.2014.12281.x

Gibson, K. T., Curtis, C. R., Turner, A. S., McIlwraith, C. W., Aanes, W. A., & Stashak, T. S. (1989). Incisional Hernias in the Horse Incidence and Predisposing Factors. *Veterinary Surgery*, *18*(5), 360–366. https://doi.org/10.1111/j.1532-950X.1989.tb01100.x

Gustafsson, K., Tatz, A. J., Slavin, R. A., Sutton, G. A., Dahan, R., Ahmad, W. A., & Kelmer, G. (2020). Intraincisional medical grade honey decreases the prevalence of incisional infection in horses undergoing colic surgery: A prospective randomised controlled study. *Equine Veterinary Journal*, *January 2020*, 1–7. https://doi.org/10.1111/evj.13407

Hann, M. J., Mair, T. S., Gardener, A., Southwood, L. L., Dechant, J. E., Barton, M. H., Garcia-Macias, J., Parker, R. A., & Archer, D. C. (2021). Acute abdominal dehiscence following laparotomy: a multicentre, international retrospective study. *Equine Veterinary Journal*, 0–3. https://doi.org/10.1111/evj.13498

Hassan, K. A., Galuppo, L. D., & Van Hoogmoed, L. M. (2006). An in vitro comparison of two suture intervals using braided absorbable loop suture in the equine linea alba. *Veterinary Surgery*, *35*(3), 310–314. https://doi.org/10.1111/j.1532-950X.2006.00149.x

Hassel, D. M. (2017). Postoperative Complications. In *The Equine Acute Abdomen* (3rd ed., pp. 624–638). John Wiley & Sons, Inc.

Hines, M. T. (2018). Clinical Approach to Commonly Encountered Problems. In S. M. Reed, W. M. Bayly, & D. C. Sellon (Eds.), *Equine Internal Medicine* (4th ed., pp. 232–310). Elsevier.

Holcombe, S. J., Shearer, T. R., & Valberg, S. J. (2019). The Effect of Core Abdominal Muscle Rehabilitation Exercises on Return to Training and Performance in Horses After Colic Surgery. *Journal of Equine Veterinary Science*, *75*, 14–18. https://doi.org/10.1016/j.jevs.2019.01.001

Immonen, I. A. M., Karikoski, N., Mykkänen, A., Niemelä, T., Junnila, J., & Tulamo, R.-M. (2017). Long-term follow-up on recovery, return to use and sporting activity: A retrospective study of 236 operated colic horses in Finland (2006-2012). *Acta Veterinaria Scandinavica*, *59*(5), 1–11. https://doi.org/10.1186/s13028-016-0273-9

Ingle-Fehr, J. E., Baxter, G. M., Howard, R. D., Trotter, G. W., & Stashak, T. S. (1997). Bacterial culturing of ventral median celiotomies for prediction of postoperative incisional complications in horses. *Veterinary Surgery*, *26*(1), 7–13. https://doi.org/10.1111/j.1532-950X.1997.tb01456.x

Isgren, C. M., Salem, S. E., Archer, D. C., Worsman, F. C. F., & Townsend, N. B. (2017). Risk factors for surgical site infection following laparotomy: Effect of season and perioperative variables and reporting of bacterial isolates in 287 horses. *Equine Veterinary Journal*, *49*(1), 39–44.

https://doi.org/10.1111/evj.12564

Lepage, O. M., Doumbia, A., Perron-Lepage, M. F., & Gangl, M. (2012). The use of maggot debridement therapy in 41 equids. *Equine Veterinary Journal*, *44*(SUPPL. 43), 120–125. https://doi.org/10.1111/j.2042-3306.2012.00609.x

Liebich, H.-G., Maierl, J., & König, H. E. (2020). Fasciae and muscles of the head, neck and trunk. In *Veterinary Anatomy of Domestic Animals Textbook and Colour Atlas* (7th ed., pp. 137–169). Thieme.

Magee, A. A., & Galuppo, L. D. (1999). Comparison of incisional bursting strength of simple continuous and inverted cruciate suture patterns in the equine linea alba. *Veterinary Surgery*, *28*(6), 442–447. https://doi.org/10.1111/j.1532-950X.1999.00442.x

Mair, T. S., & Smith, L. J. (2005a). Survival and complication rates in 300 horses undergoing surgical treatment of colic. Part 1: Short-term survival following a single laparotomy. *Equine Veterinary Journal*, *37*(4), 296–302. https://doi.org/10.2746/0425164054529409

Mair, T. S., & Smith, L. J. (2005b). Survival and complication rates in 300 horses undergoing surgical treatment of colic. Part 2: Short-term complications. *Equine Veterinary Journal*, *37*(4), 303–309. https://doi.org/10.2746/0425164054529364

Marshall, J. F., & Blikslager, A. T. (2019). Colic: Diagnosis, Surgical Decision, Preoperative Management, and Surgical Approaches to the Abdomen. In J. A. Auer, J. A. Stick, J. M. Kümmerle, & T. Prange (Eds.), *Equine Surgery* (5th ed., pp. 521–528). Elsevier.

Mueller, T. C., Nitsche, U., Kehl, V., Schirren, R., Schossow, B., Goess, R., Friess, H., Reim, D., Mihaljevic, A., Vay, C., Olbrich, H. G., Bouchard, R., Izbicki, J., Bork, U., Gassmann, P., & Albertsmeier, M. (2017). Intraoperative wound irrigation to prevent surgical site infection after laparotomy (IOWISI): Study protocol for a randomized controlled trial. *Trials*, *18*(1), 1–12. https://doi.org/10.1186/s13063-017-2154-6

Phillips, T. J., & Walmsley, J. P. (1993). Retrospective analysis of the results of 151 exploratory laparotomies in horses with gastrointestinal disease. *Equine Veterinary Journal*, *25*(5), 427–431.

Provost, P. J. (2019). Wound Healing. In J. A. Auer, J. A. Stick, J. M. Kümmerle, & T. Prange (Eds.), *Equine Surgery* (5th ed., pp. 53–69). Elsevier.

Sanders, R. J., Diclementi, D., & Ireland, K. (1977). Principles of Abdominal Wound Closure. Part II Prevention of Wound Dehiscence. *Archives of Surgery*, *112*(10), 1184–1187. https://doi.org/10.1001/archsurg.1977.01370100038007

Sanders, R. J., DiClementi, D., & Ireland, K. (1977). Principles of Abdominal Wound Closure Part I. Animal Studies. *The Archives of Surgery*, *112*, 1184–1187.

Scotti, G. B., Lazzaretti, S. S., Zani, D. D., & Magri, M. (2013). Transrectal decompression as a new approach for treatment of large intestinal tympany in horses with colic: Preliminary results. *Equine Veterinary Education*, *25*(4), 184–188. https://doi.org/10.1111/j.2042-3292.2012.00445.x

Smith, L. J., Mellor, D. J., Marr, C. M., Reid, S. W. J., & Mair, T. S. (2007). Incisional complications following exploratory celiotomy: Does an abdominal bandage reduce the risk? *Equine Veterinary Journal*, *39*(3), 277–283. https://doi.org/10.2746/042516407X193963

Southwood, L. (2015). Postoperative Colic Patient. In L. L. Southwood & P. A. Wilkins (Eds.), *Equine Emergency and Critical Care Medicine* (1st ed., pp. 757–787). Taylor & Francis Group.

Southwood, L. L. (2021). Complications of the Posteoperative Colic Patient. In L. M. Rubio-Martinez & D. A. Hendrickson (Eds.), *Complications in Equine Surgery* (1st ed., pp. 310–373). John Wiley & Sons, Inc.

Stewart, S., & Richardson, D. W. (2019). Surgical Site Infection and the Use of Antimicrobials. In J. A. Auer, J. A. Stick, J. M. Kümmerle, & T. Prange (Eds.), *Equine Surgery* (5th ed., pp. 77–103). Elsevier.

Theoret, C. (2017). Innovative Adjunctive Approaches to Wound Management. In J. Schumacher & C. Theoret (Eds.), *Equine Wound Management* (3rd ed., pp. 508–529).

Tnibar, A., Grubbe Lin, K., Thurøe Nielsen, K., Christophersen, M. T., Lindegaard, C., Martinussen, T., & Ekstrøm, C. T. (2013). Effect of a stent bandage on the likelihood of incisional infection following exploratory coeliotomy for colic in horses: A comparative retrospective study. *Equine Veterinary Journal*, *45*(5), 564–569. https://doi.org/10.1111/evj.12026

Torfs, S., Levet, T., Delesalle, C., Dewulf, J., Vlaminck, L., Pille, F., Lefere, L., & Martens, A. (2010). Risk Factors for Incisional Complications after Exploratory Celiotomy in Horses: Do Skin Staples Increase the Risk? *Veterinary Surgery*, *39*(5), 616–620. https://doi.org/10.1111/j.1532-950X.2009.00636.x

Trostle, S. S., Wilson, D. G., Stone, W. C., & Markel, M. D. (1994). A Study of the Biomechanical Properties of the Adult Equine Linea Alba: Relationship of Tissue Bite Size and Suture Material to Breaking Strength. *Veterinary Surgery*, *23*(6), 435–441. https://doi.org/10.1111/j.1532-950X.1994.tb00504.x

Wang, X. C., Zhang, D., Yang, Z. X., Gan, J. X., & Yin, L. N. (2017). Mesh reinforcement for the prevention of incisional hernia formation: a systematic review and meta-analysis of randomized controlled trials. *Journal of Surgical Research*, *209*, 17–29. https://doi.org/10.1016/j.jss.2016.09.055

White II, N. A. (2017). Decision for Surgery and Referral. In *The Equine Acute Abdomen* (3rd ed., pp. 285–288). John Wiley & Sons, Inc.

Whitfield-Cargile, C. M., Rakestraw, P. C., Hardy, J., Cohen, N. D., & Davis, B. E. (2011). Comparison of primary closure of incisional hernias in horses with and without the use of prosthetic mesh support. *Equine Veterinary Journal*, *43*(SUPPL.39), 69–75. https://doi.org/10.1111/j.2042-3306.2011.00377.x

Wilson, D. A., Badertscher, R. R., Boero, M. J., Baker, G. J., & Foreman, J. H. (1989). Ultrasonographic evaluation of the healing of ventral midline abdominal incisions in the horse. *Equine Colic*, 107–110. https://doi.org/10.1111/j.2042-3306.1989.tb05667.x

Wilson, David A., Baker, G. J., & Boero, M. J. (1995). Complications of Celiotomy Incisions in Horses. *Veterinary Surgery*, *24*(6), 506–514. https://doi.org/10.1111/j.1532-950X.1995.tb01362.x