Abdominal Closure and Complications

David E. Freeman, MVB, PhD, Diplomate ACVS, Anna K. Rötting, Dr. med. vet., and Olivia J. Inoue, DVM, MS. Diplomate ACVS

Complications can develop in the ventral median incision in 40% of horses after intestinal surgery, with incisional drainage in 32 to 36% of horses, dehiscence in 3 to 5%, and hernia formation in 6 to 17%. Factors associated with incisional complications include age, size, type of incision, type of suture material, method of closure, the degree of surgical trauma, length of surgery, and the difficulty of anesthetic recovery. For ventral midline closure, polyglycolic acid is significantly stronger than polydioxanone and monofilament nylon, but polydioxanone has better mechanical performance after implantation. A continuous suture pattern in the linea alba is quicker to perform and is stronger than most interrupted patterns. The optimal bite size for adult equine linea alba is 15 mm from the edge, and sutures are usually placed that distance apart. Closure of subcutaneous tissues is optional and skin can be closed with a variety of materials and patterns. A temporary, water-impervious, self-adhesive, plastic drape may reduce incisional contamination in the recovery stall. Bandages are expensive and not used routinely, but can protect the incision from contamination and trauma, and reduce edema. Treatment of infection involves removal of skin sutures and topical cleaning, with or without systemic antibiotics. Dehiscence of the linea alba is usually caused by tearing of the body wall and not suture breakage. Hernias develop slowly and repair by suture closure or by mesh should be postponed for approximately 3 to 4 months after the initial surgery.

Key Words: Ventral median incision, horse, drainage, infection, dehiscence, herniation, herniorrhaphy, complications, surgery.

In equine gastrointestinal tract surgery, abdominal closure is a daunting component of the surgical procedure, and can cause troublesome postoperative complications that influence final outcome.[1–7] Incisional complications can develop in 40% of horses that have intestinal surgery,[1] with incisional drainage reported in 32 to 36% of horses, dehiscence in 3 to 5%, and hernia formation in 6 to 17%.[1–3] Other complications can include swelling,[4–6] local infection,[1,4,6] suture sinuses,[1,4,6] hematoma formation, and peritonitis.[4,6] Patient factors that have been associated with incisional complications include age,[1] anemia, chronic illness, dehydration, postoperative leukopenia,[10] hemorrhagic shock,[6] hypoproteinemia, concurrent infection, increased concentrations of peritoneal fibrinogen,[11] neoplasia, increased intraabdominal pressure, muscle strain, size,[1] postoperative ileus,[12] postoperative protein and lipid mobilization,[12] elevated hematocrit,[13] and nutritional status.[4,7] Surgical factors can include the type of incision,[4,5] type of suture material used,[1,4–8,14,15] method of closure used,[2,5] the degree of surgical trauma, length of surgery,[1,13] and the difficulty of anesthetic recovery.[4,6,7] The following is a discussion of those factors under the surgeon's control that could be relevant to the development and prevention of incisional complications.

Patient Preparation

Preoperative preparation involves clipping hair from a large area around the proposed incision from the inguinal region to slightly cranial to the xiphoid, laterally to the level of the flank fold and around the costal arch. The penis is sutured into the prepuce in males and the skin is given a gross scrub with a surgical soap until a wipe with a moist sponge fails to pick up any surface debris. These steps are completed outside the surgery room, and a final surgical scrub then follows in the surgery room with either povidone-iodine or chlorhexidine. These scrubs are effective against the most common types of pathogens, although chlorhexidine is reported to have greater residual activity and therefore might be more suitable for a long surgical procedure.[16] Chlorhexidine also has a rapid onset of action and, compared with iodine preparations, it is less susceptible to inactivation by organic debris.[16] Inorganic or elemental iodine has a very short kill time at low concentrations and is viricidal, bactericidal, and fungicidal.[16] Skin should be well cleaned before final application of iodophor compounds to remove organic debris that can reduce the bactericidal activity of the iodophor.[16]

In one study,[17] a povidone iodine scrub and alcohol application was similar to an iodophor in alcohol complex that was applied after hexachlorophene scrub in reducing the number of bacterial colony-forming units (CFU). This alcohol in an iodophor-polymer complex forms a water-insoluble film with chemical and physical barrier properties on skin and sustained antimicrobial activity.[16] An adhesive iodine impregnated drape is applied for further protection by some surgeons, but adherence of this to the skin is not always satisfactory and requires thorough drying of the skin and even application of an adhesive.[17]

The Abdominal Incision

The caudal ventral median celiotomy is the most popular approach for correction of gastrointestinal lesions in the horse, largely because of access to most of the abdomen and simplicity of opening and closing compared with other incisions (Fig 1). This incision spans the ventral abdomen for 25 cm or more from a point 2.5 cm cranial to the umbilicus. Some surgeons use a paramedian approach because of improved access in their

From the University of Illinois, College of Veterinary Medicine, Urbana, IL.

Address reprint requests to David Freeman, MVB, PhD, University of Illinois, College of Veterinary Medicine, 1008 West Hazelwood Drive, Urbana, IL 61802.

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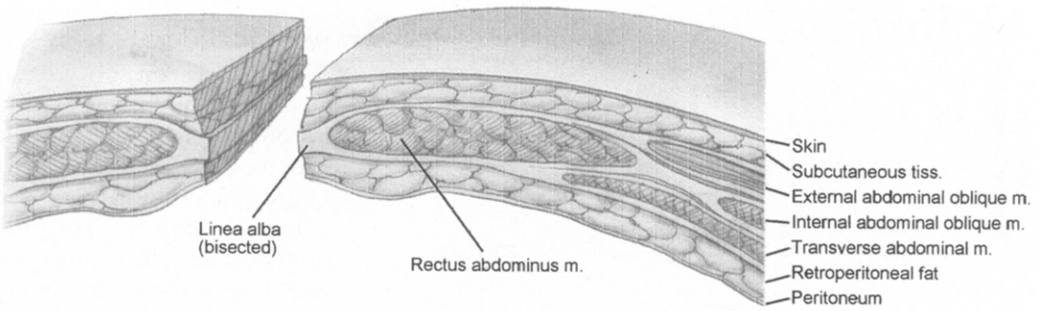

Fig 1. Anatomy of equine body wall through ventral median incision.

surgical suite, and find it to be well suited for exploratory celiotomy.[18] Under certain circumstances, the caudal to cranial location of the incision needs to be altered. For example, a more cranial location facilitates correction of a large colon volvulus, places a colopexy in a more favorable location in the pregnant mare, and would allow a more caudal approach if a second procedure were required.[19] A more cranial approach would also be indicated if preoperative information suggested a lesion in the cranial part of the abdomen, such as diaphragmatic hernia, gastroduodenal lesion, and renal and ureteral surgery in a foal. To improve access, the cranial end of this cranial incision might need to be extended laterally in a paracostal fashion for approximately 12 to 15 cm at an angle of 60 to 90° to form a J-shaped incision. A more caudal incision is required for cesarean section, surgery of the bladder and umbilical components, and for access to lesions in the distal part of the small colon. Caudal incisions in male horses require a paramedian skin incision around the prepuce and reflection of the skin edge laterally to expose the body wall.

Although cautery for incisional bleeders is time-consuming and therefore not advisable in a horse that is a poor anesthetic risk, incisional hemorrhage could increase postoperative swelling and provide a suitable environment for bacterial proliferation. In fat horses, some of the retroperitoneal fat can be excised, but no attempt should be made to undermine or separate the more superficial layers during incision or subsequent closure. Such undermining is traumatic, creates deadspace, and could reduce vascular perfusion of wound margins.

Closure of the Peritoneum

The peritoneum does not need to be sutured and the rate of adhesion formation can increase with its closure.[20] Also, the peritoneum is very thin and tears easily, even when the falciform ligament is used to appose the edges. One advantage to suturing the peritoneum is to exclude bowel from the field during closure of the linea alba, thereby facilitating this step. Peritoneal closure could also retain peritoneal fluid in the abdomen, so that postoperative drainage and incisional swelling are reduced. The use of a synthetic absorbable suture material of size 2-0 can be used in a simple continuous pattern in peritoneum.[5]

Linea Alba Closure—Tissue Layers

Fibers of the linea alba run perpendicular to the direction of suture tension and this feature would appear to provide a strong closure of the ventral median incision.[14,15] With a paramedian approach, the external fascia of the rectus sheath is closed (Fig 1). This fascia comprises the abdominal tunic and the aponeurosis of the external abdominal oblique, which has fibers interwoven with those of the aponeurosis of the internal abdominal oblique (Fig 1). There is no advantage to including the internal sheath (aponeurosis of the transverse abdominal muscle) because its fibers run along the line of suture tension and are therefore easily torn. Also, in the dog, inclusion of this layer in closure of a paramedian incision did not provide greater strength of closure than suturing only the external sheath.[21] The linea alba is thicker and has greater breaking strength near the umbilicus than it has in the more cranial parts of the abdomen.[14]

Linea Alba Closure—Suture Material

The type of suture used, the method of closure and the number of layers used to close a ventral midline incision are often dictated by surgeons' preferences. Monofilament suture (polydioxanone and polyglyconate) is generally manufactured by the melt extrusion process that creates an outer core and inner core as the material cools during processing.[15] Therefore, when monofilament suture undergoes rough handling (bending, twisting, crimping), the outer core can be damaged and this decreases the strength of the suture by decreasing its cross-sectional area and by altering its mechanical properties (cross linking of polymers). Examples of rough handling are grasping in hemostats or using edges of an instrument to pull up on suture to tighten a continuous suture line.

Polyglycolic acid or polygalactin-910 are absorbable sutures that have been treated with a lubricant to decrease tissue drag and increase ease of handling, but have poor knot security.[5] They require at least four to five throws per knot and square knots should be used instead of half hitches to decrease the chances of the knots untying. Rough handling of multifilament suture (polyglactin 910 and polyglycolic acid) can have little effect on its overall strength.[14,15] Multifilament suture does not stretch or elongate as much as monofilament suture, is supple, and has little or no memory, but can harbor bacteria and cause tissue drag. Suture size should be the smallest available to accomplish the task.[15] The USP size will be used throughout this paper, but metric equivalents are given for comparison in Table 1.

TABLE 1. Metric Measures and USP Suture Diameter Equivalents for Synthetic Absorbables and Nonabsorbable Materials

USP Size	4-0	3-0	2-0	0	1	2	3
Metric measures	1.5	2.0	3.0	3.5	4.0	5.0	6.0

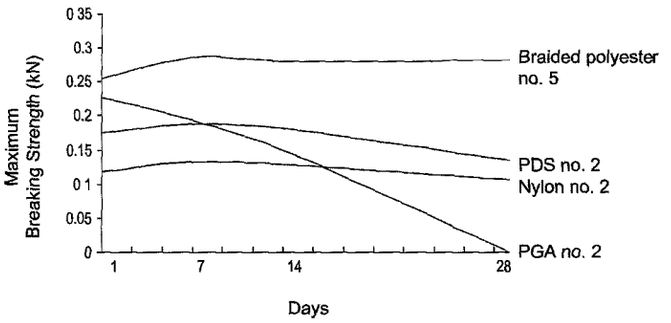

Fig 2. Graph constructed from Table 1, Reference 22, to show changes in the mechanical properties of suture materials before (Day 1) and after in vivo implantation (Days 7, 14, and 28) in horses.

In a study on closure of equine cadaver linea alba, size 5 polyester (nonabsorbable) had a greater breaking strength and stiffness than size 2 polyglycolic acid and size 3 polyglactin 910 (both absorbable), followed by size 2 polydioxanone, size 2 polypropylene, and size 1 polyglyconate.[14] Size 2 nylon had the lowest breaking strength.[14] In a study on suture material in vitro and after subcutaneous implantation for up to 28 days in horses (Fig 2), size 5 braided polyester had the highest maximum breaking strength and polyglycolic acid was significantly stronger than polydioxanone and monofilament nylon.[22] However, polydioxanone had better mechanical performance after 28 days of implantation than did polyglycolic acid.[22] In general, a nonabsorbable material is not recommended because of the risk of suture sinus formation.[23] In addition, currently available absorbable sutures retain their breaking strength for longer than older materials (eg, chromic gut) and can even prevent herniation in a wound compromised by infection. Therefore, there is no real advantage to a nonabsorbable material. Suture sinus formation is more likely with multifilament or braided material than with monofilament, largely because they have greater capillarity and are more likely to retain bacteria.[5,23] However, large monofilament suture, such as polypropylene, has a high memory and therefore, poor knot security and requires several throws and a bulky knot.[23] The resulting volume of material, combined with stiffness of this suture, is likely to cause mechanical irritation and lead to suture sinus formation.[23] Unfortunately, there is no single suture material among those used routinely for closure of the equine linea alba that is initially as strong as the normal tissue in which it is placed.[14] In in vitro studies with simple interrupted patterns, the suture materials break before the linea alba tears and the weakest point of the suture is near the knot.[14]

Chromic gut is not used currently for linea alba closure in the horse.[5] Chromic gut is degraded by proteolytic enzymes produced by inflammatory cells and this process is accelerated in an unpredictable fashion by the presence of infection, and can be complete in seven days.[5] In humans and in horses, the use of chromic gut has a much higher incidence of dehiscence because of its rapid loss of strength.[10]

Polyglycolic acid or polygalactin-910 sutures degrade by hydrolysis at a rate that is predictable, even in the face of infection, and these materials induce minimal foreign body reaction.[5] Polyglactin-910 is available in size 3 on a conventional cutting needle, and is the largest absorbable suture material available, an attractive feature when closing linea alba of an adult horse. In a recent retrospective study, the use of polyglactin-910 sutures had an increased risk of incisional infections when compared with polydioxonone sutures, but the number of horses closed with polyglactin-910 was small.[11] Presumably, the braided suture entrapped bacteria in its interstices, which favored infection.[11] Foals, ponies, and American Miniature Horses can be closed with appropriately smaller sized sutures, such as size 1 or 2.

The synthetic nonabsorbable suture materials are very strong and can be coated to improve tissue-handling characteristics. Polymerized caprolactam (Vetafil or Braunamid) is a braided multifilament suture ensheathed in polyamide to reduce capillarity.[5] This material was used successfully in clinical cases as a doubled strand after preparation with a coating of bacitracin, neomycin, polymyxin B triple antibiotic ointment, followed by gas sterilization.[24] The polyester sutures consist of Dacron that is uncoated (Mersilene), or coated or impregnated with silicon (Ticron) or polybutylate (Ethibond).[5] The coating substances improve the handling of the suture material but reduce the knot holding ability; therefore, the number of throws per knot should be at least five or six.[5] These suture materials can become a nidus for infection when buried and cause suture abscesses and suture sinuses resulting in recurrent purulent discharge.[5]

Advantages of monofilament stainless steel suture, such as strength and knot security, would make it suitable for equine linea alba.[25] Simple interrupted or interrupted far-near-near-far sutures can be used and are tied with a square knot that is buried into the external rectus sheath.[25] Because steel does not wick, it is suitable for infected areas and for secondary closure of infected incisions.[5,26] However, stainless steel sutures are difficult to handle. Also, metal fatigue can cause the stainless steel suture to break, and may cause suture sinus tracts many years after their original placement[5] and even projection of wire ends through the skin.

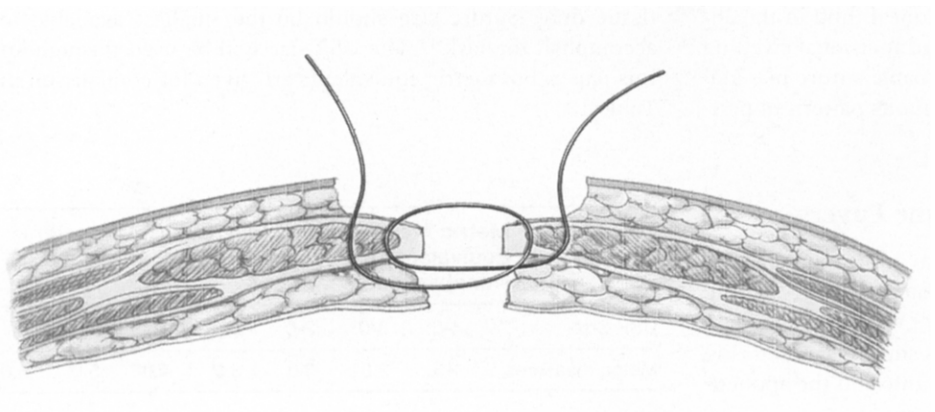

Fig 3. Far-near-near-far suture pattern for the linea alba.

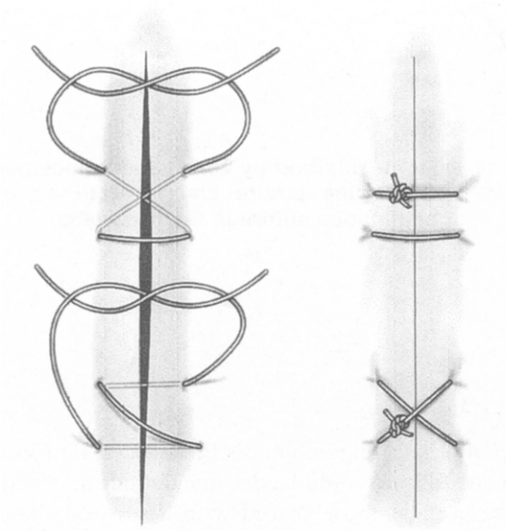

Fig 4. Inverted cruciate, or figure-of-eight (top), and cruciate patterns, placement (left) and on completion (right). The difference is that the crossover point of the sutures is close to the knot in the cruciate pattern, which could stress this vulnerable part of the suture.

Closure of the Linea Alba—Suture Patterns

Numerous suture patterns have been used to close the linea alba, including simple continuous,[27] simple interrupted, near-far-far-near (NFFN), far-near-near-far (FNNF; Fig 3), cruciate (Fig 4), inverted cruciate (figure-of-eight; Fig 4), and mattress patterns.[5] A continuous suture pattern allows the biomechanical forces to be more evenly distributed over the entire incision line and is quicker to perform than interrupted patterns.[16,28] In a recent study on equine cadavers, the simple continuous pattern was found to be significantly stronger than the inverted cruciate pattern,[28] and, in a survival study, there was no difference in clinical appearance, histologic changes, or breaking strength between incisions closed with simple continuous versus simple interrupted patterns.[29] In studies on rats, the continuous suture was also found to have greater wound-bursting pressure than a simple interrupted pattern and figure-of-eight (inverted cruciate) technique.[30] The continuous pattern also places less suture in the tissues and therefore should incite less foreign body reaction and reduce the risk of infection, compared with interrupted patterns.[5] Of course, breakage of the continuous suture would completely disrupt the closure.

The use of a NFFN pattern to close the linea alba requires more time to place than does a simple continuous suture pattern but is an excellent pattern where there is a great deal of tension.[5] In one study, horses closed with the NFFN pattern had a higher rate of purulent incisional drainage.[2] This could be attributed to the increased dead space created by the extent of tissue undermining needed for suture placement,[2] and the greater tissue strangulation and ischemia.

Closure of the Linea Alba—Retention Sutures

In large breed horses (>700 kg), mares in advanced pregnancy, or horses that have undergone a second exploratory through a recent incision, approximately 3 to 5 retention sutures can be placed to give additional support a ventral median incision during recovery and the immediate postoperative period (Fig 5). These are vertical mattress sutures with doubled #2 nylon placed through polypropylene bolsters (see secondary closure below). The far bites are placed through all layers and close bites are placed ≤2.5 cm from the skin edge and only through the skin and subcutaneous tissues. These sutures are at 8- to 10-cm intervals along the incision, and should be inserted on a large curved needle immediately ahead of the continuous pattern in the linea. In this way, deep insertion of the needle can be guided and the risk of inadvertent penetration of an existing suture strand (Fig 6) or bowel is avoided. Because these sutures

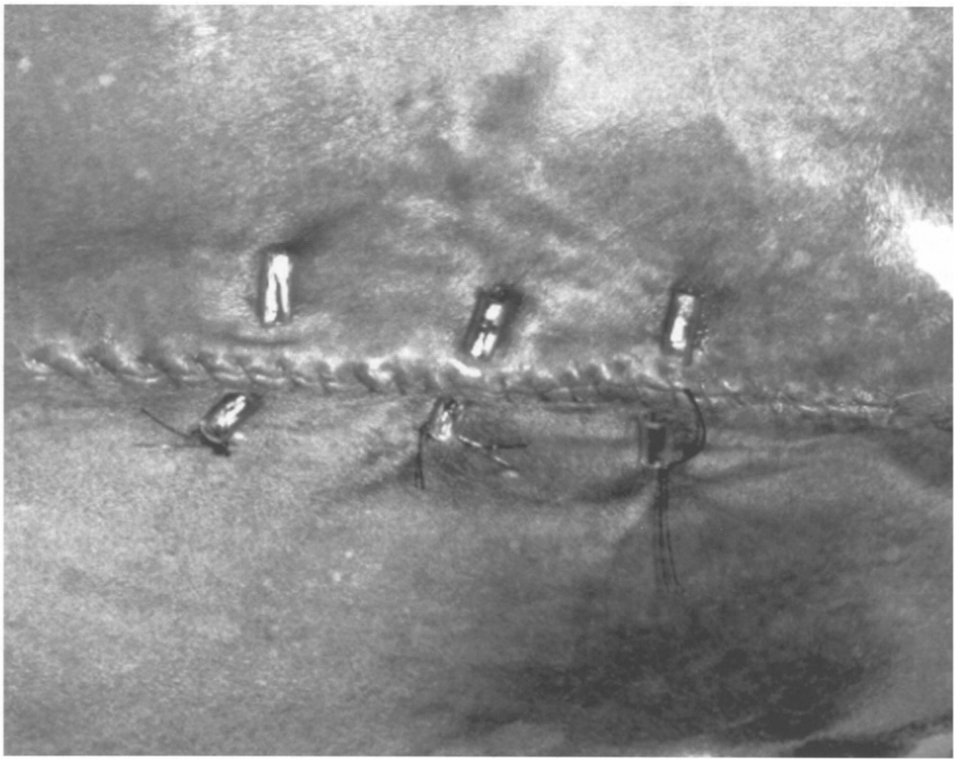

Fig 5. Retention sutures in body wall to support repair in a pregnant broodmare. These are placed as for secondary closure.

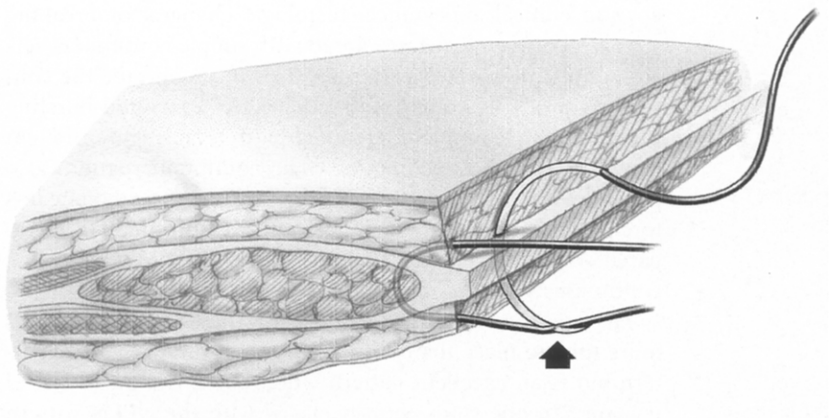

Fig 6. Method by which blind placement of a supporting suture can lacerate an existing continuous suture in the linea alba.

can induce incisional infection, they should be removed in <7 days, unless integrity of the incision is suspect. It is not necessary to reinforce continuous suture patterns with interrupted patterns in most horses, and this procedure also carries the risk of suture laceration or bowel puncture if placed after the continuous pattern has passed through that section of body wall (Fig 6).

Techniques and Principles

Intraoperative decompression of distended or impacted bowel reduces postoperative strain on a suture line in the linea alba and reduces bowel protrusion into the incision so closure can be faster. To prevent inadvertent bowel puncture during each bite, the back end of a thumb forceps can be placed under the edge away from the surgeon and be used as a backstop for the needle directed toward it. For the near side, the skin and subcutaneous tissue can be grasped with forceps and elevated to bring the linea edge into view, or the linea itself can be grasped and brought into view. A visceral retainer or "fish" can also be placed to retain bowel from the suture line. Peritoneal fat should not be included in the closure because it interferes with apposition of the linea alba.

The optimal tissue bite size for adult equine linea alba is 15 mm from the edge,[15] and sutures are usually placed about that distance apart. Wider suture bites incorporate the rectus muscle and sheath, increasing the chances for tissue necrosis and tearing. The incision edges should be pulled into snug apposition, and tissue should not be tied too tightly, because this will strangulate the edges and cause foci of incisional necrosis.[31] Because polyglycolic acid and polygalactin-910 have poor knot security,[5] they require at least 5 to 7 throws per knot. In general, knot security is inversely proportional to the memory and size of the suture material.[14,15] Rough handling by pulling up on sutures with instruments or by clamping knots is more harmful to monofilament suture than to braided (see above).

Knots are the weakest points of a suture line, because they undergo shear stress when loaded.[15] There is also evidence that the method of knotting influences the structural properties of suture materials and could be detrimental in knots tied under tension, especially those placed with a surgeon's knot or a sliding half-hitch.[32] However, equine linea alba poses a challenge to knot security, because the edges are under some tension and closure requires large synthetic absorbable materials that have poor knot security. One technique to improve knot security is to use one and a half surgeon's knots on the first throw followed by a surgeon's knot on the second, and then a succession of single throws. Square knots should be used instead of half hitches to decrease the chances of the knots untying. Another technique is to place a surgeon's knot and then pull the knot into the subcutaneous tissue as it is being tightened so that it binds in this tissue and cannot slip as the second throw is placed. The first author prefers to start with a sliding half hitch that is guided loosely down to the tissue surface and then is tightened to produce a secure purchase before subsequent throws are placed (Figs 7 and 8). Subsequent throws should be square knots to reduce slippage of the sliding half hitch.

The first author prefers to end continuous patterns in the linea alba by having surgeons on opposite sides of the horse starting at each end of the incision and meeting in the middle to tie the long ends of the sutures together (Fig 9 and 10). Other alternatives are to tie the end to a loop formed from the second last bite (Fig 11) or to place a simple interrupted suture at the end of the incision and tie the end of the continuous pattern to it (Fig 12). If the incision is so long that several continuous strands are required, the new strand can be started and tied and the previous strand can be tied to its short end (Fig 13).

Subcutaneous Closure and Skin

The subcutaneous or subcuticular tissues can be closed with a simple continuous pattern or in a horizontal mattress fashion, with a small size (2-0 or 3-0) synthetic absorbable material. This closure protects sutures in the linea alba and supports skin

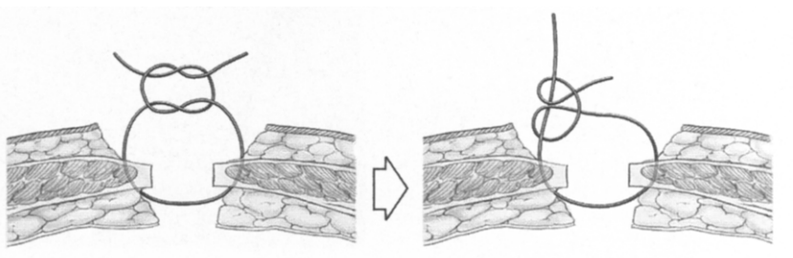

Fig 7. Method of converting a square knot to a sliding half hitch by pulling up on one end of the square knot.

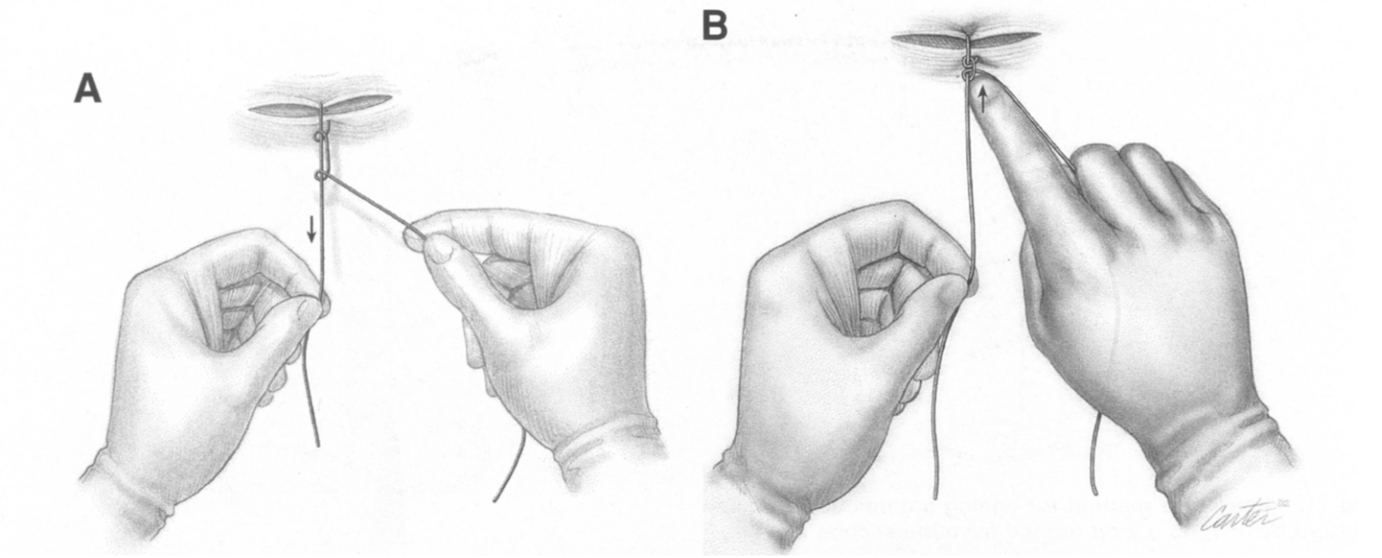

Fig 8. A. Method of starting the sliding half hitch with upward traction on one end of a square knot in direction of arrow. B. Method of sliding the loose sliding half hitch down (arrow) until it apposes the edges and tightens. The knot can be tightened once it has opposed the edges with desired tension and should be reinforced with several square knots.

apposition. The first author does not close the subcutaneous tissues in the belief that subcutaneous sutures add foreign material to the wound, serve as a nidus for infection, and retain infection in the body wall and deeper sutures. This concern is justified by studies in human patients and in laboratory animals that demonstrated greater wound induration and increased infection rates with subcutaneous sutures.[33] In one study on feline linea alba, the lack of a subcutaneous closure reduced incisional inflammation but caused microscopic evidence of seroma formation.[34] In a similar feline study, subcutaneous sutures increased early incisional swelling compared with no subcutaneous suture and did not seem to be essential to healing of the abdominal incision.[35] Without subcutaneous sutures, drainage of an infected incision is easily established and healing does not seem to be adversely affected.

The skin can be closed with a variety of materials and patterns with synthetic nonabsorbable or synthetic absorbable material. Staples have the advantage of being very quick and easy to use but can be expensive. The disadvantage of staples and nonabsorbable suture materials is they need to be removed and staple removal can be painful and difficult, even with the staple remover. The skin can be closed with polyglycolic acid size 2-0 or 3-0 in a simple continuous pattern, so these sutures do not need to be removed, a distinct advantage with some horses. Despite concerns about leaving sutures in for this duration, there do not seem to be any adverse effects on wound healing

Fig 9. Method for ending a continuous suture pattern in the linea alba. The ends of strands started by two surgeons from opposite ends of the incision meet at the midpoint, where they will be tied together.

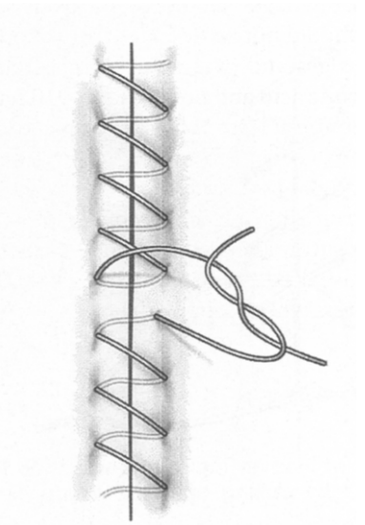

Fig 10. Method for ending a continuous suture pattern by tying two continuous strands each started from opposite ends of the incision and meeting in the middle.

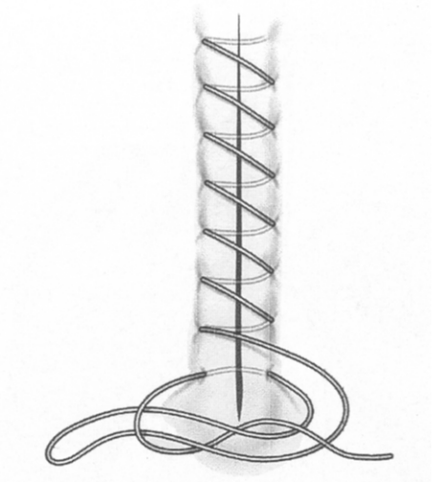

Fig 11. Alternative method for ending a continuous suture pattern by tying to a loop formed from the second last bite.

(Fig 14) and this suture material is usually gone in 3 to 5 weeks. Polydioxanone is not recommended for skin as it takes weeks to months to disappear.

Incisional Dressing

A water-impervious self-adhesive plastic drape (Steri Drape, 3M) may be beneficial in reducing the risks of incisional contamination from dirt and debris in the recovery stall.[6] While the horse is on the surgery table, one or more dry dressings (Telfa pads) are applied to the incision and the surrounding skin is then sprayed with a medical grade adhesive (Medical Adhesive, Hollister Inc, Libertyville, IL, USA; Fig 15). This improves adhesion of the plastic drape to skin and the drape can then be removed when the horse has stood or later.[6] Alternatively a roll of towel or gauze can be applied to the wound and secured in place with temporary horizontal mattress sutures in the skin along the edge of the material.[27] Care must be taken with this technique, because the mattress pattern can distract the edges of the skin incision if the suture is tightened sufficiently to draw the skin upward along each horizontal bite.

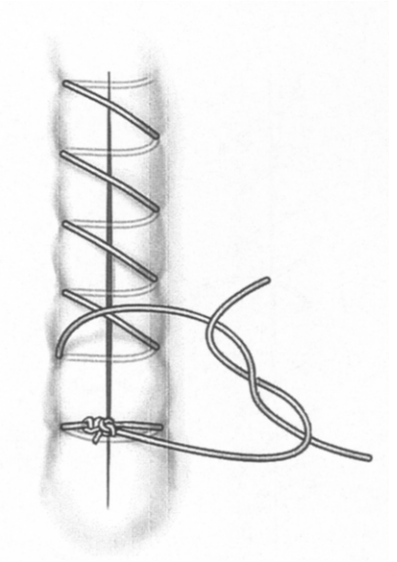

Fig 12. Alternative method for ending a continuous suture pattern by tying the end of the continuous pattern to the long end of a simple interrupted placed for this purpose.

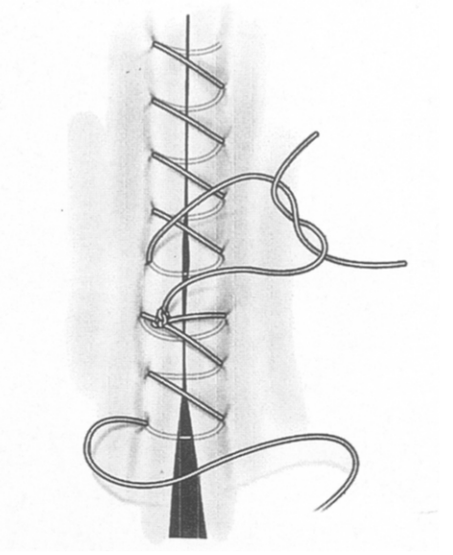

Fig 13. Method for starting the second strand of a continuous suture pattern by tying the completed strand (top) to the short end of the new strand (bottom).

Recovery Stall

The recovery stall plays a big part in incisional complications and should be as clean and dry as possible, to reduce contamination of the incision when the horse lies in sternal recumbency. A wet and slippery floor can lead to awkward falls that stress the incisional closure. Adhesive drapes over the incision can protect against contamination during recovery from the floor of the stall and from sweat and dirt from the horse's body.[17] A tail rope might help to provide a smooth recovery.

Abdominal Bandages

Abdominal bandages can be composed of Army Navy bandage or similar material retained with brown gauze and Elastikon adhesive bandage material (Fig 16) or with commercially available bandages (Fig 17) that can be laundered and reused (Equus Therapeutics™, Afton, VA or DePuy Inc, Warsaw, IN, USA). Bandages are not used routinely in this clinic and probably provide little support to the abdominal wound, but can protect it from contamination and trauma, reduce edema,[4–6]

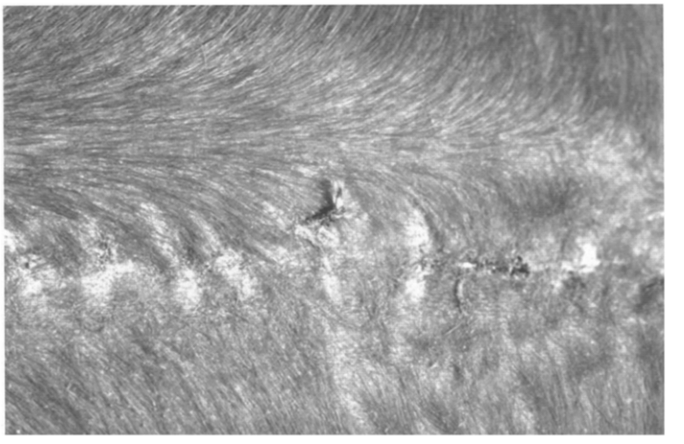

Fig 14. Skin at 3 weeks after closure with 2-0 polyglactin 910. Most of the suture has been broken down and the incision has healed well.

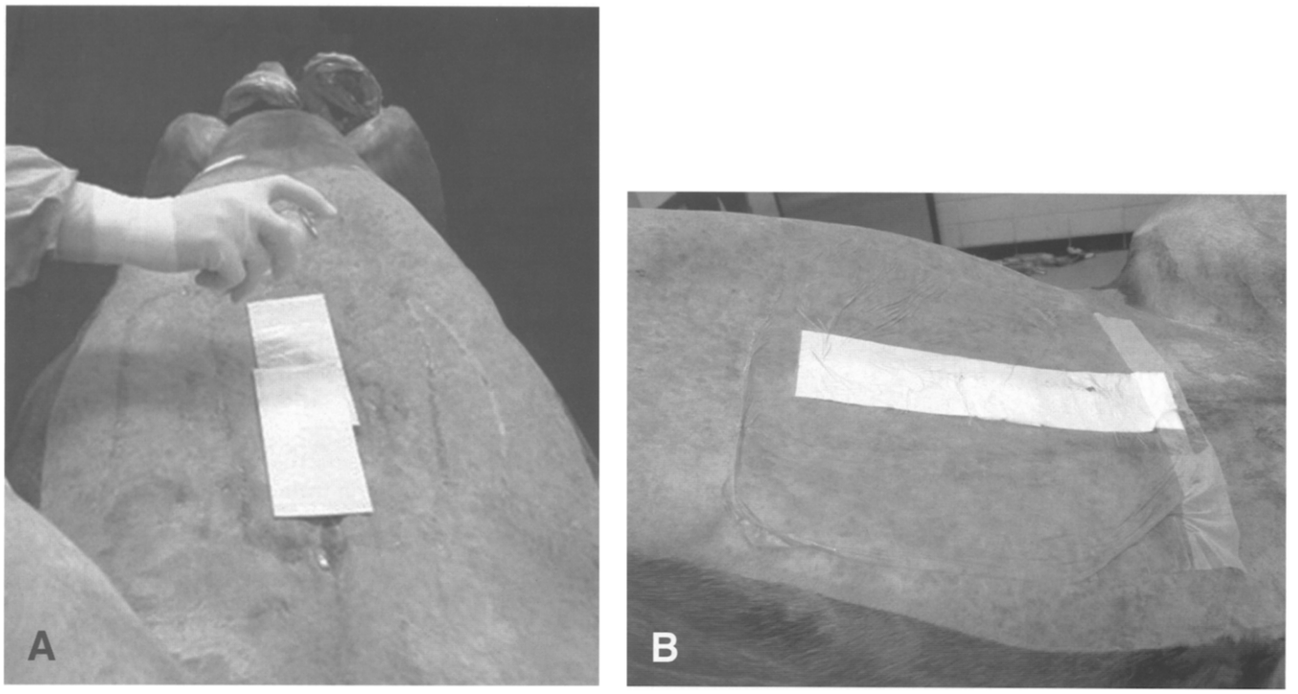

Fig 15. A. Method for applying an incisional dressing to the ventral median suture line. A Telfa pad is applied to the incision and the skin around the incision is sprayed with a medical grade adhesive. B. The iodophor impregnated plastic drape is applied to cover the dressing. This can be removed shortly after recovery from anesthesia.

and retain prolapsed bowel (Fig 18). They are expensive and require frequent changing. The abdominal bandage can be especially useful to protect the incision in a nursing mare from contamination by the foal and to protect an incision in the horse that has developed laminitis and tends to lie down. Abdominal bandages can become a source of contamination, especially if they are wet and remain in place for too long[4,6] and male horses tend to urinate on and in the abdominal bandage.[4] A wet abdominal wrap should be changed every 12 to 24 hours or sooner if is soaked.[4,6]

Postoperative Care

The goals of most postoperative procedures after colic surgery are to facilitate early return of normal gastrointestinal function and to prevent complications related to the gastrointestinal tract. Indirectly, these measures will also protect the abdominal incision and facilitate its healing. Postoperative pain should be managed as the individual case dictates, but those cases that are refractory to analgesics and gastric decompression may warrant a second celiotomy. Anything that stresses the repair, such as rectal examinations or any physical activity, should be avoided after surgery.[36]

Potassium penicillin and gentamicin sulfate should be given intravenously (IV) ≥30 minutes before induction of anesthesia,[17] although they do not seem to provide adequate prophylaxis against incisional infection. Postoperative rest is critical and we recommend 14 days in a stall, followed by another 14 days in a stall with handwalking exercise, and 30 days in a small paddock before work resumes, provided that incisional healing has been uncomplicated. This program is justified by the finding that incised and sutured linea alba in horses has a tensile

Fig 16. Belly bandage constructed from gauze bandage material and Elastikon. This type of bandage can be expensive, especially if it needs to be changed frequently.

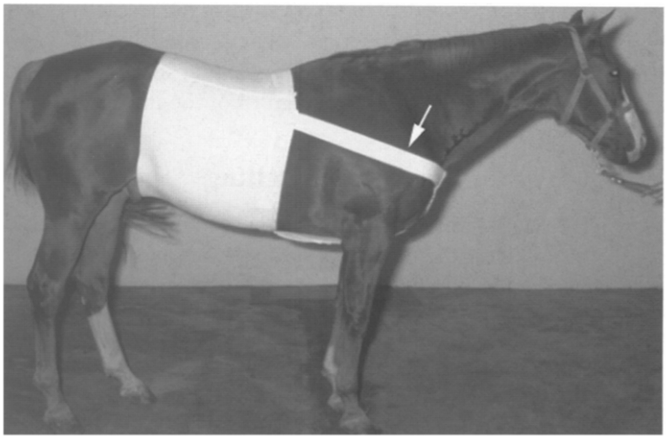

Fig 17. Commercially available abdominal bandage (Equus Therapeutics™, Afton, VA, USA). A length of bandage material can be placed at the arrow and brought over the neck to tie to the same level on the other side to prevent the breast plate from falling down.

Fig 18. Bowel contained within an abdominal bandage in a horse anesthetized for repair of a complete incisional dehiscence. Note drainage through the bandage that preceded dehiscence.

Fig 19. Drainage of fibrin from an infected abdominal incision.

strength comparable to that of noninciced linea alba at 8 weeks and is composed of mature collagen.[37]

Repeat Celiotomy

A repeat celiotomy is required in 14.7% to 28% of horses that have colic surgery, mostly after correction of small intestinal lesions.[38] In a recent study of small intestinal surgeries in this clinic, infection of the abdominal incision was recorded in 7.4% of horses that had one surgery and in 56% that had more than one surgery through the same ventral median approach.[38] This is similar to the findings of Phillips and Walmsley of an overall infection rate of 28% after colic surgery, but with a 67% wound complication rate after a repeat celiotomy.[39] Incisional infection after repeat celiotomies is probably caused by transfer of bacteria from the raw edges and diminished resistance in the friable and edematous tissues.

To avoid the risk of infection caused by repeat celiotomy, a separate paramedian approach could be used instead. However, there is concern that the second incision parallel to the first could create a section of ischemic skin or body wall between the two incisions. If the same ventral median incision is used, it could be closed with a simple continuous size #3 polyglactin 910, bolstered with vertical mattress sutures of doubled size #2 nylon through 2.5-cm segments of plastic or hard rubber tubing. Another alternative is to use secondary closure (see below) if the surgeon is concerned about health of the incision edges.

Incisional Swelling

Peri-incisional edema is common, even in horses that do not develop incisional infections and related complications, and is usually most obvious at 5 to 7 days after surgery. This develops as a flat plaque on both sides of the incision and extends caudally to involve the prepuce and rostrally to reach the forelimbs, and can remain for weeks after surgery. Possible causes are an inflammatory response during healing or subcutaneous collection of peritoneal drainage. Although severe cases signify a slowly developing infection, edema alone could be harmful by decreasing local oxygen tension in the incision,[17] putting tension on suture lines, weakening the tissues, reducing blood supply, and separating any bacteria in the incision from the immune system. Mild edema can persist for months after surgery, possibly because some residual size #3 polyglactin 910 induces inflammation or harbors bacteria within its interstices.

Incisional Infection

Focal drainage of serum, fibrin strands, or mucopurulent material from an incision (Fig 19), with or without fever, is evidence of incisional infection.[1] These signs can develop during hospitalization but also in the second week after surgery, when the horse is at home, and can lead to complete disruption of the skin incision (Fig 20). The mean time to incisional drainage in one study was 17 days after surgery.[17] Ultrasonography should be used for early diagnosis because it reportedly has a sensitivity of 100% and a specificity of 88% in detecting infection, which is superior to clinical judgment.[12] Ultrasonography can also be used to evaluate integrity of the infected body wall and to locate abscesses.[12,40]

The risk of incisional infection and related complications seems to be greatest in horses older than 1 year and in horses that weigh more than 300 kg.[1] In one study, the incisional complication rate was the same whether horses had a procedure that opened the intestinal lumen or a procedure that did not;[1] however, in another study, enterotomy, but not resection and

Fig 20. An infected and gaping skin incision at two weeks after repeat celiotomy. This subsequently formed a hernia.

anastomosis, was significantly associated with wound infection.[11] Other factors that have been significantly associated with increased risk of wound infection are increased fibrinogen concentration in the peritoneal fluid, use of polyglactin 910 to close the linea alba,[11] use of a far-near-near-far suture pattern in the linea alba,[2] incisional contamination in the recovery stall, high numbers of bacterial CFU obtained after anesthetic recovery, poor intraoperative drape adherence, high numbers of CFU obtained from surgery room contamination, and pre-existing dermatitis.[17] Unfortunately, isolation of bacteria from the incision at the time of closure is not useful for predicting incisional complications in horses.[17,41] There is no evidence that peritonitis can cause incisional infection and the reverse also seems to be true. Incisional infection is also common after repeat celiotomies (see above).

Treatment of infection involves removal of skin sutures to enhance drainage, and cleaning the incision as often as needed with a dilute antiseptic soap, with or without systemic antibiotics selected by culture and sensitivity testing. Empiric selection of antibiotic therapy is of questionable value, because a wide range of organisms can be cultured from infected abdominal incisions[17] and repeated contamination of the open incision could lead to changing bacterial populations. An abdominal bandage and topical antibiotics can be applied if the infection is extensive, but the bandage must be replaced frequently.

Each hospital should develop an epidemiologic profile of its incisional infections to devise a method for prevention. Based on available evidence, prevention would require an examination of suture size and material, suture pattern, colotomy techniques, recovery stall floors, and other sources of direct contamination. Other possible sources of incisional infection are suction tips[42] and cracks in visceral retainers, both of which can harbor bacteria and protect them from sterilization.

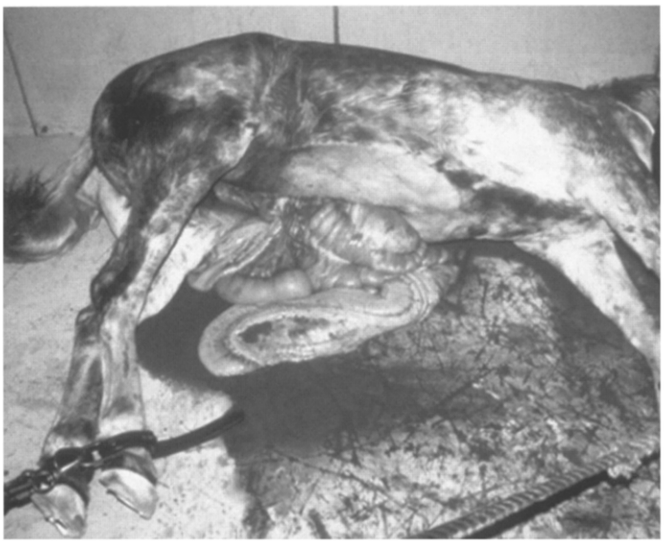

Fig 21. Evisceration in recovery stall as a result of a heavy fall as the horse stood after surgery that involved a small intestinal resection. The bowel was lavaged with sterile polyionic fluids, supported in paper drapes and replaced in the abdomen, and the abdomen closed with wire and #3 polyglactin 910 in simple interrupted patterns. This horse made a full recovery and has shown no adverse effects over a 4-year follow-up period.

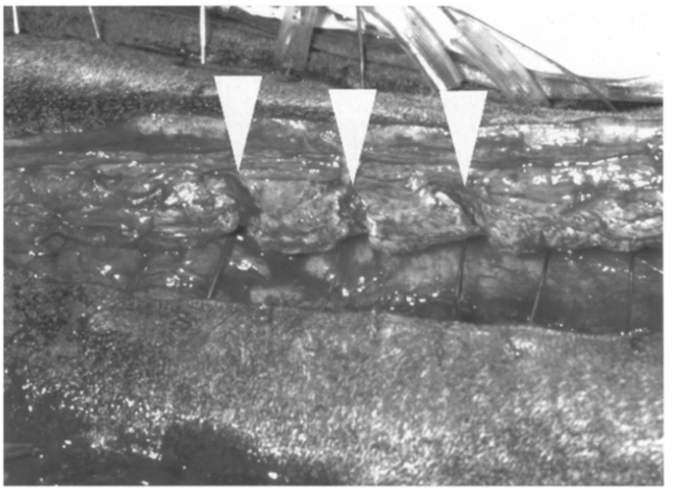

Fig 22. Closeup of the linea alba repair that completely dehisced 7 days after closure with a continuous pattern, showing where sutures tore through the linea alba (arrowheads). Wire has been placed for secondary closure.

Dehiscence of Body Wall Incision

Dehiscence of the body wall, with or without eventration, is the most serious wound complication after an exploratory celiotomy. The main reasons for wound dehiscence include loss of strength in absorbable sutures, breakage of sutures, knot failure, and tissue failure. Excessive strain on the suture line is probably the greatest cause of wound dehiscence and the strain can occur during recovery (Fig 21) or during the postoperative period, as from continued abdominal pain. Good surgical technique, decompression of all distended bowel, and smooth anesthetic recovery can reduce the risk of partial or complete wound disruption.

Severe incisional infections can delay healing and cause tissue necrosis and dehiscence in as little as 5 to 7 days after surgery.[1,2,4,5] In a study on closure of equine cadaver linea alba, all suture loops failed before fascial disruption, and 93% of suture loops failed at the knot.[14] Therefore, suture material at least as strong as normal linea alba is not available to equine surgeons,[14] and suture failure could explain disruption during anesthetic recovery. There is a trend for wound strength to decrease in the equine linea alba at 5 to 10 days after surgery, regardless of suture pattern,[29] which could explain the risk of disruption during this period. This disruption could be attributed to suture failure or to tearing of an abdominal wall that has become weaker with time from inflammation, edema, and ischemia. Although the risk of incisional dehiscence can be increased by infection, infection is not a necessary prerequisite for dehiscence. In the first author's experience, dehiscence of the linea alba repair after closure with a simple continuous pattern is usually caused by tearing of the body wall and not suture breakage (Fig 22), regardless of the interval after surgery. This is in agreement with results of clinical trials and research.[33]

Delayed disruption of a ventral midline incision (3 to 8 days after surgery) is usually preceded by copious drainage of peritoneal fluid and gap formation in the linea alba, followed by prolapse of omentum or bowel.[5] In such cases, the horse should be anesthetized, all suture material removed, and the incision repaired by secondary closure (see below). Acute dehiscence in the recovery stall is more catastrophic because there is little

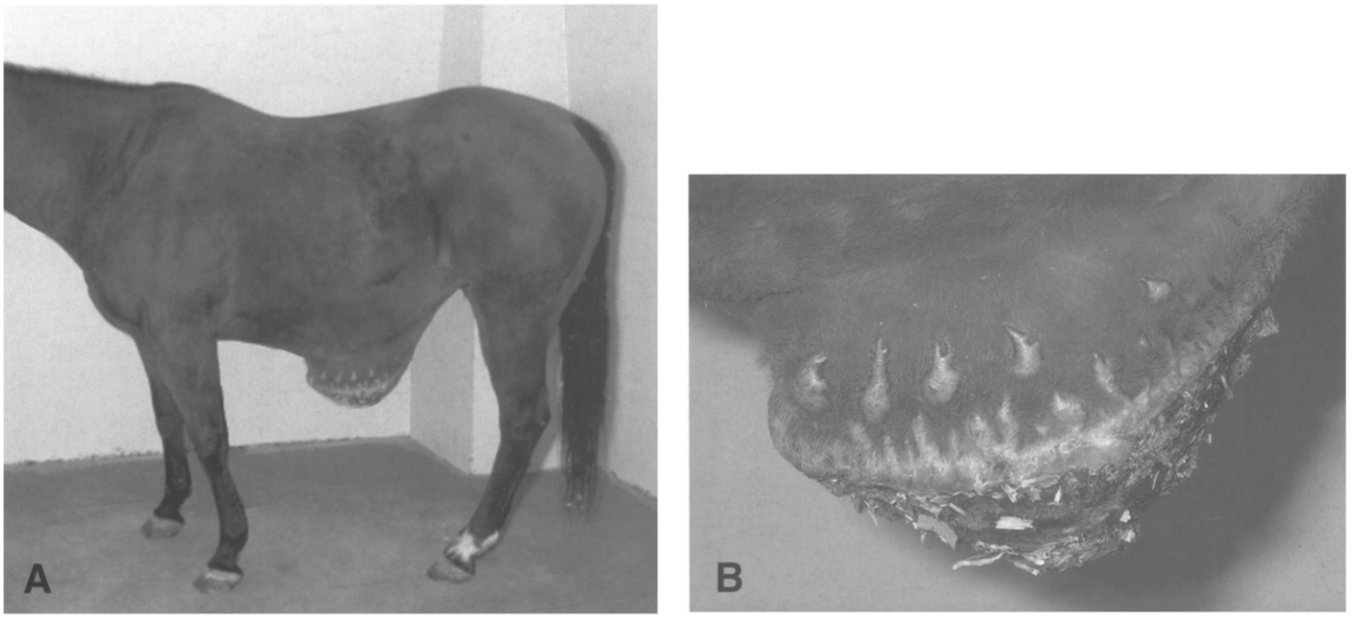

Fig 23. A and B. A large incisional hernia at 8 months after surgery for colic. This formed after a dehisced incision was repaired by secondary closure with inadequate tension and wide gaps between the vertical mattress sutures. The large keloids and raw areas on the skin would make this unsuitable for mesh herniorrhaphy.

warning, the horse is not easily controlled, and a large amount of bowel is usually prolapsed (Fig 21). This accident requires immediate immobilization of the horse and rapid induction of anesthesia, followed by lavage of the bowel, replacement in the abdomen, and repair by secondary closure[26] or another technique that supports a primary repair. The first goals are to minimize the amount of bowel prolapsed and to protect prolapsed bowel from being trod on by the horse. Speed is essential to prevent postanesthetic complications in a horse that is already compromised by its original intestinal disease, followed by 2 anesthesia periods and surgeries.

Despite the extensive contamination, intestinal bruising, and venous congestion associated with evisceration, resection is rarely needed and the prognosis for full recovery is good, provided self-inflicted trauma is prevented. Eviscerated bowel becomes hemorrhagic and even black very rapidly after evisceration, but these findings must be interpreted with regard for the pathophysiology of such changes. Unlike bowel that becomes incarcerated in a closed abdomen, eviscerated bowel is no longer exposed to intraabdominal pressure and the weight of the prolapsed bowel favors gravitational forces that impede venous drainage. Consequently, venous congestion sets in rapidly, but without any loss of viability, so the bowel can recover fully from these changes. However, extensive self-inflicted damage to bowel and disruption of mesentery can be grounds for euthanasia.

Hernia Formation

Hernias of ventral midline incisions may appear weeks to months after the initial surgery.[1,4–8,10] Although an incision can heal with scattered areas of attenuation in the body wall, these are not true hernias and can withstand full athletic activity and foaling.

Hernias develop because the linea alba does not heal and the sutures may have cut through one side or both sides of the linea alba.[7] Horses with incisional complications have an increased risk of developing hernias, especially those incisions that become infected.[1,5–7,9,10] Incisional drainage,[1,2,7] excessive edema,[7] postoperative leukopenia,[10] postoperative pain,[7] an enterotomy,[11] and repeat celiotomy through a recent incision[38,39] can predispose an incision to infection and hernia formation. Horses larger than 300 kg have a greater risk for the development of a hernia than do smaller patients.[1] Odds of incisional hernia are 62.5 times greater for horses that had incisional drainage, and incisional drainage and herniation can have a negative association with survival.[41]

Hernia repair should be postponed for approximately 3 to 4 months after the first surgery to allow inflammation and infection to fully resolve and for the hernial ring to become firm and

Fig 24. A small hernia that was not repaired but became considerably smaller and less noticeable with time (at 7 year follow-up).

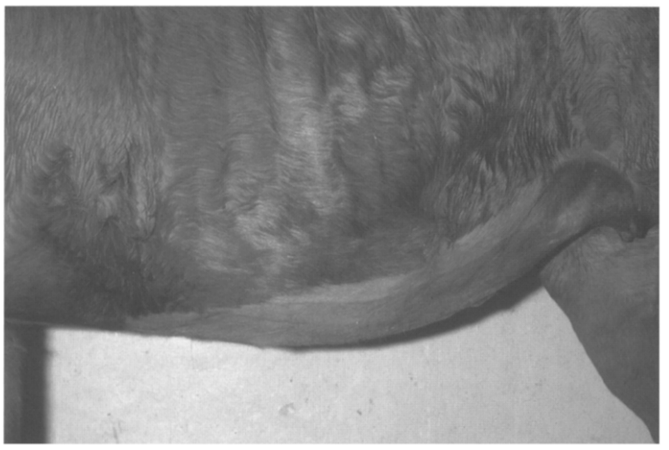

Fig 25. Same hernia as in Fig 23, at 6 weeks after repair with suture closure with FNNF and interrupted sutures of #3 polyglactin 910 with an overlay formed by the unusually dense fibrous tissue that formed the sac in this case.

well organized.[7] Timing of hernia formation in a broodmare might not allow for repair before foaling, but mares can foal uneventfully with very large hernias, that correspond in length to the original incision. However, the concern exists for conversion of this sized hernia to a more complete rupture of the abdominal wall, and assisted foaling is encouraged to reduce this risk.

Large hernias can be repaired by suture closure (Fig 23) or by mesh.[7,8] Mesh should never be placed in an infected area or even in skin with a raw defect or suspect integrity, because bacteria will become established within the interstices of the mesh, and the mesh will be rejected.[7] This will delay final resolution considerably, because mesh removal will have to be followed by sufficient time to allow the infection to resolve before final repair. One means of solving this problem is to remove the mesh and repair the wound by secondary closure.[26] Closure without mesh is preferable when possible,[7] although mesh herniorrhaphy can be very effective.[43,44] Also, some hernias can get smaller over time to reach a tolerable size that does not limit performance (Fig 24), and defects that do not alter the ventral abdominal contour usually do not need to be repaired.

With any method of repair for a ventral median incisional hernia, the skin and subcutis can be incised in a semicircle around one edge of the ring to create a flap that can be trimmed of redundant skin later. This flap can be drawn over the final body wall repair to protect it with an intact tissue layer. Hemostasis should be established by cautery during dissection. The goal of dissection is to expose the edges of the ring, which can be irregular and attenuated in areas where sutures tore through, and separate it from the underlying retroperitoneal fat and peritoneum. The latter step can be accomplished with finger dissection to create a 3 to 4 cm deep shelf for the mesh, and inadvertent penetration of the peritoneum is likely during this step because it is usually so close to the fascial layer of the sac. Peritoneal puncture is usually of no consequence, adhesions to underlying viscera are rare, and peritoneal closure is rarely necessary.

Mesh is usually placed between the internal sheath of the rectus muscle and the peritoneum as a single sheet, although a doubled application has been described.[43] Mesh placement between skin and body wall has the disadvantage of allowing little soft tissue protection of the mesh in such a superficial location. Mesh edges are folded on themselves for 3 to 4 cm to reinforce the point of suture purchase, and the edges of the mesh are placed ventrally, toward the fascia. Sutures can be preplaced in horizontal mattress fashion with bites of 2 to 2.5 cm wide on one side of the mesh to facilitate placement along one side of the ring. The mesh should overlap the ring so that sutures are approximately 2-cm lateral to the edge, and the mesh should be placed under even tension to reduce the size of the defect and to prevent subsequent sagging. The size of the ring can be reduced by tension on the mesh to the point that suture apposition of the commissures is possible.[44] Some sutures can be preplaced to facilitate inclusion of the mesh in the last few sutures. Care must be taken not to tear the mesh, because small intestine can become strangulated in such tears, and all fibrous layers that can be identified superficial to the mesh should be closed. If possible, a flap of hernial sac fascia should be laid over the mesh to protect it, strengthen the repair, and reduce swelling. An abdominal bandage should be applied to reduce postoperative swelling.

Materials used for mesh herniorrhaphy in horses[43,44] are polypropylene (Prolene®, Ethicon, Somerville, NJ, USA; and Marlex®, C R Bard, Inc, Murray Hill, NJ, USA) and the less available woven plastic (Proxplast®, Goshen Laboratories, Goshen, NY, USA). Compared with polypropylene, the plastic mesh is less expensive and less elastic, a property that reduces abdominal wall sagging.[43,45] However, its edges tend to unravel. Complications of mesh herniorrhaphy are drainage/infection and, rarely, peritoneal adhesions and bowel abrasion. Absorbable mesh materials (Vicryl woven or knitted mesh, Ethicon, Somerville, NJ, USA) and porcine small-intestinal submucosa

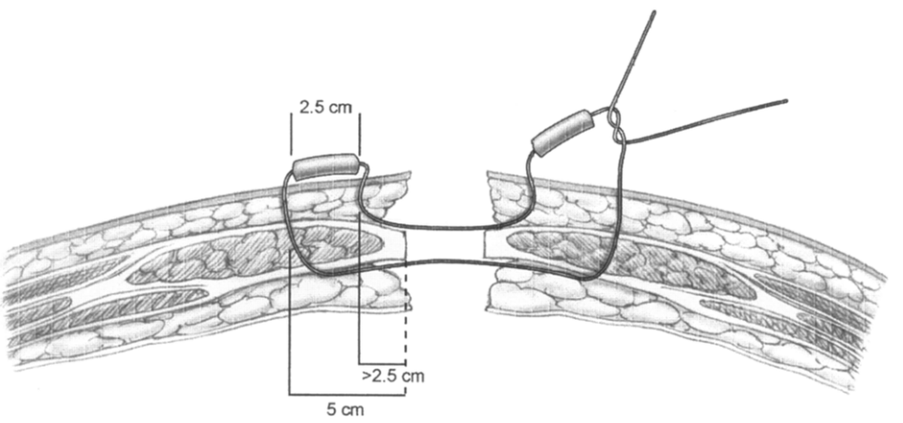

Fig 26. 2 to 6. Method of suture placement for a secondary closure.

(Surgisis®, Cook Surgical, Bloomington, IN, USA) could find applications as temporary scaffolds in equine herniorrhaphy.[45,46] Most large-size nonabsorbable suture materials are suitable for mesh attachment.

Large incisional hernias can be closed by direct suture repair without mesh, depending on surgeon preference, thickness of the hernial ring, and chances of apposition with acceptable tension. Techniques used for this purpose are interrupted mattress, NFFN, and simple interrupted patterns, as well as secondary closure techniques.[8] Another technique is to appose the ring edges by 2 surgeons working simultaneously from opposite sides of the horse, each alternating bites to form a continuous crossing pattern.[7] If the hernia has developed an indurated sac (Fig 23), a crescent-shaped flap of this subcutaneous tissue can be preserved as an onlay graft to cover the repair (Fig 25). All these direct hernial repairs can be performed with an absorbable material, either size #2 or #3, and some attempts should be made to freshen the ring edges before apposition. Dissection and preparation of the hernial ring is the same as described for mesh herniorrhaphy.

The success of any technique for repair of a large hernia can be influenced by preoperative diet, such as 7 to 14 days' on Equine Senior® (Purina Mills) or a similar all pellet, low bulk diet, to reduce intestinal fill. The horse can be starved for 12 to 24 hours before surgery and slowly reintroduced to the same diet for 7 days after surgery, to be continued for another 14 days. Some horses have low-grade abdominal pain for 24 hours after herniorrhaphy, and require analgesics. Management also includes perioperative antibiotics and stall confinement for at least 6 to 8 weeks after surgery before turnout in a small paddock for the same period.

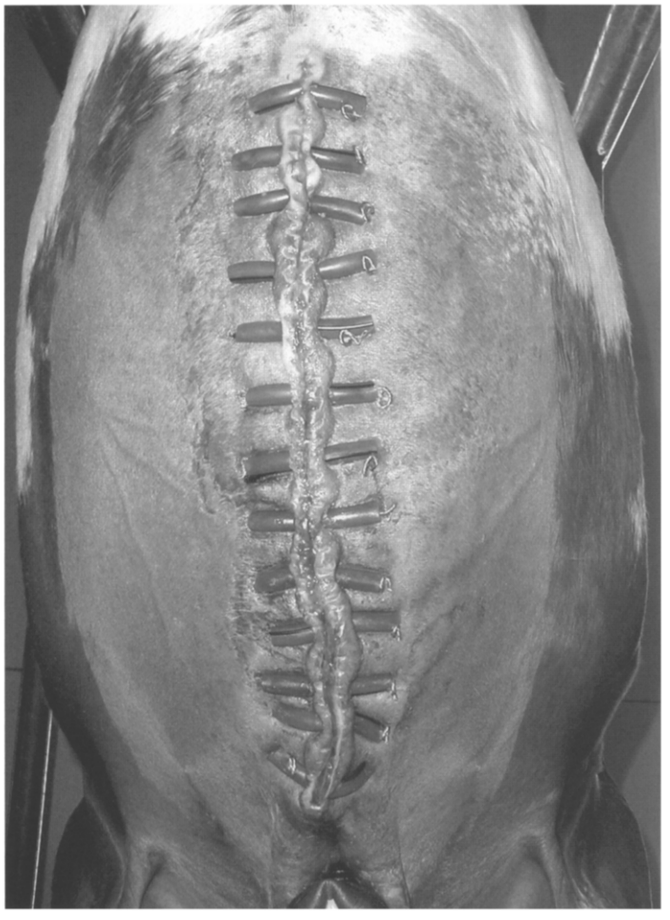

Fig 27. Secondary closure with wire on day after surgery. Note spacing of the sutures and the large and thick tubing used for bolsters.

Fig 28. Same horse as in Fig 27 at 3 weeks after surgery, when some of the wires have been removed. Note healthy granulating wound and that some of the wires and bolsters have pulled through.

Secondary Closure

Secondary closure of an equine linea alba can be used to repair wounds with infection, wound dehiscence, and necrosis, or to correct infected hernias.[26] All existing suture is removed and the tissue edges debrided by sharp dissection and abrasion with a saline-soaked sponge. Retention sutures of 18 gauge stainless steel wire are preplaced in vertical mattress fashion with a large cutting needle so that each suture spans a bite 5 cm from the skin edge through the full thickness of the body wall (excluding retroperitoneal fat) and then is passed through skin and subcutis at 2.5 cm from the skin edge (Figs 26 and 27). To protect the skin, the wire is passed through hard and thick plastic or rubber tubing (stomach tube or thick suction tube) cut to a length of 2.5 cm, and the suture knot is placed at the end of the tubing furthest from the incision (Figs 26 and 27), where it can be subsequently located for removal. Silicone rubber or fine plastic tubing should not be used, because these will allow premature recession of the wire into the skin and rapid loss of tension. The retention sutures are spaced 2.5 cm apart and then the ends are twisted down securely to produce eversion of skin and subcutis for ventral drainage (Fig 27). It is essential that, as the wires are tightened, all the slack is taken out of the deep component so it cannot form a loop to ensnare small intestine. Once the twist is

secure, the wire is cut to leave 1 to 1.5 cm of the twist, which is then coiled so the sharp ends turn into the tubing.

The sutures and bolsters should be removed in approximately 3 to 5 weeks, by which time most sutures are loose and no longer effective (Fig 28). Removal can be staged so that some sutures that appear functional are left in place as long as possible. Ultrasound can aid in the location of bolsters because some can become embedded in granulation tissue and are not visible. The tissue reaction around the tubing usually resolves after removal and after local wound care.[26] Although this procedure exposes infected tissue to the abdominal cavity, peritonitis does not ensue. The first author has experienced a high prevalence of hernia formation with this procedure, that could be prevented by placing bites further from the wound edge (Fischer AT, personal communication), or by looser placement.

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