Key Points

- Postoperative abdominal adhesions in foals continue to be a source of frustration to surgeons.
- An emphasis should be placed on adhesion prevention because treatment of adhesions once they have formed is unrewarding, costly, and associated with high patient morbidity and mortality.
- Atraumatic surgical technique and a number of pharmacologic agents and devices have demonstrated efficacy in minimizing the incidence of postoperative adhesion formation.

Despite considerable efforts to understand the formation and prevention of postoperative abdominal adhesions, adhesions continue to present clinical complications and challenges to the surgeon. This is especially true when dealing with foals. The thin, delicate nature of the intestinal serosa and mesentery, along with an increased propensity for peritoneal healing or “over-healing” may make foals more susceptible to adhesion formation. Depending on the location and organization of the adhesion, and age and diet of the foal, adhesions may remain clinically “silent” or cause clinical complications. Fibrinous and omental adhesions are a normal response to peritoneal injury and inflammation and rarely cause clinical signs.

Adhesions become a clinical problem when fibrinous adhesions mature to restrictive fibrous adhesions that compress or anatomically distort the intestine, narrowing the intestinal lumen and impeding the normal passage of ingesta.

Pathophysiology of Adhesion Formation

Peritoneum covers the interior of the abdominal cavity (parietal peritoneum) and the visceral organs (visceral peritoneum). It is composed of loose connective tissue beneath a single layer of mesothelial cells, separated by a basement membrane. These layers provide external support to the muscular layer of the intestine as well as maintain a lubricating layer at the serosal surface. Injury or inflammation of the peritoneal mesothelium initiates adhesion formation by stimulating an immediate procoagulative state characterized by secretion of serofibrinous exudate and deposition of fibrin. This results in a fibrin matrix that forms fibrinous adhesions between adjacent viscera or peritoneum within one-to-two hours of injury. The purpose of this initial fibrin matrix is to provide restoration of tissue integrity by providing a scaffold for vascular and cellular migration. As normal peritoneal healing progresses, fibroblasts and endothelia cells migrate into the fibrin and form a layer of granulation tissue in the original mesothelial defect. Primordial mesenchymal cells form fibroblasts or differentiate into mesothelial cells and cover the granulation tissue.

Several complex biological processes have been identified in the pathogenesis of adhesion formation including coagulation, fibrinolysis, kinin/bradykinin, arachidonic acid metabolism, and complement. The fibrinolytic system is the principal modulator of adhesion formation and involves the lysis of fibrin into fibrin degradation products through the action of the enzyme plasmin. Plasmin is stored as the inactive substrate plasminogen, which is converted to the active form primarily by tissue plasminogen activator (tPA), and to a lesser extent,
urokinase-type plasminogen activator (u-PA). Tissue plasminogen activator is present in virtually all tissues and is responsible for 95% of plasmin generation.

Fibrinolysis is a very potent process and tightly regulated by plasminogen activator inhibitors type 1 (PAI-1) and type 2 (PAI-2) which are induced by stimuli such as trauma, infection, or endotoxin. The inhibitors bind and form inactive complexes with tPA and uPA. Depressed plasminogen activator activity may result from decreased concentrations of plasminogen activators, and/or increased expression of plasminogen activator inhibitors.

The distinction between normal peritoneal healing and adhesion formation lies in the balance of fibrin deposition and degradation. Under normal conditions, local peritoneal fibrinolytic activity causes lysis of the fibrin and fibrinous adhesions within 48 to 72 hours and adhesions are resolved before fibrous maturation occurs. However, intestinal ischemia or inflammation from strangulation or distention, or surgical manipulation and the corresponding incidental trauma may prolong the inflammatory process and depress peritoneal fibrinolytic activity, thereby, predisposing to the persistence of intra-abdominal fibrin and the development of permanent fibrous adhesions. Correspondingly, exploratory celiotomy and intestinal manipulation in horses has been associated with significant decreases in peritoneum tPA activity 60 and 90 minutes after the start of surgery.1

Prevention of Adhesion Formation

An emphasis should be placed on prevention of adhesion formation, because treatment of adhesions after they have formed is unrewarding, costly, and associated with high patient morbidity and mortality. The primary objectives in preventing adhesions are to: 1) minimize peritoneal and serosal inflammation, 2) maintain or enhance peritoneal fibrinolysis 3) mechanically separate potentially adhesiogenic surfaces, and 4) stimulate adequate intestinal motility. Perioperative administration of broad-spectrum antimicrobials, NSAIDS, and dimethyl sulfoxide (DMSO) has been demonstrated to minimize peritoneal inflammation and ischemia-induced postoperative adhesion formation associated with abdominal surgery in foals.2 These medications are routinely administered to foals undergoing abdominal exploratory surgery.

The most important principal in adhesion prevention is meticulous aseptic and atraumatic surgical technique. This is of particular importance when dealing with foals because of their delicate, thin, intestinal serosa and mesentery, which is prone to tearing during normal manipulation (Fig 1).
Figure 1. Intra-operative photograph of tear in the jejunal mesentery that occurred during correction of a small intestinal volvulus in a foal.

Therefore in foals, it is especially important to limit handling of the intestine to only those instances when it is absolutely necessary. Strict adherence to Halsted’s principles of surgery, including minimal and atraumatic tissue handling, meticulous hemostasis, minimizing tissue contamination from exposed bacterial laden mucosa, minimizing exposure of foreign materials, and short surgery time are all essential to minimize the incidence of postoperative adhesion formation. Starch powder used on commercially available surgical gloves has been shown to incite peritoneal inflammation and significantly increases adhesion formation in a dose-dependent manner. Simple rinsing of the gloves before surgery does not effectively remove the starch powder. Therefore, powder-free, hydrogel coated gloves (Biogel Powder Free Surgical Gloves, Regent Medical, Norcross, GA) should be utilized for intra-abdominal procedures in foals.

Serosal surfaces should be kept moist with balanced electrolyte solutions to prevent direct mesothelial damage from desiccation. Protective coating solutions such as 1% sodium carboxymethylcellulose (SCMC) or 0.4% hyaluronate solution (see protective coating solutions) should be applied to serosal surfaces and the surgeon’s gloved hands before and during intestinal manipulation to provide a protective lubricating barrier and minimize serosal friction, abrasion, and incidental surgical trauma. Potentially adhesiogenic tissues such as devitalized intestine, or intestine of questionable viability should be removed. Inverting or appositional suture patterns that minimize exposure of bacteria-laden mucosa and suture should be utilized. Early return to enteral feeding is important to promote and maintain intestinal motility and function, thereby, minimizing adhesion formation between adjacent stagnant serosal surfaces.

Protective Tissue Coating Solutions: One approach to preventing adhesions is to reduce the extent and severity of unintentional tissue damage that occurs during surgery by precoating tissues with protective lubricating barrier solutions. Precoating visceral tissues involves manual application of these solutions to the serosal surface before manipulation, and is more effective at reducing adhesion formation than intraperitoneal administration of the solutions at the end of surgery, after tissue damage has already occurred. Additionally, these solutions provide a mechanical lubricating barrier between serosal and peritoneal surfaces, preventing the formation of adhesions in the early postoperative healing period. Protective tissue coating solutions commonly used in equine abdominal surgery are high-molecular weight viscous polymer solutions such as 1% sodium carboxymethylcellulose (SCMC), and 0.4% sodium hyaluronate solution. Administration of SCMC has been shown to prevent the reformation of adhesions after surgical lysis in laboratory animals. Studies in our laboratory have demonstrated that intraperitoneal SCMC significantly decreases experimentally induced adhesion formation in horses without adversely effecting intestinal healing. Based on our previous experience, and experimental studies, we presently recommend using 5-7 ml/kg of 1% SCMC solution (250-350-ml per 50-kg foal). The solution is applied to the surgeon’s gloved hands and serosal surface of the intestine at the start of surgery. The solution is reapplied as necessary to keep the intestinal and peritoneal surfaces well lubricated, thereby minimizing incidental serosal trauma. The SCMC solution does not support bacterial growth and is removed from the abdomen by peritoneal macrophages within 4-7 days after administration. Doses exceeding 7 ml/kg may result in lethargy and fever in the immediate postoperative period (2-5 days).

A 1% w/w solution of SCMC is prepared by adding boiling, sterile water to 10 g of SCMC powder (Aqualon Co., Wilmington, DE) to bring the total volume to 1 L. Cold filtering
of the SCMC through a 143 um filter increases the viscosity of the solution, but is extremely tedious and not performed in our hospital. The SCMC solution is then transferred into 0.5-1L-glass bottles and autoclaved at 121 °C for 20 minutes. The shelf life is 60 days.

Sodium hyaluronate, a naturally occurring hydrophilic polymer has proven effective in reducing postoperative adhesions after abdominal surgery. Sodium hyaluronate prevents adhesions primarily by forming a protective lubricating barrier on the intestinal serosal surface, much like SCMC, preventing abrasive manipulative trauma and desiccation, and preserving the integrity of the mesothelium. Concentrations of 0.4% sodium hyaluronate have been shown to maximally inhibit adhesion formation. The 0.4% sodium hyaluronate solution is resorbed from the peritoneal cavity and excreted within 5 days of administration.

An additional benefit of sodium hyaluronate solutions over SCMC may be chemical modulation of adhesion formation by increasing tPA concentrations at the visceral peritoneal surface and promoting mesothelial fibrinolysis. This pro-fibrinolytic effect is attributed to preservation of mesothelial cell layer integrity during intestinal manipulation, thereby, minimizing the release of tPA from the visceral peritoneum. Additionally, more recent in vitro studies demonstrated that sodium hyaluronate also enhances the fibrinolytic response of human mesothelial cells exposed to tumor necrosis factor-α by decreasing plasminogen activator inhibitor transcription and release. Irrespectively, the result is dissolution of early fibrinous adhesions before they become organized, irreversible, fibrous adhesions.

We have demonstrated that a 0.4% HA solution (SepraCoat, Genzyme, Cambridge MA) significantly decreases the incidence and severity of experimentally induced intra-abdominal adhesions in horses without adversely effecting jejunal anastomotic healing. Unfortunately, cost effective commercial preparations of sodium hyaluronate in sufficient volumes are not presently available.

Post-operative abdominal lavage is advocated to separate serosal surfaces and remove blood, peritoneal fibrin and inflammatory mediators from the peritoneal cavity during early peritoneal healing. We use postoperative abdominal lavage in adult horses that are at an extremely high risk of adhesion formation (severe, diffuse peritoneal inflammation and/or potential intraoperative bacterial contamination). Heparin sulfate (30,000–50, 000 I.U./10L LRS) is routinely added to the lavage fluid. The small size of the foal peritoneal cavity allows for a thorough intra-abdominal lavage at the end of surgery, thus post-operative lavage is not routinely performed.

Fucoidans (Peridan™, Bioniche Animal Health, Belleville, Ontario, Canada) are broad molecular weight sulfated polysaccharides that are extracted from the extra-cellular matrix of various brown seaweeds. Fucoidan extracts have been shown to posses a variety of biological properties including anti-adhesive, anti-coagulative, and anti-inflammatory effects through interactions with thrombin, anti-thrombi III, heparin cofactor and leukocyte membrane receptors. In studies in laboratory animals and pony foals, intra-peritoneal administration of fucoidan solution prior to abdominal closure demonstrated safety and efficacy in minimizing the number and severity of experimentally induced postoperative adhesions. Safety has also been demonstrated in a small intestinal resection and anastomosis model in adult horses. For foals, Fucoidan is commercially available as a 5% fucoidan solution in single use 5 ml vials. The 5 ml vial is diluted in 1L of Lactate Ringers solution (.25 g fucoidan/L) and dispensed directly into the peritoneal cavity (1L/50 kg foal) at the end of surgery.

Resorbable Barrier Substances: Various resorbable barrier materials have been evaluated in laboratory animal adhesion models. Such material include oxidized regenerated
cellulose (Interceed TC-7), expanded polytetrafluoroethylene (Gor-Tex Surgica Membrane), synthetic biodegradable polymers, fibrin glue (Tissucol), and a bioresorbable hyaluronate-carboxymethylcellulose membrane (Seprafilm®, Genzyme, Cambridge Mass). These barrier agents are available in small sheets ideally suited for use in foals because of their relatively small peritoneal cavity as compared to the adult horse. The ideal barrier substance should effectively prevent adhesion formation, have a high biocompatibility, be resorbable, be effective on oozing surfaces, be applicable through a laparoscope, and cost-effective. As of yet, the ideal barrier substance does not exist, however, the barrier substance that has received the most attention and use in equine surgery is a bioresorbable hyaluronate-carboxymethylcellulose membrane (HA-membrane).

The flexible HA-membrane is applied to the serosal surface of the intestine or parietal peritoneum, forming a temporary protective barrier against serosal-serosal or serosal-peritoneal adhesion formation during early postoperative healing. Following application the membrane hydrates to a gel that adheres to tissues and most surfaces. It remains at the site of application for up to 7 days to separate adhesiogenic surfaces and is then cleared from the abdominal cavity by peritoneal macrophages. The HA-membrane has been shown to significantly reduce postoperative adhesion formation in horses with no adverse effects on intestinal or peritoneal healing.

The HA-membrane is used as an adjuvant in abdominal surgery for reducing the incidence, extent, and severity of postoperative adhesions at the site of placement. The surgical lesion is addressed and corrected and HA-membranes applied to potentially adhesiogenic surfaces just prior to abdominal closure. For optimal results, the desired site of application should be dry and free of blood or debris. The site is elevated and exteriorized from the abdominal cavity and held by an assistant. Any excess fluid is thoroughly aspirated and the intestinal serosal surface and adjacent mesentery are gently patted dry with dry 4x4’s or laparotomy sponges.

We routinely use one-to-two 12-cm x 15-cm HA-membranes in areas of localized serosal or peritoneal trauma that are at an increased risk of postoperative adhesion formation. The individual sheets may be trimmed to more closely conform to various visceral surfaces. Such areas would include focal areas of intestinal inflammation, segments of intestine that have been vascularly compromised, but deemed viable by subjective or objective measures, and focal adhesion formation in which adhesiolysis was subsequently performed.

Treating Adhesions

When recurrent colic or a complete intestinal obstruction results from adhesion formation, surgical intervention is necessary. There are a variety of surgical options at the surgeon’s disposal. A traditional ventral midline celiotomy may be used to perform a complete exploratory of the abdomen. Adhesions are identified, determined if they are the inciting reason for the obstruction or clinical problem, and if necessary manually broken down or transected (adhesiolysis). The method and extent of adhesiolysis is largely dictated by the location of the adhesion within the abdomen and the associated vascular supply. Relatively avascular, focal, small adhesions may be sharply transected. More vascular adhesions require careful dissection and fastidious hemostasis. Electrical vessel sealing devices (Ligasure®, Covidien, Mansfield, MA) have proven to be especially helpful for dividing adhesions while providing excellent hemostasis. However, caution must be used when using these devices in close proximity to visceral or parietal serosal surfaces in order to avoid secondary thermal damage to adjacent
tissues and increasing the likelihood of de novo adhesions. Sharp transection is less traumatic to tissues than either blunt dissection, manually breaking down of the adhesions, or division with electrocautery or thermal ligating devices. Therefore, whenever possible, every effort should be made to sharply transect, rather than tear apart mature, fibrous adhesions. An unfortunate sequela to celiotomy and subsequent adhesiolysis is the inherent peritoneal and serosal inflammation and tissue trauma that results (Fig. 2), increasing the likelihood of recurring adhesion formation.

Figure 2. Intra-operative photograph of a fibrous adhesion between the jejunum and left dorsal colon after adhesiolysis. The resultant serosal inflammation and hemorrhage may serve as a nidus for future de novo adhesion formation.

In many circumstances, adhesions reform shortly after surgery. In an effort to decrease the amount of tissue trauma caused by celiotomy and adhesiolysis, several reports of laparoscopic or laparoscopic assisted adhesiolysis have been described. Intra-abdominal adhesions were once considered a contraindication for laparoscopy due to an increased risk of inadvertently penetrating a viscus. However with careful preoperative examination and cautious insertion of the laparoscopic cannulas, this risk can be minimized. In an experimental rabbit model, laparoscopic adhesiolysis was associated with significantly less adhesion reformation as compared to adhesiolysis via conventional celiotomy. The combination of being minimally invasive and allowing visualization of areas of the abdominal cavity that are impossible to see with traditional midline celiotomy has made laparoscopic adhesiolysis a very useful modality in equine surgery.

Another approach that has been successfully used to manage adhesion formation is leaving mature adhesions and the affected segment(s) of intestine in situ and performing an incomplete by-pass procedure via an anastomosis between loops of intestine proximal and distal to the site of obstruction. This technique has the benefit of minimizing the tissue injury and inflammation associated with adhesiolysis that may serve as a nidus for de novo adhesion formation. A decision must be made with each individual foal as to which procedure poses the least short and long-term morbidity and/or mortality to the patient. In a foal with extensive adhesions in an inaccessible portion of the abdomen it may be less traumatic to bypass the adhesion and obstruction rather than attempt extensive adhesiolysis. However if a focal,
surgically accessible adhesion is identified, it may be faster and less traumatic to simply transect the adhesion. In these cases, it is optimal to cover the area in which adhesiolysis was performed with a temporary biodegradable barrier (Seprafilm®) or a high molecular weight viscous solution such as 1% sodium carboxymethylcellulose in an attempt to further minimize adhesion recurrence.

Prognosis

The prognosis for foals undergoing abdominal surgery largely depends on the primary lesion. In one retrospective study, foals with a simple intestinal obstruction requiring only intestinal manipulation were reported to have a significantly higher long-term survival (84%) than those with strangulating obstruction requiring resection and anastomosis (43%). In foals with surgical colic, 10% of foals under 14 days survived to maturity compared with 46% of foals 15 to 150 days old. Although foals are considered to be especially prone to adhesion formation, retrospective reports are controversial. In one study, 33% of foals examined at a second surgery or post-mortem examination had evidence of intra-abdominal adhesions, with 16% resulting in clinical symptoms. However, another study evaluating survival and racing performance in Thoroughbreds that had undergone colic surgery as juveniles reported an 8% incidence of postoperative adhesions, a percentage similar to that reported for adult horses. In my experience and similar to previous reports, younger foals especially those less than 4 weeks of age appear to be more likely to develop postoperative adhesions that cause significant clinical complications.

References


