FELINE ABDOMINAL CAVITY. HERNIAS 20

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Introduction

The **abdomen** is the cavity between a cat's **thorax** and its **pelvis**. Its interior is lined by the **peritoneum**, a serous membrane that itself forms a parallel cavity. It is composed of a layer of flat mesothelial cells over a basement membrane. The mesothelial cells of the peritoneum produce a surfactant that acts as a lubricant and facilitates mobility of the abdominal contents. The basement membrane is made up of fibroelastic tissue that contains macrophages, mast cells, lymphocytes and glycosylated proteins over a network of elastic fibers. This membrane is not present in diaphragm, omentum and mesentery areas, leading to spaces between the mesothelial cells. These mesothelial cells are in direct contact with lymphatic channels, which absorb fluids and material, especially in the diaphragm.

The peritoneum is divided into:

- **Parietal peritoneum:** covers the abdominal wall and the diaphragm.
- **Visceral peritoneum:** contains the stomach, liver, intestines, spleen, uterus and ovaries (in females), part of the bladder, as well as numerous lymph nodes and a complex network of blood vessels, lymph vessels and nerves.

Also found in the abdomen is the **retroperitoneal space**, which contains the organs that rest on the abdominal wall or the pelvic cavity and which are only covered by peritoneum on one surface. These are the kidneys, ureters, adrenal glands, the aorta and its major branches, most of the vena cava, the sublumbar lymph nodes (external and internal iliac node and coccygeal node), prostate (in males), most of the rectum, the urethra, the vagina (in females) and variable parts of the bladder.

Highly important for the surgeon, the abdomen also contains the **epiploon or omentum**, a mesenteric structure that lies between the stomach and the intestines (Fig. 1). It is composed of:

- **Greater omentum:** comprises the visceral and parietal layers. Each of these layers, in turn, is composed of two peritoneal sheets. Between these sheets is a complex network of blood and lymphatic vessels surrounded by adipose tissue, giving them a mesh-like appearance. The visceral layer of the greater omentum originates with the transverse mesocolon from the dorsal abdominal wall and extends caudally, covering the ventrolateral aspect of the small intestine. At the pelvic inlet, it folds back on itself to form the parietal layer of the greater omentum, which is adjacent to the ventrolateral abdominal wall, continues cranially and inserts on the greater curvature of the stomach. The potential space between the visceral and parietal layers of the omentum is called the omental bursa. The left lobe of the pancreas is found between the sheets of the visceral layer of the greater omentum, adjacent to the dorsal aspect of the stomach, and the spleen is found between the sheets of the parietal layer of the greater omentum.
- **Lesser omentum:** the stomach is located between the two layers of the greater omentum, which converge at the lesser curvature of the stomach to form the lesser omentum.

The crucial function of the omentum is to protect the cavity from infection and inflammation. It also encourages healing since it promotes angiogenesis, improves immune function and acts to drain the accumulation of fluid in the tissues. It helps isolate and seal the source of an infection by forming omental adhesions. Present on it are aggregates of cells known as milky spots, which are a source of neutrophils, macrophages and lymphocytes. These milky spots are an important component of this protective function. In medical practice, the omentum is used autologously for wound drainage (e.g., abscesses in the abdominal cavity), as an adjuvant for healing around sutures in enterotomies, and even for drainage in flaps outside the abdominal cavity. The only limitation of these uses is that the availability of omentum depends on its distance from the wound.

Another organ located in the abdominal cavity is the **mesentery**. All the abdominal digestive organs lie on or in it. It consists of a set of tissues that maintain the digestive organs in their place, seamlessly arranged among other systems found in the

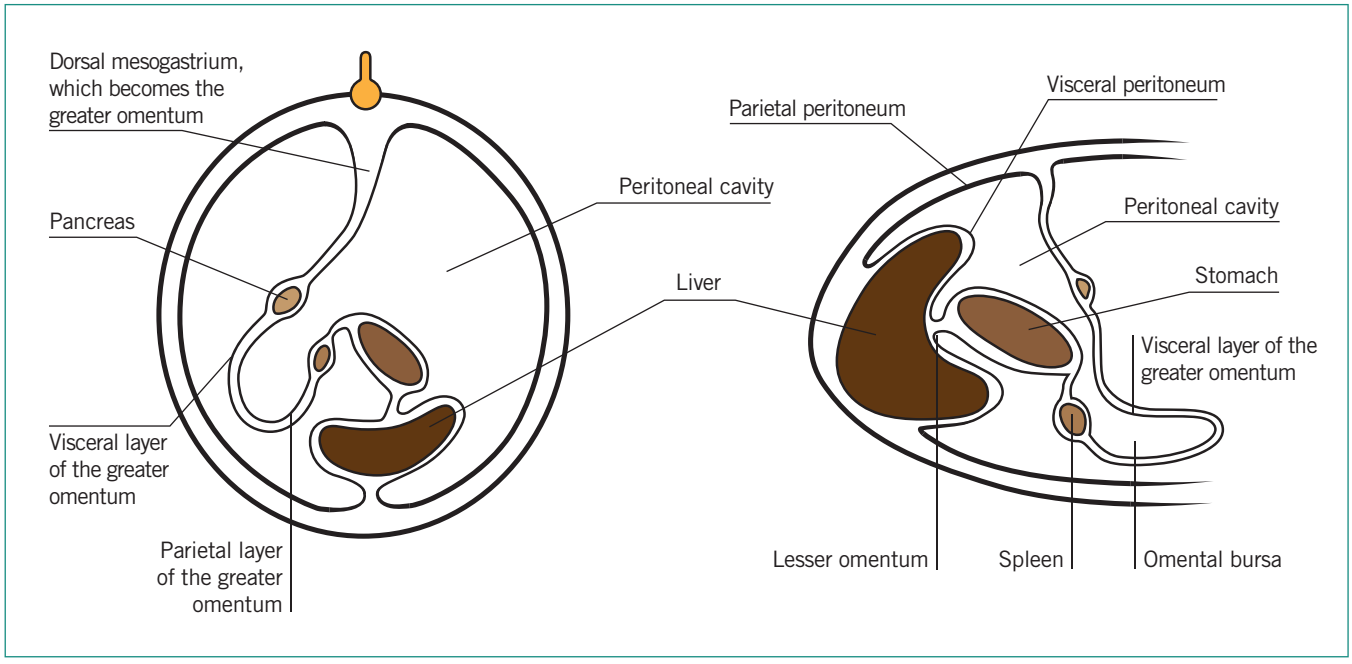

FIGURE 1. Relationship between the peritoneum and some structures of the abdominal cavity over the course of development.

abdomen. It continues uninterrupted from the esophagogastric junction to the anorectal junction. Its function is protective, activating an immune response when faced with bacterial translocation. More and more importance is being attributed to it in human medicine due to this immune response. Changes in its immune regulation is closely associated with Crohn's disease.

From a surgical perspective, detailed knowledge of all the structures of the abdominal cavity is very important, given that we may have to access it for a wide range of reasons using various approaches.

Anatomy of the abdominal cavity

The **vertebral column** and the **psoas muscles** (group of sublumbar muscles) form the dorsal boundary of the abdominal cavity. The **diaphragm** makes up the cranial boundary, the **abdominal walls** make up the lateral and ventral sides, and the pelvis constitutes its caudal wall.

The **diaphragm** (Fig. 2) projects over the abdominal cavity in the shape of a dome. It is made up of an **external muscular part**, which, in contrast to the abdominal wall, is only composed of one layer (which makes it weaker). This muscular portion of the diaphragm consists of a lumbar part, a costal part on each side, and a sternal part (attached to the sternum). The lumbar part, in turn, is composed of the right and left **diaphragmatic crura**, the right crus being larger than the left. The costal and sternal parts measure 2–3 mm in thickness, while the medial zone of the lumbar part measures 3–4 mm. Viewed from the abdominal cavity, the diaphragmatic crura are in the shape of two triangles. Fibers radiate from the muscular part of the diaphragm (lumbar and costal) towards the **central tendon**, which is relatively small in cats. The costal part of the diaphragm is attached to the internal surface of the last ribs, and the dome of the diaphragm originates in the caudal region of the thoracic cavity. There are three natural openings:

- **The esophageal hiatus**, through which the esophagus, vagal trunks, and esophageal vessels pass.
- **The caval hiatus**, through which the caudal vena cava passes.
- **The aortic hiatus**, through which the aorta, the thoracic duct, and the azygos and hemiazygos veins pass.

Dorsal to the diaphragm and ventral to the psoas muscles are also two linear openings on each side. Only a fascia separates thorax from abdomen in these openings. The splanchnic nerves and the sympathetic trunks enter the abdominal cavity through them. In this area, conditions affecting one cavity can pass into the other, without there being any tears in the diaphragm. Ligaments connect the stomach and the liver to the peritoneum, which covers the abdominal aspect of the diaphragm.

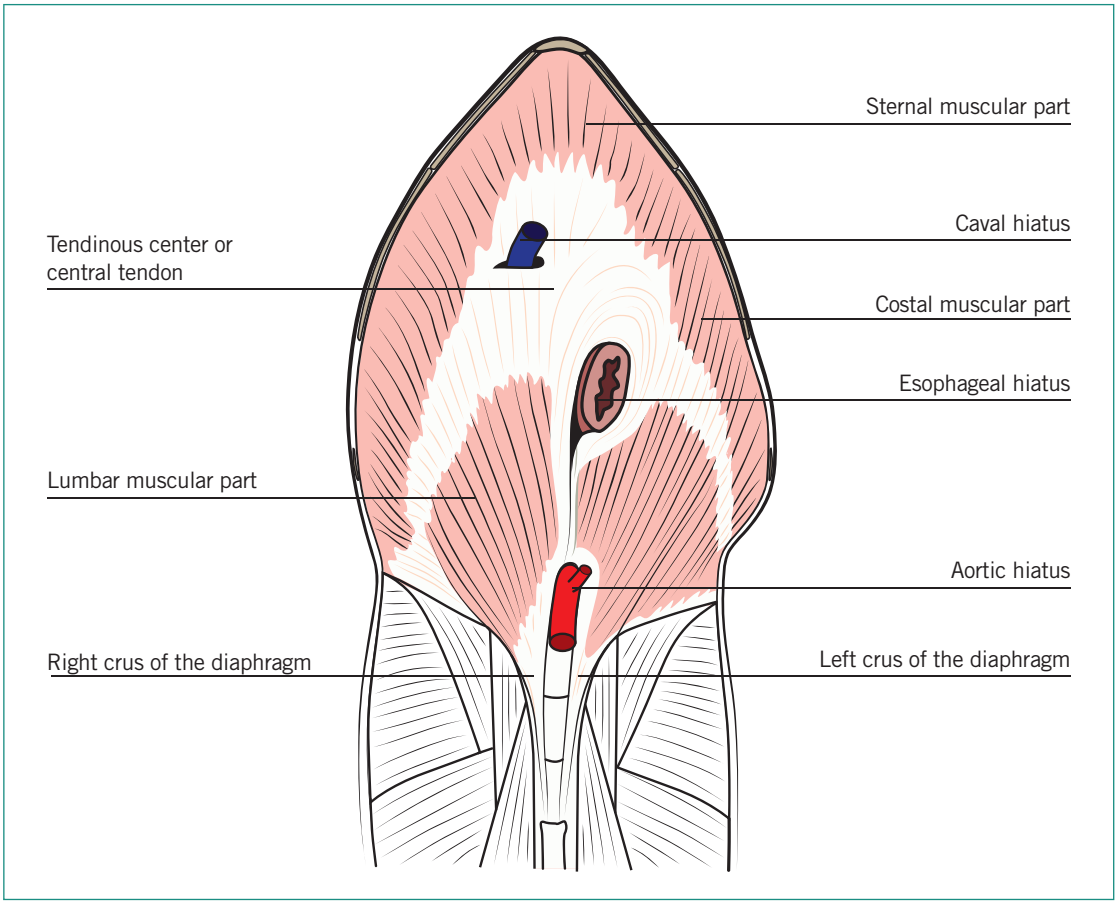

FIGURE 2. Structure of the diaphragm.

The **abdominal walls** delimit the abdominal cavity laterally and ventrally. They support most of the weight of the viscera. They are composed of the abdominal muscles, which are arranged in three layers superimposed upon each other and with their muscle fibers in contrasting orientation (Fig. 3):

- The **external oblique muscle** (fibers in a caudoventral direction) also covers a significant portion of the costal arch.
- The **internal oblique muscle** (fibers in a cranioventral direction) originates mainly in the coxal tuberosity and its caudal margin is free.
- The **transverse abdominal muscle** (fibers in a dorsoventral direction) originates on the internal surface of the last ribs and the transverse processes of the lumbar vertebrae.
- The **rectus abdominis muscle** (fibers in a craniocaudal direction) also covers the caudal portion of the sternum and its associated costal cartilage.

The attachment of the aponeuroses of the abdominal muscles at the ventral midline gives rise to the **linea alba**, which is also associated with the umbilicus, although this is often difficult to see in cats. It is a 3–4 mm wide fibrous and avascular tissue. It is excessively wide in some cats due to a birth defect. The rectus abdominis muscle is situated on either side of the linea alba. It extends from the xiphoid process to the pubis.

Adjacent to the groin in both males and females, the caudoventral abdominal wall presents two discontinuous zones: the **deep and superficial inguinal rings**. A vaginal process or ring has not been found in female cats, although there is one in female dogs. The tunica vaginalis, testicles (in males), external pudendal vessels, genitofemoral nerve, and adipose tissue pass through the inguinal rings:

- The **deep inguinal ring** is formed medially by the rectus abdominis muscle, cranially by the caudal margin of the internal oblique muscle, and caudally by the inguinal ligament. The latter runs from the coxal tuberosity to the pubis, is triangular in shape, and is made up of connective tissue.
- The **superficial inguinal ring** is an elliptical opening in the caudal aponeurosis of the external oblique muscle.

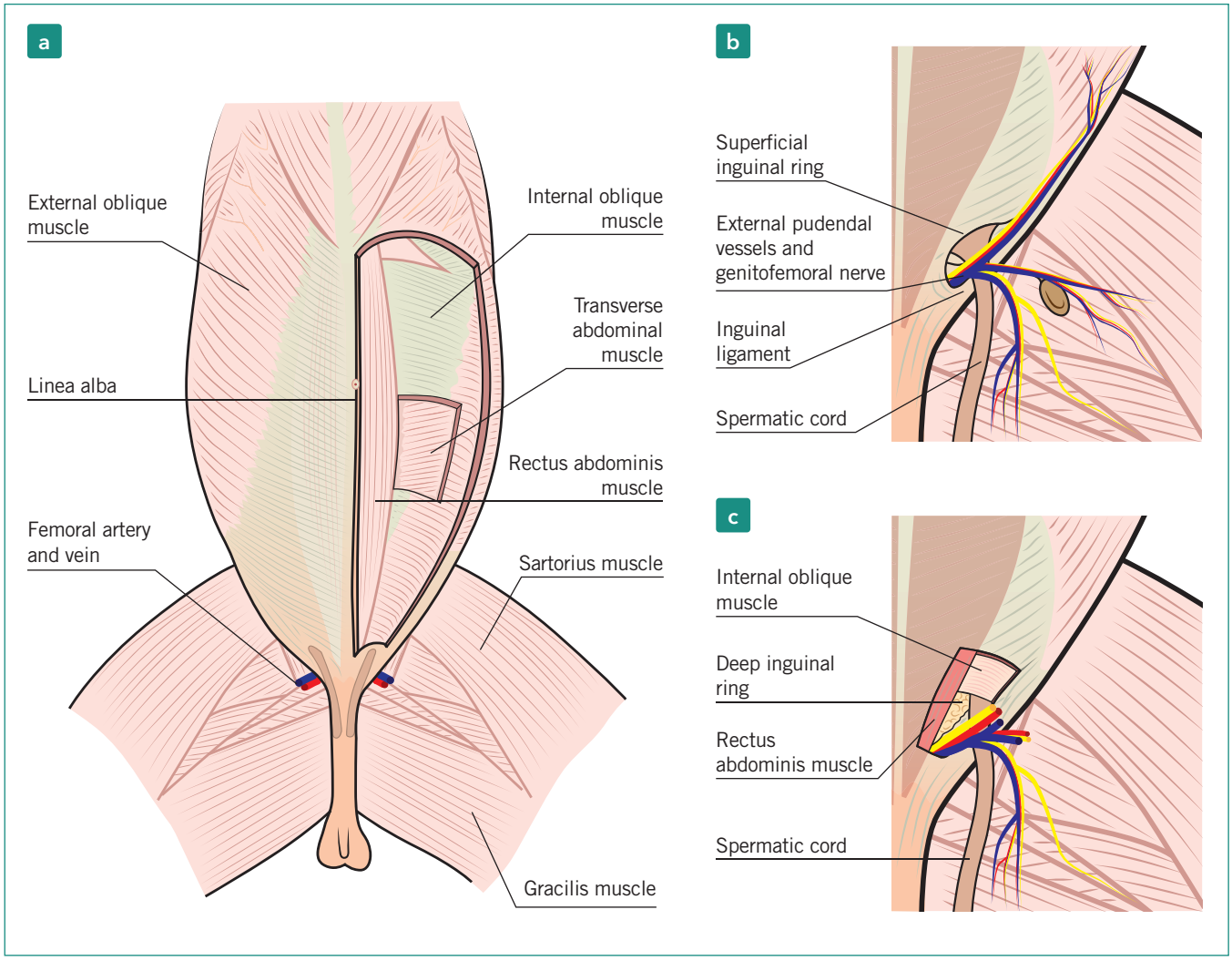

FIGURE 3. (a) Structures that make up the abdominal walls in cats. (b) Superficial inguinal ring. (c) Deep inguinal ring.

Surgical diseases of the abdomen

Exploratory laparotomy

This is not a disease per se, but a surgical technique for the diagnosis and treatment of different pathologies inside the abdominal cavity.

The definitive diagnostic test that will help us decide whether to perform an exploratory laparotomy is an ultrasound. The patient's medical history, a physical examination and laboratory tests will also support our diagnosis. We can perform ultrasounds at regularly scheduled intervals if we suspect cats may have an abdominal neoplasm (Fig. 4), chronic digestive conditions, or kidney conditions that require a biopsy for accurate diagnosis, or we can perform an emergency ultrasound. In the latter case, we can observe the sudden onset of clinical signs associated with the abdominal cavity, such as vomiting, pain on palpation, abdominal rigidity, etc. These signs may or may not be caused by trauma.

An exploratory laparotomy should be performed when there is a suspected digestive perforation, a tear in the urinary or genital tract, pyometra, bacterial peritonitis (or peritonitis for which there is no explanation), or puncture wounds in the abdomen, among many other reasons. It is not always an easy decision to anesthetize a very sick cat for a surgical intervention, but the presence of free abdominal fluid compatible with urine or bile, a cytology indicative of infection of the cavity, or bleeding for which we have no explanation are indications for a laparotomy. For those cats with nonspecific abdominal clinical signs that decompensate quickly and progressively, despite having been medically stabilized,

FIGURE 4. Mesenteric carcinoma in a female cat.

exploratory laparotomy is indicated, even if laboratory and imaging tests are not completely conclusive.

Surgical technique

- **Patient positioning:** dorsal recumbency.
- **Surgical field:** the abdomen is explored via a ventral incision. The length of this incision may vary, depending on the underlying disease. If the entire abdominal cavity must be explored, it may originate as far as the xiphoid process and end as far as the pubis. When we perform an emergency celiotomy due to an acute condition, we should surgically prepare the caudal thoracic region and the inguinal region, in addition to the entire abdominal surface. It may be necessary to examine the thorax or pelvic cavity.
- **Technique**
  1. An incision is made in the skin of the ventral midline; the incision length depends on the intervention, as explained above. The incision is continued through the subcutaneous tissues until reaching the rectus abdominis muscle fascia. The linea alba is identified. Any subcutaneous vessels that bleed excessively may be ligated if necessary.
  2. An assistant applies traction to the muscular fascia in an upward direction with baby Allis forceps, forming a tent so the surgeon can make an incision with the scalpel in the linea alba. Any adhesions to the abdominal wall are checked for. Using baby Metzenbaum scissors, the incision is widened cranially and caudally until reaching the edges of the cutaneous incision.
  3. Two surgical maneuvers used during abdominal exploration to help visualize and work in areas of difficult access are as follows:
     - **Duodenal maneuver:** used to visualize the right kidney and its vascularization. Consists of using the mesoduodenum as a natural retractor to contain the intestines and stomach. After locating the duodenum, it is lifted, along with its mesentery, from its position in the right epigastrium, upwards and to the left, taking care not to injure the right pancreatic lobe (Fig. 5).
     - **Colonic maneuver:** in this case the mesentery of the descending colon is used as a retractor (and sometimes the spleen can be included) to be able to visualize the left retroperitoneal space and all of the sublumbar canal (left ureter and kidney with all their vascularization and retroperitoneal lymph nodes) (Fig. 6).
  4. We should note that if a lavage of the abdominal cavity is needed after the surgery (severe ascites, surgical contamination, excessive bleeding), all of the fluid must be removed with gauze dressings or with a surgical aspirator. This prevents disruption of neutrophil activity due to dilution. The solution used for lavage should always be warm and preferably buffered.
  5. Once the intervention or examination is complete, the incision is closed with a simple continuous suture (an interrupted pattern is also possible) using 3-0 or 2-0 absorbable monofilament or absorbable braided (slow-absorbing polyglactin 910). The needle is suitably anchored in the rectus abdominis muscle fascia and the full thickness of the rectus abdominis muscle is taken to prevent or minimize the risk of dehiscence. The suture should be made tight without strangling the muscle. The stitches are made at 3–4 mm intervals and 4 knots are made at each end. If the incision is paramedial, only the rectus abdominis muscle fascia is taken, avoiding the peritoneum or muscle fibers. Next, an inverting Lembert suture (or inverting Cushing suture) is applied with the same material and method. Finally, whenever possible the skin is closed with

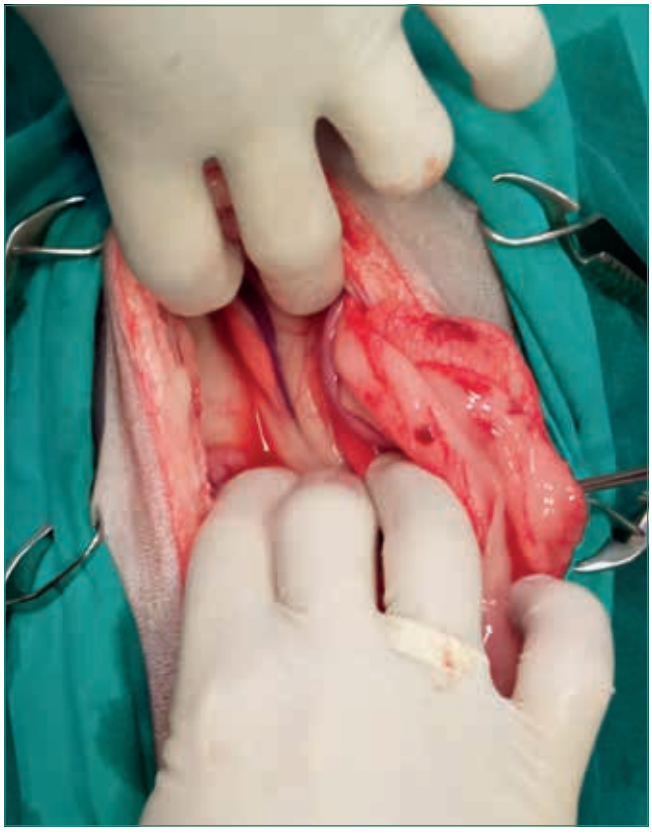

FIGURE 5. Duodenal maneuver.

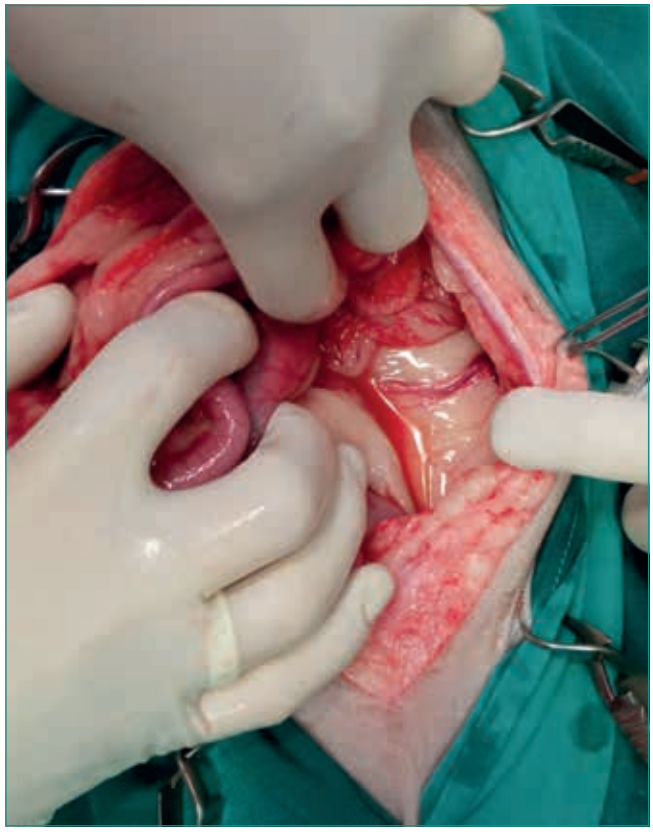

FIGURE 6. Colonic maneuver.

an intradermal suture using 3-0 absorbable monofilament to facilitate postoperative recovery and avoid the need for an Elizabethan collar, which is very stressful for cats. For very large incisions, a continuous or interrupted suture with 3-0 nonabsorbable material is required.

Key point: each stitch to close the abdominal cavity should include the muscular fascia of the abdominal wall. Only this way do we avoid dehiscence during postoperative recovery.

Postoperative complications

Issues that can arise after a laparotomy are:

- Suture dehiscence: associated with an inadequate preoperative assessment of the patient, severe immunosuppression, poor suture technique, or a postoperative infection.
- Accidental incision of the spleen or bladder due to excessive pressure or incorrect technique when accessing the abdominal cavity.
- Retained gauze in the abdominal cavity (especially small pieces) due to not accounting for the number of gauze pads at the beginning of the surgery.
- Intra-abdominal bleeding after invasive techniques performed on viscera, such as biopsies.

Hernias in the abdominal cavity

A **hernia** is the partial or complete protrusion of an organ through a defect in the wall of an anatomical cavity where it is normally situated.

Depending on the origin of the issue, hernias can be:

- **Congenital:** the defect in the wall originates in a malformation of muscle or connective tissue.
- **Acquired:** the defect is caused by a tear of a natural orifice or the wall structure itself. In this case, the origin is usually traumatic. In cats, this is often caused by falls from heights, vehicle accidents, or animal bites. Clinical signs can appear several days or even weeks after the accident.

The **hernial ring or defect** is the opening through which the herniated organ or material passes. The hernial sac is usually made up of a fine pouch of serosa that surrounds the contents of the hernia (e.g., in the abdomen, it would be the peritoneum). There may be additional layers of tissue in the hernial sac (muscle, subcutaneous tissue, skin) depending on the location of the hernia.

The clinical presentation of hernias varies depending on the contents of the hernial sac:

- **Reducible hernia:** there are no adhesions between the contents and adjacent structures, allowing them to easily be returned to their original cavity.
- **Irreducible hernia**: repositioning is not easy due to adhesions, and breaking them is required.
- **Incarcerated hernia:** when structural adhesions between the herniated organ tissue and surrounding tissue come to alter the functionality of the herniated organ. Tends to involve chronicity and may impact the decision on whether or not surgical reduction is desirable.
- **Strangulated hernia:** vascular supply of the contents inside the hernia is compromised by torsion, compression or narrowing of the hernial ring. Usually results in an emergency situation both if we want to recover functionality of the affected organ and because it could put the animal's life in danger.

It is important to note that traumatic hernias in cats are caused by falls from heights, vehicle accidents, or dog bites. Clinical signs can sometimes appear days or weeks after the accident.

Peritoneal–diaphragmatic hernias

Any defect in the diaphragm muscle, whether congenital or acquired (traumatic), can cause one or several abdominal organs to pass into the thoracic cavity, resulting in the lungs, the heart, or both, lacking the space they need to exercise their functions. Three situations have been described:

- **Congenital pleuroperitoneal hernia (CPPH):** very rare, only a few confirmed cases. Can affect any diaphragm zone. The herniated organs (especially the liver) directly occupy the pleural space, and thus exert pressure on the lung. Causes dyspnea to varying degrees, depending on the size of the herniated sac.
- **Acquired pleuroperitoneal hernia (APPH):** traumatic origin in most cases. A heavy impact to the abdominal area results in an abrupt increase in pressure on the diaphragm, and it breaks. Most common are unilateral tears to the intercostal muscles in the ventral diaphragm under the esophageal hiatus. Tears of the sternal muscle and radial tears may also occur. The most frequently herniated organs in tears of the right diaphragm are the liver, small intestine, and pancreas. If the tear is on the left side, the most frequently herniated organs are the stomach, spleen, and small intestine.
- **Congenital peritoneopericardial diaphragmatic hernia (CPPDH):** caused by a developmental alteration in the pleural and peritoneal cavities, which do not separate and fuse to the pericardium, dorsally to the xiphoid process. The three cavities are joined through an orifice, and sometimes other congenital defects are present at the same time, such as in the distal sternebrae (pectus excavatum) or in the linea alba (umbilical hernia). The contents of the hernia tend to be liver tissue, abdominal fat, or intestine. Clinical signs may be respiratory (dyspnea), cardiac (cardiac tamponade), digestive, or, very often, absent.

Clinical signs

All peritoneal–diaphragmatic hernias can be **asymptomatic** (up to 50% of the cases and more often in congenital hernias). In traumatic hernias, clinical signs associated with the hernia can appear days or weeks after the accident.

A respiratory clinical sign that can be observed is **dyspnea**, caused by:

- Direct pulmonary compression by herniated organs (Fig. 7).
- Pleural effusion (transudate) due to venous congestion of the herniated organs.
- Pneumothorax caused directly by lung contusion or indirectly as a result of fractured ribs.

The herniated organs can also present clinical signs such as **congestion** due to vascular compression:

- Liver: obstructive jaundice.
- Stomach: gastric dilatation–volvulus syndrome.
- Intestine: signs of intestinal obstruction associated with ischemia and necrosis.

Cardiac clinical signs such as tachycardia, panting, positive jugular pulse and weak femoral pulse are due to **cardiac tamponade** resulting from an excess volume of abdominal organs inside the pericardium. This occurs more frequently in congenital peritoneopericardial diaphragmatic hernia.

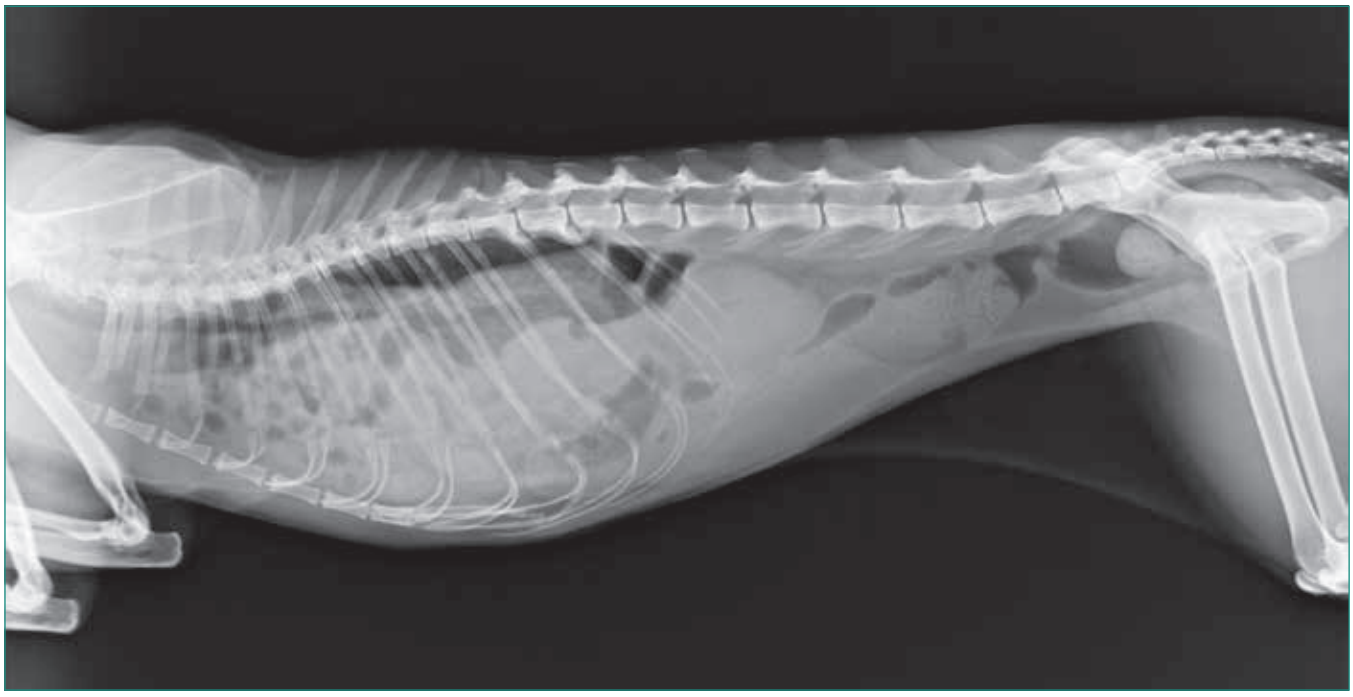

FIGURE 7. X-ray of a patient with peritoneopericardial diaphragmatic hernia. The liver, intestine, and part of the stomach are present in the hernial sac.

The following is heard on thoracic auscultation:

- An increase of borborygmus in the pleural cavity.
- Muffled heart and lung sounds.
- Cardiac sounds that are out of place due to displacement of the heart.

Diagnosis

The diagnosis of hernias in the abdominal cavity is based on the patient's clinical examination and the results of diagnostic imaging tests (Table 1).

Preoperative considerations

Preoperative management of the patient involves:

- Pain control with pure opioids, keeping in mind that respiratory depression may occur. Sometimes local anesthesia is additionally used in intercostal spaces or traumatized areas.
- Intensive fluid therapy.
- The cat must be kept in absolute rest and given oxygen.
- Thoracentesis should be planned if pneumothorax or pleural effusion must be mitigated.
- After stabilizing the patient, the effectiveness of the process must be evaluated in the first 12 hours. If a deterioration of vital signs is observed despite intensive care, if there is evidence of bleeding due to organ damage, or if the stomach

How to take a positive-contrast peritoneography?

This technique is used to verify the presence of communication between the abdominal and thoracic cavities when other imaging techniques are not conclusive. The only limitation is the chronic presence of omentum or some other organ blocking the opening of the defect, which could stop the passage of contrast agent and give a false negative.

The cat is anesthetized for the procedure and placed in dorsal recumbency. The umbilical area is shaved and disinfected. A syringe with 2 ml/kg of contrast medium, tempered to 77°F (25°C), is prepared (intravenous iopamidol, 300 mg/ml) along with a short 23-gauge needle. The injection site is 1 cm to the right of the umbilicus. Prior to this, the abdomen is palpated to avoid the bladder and spleen. After the needle is inserted, aspiration is applied to ensure that a visceral organ has not been punctured. The contrast agent is injected, and the abdomen is gently shaken so that it is distributed well. After waiting for 2–5 minutes, an X-ray of the abdomen and thorax is taken. If the contrast agent has passed into the thorax, the diagnosis of diaphragmatic hernia is confirmed.

TABLE 1. Diagnostic approach to peritoneal–diaphragmatic hernias in cats

Diagnostic test	Congenital pleuroperitoneal hernia	Acquired (traumatic) pleuroperitoneal hernia	Congenital peritoneopericardial diaphragmatic hernia
Clinical signs (see text for more information)	Very often without clinical signs, or with signs associated with herniated organs.	Frequent respiratory clinical signs, associated with trauma and herniated organs.	Often without clinical signs, and if there are any, they are due to cardiac tamponade and herniated organs.
Plain thoracic radiography	■ Loss of diaphragmatic contour in any area. ■ Accumulation of gas in the thorax. ■ Cardiac and pulmonary shadows displaced cranially or dorsally. ■ Pleural effusion (radiography must repeated after draining to improve diagnosis).	■ Loss of diaphragmatic contour in any area. ■ Accumulation of gas in the thorax. ■ Cardiac and pulmonary shadows displaced cranially or dorsally. ■ Pleural effusion (radiography must repeated after draining to improve diagnosis). ■ Signs of thoracic trauma: pulmonary contusion, broken ribs.	■ Ventrodorsal projection: loss of contour only in the dome of the diaphragm. ■ Cardiomegaly. ■ Accumulation of gas only in the pericardium. ■ Sometimes associated with pectus excavatum (malformation of the sternum).
Plain abdominal radiography	■ Cranial displacement of the gastric axis. ■ Abdomen “empty” of certain organs (liver, intestine, spleen, stomach).	■ Cranial displacement of the gastric axis. ■ Abdomen “empty” of certain organs (liver, intestine, spleen, stomach).	The same signs as in other hernias, but less evident (smaller volume of herniated organs).
Contrast radiography of the abdomen	This is the test of choice if we suspect that the stomach or intestine are in the thorax.	This is the test of choice if we suspect that the stomach or intestine are in the thorax.	This is the test of choice if we suspect that the stomach or intestine are in the pericardium.
Positive-contrast peritoneography (see p. 191)	To verify whether there is communication between the abdominal and thoracic cavities when other techniques are not conclusive.	To verify whether there is communication between the abdominal and thoracic cavities when other techniques are not conclusive.	To verify whether there is communication between the abdominal and thoracic cavities when other techniques are not conclusive.
Ultrasound	■ Helpful when there is pleural effusion and organs in the thorax. ■ The diaphragm is difficult to evaluate with ultrasound.	■ The presence of pleural effusion is more common. ■ The diaphragm is difficult to evaluate with ultrasound.	■ Good test to diagnose the contents of the pericardium (Fig. 8). ■ The diaphragm is difficult to evaluate with ultrasound.
Computed tomography	Good technique to identify the presence of abdominal viscera inside the thorax.	Good technique to identify the presence of abdominal viscera inside the thorax.	Good technique to identify the presence of abdominal viscera inside the pericardium.

is detected inside the hernial sac, with the consequent risk of gastric dilatation–volvulus syndrome, **an emergency intervention to resolve the hernia is obligatory**, even though these cases entail a higher mortality rate (33%).

- If possible, the patient should be shaved and preoxygenated as quickly as possible before anesthetizing.
- Intravenous induction is preferred, and intubation should be done quickly.
- Once intubated, intermittent positive pressure ventilation is initiated (automatic ventilators are used rarely in feline medicine due to the difficulty of properly regulating pressure on the pulmonary tissue and the increased risk of edema).
- The patient is placed in dorsal recumbency with the thorax somewhat higher than the abdomen to decrease the pressure exerted by the herniated organs on the lungs and the heart, until the reduction of the hernia.
- The time between anesthetic induction and the reduction of the hernia should be as short as possible.

The decision whether or not to operate a diaphragmatic hernia depends on several factors: surgery is not recommended if the patient is asymptomatic and the hernia is congenital, unless the patient's clinical condition worsens for reasons associated with the congenital defect (strangulated herniated organ, vascular compromise that causes effusion, progressive pulmonary compression). Ideally, if the cat is symptomatic, and a diaphragmatic hernia has been diagnosed, the defect should be repaired after the patient has been stabilized for 24–48 hours.

Surgical technique

- **Patient positioning:** dorsal recumbency.
- **Surgical field:** the distal half of the thoracic cavity and the entire abdominal area are shaved and disinfected.
- **Approach:** a midline incision is made in the linea alba, from the xiphoid process to the distal umbilicus, sufficient to examine the entire abdominal cavity and the full surface of the diaphragm (there may be more than one tear). Gauze pads moistened with warm saline solution are used to demarcate the surgical field around the diaphragm.

  In general, the approach via lateral thoracotomy is not advisable, as it requires knowing the exact location of the lesion in advance and it does not enable full examination of the abdomen.

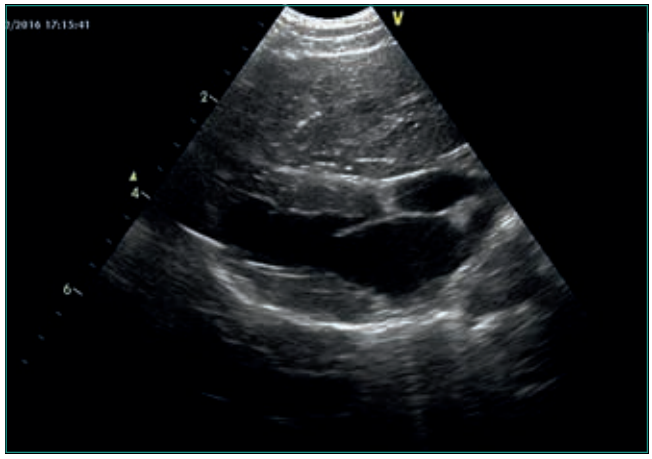

FIGURE 8. Ultrasound of a patient with peritoneopericardial diaphragmatic hernia. A piece of hepatic parenchyma is visible in the pericardium.

- **Technique**

1. The first step is to examine the herniated organs and evaluate whether they are viable. If they are strangulated and necrotic or if their blood supply is highly compromised (cyanosis, hemorrhagic effusion, thrombosed vessels), they must be quickly excised or resected without releasing any toxins or pro-inflammatory factors into general circulation. If they are viable, they are repositioned in the abdominal cavity. If there are adhesions, they can be resolved by slightly opening the tear to facilitate examination of the thoracic cavity.

Key point: when the abdominal cavity is opened and work is begun on the torn diaphragm, an anesthesiologist must initiate intermittent positive pressure ventilation.

2. **Closure of the diaphragm defect:** the most frequent tear affects the muscle and is located in the ventral area. Before proceeding to wound closure, we can place a chest drain through the defect. This is inserted through a subcutaneous tunnel near an intercostal space, using the surgical field itself. Taking advantage of our view of the thoracic cavity, we situate the end of the fenestrated drain tube in the ventral area. This drain will help eliminate any remaining pneumothorax after the hernia is sutured, especially in cases in which we are unable to achieve an airtight seal.

3. The type of suture used is always 2-0 or 3-0 monofilament. The option to use absorbable or nonabsorbable material is largely up to the surgeon, although nonabsorbable material tends to be used with larger defects. In general, continuous sutures are used, always starting at the most dorsal point (the furthest from the surgical field) and continuing in the ventral direction. U-stitches can also be used, especially when closing paracostal areas of the diaphragm. It is important to always include diaphragmatic fascia to make the suture more secure.

   We are faced with several possible scenarios when designing the suture pattern:

   - **Radial tears:** simple continuous suture pattern, from the dorsal to the ventral area (Fig. 9a).
   - **Paracostal tears:** in this case, a simple continuous pattern is used to close the edge of the lesion around the rib. U-stitches can also be used around the rib (Fig. 9b).
   - **Combined radial and paracostal tears:** first one or several initial stitches are applied for approximation and paracostal anchoring of the sections of tissue. Next, closure is effectuated with one or more continuous sutures (Fig. 9c).

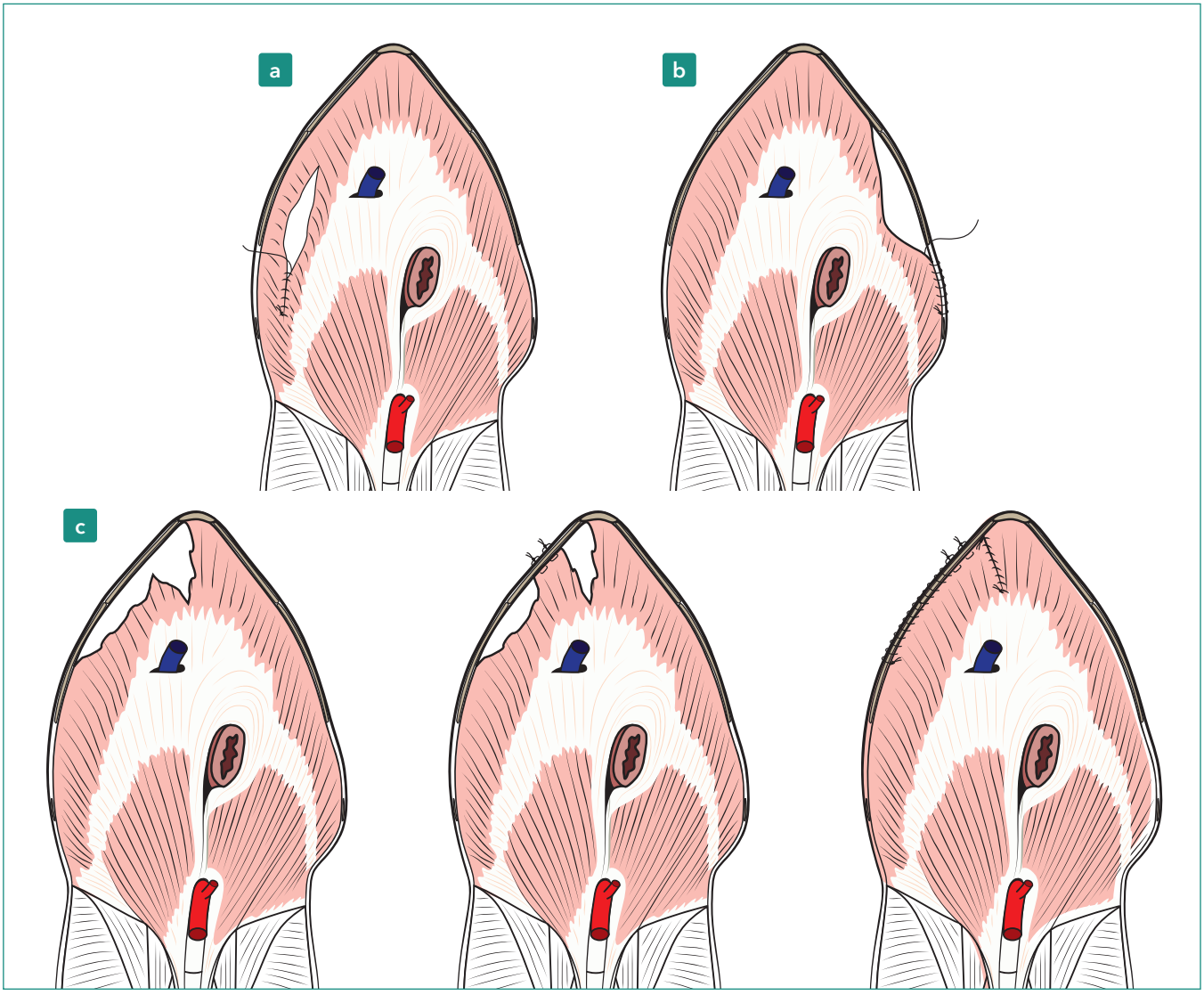

FIGURE 9. Suture patterns for radial, paracostal and combined tears. (a) Radial tear, with closure via continuous suture. (b) Paracostal tear, with closure via continuous suture around the rib. (c) Combined radial and paracostal tear, paracostal anchoring with U-stitches and radial and paracostal continuous sutures.

- **Congenital defects:** there is not enough muscle tissue to effectuate the closure in these cases. This is resolved through two paracostal incisions in the diaphragm, one on each side of the defect (Fig. 10). This prevents excessive tension on the muscle and suture after the repair, which would increase the risk of dehiscence. Once the defect is corrected with a continuous suture, the paracostal incisions are closed with U-stitches around the rib and sternum. Sometimes, the area of insertion of the sutures from the diaphragm to the abdominal wall must be displaced distally in order to compensate for the congenital lack of muscle.
- **Very large congenital defects:** in this case the use of polypropylene mesh is justified. To correct the defect, this mesh is sutured with polypropylene U-stitches to the walls of the diaphragm. Prior to this, the mesh should be lined with a double layer of greater omentum (thoracic and abdominal aspects of the implant) to prevent the mesh from scraping against the lung and abdominal organs (Fig. 11).

Once the defect/tear is sutured, the next step is to drain the pneumothorax as much as possible. This can easily be done with the help of a syringe attached to a three-way stopcock and a 20-gauge needle that goes through the diaphragm and empties out the air while an assistant promotes ventilation with gentle positive pressure. Once barely any air is coming out, the pneumothorax is resolved, and the needle is withdrawn from the diaphragm. If a chest drain has been placed, it will continue operating over the next few hours after surgery, connected to a three-way stopcock. The average amount of time to keep these devices inside cats is 12 hours if we wish to avoid the associated pain and respiratory depression. Another device used as a chest drain in cats is a 14-gauge J catheter.

Postoperative care

Analgesia with pure opiates is mandatory during the first week. The patient should be monitored for **dyspnea**, which could be caused by pneumothorax, pleural effusion, reexpansion pulmonary edema, or dehiscence of the diaphragm suture. The patient should rest for at least a week, until the diaphragm suture becomes strong enough for the cat to return to a normal level of activity.

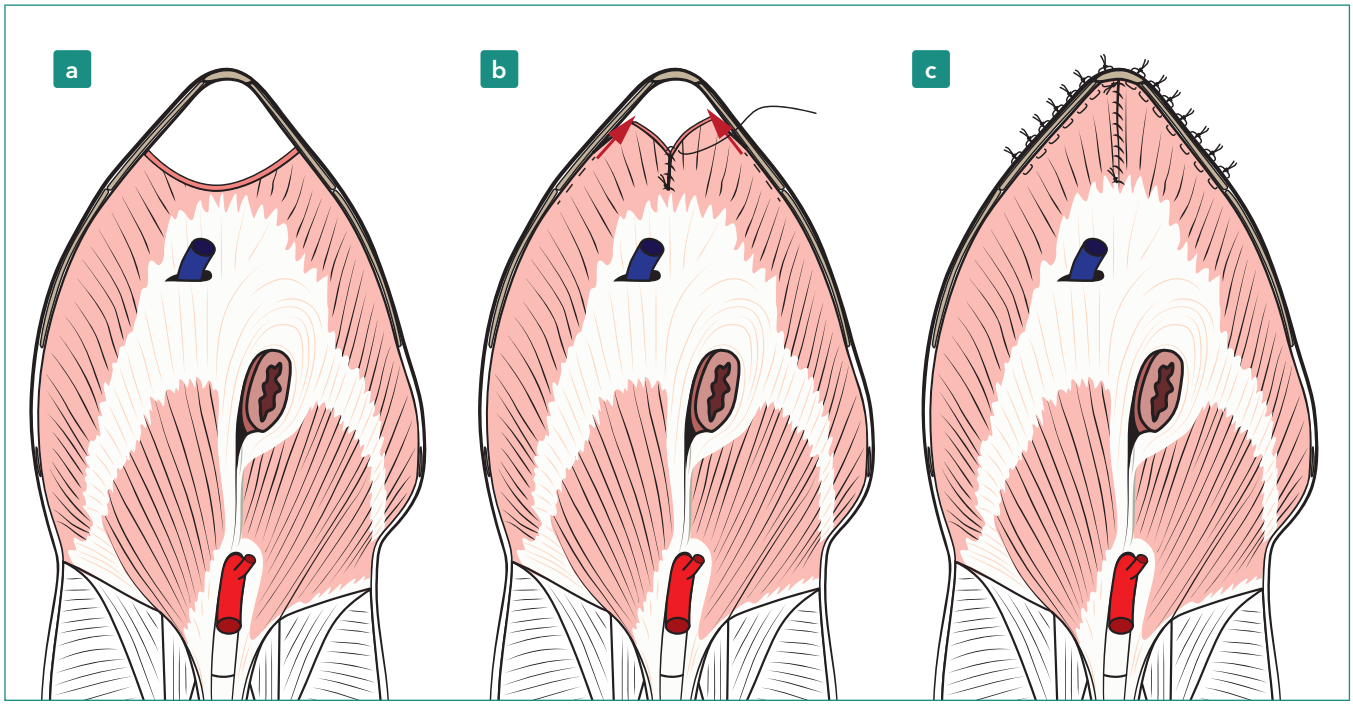

FIGURE 10. (a) Congenital defects. (b) The lack of muscular tissue needed to effectuate the closure is resolved via paracostal incisions in the diaphragm on each side of the defect. (c) Once the defect is corrected with a continuous suture, the paracostal incisions are closed with U-stitches around the rib and sternum.

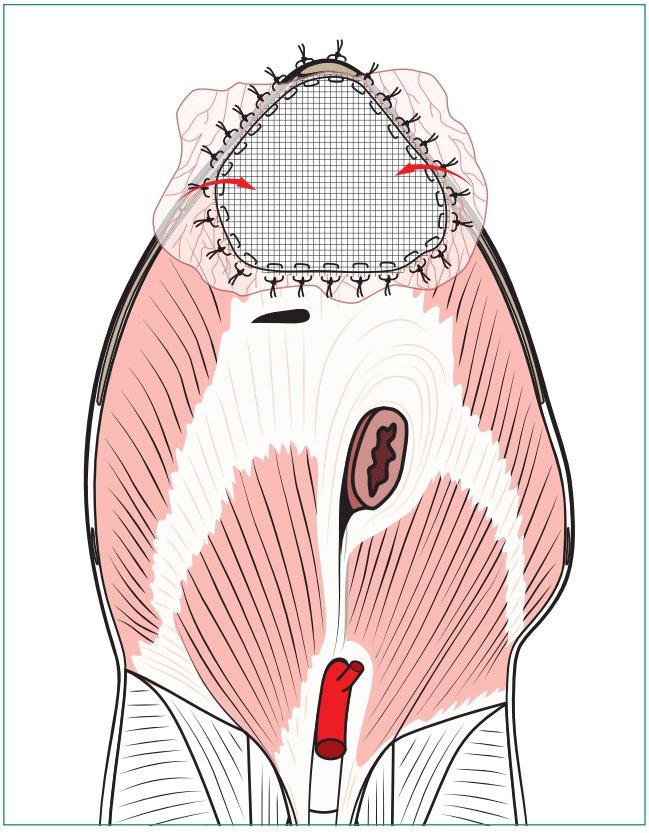

FIGURE 11. Closure of large congenital defects: use of a polypropylene mesh covered with omentum and sutured with U-stitches to the diaphragm walls.

Complications

Published data suggest a mortality rate of 14% in peritoneopericardial diaphragmatic hernia surgery. In cases of traumatic hernia, the rate drops to only 8%. The majority of these deaths occur in the first 24 hours after surgery. The principal cause of death in patients with surgically resolved diaphragmatic hernia is reexpansion pulmonary edema. To avoid this, positive pressure ventilation must be monitored the entire time while under anesthesia. Another complication that has been described is elevated intra-abdominal pressure as a consequence of the lack of space for the herniated organs, along with an inability of the abdominal walls to adequately distend. This occurs more often in cases of congenital hernia. The associated risks are suture dehiscence and dyspnea caused by restricted diaphragm mobility. To avoid this, a preventive splenectomy or partial hepatectomy can be effectuated.

Inguinal hernias

The double pillar structure of the prepubic tendon (called the **external oblique abdominal aponeurosis** in cats) as well as the very narrow and taut femoral and inguinal canals mean that this type of hernia is not very common in cats. Case studies in the literature are due to traumas or very large congenital defects of the wall (see the following sections), and they do not exclusively involve these two natural orifices.

Umbilical hernias

Real umbilical hernias occur rarely in cats (0.15% according to studies). They are always congenital and result from defects in the closure of abdominal muscle folds during fetal development. They should not be confused with **cranial abdominal hernias**, which are defects of the wall associated with peritoneopericardial hernias. Nor should they be confused with **omphaloceles**, which consist of a complete agenesis of the abdominal midline and the skin, causing congenital evisceration.

The technique used to resolve umbilical hernias consists of dissecting the hernial sac of its adhesions until the hernial ring is revealed. A cut is made around the ring to debride the edges of the wound so that it subsequently heals safely. The usual suture used for abdominal closure is then effectuated.

Abdominal wall hernias and ruptures

The majority of abdominal hernias in cats occur after blunt trauma to the caudomedial wall or the paracostal region (areas of osseous insertion of the pelvis and the ribs, respectively). Other possible origins of abdominal hernias are iatrogenic; due to suture dehiscence, either as a result of careless technique or poor choice of suture materials; or as a result of defects of the abdominal wall in cats with cutaneous asthenia. In such cases, the linea alba is very wide and weak. Therefore, any sutures should include well formed muscle fascia, which sometimes means that a large part of the weakened fascia must be cut before repairing the surgical wound (Fig. 12).

Agenesis of the abdominal wall is due to congenital defects in the formation of one or several abdominal muscles, either partially or completely. If the defect is limited to one area, the cat may survive and present abdominal hernia. Such cases can be associated with cutaneous asthenia due to a defect in the structure of the connective tissue.

Resolution always consists of reconstructing the damaged muscle along with its anchors. The earlier the diagnosis and intervention is done, the more effective the results. When the damage is very severe, in very chronic cases or if the defect is congenital and very extensive, the use of polypropylene mesh to repair the defect is mandatory (Fig. 13).

FIGURE 12. Rupture of the abdominal wall in a cat with cutaneous asthenia and congenital perineal hernia. Greater omentum lodged in the subcutaneous space following dehiscence of the surgical wound 2 days after performing an ovariohysterectomy.

FIGURE 13. Placement of a polypropylene mesh to resolve a bilateral prepubic tendon tear in a cat. The disinsertion was very large and required the help of mesh to ensure the proper reconstruction of the insertions in the pubis.

Bibliography

Bellah JR. Diafragma. In: Bojrab JM (ed.). *Técnicas actuales en cirugía de pequeños animales*, 4th ed. Buenos Aires: Intermédica, 2001; pp. 289–298.

Benitah N, Matousek JL, Barnes RF et al. Diaphragmatic and perineal hernias associated with cutaneous asthenia in a cat. *J Am Vet Med Assoc*, 2004; 224(5):706–709, 698.

Boothe HW, Slater MR, Hobson HP et al. Exploratory celiotomy in 200 nontraumatized dogs and cats. *Vet Surg*, 1992; 21(6):452–457.

Burton C, White R. Surgical approach to a ruptured diaphragm in the cat. *In Pract*, 1997; 19:298–305.

Cariou MP, Shihab N, Kenny P, Baines SJ. Surgical management of an incidentally diagnosed true pleuroperitoneal hernia in a cat. *J Feline Med Surg*, 2009; 11(10):873–877.

Clugston RD, Greer JJ. Diaphragm development and congenital diaphragmatic hernia. *Semin Pediatr Surg*, 2007; 16(2):94–100.

Charlesworth TM, Moores AL. Post-trauma inguinal seroma formation in the cat. *J Small Anim Pract*, 2012; 53(5):301–303.

Coffey JC, O'Leary DP. The mesentery: structure, function, and role in disease. *Lancet Gastroenterol Hepatol*, 2016; 1(3):238–247.

Formaggini L, Schmidt K, De Lorenzi D. Gastric dilatation-volvulus associated with diaphragmatic hernia in three cats: clinical presentation, surgical treatment and presumptive aetiology. *J Feline Med Surg*, 2008; 10(2):198–201.

Fossum TW. Surgery of the lower respiratory system: pleural cavity and diaphragm. In: Fossum TW (ed.). *Small Animal Surgery*. St Louis, MO: Mosby Elsevier, 2007; pp. 896–929.

Larson MM. Imaging the thorax. Diaphragm. In: Holland M, Hudson J (eds.). *Feline Diagnostic Imaging*. Hoboken, New Jersey: Wiley Blackwell, 2020; pp. 315–322.

Liptak JM, Bissett SA, Allan GS et al. Hepatic cysts incarcerated in a peritoneopericardial diaphragmatic hernia. *J Feline Med Surg*, 2002; 4(2):123–125.

Parry A. Positive contrast peritoneography in the diagnosis of pleuroperitoneal diaphragmatic hernia in a cat. *J Feline Med Surg*, 2010; 12(2):141–143.

Pratschke KM. Abdominal wall hernias and ruptures. In: Langley-Hobbs SJ, Demetriou JL, Ladlow JF (eds.). *Feline Soft Tissue and General Surgery*. London: Elsevier Saunders, 2014; pp. 269–280.

Reimer SB, Kyles AE, Filipowicz DE, Gregory CR. Long-term outcome of cats treated conservatively or surgically for peritoneopericardial diaphagmatic hernia: 66 cases (1987–2002). *J Am Vet Med Assoc*, 2004; 224(5):728–732.

Reina Rodriguez FS, Buckley CT, Milgram J, Kirby BM. Biomechanical properties of feline ventral abdominal wall and celiotomy closure techniques. *Vet Surg*, 2018; 47(2):193–203.

Schmiedt CW, Tobias KM, Stevenson MA. Traumatic diaphragmatic hernia in cats: 34 cases (1991–2001). *J Am Vet Med Assoc*, 2003; 222(9):1237–1240.

Sieck GC, Roy RR, Powell P et al. Muscle fiber type distribution and architecture of the cat diaphragm. *J Appl Physiol Respir Environ Exerc Physiol*, 1983; 55(5):1386–1392.

Spattini G, Rossi F, Vignoli M, Lamb CR. Use of ultrasound to diagnose diaphragmatic rupture in dogs and cats. *Vet Radiol Ultrasound*, 2003; 44(2):226–230.

Stampley AR, Waldron DR. Reexpansion pulmonary edema after surgery to repair a diaphragmatic hernia in a cat. *J Am Vet Med Assoc*, 1993; 203(12):1699–1701.

Williams J, Leveille R, Myer CW. Imaging modalities used to confirm diaphragmatic hernia in small animals. *Comp Cont Ed Pract Vet*, 1998; 20(11):1199–1209.

Worth AJ, Machon RG. Traumatic diaphrragmatic herniation: pathophysiology and management. *Comp Cont Educ Pract Vet*, 2005; 27(3):178–191.

Yool DA. Diaphragm. In: Langley-Hobbs SJ, Demetriou JL, Ladlow JF (eds.). *Feline Soft Tissue and General Surgery*. London: Elsevier Saunders, 2014; pp. 521–530.