THE MORPHOLOGY OF THE CANINE OMENTUM
AND ITS SURGICAL IMPLICATIONS

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Voor Oskar, Jule

& Billy
“I don’t know what I knew before

But now I know I want to win the war”

Feist
The morphology of the canine omentum
and its surgical implications

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# Chapter 5: The omental pedicled flap in dogs revised and refined: a cadaver study

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CHAPTER 1: GENERAL INTRODUCTION
1.1. History

The first historical account of the greater omentum is found in Homer’s Odyssey (8th century BC). In the underworld, the giant Tityos was given an eternal punishment. Vultures were to “plunge deeply into his dertron to feed on his liver”. The term dertron also appears in the Hippocratic writings (5th-4th century BC). It refers to the membranous character of the omentum. In these writings, however, the very appropriate term epiploon is frequently used, which can be translated as “floating freely”. The Romans introduced the Latin term omentum that is still used in English medical literature today. Etymologists trace it back to ovimentum, from induo (I clothe or I cover) (Liebermann-Meffert et al., 1983; Liebermann-Meffert, 1988).

Throughout centuries, searches for the true nature of the omentum resulted in wild speculations, ranging from no particular function at all to fat transporter or lubricant producer. According to Galen (AD 128-199), the role of the omentum was to heat the intestines. He based his hypothesis on the observation of a gladiator who, after incurring an abdominal stab wound and subsequent omental resection, suffered greatly from cold for the rest of his life (Liebermann-Meffert, 1983). In 1874, the French anatomist Ranvier described the “taches laiteuses” (milky spots) and put into writing the first scientific discovery of an omental function. Although the greater omentum has not yet revealed all of its mysteries, the belief that its sole function lies in clothing the intestines has long been abandoned.

Interestingly, already in 1826, de Lamballe, future court surgeon of Napoleon III, launched the idea of using the protective capacities of the omentum in surgery. De Lamballe reported on his surgical experiences during the civil wars and described the ‘willingness’ of the omentum to adhere to injured intestines (Liebermann-Meffert, 1988). Literature shows sporadic but enigmatic use in surgery from the late 19th century onward. It was, however, surgical pioneers such as O’Shaugnessy (1937) who gave the first descriptions of successful use of pedicled omentum to vascularize ischemic cardiac muscle tissue. These interventions opened the door for new experimental surgical ideas involving the omentum.
In the past decennia, growing knowledge and insights on the multiple qualities of the omentum led to a responsive development of new clinical applications that fully embraced these beneficial features (Liebermann-Meffert, 1983; Collins et al., 2009; Kawamura et al., 2013).

Surprisingly, the omentum has not entirely found its way into veterinary surgery and for a long time, veterinary researchers and practitioners showed little interest in this “neglected organ”. Consequently, the potential applications in veterinary medicine are not fully explored (Bright and Thacker, 1982, Hosgood, 1990). Moreover, much of the current information on the greater omentum in companion animals is extrapolated from human medicine.

1.2. Morphological definitions

The greater and lesser omentum (Omentum majus and minus) are mesenterial sheets in the abdominal cavity that are associated with the stomach (Nickel et al., 1973). The greater omentum is the first structure that can be observed when opening the abdomen through a ventral midline incision. It is a cribriform serosal fold of considerable size. It is charged with many blood vessels and lymphatics that are embedded in streaks of variable amounts of abdominal fat (Nickel et al., 1973; Barone, 2009). The larger part of the omentum floats freely in the abdominal cavity. The greater omentum attaches to the greater curvature (Curvatura major) of the stomach, whilst the lesser omentum passes from the lesser curvature (Curvatura minor) and cranial part of the duodenum to the visceral surface of the liver (Nickel et al., 1973; Barone, 2009). The omenta enclose a virtual cavity named the omental bursa (Bursa omentalis) (Nickel et al., 1973; Barone, 2009).
1.3. Morphological characteristics of the canine omenta

1.3.1. Embryonic development of the omenta

The greater and lesser omentum arise from respectively the dorsal and ventral mesogastrium that suspend and anchor the developing stomach in the coelomic (prospective: peritoneal) cavity (Evans, 1993; Barone, 2009). Both mesogastria are initially composed of a large but relatively short mesenchymal core, which is bilaterally lined by a thin layer of mesothelium. During subsequent development, the mesogastria lose their initial role of anchoring the stomach to the dorsal and ventral body walls. They develop into more flattened, sheet-like structures that are charged with blood and lymph vessels and that will follow the growth, expansion and changing topography of the stomach. Meanwhile, primordia of surrounding organs, notably the spleen, liver and pancreas, invade and expand into the developing omenta (Dodds et al., 1985; Hyttel, 2010).

The primitive stomach can initially be recognized as a local enlargement of the foregut that bulges dorsally (Dodds et al., 1985). As the stomach expands, its greater curvature topples towards the left. The elongating dorsal mesogastrium allows and follows this movement. As it develops, the left pancreatic lobe grows into the dorsal mesogastrium near the latter’s attachment to the dorsal body wall, while the developing right pancreatic lobe expands in an arboreal fashion in the mesoduodenum (Hyttel, 2010).

In subsequent stages of development, the fundic region of the stomach undergoes a marked craniodorsal enlargement towards the left. This expansion alters the orientation of the stomach to a more transverse position with the pylorus being pushed to the right. It also forces the dorsal mesogastrium to bend and curve along the bulging left and ventral surface of the stomach. In subsequent fetal and postnatal life, the dorsal mesogastrium further extends caudally, hereby creating a bag-like serosal fold. The superficial and deep walls of this fold surround an empty virtual cavity. In man, unlike in domestic animals, these walls adhere and fuse, thereby obliterating most part of the virtual cavity (Dodds et al., 1985; Sompayrac, 1997). The greater omentum has now reached its full development (Hyttel, 2010).
1.3.2. Anatomy of the greater and lesser omentum

**General outline of the greater omentum**

The greater omentum is typically subdivided into a bursal and a splenic portion. Each portion is composed of two walls, namely a superficial wall (Paries superficialis) and a deep wall (Paries profundus) (Budras, 2002). A third portion, the veil portion (Velum omentale), is described in carnivores (Zietzschmann, 1939; Evans, 1993; Budras, 2002; Barone, 2009; Habel, 2012).

In carnivores, the bursal portion extends caudally between the abdominal wall and the intestinal loops, towards the vicinity of the pelvic cavity (Fig. 1). The deep wall originates dorsally from a line that runs from the esophageal hiatus, along the left crus of the diaphragm, to the celiac artery and onward along the left lobe of the pancreas. There it reaches the dorsal border of the omental foramen (Nickel et al., 1973; Barone, 2009). The deep wall then descends caudally towards the pelvic inlet. It extends ventral to the intestinal coils but dorsal to the urinary bladder (Nickel et al., 1973; Barone, 2009). At its periphery, the deep wall of the greater omentum folds on itself ventrally and proceeds its course cranially as the superficial wall, inserting on the greater curvature of the stomach (Nickel et al., 1973). The splenic portion, often referred to as the gastrosplenic ligament (Ligamentum gastrolienale), passes between the greater curvature of the stomach and the splenic hilus (Nickel et al., 1973; Habel, 2012).

The omental bursa (Bursa omentalis) lies between both walls of the greater omentum. It is a virtual cavity, which communicates with the rest of the peritoneal cavity only through the omental foramen (Foramen omentale) (Budras, 2002; Barone, 2009). The foramen is a slitlike opening to the right of the median plane. It is bounded craniodorsally by the caudate process of the liver and the caudal vena cava, ventrally by the portal vein included into the free border of the hepatoduodenal ligament (part of the lesser omentum, see further) and caudally by the pancreas (Nickel et al., 1973).

Apparent interspecies differences in the omental anatomy can be noted. In dogs and pigs, the greater omentum is large and extends from the stomach to the urinary bladder. It covers the intestinal coils both ventrally and bilaterally. In humans, rabbits and equines, the omentum is considerably smaller (Barone, 2009). In man, but also to a certain extent in the horse (Nickel et al., 1973), both walls of the greater omentum adhere to each other over a relative extensive surface, with relatively reduced dimensions of the omental bursa (Dodds et
al., 1985; Sompayrac, 1997). In most domestic animals, the deep wall of the greater omentum also inserts on the transverse colon. In carnivores, however, it does not (Barone, 2009). On the other hand, the veil portion is exclusively described in carnivores, as a sagittal serosal membrane that inserts cranially on the deep wall of the greater omentum at the level of the splenic artery and that blends dorsally with the mesocolon descendens, retaining a free caudal border. As a single-sheeted membrane, it does not contribute to the delineation of the omental bursa (Zietzschmann, 1939; Evans, 1993; Budras, 2002; Barone, 2009; Habel, 2012).

In 1939 Otto Zietzschmann described the canine omentum in great detail. In his elaborated study, published in German, he introduced a new nomenclature that was unfortunately not adopted in official anatomical nomenclature. The difficulty of the report and the obvious language barrier obstructed the report’s accessibility. Zietzschmann’s work was cited by many, although probably not consulted, let alone studied in detail. In the subsequent decennia, little to no additional research was performed on the omentum of the dog.
Fig. 1: Morphology of the canine omentum demonstrated in a fresh cadaver via a ventral midline approach. A: Oblique ventral survey of the abdominal organs. B: Oblique ventral view, showing the veil portion (arrow) by retraction of the spleen towards the midline. C: Ventral view; the bursal portion of the greater omentum stretches from the stomach to the empty urinary bladder, covering the intestinal coils. D: Ventral view, showing the splenic portion spanning between the greater curvature of the stomach and the splenic hilus. E: Right lateral view, demonstrating the omental foramen (arrow) exposed by retracting the mesoduodenum towards the midline.
Vascular supply of the greater omentum

In human medicine the increasing number of clinical applications has motivated research in the blood supply of the greater omentum. These studies include cadaver studies (Alday and Goldsmith, 1975; Liebermann-Meffert, 1983) and, more recently, morphological studies through imaging techniques (Jin et al., 2008; Coulier, 2009). It goes without saying that a thorough knowledge of the vascular supply is essential to preserve the main vessels during surgical use of the omentum (Liebermann-Meffert, 2000).

In companion animals, however, data on the morphology of omental arteries are very scarce. Only one study has been performed in dogs (Gravenstein, 1938) and none in cats. Surgical applications in companion animals are based on human anatomical data (Bright and Birchard, 1982; Bright and Thacker, 1982; Hosgood, 1990) or on the sole canine experimental report on surgical techniques of the omentum (Ross and Pardo, 1993). Since veterinary surgery is rapidly progressing, an increasing need for veterinary morphological knowledge on the greater omentum is to be expected. In 1938, a detailed anatomical study (Gravenstein, 1938) described the canine omental vascular supply. This study in German, however, was performed on one single dog only. It describes the major omental blood supply in the dog as derived from three stem arteries, namely the left and right gastroepiploic arteries and the continuation of the splenic artery in the omental wall. The study described that both the superficial and deep omental walls are predominantly supplied by a left and right marginal artery, which originate from the splenic artery (A. lienalis) and the right gastroepiploic artery (A. gastroepiploica dextra), respectively. Multiple smaller arteries are shown to form anastomoses between the arteries of the superficial and deep omental walls (Gravenstein, 1938).

In humans, the vascular pattern upon which clinical applications are based, is deduced from a study on 136 adult cadavers by Alday and Goldsmith (1975). The major arterial branches that distribute blood throughout the bursal portion of the greater omentum originate from the gastroepiploic arch, which is a conjunction of the right and left gastroepiploic artery (A. gastroepiploica dextra and sinistra) along the greater curvature of the stomach. This arterial arch gives rise to the major omental arterial branches, namely a right, a middle and a left omental artery. It also gives rise to an accessory omental artery that arises from the gastroepiploic arch immediately proximal to the take-off of the right omental artery. The gastroepiploic arch further generates short omental arteries in between the major omental
vessels (Alday and Goldsmith, 1975). The middle omental artery bifurcates into a left and right branch, which join the left and right omental arteries, respectively, thus forming a left and right arcade. There are five major variations of these arcades, depending upon the level of the bifurcation or the absence of the middle omental artery. Surgical techniques are adapted according to the vascular pattern encountered (Alday and Goldsmith, 1975).

**General outline and vascular supply of the lesser omentum**

The canine lesser omentum is small and relatively simple. It spans the area lined by the liver, the lesser curvature of the stomach and the cranial part of the duodenum (Barone, 2009). Based on the site of attachment, it is subdivided into the hepatogastric ligament (Ligamentum hepatogastricum) and the hepatoduodenal ligament (Ligamentum hepatoduodenale). The hepatoduodenal ligament contains the portal vein, the hepatic artery and the common bile duct (Evans, 1993; Barone, 2009). Anatomical studies in humans report on the topographic variation of the clinically significant arteries in the lesser omentum, namely the hepatic artery (A. hepatica) and the left gastric artery (A. gastrica sinistra) (Weiglein, 1996), rather than on the vascular supply of the lesser omentum itself. In companion animals, only textbooks report on the anatomy of the lesser omentum (Evans, 1993; Barone, 2009).

1.3.3. Histological aspect of the omenta

The omental walls of humans, mice and companion animals are built of a thin layer of loose connective tissue that is lined on both sides by a continuous layer of mesothelial cells with numerous surface microvilli (Wilkosz et al., 2005; Owaki et al., 2013; Huyghe et al., 2015). This layer provides a protective nonadhesive surface, which facilitates intraperitoneal movement (Wilkosz et al., 2005). The submesothelial connective tissue contains collagen fibrils, fibroblast-like cells, blood vessels and adipose tissue. This adipose tissue is unequally distributed and runs in fatty streaks in which the major omental blood vessels are embedded (Cui et al., 2002; Wilkosz et al., 2005; Owaki et al., 2013; Huyghe et al., 2015). In between those streaks, the omenta consist of translucent regions, poorly vascularized regions of which the mesothelial lining is pierced by numerous fenestrations of varying size (Cui et al., 2002; Wilkosz et al., 2005; Owaki et al., 2013; Huyghe et al., 2015).

Small aggregates of lymphoid tissue, known as omental milky spots, are displayed in the omentum of numerous species such as humans (Beelen et al., 2005; Wilkosz et al., 2005; Zareie et al., 2006), rodents (Dux, 1988), rabbits (Di Paolo et al., 2005) and pigs.
These perivascular accumulations of leukocytes mainly contain macrophages, lymphocytes and mast cells (Cui et al., 2002; Beelen et al., 2005; Zareie et al., 2006). They vary greatly in number, size and cell composition depending on animal species, strain, sex and functional state. They have been indicated as important reactive tissue involved in intraperitoneal defence mechanisms (Dux, 1988; Krist et al., 1995; Cui et al., 2002; Beelen et al., 2005; Wilkosz et al., 2005; Zareie et al., 2006). At the site of the milky spots the mesothelial lining is no longer continuous because of the presence of intercellular gaps (Cui et al., 2002; Wilkosz et al., 2005). Beneath the cells covering the milky spots, no basement membrane is present. This results in a direct contact of the surface layer cells with underlying cells or connective tissue matrix (Cui et al., 2002). In humans (Shimotsuma et al., 1989), rats (Ackermann et al., 1991) and mice (Dux, 1988) the omental capillary beds at the level of the milky spots are arranged in glomeruli-like convolutions. These capillaries are fenestrated (Hodel, 1970).

Recently, the absence of such distinct and organized aggregates of immune cells was reported in healthy canine omenta (Huyghe et al., 2015). In that study the mesothelial cell layer and the underlying basement membrane were continuous in both the translucent and the adipose-rich regions in all samples of the dogs. In some areas of the translucent regions, the opposite monolayers of the mesothelial lining fused, forming fenestrations (Huyghe et al., 2015).

1.4. Functional characteristics of the greater omentum

The greater omentum is not a vital, i.e. essential, abdominal organ and one could live without it (Das, 1976). The functions attributed to it can, however, be lifesaving (Platell et al., 2000). Moreover, it remains to be clarified whether omentectomy has deleterious side effects such as an increased susceptibility to peritonitis (Platel et al., 2000). The unique beneficial functions of the greater omentum have led to different surnames such as “policeman of the abdomen” in humans by the British surgeon Morison in 1908 (Liebermann-Meffert, 1983) and “the surgeon’s best friend” in companion animals (Valat and Moisonnier, 2004).
1.4.1. Adhesive capacity

The omentum is able to adhere to adjacent structures (Platell et al., 2000; Valat and Moisonnier, 2004). Mesothelial injury, even as light as exposure to air, and certainly in combination with the presence of free abdominal blood, leads to the formation of adhesions (Ryan et al., 1971). Since the greater omentum is a rather large and freely floating structure, it is strategically placed to form adhesions on injured areas anywhere in the abdominal cavity (Ryan et al., 1971) (Fig. 2). It can seal off gastrointestinal defects and can promote their healing through other innate properties such as its angiogenic activity (Platell et al., 2000; Valat and Moisonnier, 2004). The omentum also plays a role in preventing the formation of life-threatening restrictive adhesions between viscera (Ryan et al., 1971; Valat and Moisonnier, 2004). By entrapping free intra-abdominal blood clots that remained in the peritoneal cavity following trauma or surgery, the omentum prevents them from getting attached to other organs (Ryan et al., 1971).

Fig. 2: Adherence of the greater omentum of a dog to an enlarged spleen containing a nodular mass (source: Department of Medicine and Clinical Biology of Small Animals, Ghent University).
1.4.2. Fat storage

The omentum contains variable amounts of fat. In obese animals, it is one of the main fat repositories (Evans, 1993). The more traditional view on adipocytes being passive cells for energy storage has recently been adjusted. The fat cell has been rediscovered as a much more active participant in physiological homeostasis through the regulated release of hormones and cytokines (Huffman and Barzilai, 2009; Lotatti et al., 2009).

The anatomical distribution of the adipose tissue seems to be a strong predictor for adverse health outcomes. Visceral adiposity in humans appears to be linked to a higher risk of diabetes, polycystic ovary syndrome, hypertension and cardiovascular disease in comparison to overweight individuals with fat stored predominantly in subcutaneous sites (Montague and O’Rahilly, 2000; Després and Lemieux, 2006; Cortón et al., 2007; Lafontan and Girard, 2008; Huffman and Barzilai, 2009; Fain, 2010). It remains unclear how exactly visceral fat is linked to an enhanced risk of metabolic disturbances in humans (Montague and O’Rahilly, 2000; Després and Lemieux, 2006; Fabbrini et al., 2010; Fain, 2010). Several mechanisms have been postulated in humans. Firstly, visceral fat could be uniquely deleterious because of its direct venous drainage to the liver in which it releases free fatty acids (FFA) and hormones/cytokines (Rebuffé-Scive, 1990; Montague and O’Rahilly, 2000; Després and Lemieux, 2006; Girard and Lafontan, 2008; Lafontan and Girard, 2008). Free fatty acids play a role in the pathogenesis of hepatic insulin resistance (Rebuffé-Scive, 1990; Girard and Lafontan, 2008; Lafontan and Girard, 2008).

Secondly, visceral fat has unique metabolic and endocrine properties as compared to subcutaneous fat (Montague and O’Rahilly, 2000; Lafontan and Girard, 2008; Fain, 2010). Recent research has demonstrated a diversity of cytokines, growth factors and proteins involved in vascular haemostasis, glucose haemostasis, angiogenesis and acute phase responses, secreted by adipocytes (Mohsen, 2010). Studies comparing omental, mesenteric and subcutaneous fat indicated that the two visceral fat depots have more in common with each other than with the subcutaneous fat depots (Fain, 2010). Although the list of mRNAs expressed by omental and mesenteric fat shows similarities, it also shows differences indicating that they too are different tissues (Fain, 2010). It has been suggested that due to a higher intra-abdominal pressure in obesity, the arterial perfusion of visceral fat is decreased. Subsequently, the visceral adipocytes are more prone to hypoxia than subcutaneous adipocytes. This might result in an increased release of adipokines (cytokines and chemokines produced by adipose tissue) (Evans, 2009). It is certainly clear that the protein profile released
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by omental fat differs from that released by subcutaneous fat (Lafontan and Girard, 2008; Fain, 2010). Studies have been performed to pinpoint differences in gene expression, hormonal sensitivity and release of adipokines by both visceral and subcutaneous fat. So far, however, these comparisons provide few clues to explain the putative harmful effect of an enhanced accumulation of visceral fat (Girard and Lafontan, 2008; Fain, 2010; Van de Velde et al., 2013). A recent study in cats demonstrated an altered location-dependent adipokine profile in obese cats compared to lean cats. In contrast to what can be noted in humans, subcutaneous fat in cats seemed to be more involved in the development of an inflammatory response compared to visceral fat (Van de Velde et al., 2013).

The third theory is that the visceral adiposity in itself is not pathological but is a marker for a genetic and/or environmental mix that may lead to disease. Furthermore, either one of the above described hypotheses does not exclude a contribution of the other (Montague and O'Rahilly, 2000).

1.4.3. Lymphatic and tissue fluid drainage

The omentum has an enormous ability to absorb fluid (Goldsmith, 1996; Goldsmith, 2012). The blood supply and blood/lymph drainage must play a crucial role in order for the omentum to perform its drainage function in an effective way (Ackermann et al., 1991). However, the exact underlying mechanisms and the relative role of the blood and lymph vessels remain unclear in current literature. For example, when the omental vessel network is interrupted or divided during surgical tailoring in human patients, the omentum seems to retain its capability to decrease edema at the recipient position (Hultman et al., 2002).

Peritoneal stomata are considered to be the principal pathways for the drainage of intraperitoneal fluids and/or cells to the submesothelial lymphatic system (Wassilev et al., 1998). Clinically they provide the basis for the absorption of ascites, intraperitoneal chemotherapy and for the therapeutic transfusion of blood cells (Wang et al., 2010). At the level of these lymphatic stomata, mesothelial cells form a continuous layer with endothelial cells lining the submesothelial lymphatic lacunae (Wilkosz et al., 2005). They are involved in the clearance of free peritoneal fluids but also in the sequestration of pathogens and tumor cells (Wassilev et al., 1998). Some authors describe their presence in humans and rodents as limited to the peritoneal surface of the diaphragm (Abu-Hijleh et al., 1995; Wilkosz et al., 2005). Others describe their distribution in those species at additional sites of the peritoneal surface including the sites where the omental milky spots are located (Wassilev et al., 1998;
This finding is contradicted by researches who claim that the gaps between the mesothelial cells overlying the milky spots, do not appear to form channels typical of lymphatic stomata (Wilkosz et al., 2005). These openings provide a means of communication between the milky spots and the peritoneal cavity, but they do not represent passage to underlying lymphatic vessels as is the case for diaphragmatic stomata (Cranshaw and Leak, 1990).

The omentum has a notable rich lymphatic network. According to Nylander and Tjernberg (1969) very fine lymph channels, provided with valves, are located parallel to the blood vessels. The collecting vessels communicate with the lymphatics from stomach and spleen (Nylander and Tjernberg, 1969). Omental lymphatics in humans often begin at the level of the milky spots and drain into lymph collectors. These lymphatic capillaries take part in the absorption of substances from the peritoneal cavity (Shimotsuma et al., 1993). However, it remains controversial whether or not the omentum makes a significant contribution to the lymphatic drainage of the peritoneal cavity. Although the lymphatic capillary network is extensive, the calibre of collecting vessels is rather limited (Nylander and Tjernberg, 1969). The major peritoneal efferent route is probably through the stomata of diaphragmatic lymphatics while the omentum provides an additional but incidental route (Nylander and Tjernberg 1969; Williams and White, 1995). Cells probably leave the peritoneal cavity mainly through the diaphragmatic stomata. Material absorbed by the omentum may eventually find its way to the diaphragmatic lymphatics through an indirect route (Mironov et al., 1979). Primarily, however, the omentum seems to act as a first defence mechanism in the peritoneal cavity. It retains particulate matter and bacterial invasions (through the resident macrophages), rather than removing them through omental lymphatics (Abu-Hijleh et al., 1995).

The arrangement of the submesothelial glomerular-like dense omental capillary beds, found in humans (Shimotsuma et al., 1989), rats (Ackermann et al., 1991) and mice (Dux, 1988), may reflect the functional activity of the mesothelium. Some of these tortuous capillaries demonstrate bulges and dilations. The larger surface areas and the retardation of blood flow enhance the exchange of substances across the capillary wall (Ackermann et al., 1991). The mesothelial gaps and the abundance of capillaries that are fenestrated at the level of the milky spots clearly facilitate the exchange of particulate matter, solutes and cells between the blood stream and the peritoneal cavity (Hodel, 1970).
1.4.4. Immune function

The omentum plays a key role in the immunity of the peritoneal cavity (Platell et al., 2000; Zareie et al., 2006). In humans and laboratory animals, any intra-abdominal irritation (e.g. due to mechanical injury, chemical agents or microorganisms) activates the milky spots. The milky spots increase in number and size while adipocytes disappear and phagocytic cells appear (Wijffels et al., 1992; Liebermann-Meffert, 2000; Wilkosz et al., 2005; Zareie et al., 2006; Litbarg et al., 2007). Milky spots are probably crucial in local macrophage generation (Wijffels et al., 1992). Under inflammatory conditions, most free peritoneal macrophages are derived from monocytes that are produced in bone marrow. In contrast, during the normal steady state, peritoneal resident macrophages seem to be derived from locally proliferating progenitor cells in the milky spots (Shimotsuma et al., 1993). Moreover, milky spots in mice represent a microenvironment in which precursor cells of the mononuclear phagocyte system house and proliferate (Wijffels et al., 1992). However, in the untriggered omentum of dogs no organized immune aggregates could be detected, but only limited numbers of leukocytes, macrophages and neutrophils scattered throughout the omental connective tissue (Huyghe et al., 2015).

The endothelium which lines the omental capillaries and the discontinuous mesothelial lining at the level of the milky spots allow a free communication between the milky spots and the peritoneal cavity (Hodel, 1970; Liebermann-Meffert, 2000). Whenever necessary, the intercellular gaps between the mesothelial cells represent a gateway for peritoneal macrophages and lymphocytes (Mironov et al., 1979; Krist et al., 1995; Cui et al., 2002; Berberich et al., 2008). Occasionally, mesothelial cells may even be covered on the milky spot surface by 2 to 3 layers of macrophages, which can trap and digest antigens in the peritoneal cavity (Shimotsuma et al., 1993). Mast cells are present in relatively high concentrations in human milky spots and accumulate in activated omentum. The proximity of the mast cells to blood vessels is significant because degranulation and release of vasoactive amines increases permeability (Williams and White, 1995; Zareie et al., 2006). As such, mast cells in milky spots probably play a regulatory role in the function of blood vessels (Shimotsuma et al., 1991).

Activated omentum becomes rich in immunomodulating cells and omnipotent stem cells (Shah et al., 2012). In laboratory animals, the omental milky spots show distinct T-cell and B-cell areas, specific macrophage subsets and specific reactions after immunization. This led to the introduction of the term omentum-associated lymphoid tissue (OALT), in analogy
with other membrane-associated lymphoid tissue such as BALT (bronchial) and GALT (gut). However, these findings could not be confirmed in humans in whom no specific T-cell and B-cell areas could be located (Beelen, 1992). These data suggest that the omentum should not be regarded as a secondary lymphoid organ, but rather as a potent immunomodulating organ (Shah et al., 2012). The immune function of the healthy omentum in dogs seems to lie in a more biding role since there is a complete lack of OALT (Huyghe et al., 2015).

1.4.5. Angiogenesis

The angiogenic properties of the omentum have been documented since the 16th century, mainly referring to empirical observations and clinical experience (Zhang et al., 1997). These insights and theories support the potential angiogenic nature of the omentum and have led to a broad range of surgical applications. Nonetheless, the underlying cellular mechanisms of omental angiogenesis and angiogenic factors, remain to be unraveled (Zhang et al., 1997; Zareie et al., 2006). The superficial capillary network on the omental surface is a potential origin for new capillary buds that can sprout following adequate stimulation (Williams and White, 1995). A number of cells have been claimed to induce angiogenesis. Angiogenesis-inducing cells include adipocytes (Zhang et al., 1997), endothelial cells (Takada et al., 1999), mesothelial cells (Sako et al., 2003), hematopoietic progenitor cells (García-Gómez et al., 2005), mast cells (Zareie et al, 2006) and omental stromal cells that express pluripotent markers (Singh et al., 2008). Data suggest that mainly Vascular Endothelial Growth Factor (VEGF) is responsible for the enhanced angiogenic activity of the omentum in the setting of ischemia and/or injury (Zhang et al., 1997). VEGF is a powerful growth factor that induces new vessel formation. Other factors such as Fibroblast Growth Factors (FGFs) also contribute to the endothelial mitogenic activity of the omentum, although probably to a lesser degree (Zhang et al., 1997; Litbarg et al., 2007; Singh et al., 2008). Additionally, FGF-2 is considered to be a potent inducer of VEGF in various cell types (Sako et al., 2003).

1.4.6. Neurotrophic property

The omentum itself is a proven source of neurotrophins in humans and rodents. It produces factors with neurotrophic potential and does not merely accumulate or stimulate the production of these substances in other areas (Siek et al., 1988; Dujovny et al., 2004; Zhan et al., 2011). The production of Nerve Growth Factor (NGF), Brain Derived Neurotrophic Factor (BDNF) and neurotrophins 3, 4 and 6 have been suggested (Siek et al., 1988; Dujovny et al., 2004; Zhang et al., 2011). Moreover, VEGF is reported to have neurotrophic properties
that stimulate axonal outgrowth, and survival and promotion of Schwann cells independent of the increased vascularisation (Zhang et al., 2011). Studies have shown that the omentum also incorporates neurotransmitters and gangliosides (McIntosh and Goldsmith, 1988; Siek et al., 1988; Goldsmith, 1994). The exact role of these neurotrophic factors needs to be determined (Siek et al., 1988). In dogs, the presence or production of these factors in the omentum has not yet been studied.

1.4.7. Hemostasis

Thromboplastin has a critical function in hemostasis and thrombogenesis. The concentration of thromboplastin is impressively high in the omentum, in contrast to the concentration of thromboplastin in other tissues such as muscle or subcutaneous fat (Logmans et al., 1995).

1.4.8. Presence of stem cells

Reports in rodents (Shah et al., 2012; Garcia-Gomez et al., 2014) and humans (Shah et al., 2015) suggest that the omentum contains cells that have stem cell functions, which create a regenerative microenvironment. Therefore, current research focuses on these subsets of cells that accumulate in the activated omentum. Studies are performed on their potential effect on tissue repair and regeneration after omental transposition (Shah et al., 2012).

1.5. Surgical applications involving the greater omentum

1.5.1. Reconstructive procedures

The unique healing power of the omentum has been realized since long by human surgeons. They observed its capability to spontaneously extend itself and fuse to an intraperitoneal injured site and its capacity to improve healing and prevent infection.

The surgical transposition of the omentum relies on its extraordinary features. The omentum is a source of angiogenic and neurotrophic factors. It acts as a reservoir of peritoneal immune cells (Liebermann-Meffert et al., 1983; de La Torre and Goldsmith, 1988; Hosgood, 1990; Logmans et al., 1996, Zhang et al., 1997; Dujovny et al., 2004). Now that the underlying biological factors are being studied and better understood, the omentum is applied in many creative ways by human surgeons. Applications go further than just wrapping omentum around an intestinal anastomosis site to promote healing (Adams et al., 1992). The omentum can nowadays even be applied to repair extraperitoneal injuries. To reach extra-abdominal sites the omentum is either lengthened in a manner that its blood vessels are
preserved (omentum transposition) or it is transposed as a detached piece of tissue (free omental graft) (Litbarg and Singh, 2010; Baltzer et al., 2015).

The omentum is not routinely applied in veterinary medicine, although most veterinary surgeons do acknowledge its exceptional wound healing capacities and make good use of it at the end of abdominal procedures. In particular, extra-abdominal applications seem less integrated, although chronic axillary (Brockman et al., 1996; Lascalles et al., 1998; Lascelles and White, 2001; Gray, 2005) and inguinal wounds (Watkins and Thomas, 1985; Williams and White, 1986) are well-known indications for omental transposition.

**Techniques**

In humans and companion animals, the greater omentum can be easily mobilized in its entirety to reach practically any spot within the abdominal cavity e.g. to reinforce suture lines. Sometimes surgical lengthening of the omentum is necessary to reach areas within the peritoneal cavity (in humans) or areas of the body distant from the abdomen (in humans and companion animals) (Alday and Goldsmith, 1972; Ross and Pardo, 1993; Brockman et al., 1996).

The omentum can be used as a free graft (Pap-Szekeres et al., 2003; Baltzer et al., 2015), as a pedicle flap (Alday and Goldsmith, 1972; Ross and Pardo, 1993), as a gastric wall island flap based on an omental pedicle (Papachristou and Fortner, 1977) or as a gastro-omentoinal free flap (Chahine, 2009). Free omental grafts demand microvascular surgical techniques, which are complicated and difficult (Pap-Szekeres et al., 2003, Lascalles et al., 1998) and have not always been proven successful in dogs (Roa et al., 1999). Free omental grafts without microvascular anastomosis have also been applied in orthopedic surgery in dogs (Baltzer et al., 2015). One must consider the sequel of the complete disruption of the lymphatic system with a free graft. This is a potential negative feature that raises the possibility of fluid accumulation in the area of the free graft (Goldsmith, 1996).

In humans, the first surgical step to lengthen the omentum with preservation of its original blood supply, is to dissect it from its attachment to the transverse colon, along the avascular plane. Next, the gastroepiploic arch is mobilized from the greater curvature of the stomach, and the left or right gastroepiploic artery is transected at its origin. When more length is surgically desired, the omental apron is further divided by an L-shaped incision (Alday and Goldsmith, 1972).
Occasional reports on the use of an omental pedicle flap in companion animals describe different techniques. They either refer to lengthening techniques reported in human medicine (Bright and Birchard, 1982; Bright and Thacker, 1982; Hosgood, 1990) or to the experimental evaluation of an omental pedicle extension technique in dogs (Ross and Pardo, 1993) (Fig. 3). The latter is a two-step procedure that includes a dorsal extension (involving the deep wall of the bursal portion being freed from its pancreatic attachment) followed by an inversed L-shaped incision starting from the left omental edge. This technique is based on the canine vascular anatomy described by Gravenstein (1938).

The omental pedicle is transferred to the extra-abdominal site either through the initial celiotomy wound or through a separate transverse body wall incision (Williams and White, 1995). Care should be taken to avoid torsion of the pedicle. To reach the recipient place, the omentum is passed through a subcutaneous tunnel (Fig. 4). Alternatively, in thoracic procedures, the omentum can be pulled through a substernal tunnel at the margin of the diaphragm or through a lateral diaphragmatic incision (Hosgood, 1990; Williams and Niles, 1999; Shrager et al., 2003). At the end of the procedure, the abdominal wall defect is kept large enough in order not to impede omental vascular flow (Hosgood, 1990).
Fig. 3: Omental pedicle extension technique in dogs. Schematic drawing of a ventral view of the oesophagus (a), stomach (b), duodenum (c), spleen (d), part of the tendinous centre of the diaphragm (p), the superficial (j’) and deep (j’’) omental wall of the bursal portion. A, B: Step one of the lengthening procedure described by Ross and Pardo (1993). Caudal reflection of the deep wall of the bursal portion after separation of its pancreatic attachment. C: Step two of the omental pedicle extension technique involves an inversed L-shaped incision starting from the left omental edge (Ross and Pardo, 1993).

Indications

Gastrointestinal surgery

Omental wrapping is a valuable tool for the protection of gastrointestinal anastomoses and is routinely used for this indication in cats and dogs (Hosgood, 1990). Application of the omentum adds a supplementary layer and a biologically viable plug. Moreover, it also provides a source of granulation tissue and additional blood supply and it stimulates immunogenic activity that aids in the local containment of small leaks (Carter et al. 1972; Williams and White, 1995). In particular the esophagus and the rectum might benefit from omental reinforcement after anastomotic surgery, since they both lack serosal lining, rendering them more prone to postoperative leakage (Carter et al., 1972). In a prospective, randomized study in humans, omentoplasty seemed to be effective in lowering the rate and the severity of anastomotic leakage after colorectal surgery (Agnifili et al., 2004). However, the beneficial effects of reinforcing rectocolonic anastomoses with omentum have been
doubted by others (Carter et al., 1972; Merad et al., 1998). The omentum did strengthen the anastomosis in the immediate postoperative period (Carter et al., 1972). But, long-term results in experimental animal models and prospective human clinical trial showed no improvement in the prevention of leakage (Carter et al., 1972; Merad et al., 1998).

**Urogenital surgery**

The omentum is commonly applied in humans in the repair of vesicovaginal fistulas, particularly when associated with radical radiotherapy in cancer treatment (Williams and White, 1995). In partial resection and omentalisation of prostatic cysts in dogs, the omentum provides beneficial features that reduce complications and recurrence (Bray et al., 1997). It provides continued drainage and enhanced immunologic protection against ascending infection from the prostate or urogenital tract. The omentum creates adhesions at the operative site, but also minimizes the risk of visceral adhesion (Bray et al., 1997).

Increasing knowledge on the omental properties leads to new surgical indications. As a source of adult stem cells, it was recently recommended to bring the omentum in contact with the remnant kidney after partial nephrectomy to preserve and possibly improve renal function (Garcia-Gomez et al., 2014).

**Thoracic surgery**

In human medicine omental transposition is frequently applied for chest wall reconstruction after surgery related to breast cancer and its treatment (Williams and White, 1995) or for the treatment of massive sternotomy wounds (Hultman et al., 2002). The omentum can also be transposed through the diaphragm to reach intrathoracic anatomical structures (Levashev et al., 1999). Omentopexy can improve vascularization and decrease stricture formation after primary esophageal anastomosis (Hayari et al., 2004). Still, the omentum is most widely used in thoracic surgery for the filling of dead spaces in case of chronic empyema, in the treatment of mediastinitis and for encircling the bronchial stump or tracheal anastomosis after broncho- and tracheoplastastic procedures (Levashev et al., 1999).
Fig. 4: Surgical treatment of a dog with a chronic inguinal wound by omental transposition. A: Open wound in the right groin. B: A subcutaneous tunnel is prepared. C-E: Through the tunnel, first a drain is passed to mobilize the omentum asatraumatically as possible. F: The omentum is transposed through the tunnel and positioned in the wound, followed by wound closure (source: Department of Medicine and Clinical Biology of Small Animals, Ghent University).

Neurosurgery

It has been suggested that the omentum provides a unique endogenous system for the sustained delivery of blood flow and neurotrophic substances (de la Torre and Goldsmith, 1988; McIntosh and Goldsmith, 1988; Siek et al., 1988; Goldsmith, 2009; Dujovny et al., 2004). These are two prerequisites of regenerative therapy for neurologic disorders and neurodegenerative diseases (Goldsmith, 2009; Dujovny et al., 2004). In dogs, experimental
placement of a pedicled omentum onto brain and spinal cord results in the development of blood vessels that penetrate directly in the underlying neurologic structures (Goldsmith, 1975a; Goldsmith, 1975b). Some human patients with specific neurologic pathologies showed clinical improvement following omental transposition on the central nervous system. This might have been due to an increased vascular perfusion in addition to the production of neurotrophic factors (McIntosh and Goldsmith, 1988; Siek et al., 1988; Goldsmith, 1994). Omental transposition to the brain in Alzheimer’s patients has shown to improve cognitive functions or at least has shown to slow down the decline (Goldsmith, 2002; Goldsmith, 2011). The discussion remains, however, whether this disease is a primary vascular disease that causes degenerative changes or a neurodegenerative process that affects cerebral vascularization. Furthermore, in patients with poorly controlled epileptic seizures, omental transposition on the epileptogenic foci has been suggested as a treatment option (Rafael et al., 2002).

Application of the omentum might be beneficial after trauma of the spinal cord due to its revascularization and absorption capacities. Acute spinal cord injury followed by oedema and hemorrhage leads to the formation of scar tissue (Goldsmith, 2009). Axons are unable to penetrate the scar tissue to make neurological connections distal to the injury site. In addition, fibrinogen inhibits neurite outgrowth by triggering an inhibitory signal transduction pathway to neurons (Goldsmith, 2009). An intact vascularized omental pedicle transposed directly on the acute traumatized spinal cord helps to absorb blood, fibrinogen and edema. As such, it reduces the formation of scar tissue (Goldsmith, 2009). In case of chronic spinal cord injuries, the existing scar tissue needs to be excised. In some cases the excision will include a portion of the spinal cord itself. In animal experimental studies (mainly cats) and in an isolated human case, the defect created by excising scar and spinal cord tissues has been successfully corrected by constructing an omental-collagen bridge. This procedure even resulted in neurological improvement (de la Torre and Goldsmith, 1988; de la Torre and Goldsmith, 1994; Goldsmith et al., 2005; Goldsmith, 2012). Other researchers, however, were unable to demonstrate the beneficial effects of the omental transposition on chronic spinal cord injuries (Clifton et al., 1996). The treatment of pathologies involving cerebral ischemia such as cerebral infarction may also benefit from omental transposition due to its angiogenic capacities (Goldsmith, 1975a; Goldsmith, 1999). The potential of omental application in peripheral nerve defects was tested in a rodent model (Zhang et al., 2011). In the repair of large nerve defects, the combined usage of a nerve scaffold with omental wrapping showed
promising results including axonal regenerations and motor function recovery (Zhang et al., 2011).

Reconstructive Surgery

In companion animal surgery, omental transposition to extra-abdominal locations is mainly applied for reconstructive procedures. Chronic non-healing wounds represent a daunting challenge to the surgeon, especially in areas where mechanical factors such as tension and motion play a role, e.g., in the axillary region. Other factors such as poor vascularisation or excessive dead space may contribute to the chronicity of these wounds and complicate surgical treatment (Brockman et al., 1996; Lascelles et al., 1998).

The size and plasticity of the greater omentum are highly beneficial properties in reconstructive surgery. Its plasticity makes it suitable to fill irregular cavities and allows it to respect and re-establish normal body contours (Petit et al., 1979; Williams and White, 1995; Valat and Moisonnier, 2004). Furthermore, it has a large surface area, and its pliability prevents scar and contracture formation (Williams and White, 1995). Omental bulk is useful to obliterate dead space after extensive eliminative procedures (Williams and White, 1995). Infected, irradiated and ischemic wounds, in particular, are good indications for reconstruction with omentum (Petit et al., 1979; Hultman et al., 2002).

Human patients with failed reconstruction involving regional muscle or fasciocutaneous flaps are often salvaged with the omentum (Hultman et al., 2002). In dogs, omentum has been used in the repair of thoracic wall (Bright and Birchard, 1982) and for diaphragmatic defects (Bright and Thacker, 1982), in wound management (Smith et al., 1995) (Fig. 4) and in the treatment of sublumbar abscesses (Woodbridge et al., 2014). In cats, wounds in the axilla frequently occur due to forelimb entrapment within a collar. These wounds are associated with certain factors that contribute to the chronicity of wounds, such as copious exudation, excessive skin-to-wound contact and motion, and the presence of hair foreign bodies. In these cases the omentum provides a permanent drain and improves the ability to resist infection and fills dead space (Brockman et al., 1996; Lascelles et al., 1998; Lascelles and White, 2001; Gray, 2005).
The omentum applied as a physiological drain

Omental transposition can be considered as a physiologic drain. It is applied in dogs for the treatment of chylothorax, particularly in those cases where thoracic duct ligation had failed or is not possible (Williams and Niles, 1999). Hepatic, pancreatic and prostatic abscesses or cysts and axillary wounds have been treated in companion animals through omentisation (White and Williams, 1995; Bray et al., 1997; Lascelles and White, 2001; Pavletic, 2010; da Silva and Monnet, 2011). In a canine experimental model, microsurgical transfer of the omentum was successful in the treatment of obstructive lymphedema of the lower limb (O’Brien et al., 1990). However, in a series of human patients who underwent omental transposition for the treatment of chronic lymphedema, clinical results were variable (Goldsmith, 1974). The omental drainage capacity has also led to the application of omental pedicles in human patients with communicating hydrocephalus, specifically in those cases in which severe and persistent complications occur with conventional shunt treatment (ventriculo-peritoneal or –atrial shunting) (Berger et al., 1988; Levander et al., 2010).

1.5.2. Ablative procedures

Omental surgery not only includes reconstructive but also ablative procedures (omentectomy). Parts of the omentum are frequently excised in humans in case of trauma, herniation, torsion or intra-abdominal tumors. Total omentectomy is less frequent but can be an integral part of abdominal oncological surgery (Williams and White, 1986).

In contrast to primary malignancy in the omentum, the presence of metastatic tumors in the omentum occurs frequently (Williams and White, 1986). In humans, ovarian carcinoma is the most common origin of omental metastatic deposits. Omentectomy is part of the standard surgical treatment in these cases, both therapeutically and/or for accurate staging of the tumoral process (Williams and White, 1995). The omentum, and in particular the milky spots, seems to be a fertile soil for cancer growth (Williams and White, 1986). The exact function and clinical relevance of omental milky spots in oncology remain to be unraveled and discussion persists. Do these structures primarily localize metastatic intra-abdominal tumor cells, which would favor omentectomy as part of early stage intra-abdominal cancer treatment in humans? Or do these structures primarily clear malignant cells from the peritoneal cavity? In the latter case omentectomy would be dissuaded for intra-abdominal tumors since this would impair defense mechanisms and facilitate tumor dissemination (Van Vugt et al., 1996; Beelen et al., 2005).
A reduction of the visceral fat is considered an important target of obesity therapy (Lafontan and Girard, 2008). In the rat model, but also in studies in human (Thörne et al., 2002) and canine patients (Lottati et al., 2009), data indicated that surgical reduction of visceral fat improves insulin sensitivity (Huffman and Barzilai, 2009). Other authors, in contrast, did not find an improvement in insulin sensitivity in obese human adults through omentectomy (Csendes et al., 2009; Fabbrini et al., 2010).

1.5.3. Potential surgical applications

Our knowledge on the multiple and diverse functions of the omentum is rapidly evolving. New insights in its fundamental biological mechanisms lead to new clinical applications. Especially in the field of stem cell research and tissue reconstruction, the potential use of the omentum remains to be fully explored (Collins et al., 2009). Omental application in support of tracheal prosthesis has been studied experimentally (Kim et al., 2004). Its extraordinary healing capacities may be harnessed in tissue transplantation. More recently, in human medicine the use of an omental flap, as site of transplantation of pancreatic islets in the treatment of diabetes mellitus came to the foreground (Chaffanjon et al., 2005; Shah et al., 2012). The omentum may be used as an in vivo bioreactor for e.g. in bladder tissue engineering (Baumert et al., 2007). Furthermore, researchers have reported omental application to improve bone healing in nonunion fractures in dogs, in experimental models (Bigham-Sadegh et al., 2012) and in clinical cases (McAlinden et al., 2012; Baltzer et al., 2015).
CHAPTER 2: SCIENTIFIC AIMS
CHAPTER 2: SCIENTIFIC AIMS

Literature describes extraordinary characteristics of the omentum, which are highly beneficial when implemented in several surgical techniques. Despite these encouraging findings, the use of the omentum is not yet imbedded to its full potential in veterinary surgery. Still, dogs have frequently served as research models to explore omental surgical applications in humans. Furthermore, despite the use of canine models, these applications have often not been transposed to companion animal patients. There is a clear lack of detailed anatomical data on the canine omentum and their vascular supply. This, in turn, restricts veterinary researchers and clinicians to explore and implement new techniques in companion animal medicine and/or to communicate the results of these studies correctly. In other words, the current anatomical nomenclature of the canine omentum hinders unambiguous scientific communication and indirectly scientific research. On the other hand, present surgical techniques on the canine omentum are based upon one anatomical vasculature study performed in one single dog only.

The general aim of this thesis is to provide anatomical data on the omentum of the dog and more specifically

- to map anatomical landmarks that will facilitate unambiguous scientific communication on the canine omentum,

- to expand the current knowledge on the canine omental vasculature.

The fragile and malleable nature of the omentum demands creative solutions to gain accurate insights into the anatomical layout of the canine omentum. Hence, in order to reach these aims it was necessary to develop a hands-on study tool.

New anatomical insights might alter the vision on currently applied surgical techniques. Therefore, we aimed to evaluate the current lengthening technique based on the results of the vasculature study and to examine whether a novel lengthening technique of the canine omentum might better respect the vascularization of the flap.
CHAPTER 3: MORPHOLOGY OF THE CANINE OMENTUM:
ARTERIAL LANDMARKS THAT DEFINE THE OMENTUM

This chapter is adapted from:

3.1. Abstract

Although the omentum remains an enigmatic organ, research during the last decades has revealed its fascinating functions including fat storage, fluid drainage, immune activity, angiogenesis and adhesion. While clinicians both in human and veterinary medicine are continuously exploring new potential omental applications, detailed anatomical data on the canine omentum are currently lacking and information is often retrieved from human medicine. In the present study, the topographic anatomy of the canine greater and lesser omentum is explored in depth. Current nomenclature is challenged and a more detailed terminology is proposed. Consistent arteries that are contained within folds of the superficial omental wall are documented, described and named, as they can provide the anatomical landmarks that are necessary for unambiguous scientific communication on the canine omentum. In an included dissection video, the conclusions and in situ findings described in the present study are demonstrated.
3.2. Introduction

The greater and lesser omentum (Omentum majus and Omentum minus) are peritoneal sheets that originate from the embryonic dorsal and ventral mesogastrium, respectively (Evans, 1993; McGeady et al., 2006; Barone, 2009). During fetal development, the mesogastria lose their initial role of anchoring the stomach to the dorsal and ventral body walls. They are charged with blood vessels and lymphatics that run in fatty streaks. As the greater curvature of the developing stomach topples to its final position, the dorsal mesogastrium elongates and is drawn to the left. Its double layer of mesothelium reflects, lining a cavity that will become the omental bursa (Bursa omentalis). From this stage of development onwards, the dorsal mesogastrium consists of a superficial and a deep wall (Noden and De Lahunta, 1985; McGeady, 2006).

In dogs, the greater omentum is remarkably large and extends as a double-folded structure from the stomach to the urinary bladder, covering the intestinal coils ventrally and bilaterally. The greater omentum is classically subdivided into a bursal, a splenic and a veil portion (Zietzschmann, 1939; Evans, 1993; Budras, 2002; Barone, 2009). The bursal and splenic portions are composed of two walls, viz. a superficial wall (Paries superficialis) and a deep wall (Paries profundus) (Budras, 2002). In the veil portion, however, both walls fuse during embryonic development (Zietzschmann, 1939). The lesser omentum is small and relatively simple. It spans the area lined by the liver, the lesser curvature of the stomach and the cranial part of the duodenum (Barone, 2009). Based on the site of attachment, it is subdivided into the hepatogastric ligament (Ligamentum hepatogastricum) and the hepatoduodenal ligament (Ligamentum hepatoduodenale), the latter of which contains the portal vein, the hepatic artery and the common bile duct (Evans, 1993; Barone, 2009).

After Otto Zietzschmann meticulously described the topographical anatomy of the canine omentum in 1939, some nomenclature introduced in this pioneer study is no longer commonly applied, and little additional research has been performed on the gross anatomy of the omentum of the dog. However, there is a need for more detailed anatomical data since surgical applications of the omentum are continuously being developed not only in human medicine (Liebermann-Meffert, 2000) but also in small animal veterinary medicine (Valat and Moisonnier, 2004). The anatomy and physiology of the omentum turn the organ into a very beneficial tool for a variety of intra- and extra-abdominal surgical procedures (Fix and Vasconez, 1989; Ross and Pardo, 1993; Hultman et al., 2002; Ito et al., 2010). Due to its large surface area, pliability, malleable volume, generous pedicle length and extremely rich blood
supply, the omentum is particularly fit to treat infected, irradiated and ischemic wounds such as radiation injuries of the chest wall in humans (Fix and Vascone, 1989; Hultman et al., 2002) or chronic axillary wounds in cats (Gray, 2005). In dogs, the omentum is also used as a physiological drain in the surgical management of prostatic abscesses and cysts (White and Williams, 1995). Moreover, the omentum is a reservoir of peritoneal immune cells and a source of angiogenic and neurotrophic factors (De la Torre and Goldsmith, 1988; Zhang et al., 1997; Dujovny et al., 2004). The latter may play an important role in the future treatment of some neurological conditions (Goldsmith, 2010). The omentum has also been identified as a source of adult stem cells, opening future prospects in the field of tissue engineering and the synthesis of vascular grafts in human medicine (Collins et al., 2009). For extra-peritoneal wounds, the omentum can be harvested for a microsurgical free graft, or it can be mobilized as a pedicle flap (Hultman et al., 2002). Knowledge on the attachment of the omentum to surrounding structures and on its vascular supply is obviously prerequisite for these surgical applications. In fact, in human medicine, the refinement of anatomic knowledge and the development of safe mobilization techniques have paralleled the increased use of the omentum in reconstructive and cardiovascular surgery (Fix and Vascone, 1989; Hultman et al., 2002). Although dogs and cats have frequently served as research models to explore these omental surgical applications in humans (Goldsmith, 1975; De la Torre and Goldsmith, 1994; Hayari et al., 2004), detailed anatomical data on the canine and feline omenta and their vascular supply are scarce. Consequently, the surgical techniques used in these exploratory studies, as well as those subsequently applied in companion animal patients, often improperly rely on human data.

Furthermore, in microscopic studies on the omentum of small animals, researchers have few anatomical landmarks to meticulously describe the place of sampling (Owaki et al., 2013). As a result, the nomenclature used in the current scientific literature on omental research in dogs and cats is based on either non-detailed veterinary anatomical terminology or ill-extrapolated human data.

The main goal of the present study was to map anatomical landmarks that will improve unambiguous scientific communication on the canine omentum. In the second part of the study (Chapter 4) the recesses of the omental cavity will be described and discussed in detail.
3.3. Materials and Methods

A total of 9 cadavers of dogs of different gender, age and breed were used (Table 1). Different techniques including casting of the blood vessels, dissection of embalmed cadavers and filming of a dissected fresh cadaver were implemented to illustrate observations. All animals had been euthanized for reasons unrelated to this study. In 6 dogs, latex injection and vessel dissections were performed. All dogs were positioned in dorsal recumbency. The thoracic cavity was opened through a rectangular window (approximately 6x4 cm) in the left 4th-6th intercostal space. A 20 Gauge intravenous catheter was placed in the thoracic aorta and secured by an encircling ligature just caudal to the aortic arch, and a 3-way stopcock was connected. Subsequently, 150-700 ml of an aqueous latex solution (Polyester Demaere©, Belgium) was injected into the catheter. After curing of the latex for at least 2 hours, the abdominal wall was incised along the ventral midline, and the peritoneal cavity was opened from the xiphoid cartilage to the pecten of the pubic bone to explore and dissect the injected blood vessels. Additionally, the abdominal cavities of 2 female embalmed dogs with injected blood vessels (Carolina’s Perfect Solution©, USA) were dissected to confirm previously gained insights and to illustrate some anatomical features more clearly due to the rigidity of the embalmed cadavers (Fig 3).

Table 1: List of dogs and techniques used in the present study

<table>
<thead>
<tr>
<th>Breed</th>
<th>Age group</th>
<th>Sex (F=female, M=male)</th>
<th>Implemented techniques</th>
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<tr>
<td>American Stafford</td>
<td>Young Adult</td>
<td>F neutered</td>
<td>Vascular casting with latex</td>
</tr>
<tr>
<td>English Cocker Spaniel</td>
<td>Young Adult</td>
<td>F</td>
<td>Vascular casting with latex</td>
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<tr>
<td>American Stafford</td>
<td>Young Adult</td>
<td>M neutered</td>
<td>Vascular casting with latex</td>
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<tr>
<td>Mongrel dog</td>
<td>Young Adult</td>
<td>M</td>
<td>Vascular casting with latex</td>
</tr>
<tr>
<td>Jack Russell terrier</td>
<td>Adult-Geriatric</td>
<td>F</td>
<td>Vascular casting with latex</td>
</tr>
<tr>
<td>Cairn terrier</td>
<td>Young Adult</td>
<td>F</td>
<td>Vascular casting with latex</td>
</tr>
<tr>
<td>Mongrel dog</td>
<td>Young Adult</td>
<td>F</td>
<td>Embalmed with injected blood vessels (*)</td>
</tr>
<tr>
<td>Mongrel dog</td>
<td>Young Adult</td>
<td>F</td>
<td>Embalmed with injected blood vessels (*)</td>
</tr>
<tr>
<td>Rottweiler</td>
<td>Immature</td>
<td>F</td>
<td>Dissection+video</td>
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(*Carolina’s Perfect Solution©, preserved dog, double color injected)

Finally, to illustrate the three-dimensional topographic anatomy of the greater omentum in situ, the omentum of a fresh cadaver was filmed while being dissected via a ventral midline approach. The resulting video can be consulted by opening the following URL: www.UGent.be/canine-omentum.
3.4. Results

In all dogs, the greater omentum was composed of a bursal, a splenic and a veil portion. The former two portions consist of a superficial and a deep wall, whereas the veil portion is a single peritoneal fold. The omentum contains several arteries, of which the topographic anatomy provides the landmarks necessary to delineate the various omental parts.

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Fig. 5: Schematic drawing of abdominal organs (stomach, spleen and left lobe of the pancreas) with supplying arteries and attached omentum, based on cadaveric dissections. A: Ventral view. B: Dorsal view.

a. Oesophagus, b. Stomach, c. Duodenum, d. Spleen, h. Left pancreatic lobe, j. Bursal portion (j’ superficial wall, j” deep wall), k. Splenic portion (k’ superficial wall, k” deep wall), p. Part of the tendinous centre of the diaphragm, q. Attachment of the deep omental wall to the dorsal abdominal wall (transected)

3.4.1. Arterial landmarks

The omental blood vessels are either located in the fatty streaks of the omental wall or are contained within folds of the superficial wall of the greater omentum, which protrude into the omental bursa (video).

The major blood supply of the bursal portion is derived from the gastroepiploic arterial arch. This anastomosis between the left and right gastroepiploic arteries (A. gastroepiploica sinistra and A. gastroepiploica dextra, respectively) is located in the superficial wall of the bursal portion, parallel to the greater curvature of the gastric corpus and pylorus. The left and right gastroepiploic arteries have a different origin. The right gastroepiploic artery is located in the pyloric region and stems from the short gastroduodenal artery (A. gastroduodenalis), which is a branch from the hepatic artery (A. hepatica) (Fig. 5, video). After arising from the celiac artery (A. celiaca), the hepatic artery courses cranioventrally towards the liver in a peritoneal fold extending from the dorsal abdominal wall, the hepatopancreatic fold (Plica hepatopancreatica) (Fig. 7C). The left gastroepiploic artery stems from the splenic artery (A. lienalis), which arises from the celiac artery and is located in the deep wall of the greater omentum in which it runs parallel to the left pancreatic lobe. At the level of the lateral tip of this pancreatic lobe, the splenic artery gives off a large gastrosplenic branch and continues towards the splenic hilus. The gastrosplenic branch gives rise to a splenic branch that supplies the dorsal part of the spleen and a cranial gastric branch that curves ventrally towards the fundus of the stomach and which it supplies by several short gastric arteries (Aa. gastricae breves) (Fig. 5, video). The cranial gastric branch is contained within a fold of the superficial wall of the greater omentum, which will be further referred to as the cranial gastrosplenic fold (Fig. 6). After giving rise to the gastrosplenic branch, the splenic artery continues its course in the deep wall of the greater omentum towards the middle segment of the spleen and proceeds along the splenic hilus. However, before reaching the hilus the artery gives off two strong branches, i.e., the left gastroepiploic artery and a second strong arterial branch that will be further referred to as the caudal gastric branch and that ramifies in short gastric arteries to the gastric fundus (Fig. 5, video). Occasionally, the caudal gastric branch arises directly from the left gastroepiploic artery (Fig. 5). Both the left gastroepiploic artery and the caudal gastric branch are contained in folds of the superficial wall of the splenic portion, designated as the caudal and middle gastrosplenic fold respectively (Fig 6).
3.4.2. Omental portions

The bursal portion of the greater omentum covers the intestinal coils both ventrally and bilaterally. Its superficial wall originates from the greater curvature of the stomach, extending from the gastric fundus to the pylorus and continuing onto the proximal part of the duodenum in alignment with the attachment of the lesser omentum to the duodenum (Ligamentum hepatoduodenale). The superficial wall extends along the ventral abdominal wall as far as the empty urinary bladder. To the right, caudally and also to the left (i.e., caudal to the spleen) the superficial wall of the bursal portion reflects dorsally and continues as the deep wall. The deep wall of the bursal portion proceeds cranially, attaches to the left lobe of the pancreas, encompasses this pancreatic lobe and then continues craniodorsally to attach to the dorsal abdominal wall (Fig. 7B). The left cranial edge of the bursal portion is attached to the hilus of the spleen. However, the ventral extremity of the spleen remains unattached to omentum (video). The cranial border of the deep wall of the bursal portion is delineated by the splenic artery (Fig. 5, video).

The splenic portion of the greater omentum also consists of a superficial and a deep wall. At the level of the spleen, i.e., in the left cranial area of the abdomen, the superficial wall of the splenic portion is continuous with the superficial wall of the bursal portion. The border between the superficial walls of the bursal and splenic portions can be set at the level of the caudal gastrosplenic fold containing the left gastroepiploic artery. The superficial wall
of the splenic portion is bordered medially by the stomach and laterally by the cranial half of the splenic hilus. The splenic portion then extends further craniodorsally beyond the spleen, forming a cranial protrusion consisting of a superficial and a deep wall. Both walls attach medially to the cardia of the stomach and the oesophagus, and insert cranially on the tendinous centre of the diaphragm, lining the left half of the oesophageal hiatus (Fig. 5, video). The caudal border of the superficial wall of the cranial protrusion is delineated by the cranial gastroplenic fold, whilst the caudal border of the deep wall of this protrusion is delineated by the gastroplenic branch of the splenic artery (Fig. 5, video).

Between the cranial and caudal gastroplenic folds, the superficial wall of the splenic portion forms a semilunar pouch, further referred to as the caudoventral outpocketing of the splenic portion (video).

![Image](image_url)

**Fig. 7:** A, B, C: Caudal-to-cranial views of the cranial abdominal viscera of an embalmed dog A: The right lateral margin of the omental veil portion blends with the left side of the descending mesocolon. The asterisk indicates the fat-free fold that splits off from the left lateral side of the omental veil and attaches to the visceral surface of the spleen. B: The transverse colon is retracted dorsally to show the attachment of the deep wall of bursal portion of the greater omentum (j”) to the left pancreatic lobe (h) (asterisks). C: The omental bursa is opened by transecting the deep wall of the bursal portion from its attachment to the left pancreatic lobe which is reflected dorsally. The single arrow indicates the hepatopancreatic fold (with the hepatic artery) and the double arrows point to the gastropancreatic fold (with the left gastric artery).


The deep wall of the splenic portion is divided into cranial and caudal parts by the position of the gastroplenic branch of the splenic artery. The caudal part is bordered laterally by the splenic hilus and both medially and caudally by the splenic artery which courses towards the splenic hilus and delineates the border between the deep walls of the bursal and
splenic portions of the greater omentum. The caudal part of the deep wall of the splenic portion forms a semilunar pouch, which is further referred to as the caudodorsal outpocketing of the splenic portion (Fig. 5, video).

The veil portion, which was remarkably large in some dogs, is characterized by a free caudal margin. Its cranial margin originates from the deep wall of the omentum at the level of the splenic artery. The right lateral margin of the veil portion blends with the left side of the mesocolon. The left lateral margin is attached to the ventral part of the visceral side of the spleen. Perpendicular to the left lateral margin a small triangular fat-free fold splits off from the dorsal surface of the veil portion and protrudes towards the spleen (Fig. 7A, video).

3.5. Discussion

The present observations of the canine omentum largely correspond to those described in the literature (Evans, 1993; Barone, 2009). The subdivision of the greater omentum into bursal, splenic and veil portions has been set a long time ago (Zietzschmann, 1939), but the definition of the exact borders between those individual omental portions was lacking until now. Moreover, some previous definitions of omental parts are ambiguous. Since research on the omentum and its clinical applications is increasing, there is a need for clear definitions.

In the present study, we attempted to set consistent and unambiguous borders for omental portions, resulting in specific definitions and a more detailed nomenclature for the canine omentum. To a large extent, these margins are defined by arterial landmarks. The smaller proper omental arteries run in the fatty streaks of the omental walls while some of the larger arteries, supplying the omentum and the attached organs (stomach and spleen), are contained within folds of the superficial wall of the greater omentum that protrude into the bursal cavity of the omentum. These arteries provide some of the landmarks that are necessary to define the various parts of the omentum properly.

The canine splenic artery presents a variable branching pattern resulting in a variety of descriptions and confusing nomenclature in the literature (Gravenstein, 1938; Horst, 1941; Godinho, 1964). Yet, some consistent findings were confirmed in the present study. Shortly after its origin from the celiac artery, the splenic artery bifurcates into a proximal and a distal branch (Gravenstein, 1938; Horst, 1941; Godinho, 1964; Barone, 1996). In all cases in the present study, this bifurcation was situated at the level of the lateral tip of the left pancreatic lobe. The proximal branch provides blood supply to the dorsal part of the spleen (through splenic branches) and additionally to the stomach (through short gastric arteries).
Chapter 3: Morphology of the canine omentum: arterial landmarks that define the omentum

(Gravenstein, 1938; Horst, 1941). This proximal branch corresponds to the gastrosplenic branch as defined in international nomenclature in pigs (Simoens, 2012). It was previously described as occasionally double and contained within a fold of the superficial wall of the splenic portion (Gravenstein, 1938; Horst, 1941). We found in all cases a single gastrosplenic branch, which ramified into a splenic branch and a cranial gastric branch. The latter was contained within the cranial gastrosplenic fold of the superficial wall of the splenic portion. The splenic artery proceeds its course towards the splenic hilus. Before reaching the hilus, it gives rise to the left gastroepiploic artery, which is also contained in a fold of the superficial omental wall (Gravenstein, 1938, Horst, 1941, Evans, 1993). This fold, which we named the caudal gastrosplenic fold, is located in the transition zone between the superficial walls of the bursal and splenic portions (Horst, 1941). Hence, it serves as a clear and consistent border between both omental portions.

The short gastric arteries arise from the cranial gastric branch and the left gastroepiploic artery, but they can also originate from an additional arterial branch, which was previously described as originating directly from the splenic artery (Gravenstein, 1938) or from the left gastroepiploic artery (Horst, 1941). This double origin was confirmed in the present study as both were observed and we designated this branch as the caudal gastric branch. It was consistently present and was contained within the middle gastrosplenic fold, serving as a landmark to define the splenic portion. A variety of smaller additional branches of the splenic artery have been described in the literature (Gravenstein, 1938, Horst, 1941) and were also found in the present study. Given their inconsistent pattern they cannot serve as landmarks to define omental portions. The same is true for smaller arteries that supplied the splenic portion itself and arose from the splenic artery or from one of its major branches. Those arteries ran superficially and in variable patterns in the fatty streaks of the splenic portion.

A precise delineation and definition of the gastrosplenic (Ligamentum gastrolienale), gastrophrenic (Ligamentum gastrophrenicum) and phrenicosplenic (Ligamentum phrenicolienale) ligaments is lacking in traditional descriptions and in official nomenclature. The gastrosplenic ligament extends from the greater curvature of the gastric fundus to the spleen (Habel, 2012). The attachment of the spleen to the superficial wall of the omentum has been considered as the cranial border of the gastrosplenic ligament (Barone, 2001). No clear caudal border has been defined. In the present observations, the gastrosplenic ligament was bordered cranially by the cranial gastrosplenic fold and caudally by the caudal gastrosplenic
fold. While this gastrosplenic ligament could clearly be defined, we failed to observe a distinct gastrophrenic ligament, which has been described as a short and robust ligament loaded with fibro-elastic fibers (Barone, 2001). It has been reported as extending between the gastric fundus and the diaphragm and continuing to the left as the phrenicosplenic ligament, which connects the diaphragm and the spleen (Barone, 2001; Barone, 2009; Habel, 2012). These ligaments have been assigned a suspensory role of the stomach and the spleen, respectively (Barone, 2001). Such strong and well delineated ligaments could not be demonstrated in the present study, but instead we observed a cranial protrusion of the splenic portion of the greater omentum, composed of both a superficial and a deep wall. This protrusion consisted of loose omental tissue, making a suspensory role doubtful. Considering these findings, one might question whether the term ligament is appropriate for this structure since a ligament is defined as an inelastic structure that joins two organs or connects an organ to the body wall in a solid way (Barone, 2001).

The gastrosplenic ligament has been considered as a synonym of the splenic portion of the greater omentum (Evans, 1993; Barone, 2001; Budras, 2002; Könich and Liebich, 2004; Barone, 2009). Based on the present findings, however, both terms are not synonymous because the splenic portion is an omental portion with a superficial and a deep wall, and includes a cranial protrusion that extends craniodorsally beyond the cranial margin and the dorsal extremity of the spleen. In contrast, the gastrosplenic ligament is a mere part of the superficial wall of the splenic portion, bordered by the cranial and caudal gastrosplenic folds.

The veil portion of the omentum (Velum omentale) is the sagittal membrane that connects the deep wall of the greater omentum with the left surface of the descending mesocolon (Habel, 2012). According to some authors (Evans, 1993), it contains the distal extremity of the left pancreatic lobe. This could not be confirmed in the present study. Other discrepancies were noted concerning the free margin of the veil portion, which has been described as a left free margin (Evans, 1993), whereas we observed a caudal free margin in the present study.

The findings of the present study lead to a number of recommendations for elaboration of the existing official nomenclature (N.A.V., 2012). In addition to the Plica hepatopancreatica and the Plica gastropancreatica, which are listed in the current N.A.V., it is suggested to include also the terms Plica gastrolienalis cranialis, Plica gastrolienalis intermedia and Plica gastrolienalis caudalis for designating the omental folds that were
observed consistently in the present study and contain major blood vessels which form valuable topographic landmarks for delineating various omental parts.

In contrast, the Ligamentum gastrophrenicum and the Ligamentum phrenicolienale, which are listed in N.A.V. without any species designations, were not observed as clearly delineated structures in any of the dogs examined in the present study.

Similar to the situation in pigs, a gastroplenic branch was given off by the A. lienalis in all examined dogs and therefore, it is suggested to list the term Ramus gastrolienalis for both the porcine and canine species. Furthermore, two constant arterial branches were given off either indirectly or directly by the A. lienalis in all dogs examined, and they were designated as the Ramus gastricus cranialis and the Ramus gastricus caudalis, respectively.
CHAPTER 4: MORPHOLOGY OF THE CANINE OMENTUM: THE OMENTAL BURSA AND ITS COMPARTMENTS MATERIALIZED AND EXPLORED BY A NOVEL TECHNIQUE

This chapter is adapted from:

4.1. Abstract

The canine omental bursa is a virtual cavity enclosed by the greater and lesser omentum. While previous representations of this bursa were always purely schematic, a novel casting technique was developed to depict the three-dimensional organization of the omental bursa more consistently. A self-expanding polyurethane-based foam was injected into the omental bursa through the omental foramen in 6 dogs. After curing and the subsequent maceration of the surrounded tissues, the obtained three-dimensional casts could clearly and in a reproducible way reveal the omental vestibule, its caudal recess and the three compartments of the splenic recess. The cast proved to be an invaluable study tool to identify the landmarks that define the enveloping omentum. In addition, the polyurethane material can easily be discerned on computed tomographic images. When the casting technique is preceded by vascular injections, the blood vessels that supply the omentum can be outlined as well.
4.2. Introduction

The greater and the lesser omentum (Omentum majus resp. Omentum minus) are peritoneal folds that originate from the dorsal and ventral mesogastrium, respectively (Barone, 2009). The canine greater omentum is remarkably large and extends from the stomach to the urinary bladder, covering the intestinal coils ventrally and laterally. It can be subdivided into bursal, splenic and veil portions (Zietzschmann, 1939). Except for the latter, each omental portion is composed of two layers, a superficial wall (Paries superficialis) and a deep wall (Paries profundus), which enclose a virtual space indicated as omental bursa (Bursa omentalis) (Budras, 2002). The omental bursa is roughly the sum of (1) the omental vestibule (Vestibulum bursae omentalis), which is enclosed by the lesser omentum, the stomach and the liver, (2) the caudal omental recess (Recessus caudalis omentalis) which is enclosed by the greater omentum, and (3) the splenic recess (Recessus lienalis) which extends at the left extremity of the omental bursa and is enclosed by the gastrophrenic, phrenicosplenic and gastrosplenic ligaments (Ligamentum gastrophrenicum, phrenicolienale and gastrolienale) (Habel, 2012).

Creative solutions are needed to gain accurate insights into the anatomical layout of the canine omentum. As a matter of fact, it is impossible to fully explore the omentum in its unaltered topographic organization within the abdominal cavity because the omentum is flaccid and its different portions are folded. In order to properly visualize and describe these portions, they need to be stretched and separated from each other (Dux, 1988). Earlier anatomical research on the canine omentum has been performed ex vivo. Zietzschmann (1939) provided schematic representations of the omental walls based on findings after the in toto excision of the omentum along with the adjacent abdominal organs. Additional anatomical schemes were provided by other authors in various handbooks (Ackerknecht, 1943; Adams, 1986) (Fig. 8). In an alternative approach in rodent cadavers, whipped egg white was successfully injected into the omental bursa in order to stretch and separate the delicate bursal walls (Dux, 1988). This renders the possibility to examine the omental vascular pattern or take histological samples of each omental wall separately. Given the far larger volume of the canine omental bursa compared to the murine model, a novel technique was developed to cast the virtual spaces enclosed by the canine omenta. Moreover, by materializing the bursa a hands-on omental study tool is created and vascular landmarks that define the different omental portions are visualized (for a full overview: see Chapter 3).
Chapter 4: Morphology of the canine omentum:
The omental bursa and its compartments materialized and explored by a novel technique

Fig. 8: Classic schematic representations of the greater and lesser omentum and the omental bursa. Adapted from A: Zietzschmann (1939), dorsal view; B: Ackerknecht (1943), caudocranial view; C: Adams (1986), right lateral view.

a. Stomach c. Spleen, d. Liver, e. Pancreas, g. Bursal portion of the greater omentum (g’ superficial wall, g” deep wall), h. Splenic portion of the greater omentum, i. Veil portion of the greater omentum, m. Lesser omentum, n. Ventral mesogastrium, o. Dorsal mesogastrium, p. Omental foramen, r. Caudal recess of the omental bursa.

4.3. Materials and Methods

Five fresh canine cadavers of different gender, age and breed were used (Table 2). All animals had been euthanized for reasons unrelated to this study. Each cadaver was placed in dorsal recumbency. The abdominal wall was incised in the ventral midline and the peritoneal cavity was opened from the xiphoid cartilage to the pecten of the pubic bone. The descending part of the duodenum was identified and pulled towards the midline, in order to uncover the omental foramen.

A polyurethane-based foam (PU-schuim©, Hubo, Wommelgem, Belgium) was used as casting material. It is a single component, self-expanding, high yield polyurethane-based foam, containing polymethylene polyphenyl isocyanate and a gaseous propellant. The foam is available in a pressurized aerosol can with a foam dispenser and a removable flexible cannula (diameter: 8 mm). The foam expands until counterpressure is met. When the prepolymer is
expelled from the can, the foam reacts with ambient moisture and cures. According to the manufacturer, the time of complete curing depends on the level of humidity and ranges from 1 to 2 hours (between 5°C and 35°C).

The flexible cannula was placed into the omental foramen and was manually held in place. Subsequently, the air compressed can was connected to the cannula and the foam was ejected. After expulsion, solidification of the polymer began immediately, making the foam less malleable. Because of the fragility of the omentum, the injection pressure was kept as low and as constant as possible by moderating digital pressure on the dispenser. During the entire procedure the omentum was minimally manipulated to avoid tears and subsequent leakage of foam, and therefore only slight manual pressure was applied to assist the polyurethane spreading uniformly in the bursa. Since the foam is self-expanding and volume occupying, the closely huddled omental walls were separated by the polymer without manual aid. Injection was stopped when the foam was uniformly spread and visible in every bursal compartment. As soon as the solidification had proceeded to such an extent that the foam would no longer leak through the omental foramen (approximately 10 to 15 minutes), the cannula was removed. The cadavers were then left undisturbed overnight at room temperature. During the entire solidification period, further expansion of the polymer was observed. After complete curing of the foam, the cast of the omental bursa (enveloped by the different parts of the omentum) was first examined in situ (Fig. 9). Leakages that had occurred, in spite of all precautions, could easily be recognized by the lack of smooth lining and by the absence of overlying tissue. In the rare occasion of leakage, the escaped polymer was cut off the cast. Subsequently the bursal cast together with the liver, stomach, greater and lesser omentum, spleen, small intestines and kidneys were excised as a whole and immersed in a solution of 25% potassium hydroxide (KOH). Weights were used to keep the cast submerged. After this maceration step the cast was immersed in a solution of 10% hydrogen peroxide (H₂O₂) in order to remove the last remnants of organic material, i.e., mostly fatty tissue of the omentum. In all cases the corrosion casts proved to be stable, hands-on study tools showing ample morphological details (Fig. 10).

In an additional dog, an older female Maltese dog (Table 2), omental casting was preceded by arterial injection of contrast loaded latex. This dog was put in dorsal recumbency and the thoracic cavity was opened through a rectangular window (approximately 6x4 cm) extending from the 4th to the 6th left intercostal space. A 20 Gauge intravenous catheter supplied with a 3-way stopcock was placed and secured into the thoracic aorta just caudal to
the aortic arch. Immediately before injection, the latex (casting material) was mixed with a contrast agent (Ultravist® (Iopromide), Bayer) in a 5:1 ratio (30mL/150mL) to create sufficient radio-opacity for detection by means of CT imaging.

Once the vascular cast had been completed, the omental bursa was approached through a ventral midline abdominal incision that was extended paracostally to the right. After inserting the flexible cannula into the omental foramen, the abdominal incision was closed completely, apart from the exit opening of the cannula. Subsequently, the air compressed device was connected to the cannula and the foam was expelled until abdominal expansion became apparent. After 15 minutes the cannula was removed, the remaining abdominal opening was sutured and the cadaver was left undisturbed overnight to allow the polymer to cure. The next day, the dog was positioned in dorsal recumbency on the table of a 4 slice helical CT scanner (Lightspeed Qx/i, General Electric Medical Systems, Milwaukee, WI). Contiguous transverse 1.25 mm thick slices with an overlap of 0.6 mm were obtained from the mid-thoracic until the lumbosacral region, parallel to the intervertebral disc spaces. Settings for the CT procedure were 120 Kvp and 120 mA using a bone and soft tissue
The DICOM data were retrieved and loaded into the Amira 4.0.1 (Visage Imaging GmbH, Berlin, Germany) application (Casteleyn et al., 2010). The projections of the stomach, duodenum, spleen and arterial tree on every fifth section image were labeled manually with the brush and/or lasso tools in the segmentation editor. The sections in-between were subsequently labeled through the interpolation command (Cornillie et al., 2008). The grey-tone values of the vertebral column and bursal cast were adequately distinct to allow an automatic segmentation (Fig. 11). After CT imaging, the abdomen of the dog was opened and the bursal cast was examined in situ, macerated following the same procedures as in the other dogs, and used to interpret the CT images.

Table 2: List of dogs and techniques used in the present study

<table>
<thead>
<tr>
<th>Breed</th>
<th>Age group</th>
<th>Sex (F=female, M=male)</th>
<th>Implemented techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jack Russell terrier</td>
<td>Young Adult</td>
<td>M</td>
<td>Polyurethane casting of the omental bursa</td>
</tr>
<tr>
<td>Golden Retriever</td>
<td>Adult-Geriatric</td>
<td>M neutered</td>
<td>Polyurethane casting of the omental bursa</td>
</tr>
<tr>
<td>American Stafford</td>
<td>Immature</td>
<td>M</td>
<td>Polyurethane casting of the omental bursa</td>
</tr>
<tr>
<td>Mongrel dog</td>
<td>Young Adult</td>
<td>F</td>
<td>Polyurethane casting of the omental bursa</td>
</tr>
<tr>
<td>Jack Russell terrier</td>
<td>Young Adult</td>
<td>M</td>
<td>Polyurethane casting of the omental bursa</td>
</tr>
<tr>
<td>Maltese dog</td>
<td>Adult-Geriatric</td>
<td>F</td>
<td>Polyurethane casting of the omental bursa + vascular casting with latex mixed with Iopromide (5:1) + CT</td>
</tr>
<tr>
<td>Rottweiler</td>
<td>Immature</td>
<td>F</td>
<td>Dissection+video</td>
</tr>
</tbody>
</table>

Finally, to illustrate the three-dimensional topographic anatomy of the greater omentum in situ, the omentum of a fresh cadaver was filmed while being dissected via a ventral midline approach. The resulting video can be consulted by opening the following URL: www.UGent.be/canine-omentum.
Chapter 4: Morphology of the canine omentum: The omental bursa and its compartments materialized and explored by a novel technique

4.4. Results

4.4.1. Omental bursa

In all dogs the greater omentum consisted of a bursal, a splenic and a veil portion. The former two portions clearly consisted of a superficial and deep wall. The omental bursa delineated by these two portions was successfully casted. In contrast, the veil portion consisted of a single sheet. Consequently, it did not participate in the formation of the bursa.

The casted omental bursae consistently demonstrated three recesses, i.e. the caudal omental recess (Recessus caudalis omentalis), the splenic recess (Recessus lienalis) and the omental vestibule (Vestibulum bursae omentalis). The folds of the superficial wall containing the arterial landmarks (see Chapter 3) clearly left impressions in the corrosion casts of the omental bursa in the form of deep clefts. These landmarks contributed to the demarcations of the aforementioned recesses and of additional compartments within the splenic recess (Fig. 10, video). The splenic recess was indeed further subdivided into a cranial, a caudoventral and a caudodorsal compartment, which were enclosed by the homonymous parts of the splenic portion of the greater omentum. The cranial gastrosplenic fold set the border between the cranial and caudoventral compartments. The caudal gastrosplenic fold formed the border between the caudal omental recess and the splenic recess, whilst the caudal omental recess was evenly enveloped by the bursal portion of the greater omentum (Fig. 10, video).

The vestibule of the omental bursa was delineated ventrally by the lesser omentum, dorsally by the dorsal abdominal wall, caudally and bilaterally by the lesser curvature of the stomach and cranially by the liver. The papillary process of the caudate lobe of the liver protruded into the vestibule in all cases. The opening of the vestibule to the caudal omental recess (Aditus ad recessum caudalem) was delineated to the left by the gastropancreatic fold (Plica gastropancreatica) containing the left gastric artery, and to the right by the hepatopancreatic fold (Plica hepatopancreatica) containing the hepatic artery. Ventrally this opening was bordered by the lesser curvature of the stomach and dorsally by the left pancreatic lobe (See Chapter 3, Fig. 3C).
4.4.2. Casting technique

Success of the casting technique highly depends on the condition of the cadaver. In one dog the bursal part of the greater omentum was found adhering to a thickened segment of the intestinal wall. At this spot the omentum was very fragile and tore by even the slightest manipulation while injecting the foam. In that particular dog only the splenic recess and the vestibule of the omental bursa were successfully casted. In another cadaver spontaneous tears arose locally while injecting the foam without any macroscopic identifiable reason.

Fig. 10. A, B: Left lateral view (right border of the image = cranial, top border of the image = ventral) and C,D: ventral view of a polyurethane cast of a canine omental bursa after maceration in KOH and H₂O₂ (same cast as Fig. 9). In the cast imprints of attached and surrounding organs such as the stomach, spleen and kidney are marked. The cranial, middle and caudal gastrosplenic folds caused deep fissures in the cast. In this particular case the left gastroepiploic artery gave origin to an additional arterial branch that supplied short gastric arteries and that was contained within a fold (v*) (C). The fatty streaks containing the proper omental vessels only caused shallow grooves.

q. Vestibule of the omental bursa, r. Caudal recess of the omental bursa, s. Splenic recess of the omental bursa (s’ cranial compartment, s” caudoventral compartment, s”’ caudodorsal compartment), t. Cleft in the cast caused by the cranial gastrosplenic fold, u. Cleft in the cast caused by the middle gastrosplenic fold, v. Cleft in the cast caused by the caudal gastrosplenic fold, w. Impression in the cast left by the stomach, x. Impression in the cast left by the spleen, y. Impression in the cast left by the left kidney, z. Impression in the cast left by fatty streak
4.5. Discussion

The fragile and malleable nature of the omentum demands a specific approach to univocally map its anatomical configuration. Traditionally, researchers took refuge in schematic representations (Fig. 8). Dux et al. (1993) proposed a technique based on injections with chicken’s egg white into the omental bursa, to separate the superficial and deep walls of the greater omentum in rodents to sample the tissue without damaging. Although such an approach is not realistic in larger animals such as dogs, the idea to cast the omental bursa proved to be crucial in the creation of an omental study tool. By materializing this space, the landmarks that border the enveloping omental parts were much easier visualized.

In the splenic portion of the greater omentum, the impressions of the folds of the superficial wall invaginating and therefore compartmentalizing the omental bursa were clearly demonstrated in all bursal casts. As such, the polyurethane-based casting technique enabled us to conclusively visualize the different compartments of the splenic recess which to date, although already described and defined by Otto Zietzschmann in 1939, still have not found recognition in the current official nomenclature (N.A.V., 2012).

The omental bursa as a whole is typically defined as the virtual space enclosed by the greater and lesser omentum, the stomach and the liver (Evans, 1993; Habel, 2012). The spleen is not mentioned in these definitions as a bounding organ. However, in the present study, the spleen was clearly shown to occupy a substantial part of the left border of this space. With regard to its compartmentalization, the omental bursa is described in literature as being the sum of the vestibule of the omental bursa with a dorsal recess, the caudal omental recess and the splenic recess (Habel, 2012), although some authors do not differentiate between the caudal omental and splenic recesses and consider the latter as an integral part of the former (Könich and Liebich, 2004).

The vestibule of the omental bursa is the antechamber of the omental bursa (Zietzschmann, 1939; Evans, 1993). It is enclosed by the lesser omentum, the stomach and the liver (Könich and Liebich, 2004; Habel, 2012). In carnivores, like in ruminants, the papillary process of the liver projects into this cavity (Habel, 2012). The vestibule of the omental bursa is said to possess a minor dorsal diverticulum (Recessus dorsalis omentalis) bordered cranially by the right crus of the diaphragm, caudally by the liver, ventrally by the oesophagus and dorsally by the caudal vena cava (Habel, 2012), to the left by the gastrophrenic ligament
Chapter 4: Morphology of the canine omentum: The omental bursa and its compartments materialized and explored by a novel technique

(Lig. gastrophrenicum) and to the right by the coronary ligament (Lig. coronarium hepatis) (Barone, 2001). According to Evans (1993), however, this dorsal recess is bounded by the lesser omentum, the liver and the lesser curvature of the stomach, and by this definition the proper vestibule is therefore restricted to merely the antechamber of the omental bursa, from which a much larger dorsal recess radiates. We considered the vestibule following the first definition. All bursal casts in the present study included a vestibule in which the papillary process of the caudate lobe of the liver protruded. This compartment was delineated ventrally by the lesser omentum, dorsally by the abdominal wall, caudally and laterally by the lesser curvature of the stomach and cranially by the liver. However, in contrast to the former description, in none of the casts could the presence of a dorsal recess radiating from this compartment be identified. On the other hand, in a similar study on the morphology of the omental bursa in horses, a distinct dorsal recess was demonstrated in all 30 casts of the vestibule of the omental bursa (van Bergen et al., 2014).

The caudal omental recess has been defined by some authors as the cavity enclosed by the greater omentum (Barone, 2001; König and Liebich, 2004; Habel, 2012), whereas others restrict it to the cavity enclosed by the bursal portion (Evans, 1993). The former definition could be rather confusing since it implies that the splenic recess is a subcompartment of the caudal omental recess which, at least according to the Nomina Anatomica Veterinaria (N.A.V., 2012), should not be the case. We found a large compartment enclosed by the bursal portion of the greater omentum in all the casts. This caudal omental recess was bordered by the stomach, the pancreas, the spleen and the free borders of the greater omentum. The boundary between this compartment and the splenic recess in the superficial wall was formed by the caudal gastrosplenic fold (Plica gastroleniens caudalis) (see Chapter 3, for description of this fold). This border was clearly discernible in all casts by the presence of a deep fissure caused by the protrusion of that fold. In the deep wall the boundary between the caudal and splenic recesses was formed by the splenic artery which left shallow but distinct imprints in all casts.

The splenic recess is defined as the left extension of the omental bursa enclosed by the gastrophrenic, gastrosplenic and phrenicosplenic ligaments (Lig. gastrophrenicum, Lig. gastroleniens and Lig. phrenicolienale, respectively) (Habel, 2012). Zietzschmann (1939) previously described this recess in detail, which he referred to as the Recessus (bursae omentalis) gastroleniens communis. Our observations of the splenic recess are very similar to his descriptions, despite some topographical inconsistencies. Based on the ex vivo
examination after an excision of the omentum together with the adjacent abdominal organs, Zietzschmann (1939) subdivided the splenic recess into a dorsal, lateral and medial splenic recess (Recessus lienalis dorsalis, lateralis and medialis, respectively). Similarly, in the present study, the splenic recess in all bursal casts could be subdivided into three compartments. However, these compartments were topographically situated cranially, caudoventrally and caudodorsally respectively (Fig. 10). According to Zietzschmann (1939) the dorsal compartment of the splenic recess was not consistently present. In the present study the cranial compartment was identified in all the casts, although it did greatly vary in size. The folds, which contain the arterial landmarks and delineate the omental parts and bursal compartments, corresponded to those described by Zietzschmann (1939).

As the single-sheeted veil portion of the greater omentum (Velum omentale) does not participate in the delineation of omental bursa, it left no remains in the produced casts. As such, the present study did not allow us to confirm the originally double-sheeted origin of this portion, of which the superficial and deep walls are believed to fuse during development (Barone, 2009; Zietzschmann, 1939).

As for the casting technique, the search for a suitable medium to cast the canine bursa needed to address two main issues, i.e., the large volume of the bursa and the fact that the omental walls are extremely flaccid and provide very little counterpressure. Casting media based on methacrylate or epoxy resins, as often applied in vascular corrosion casting, are less suitable for voluminous organs since they produce relatively heavy casts, which may show distortions due to their own weight. The lack of elasticity of these media also results in unwanted breaking of the material during the casting procedure or subsequent maceration and handling (Viggiano et al., 2003; Krucker et al., 2006). Silicone rubber and latex are more elastic materials, but they do not offer dimensional stability and are not corrosion resistant (Meyer et al., 2007). The polyurethane elastomer (PU4ii®, VasQ Tec), recently introduced for corrosion casting of blood vessels, has been reported to result in elastic casts that retain the original shape of the vascular trees (Krucker et al., 2006; Meyer et al., 2007), but is rather expensive. Moreover, all aforementioned products are only available as liquid casting media. Since the omental walls yield easily to pressure, liquids would collect in a pocket at the lowest point of the cavity and would not spread uniformly. Therefore, they do not have the most suitable physicochemical properties. On the other hand, polyurethane-based foam, which is available in aerosol cans and which is widely applied as insulation material has an ideal consistency. Moreover, the self-expanding qualities of this foam make it a suitable
product to uniformly fill and cast larger volumes with thin, flexible and fragile walls. In addition, it ensures active filling of blind spaces. The casting technique with expanding polyurethane has previously been used successfully to cast the tracheal-bronchial tree, blood vessels and intestines (Viggiano et al., 2003; Casteleyn et al., 2009; De Sordi et al., 2014). The foam is hydrophobic and sticks to dry surfaces. Therefore, Viggiano et al. (2003) suggested to moisten the workbench and gloves as part of the casting procedure. However, in our study we found it unnecessary to take such preparatory measures since the foam was directly injected with the omentum still in situ, hence avoiding tissue desiccation or inadvertent contact of the foam with the equipment and tools. Furthermore, it turned out unnecessary to leave the cannula in place during the entire polymerization process to prevent reflux of the foam through the insertion place. During the casting of hollow organs with rigid walls such as bronchial trees or blood vessels, pressure may indeed build up excessively (Viggiano et al., 2003). However, the omentum is more flexible and the potential bursal space is voluminous. In addition, the gaseous component of the foam is most likely able to escape through pores in the omental lining, posing less problems with overpressure. Such microscopic pores have recently indeed been identified in the feline omentum (Owaki et al., 2013). In the present experiments, the cannula was only left in place until solidification started, but soon thereafter it was removed.

On no occasion was inconvenient leakage through the omental foramen encountered. Leakage, however, did occur when the correct placement of the flexible cannula into the omental foramen failed as experienced in preliminary studies in which a ventral midline approach was applied and direct view on the omental foramen was obscured (data not shown). To allow visual confirmation of the correct placement of the cannula, the internal organs were manually slightly shifted to the left to expose the omental foramen. However, in the dog used for the CT-study, it was opted to leave the internal organs as undisturbed as possible in order to minimize the deformation. Therefore, the ventral midline incision was extended paracostally to the right to directly approach the omental foramen. Subsequently, to prevent remnant free abdominal air negatively influencing the contrast on CT images, the abdominal incision was closed. Surprisingly, full abdominal exposure prior to CT imaging did not result in relevant loss of contrast. Presumably, the high abdominal pressure caused by the expanding foam had efficiently expelled the remaining free abdominal air through the suture line.

The foam kept expanding for hours after the injection. The degree to which the foam extended while curing, was not predictable. Therefore, it remains difficult to determine the
optimal amount of foam to be injected. The injection was stopped as soon as the foam was visually spreading into the complete bursa or, in the case when the abdomen was closed, until abdominal expansion became clear. The subsequent expansion of the foam gave extra volume to the cast. The outer surface of the cast was sliceable after two hours, which was in accordance to the foam’s technical manual.

The fragility of the omental walls remains a particular bottleneck in the study of this organ. During the solidification process the foam quickly becomes sticky. Manual aid in spreading the foam without tearing the omentum can then be difficult. The omentum is strategically placed in the peritoneal cavity to adhere to injured areas (Ryan et al., 1971). In one dog, focal adhesions of the omentum to adjacent tissues, as a remnant of an old inflammatory process, were present, and at these locations the omentum seemed more prone to tears.

The proposed study tool for the canine omentum was further optimized by simultaneous identification of its vasculature. In a pilot study in which different techniques for casting the omental blood vessels were explored (unpublished data), the production of vascular corrosion casts of the omentum seemed to be extremely difficult. The omental fat in which the blood vessels are embedded had the tendency to saponify during maceration rather than dissolving. Moreover, separating the superficial and deep walls of the omentum in order to chart the proper vasculature of each wall in an acrylic resin cast, without damaging the cast, is impossible. The flexible (but not corrosion resistant) latex turned out to be a suitable polymer to study the omental vasculature. It was thought that the non-destructive separation of the omental walls in the described polyurethane technique could be an asset to the omental vasculature research. However, on in situ examination of omental bursal casts combined with latex filled blood vessels, the vasculature outline remained unintelligible because some major supplying vessels were engulfed by the expanding polyurethane and as such became embedded in the cast. This issue can be overcome by the use of CT techniques. Vascular contrast injections are a valuable tool for the topographic evaluation of the vascular tree on CT-images (Rivero et al., 2009). Injection of latex loaded with contrast medium into the aorta just prior to the foam injection into the omental bursa allowed assessment of the main arterial omental supply on the CT-images of the final casts. The CT scanning of the cast resulted in grey-tone values that could be discerned from values of other surrounding air and gas filled structures, allowing automatic labeling and precise three-dimensional reconstruction.
Mapping smaller arteries in this setting was more difficult and not superior to in situ examination of the latex injected vessels without bursal casting.

4.6. Conclusion

The fragile and malleable nature of the omentum demands creative solutions for detailed morphological investigations. In the present study these challenges were faced by casting the omental bursa. One could argue that casting a virtual space can never provide a replica of the true in situ situation. However, the goal of this study was to develop a study tool and to challenge the traditional schematic representations of the omental walls. The cast remains an artificial representation and a distortion of reality, but this distortion was consistent. Furthermore, casting the omental bursa resulted in a hands-on, three-dimensional and reproducible study tool that showed anatomical landmarks that define the enveloping omentum. In addition, the reconstructed CT images proved to be a valuable tool to demonstrate the course of blood vessels that are engulfed by the foam.

The described technique has already successfully been adapted to cast and demonstrate the omental vestibule in horses (van Bergen et al., 2014) and further application of the technique might easily be extended towards morphological studies of many other virtual, expandable or fragile spaces such as the ovarian bursae, serosal cavities or fetal membranes, making it an interesting and promising anatomical study tool.
Chapter 4: Morphology of the canine omentum: The omental bursa and its compartments materialized and explored by a novel technique

Fig. 11: Three-dimensional reconstructions of CT images of a casted omental bursa and blood vessels, showing the stomach and duodenum, liver, spleen, arterial tree and the polyurethane cast. A-C: Ventral views (left side of the images = right) and D-F: left lateral views (top of the images = dorsal). The quadrangles indicate the dorsal (B) and sagittal plane (E), respectively, that result in the corresponding section planes (C and F, respectively). Notice that some vascular trunks that border different compartments of the omental bursa are engulfed by the expanded foam in some areas on the cast surface, while their course can be tracked in the section planes.

- a. Stomach, c. Spleen, d. Liver, r. Caudal recess of the omental bursa, s. Splenic recess of the omental bursa (s’ cranial compartment, s” caudoventral compartment), 1. Cranial gastric branch of the gastroplenic branch, 2. Left gastroepiploic artery
CHAPTER 5: THE OMENTAL PEDICLED FLAP IN DOGS REVISED AND REFINED: A CADAVER STUDY

This chapter is adapted from:

5.1. Abstract

Twenty canine cadavers were dissected to expand the current knowledge on the canine omental vasculature, and to refine the existing lengthening technique of the canine omentum. In 10 canine cadavers, the omental arteries were mapped through intravascular latex injection. Based on the results of the vascular study, an omental pedicled flap was created in 10 additional cadavers. An incision was made through both omental walls starting from the right free omental border and parallel to the gastroepiploic arterial arch. The incision was then lengthened caudally, parallel to the major omental arteries, thereby creating a pedicle supplied by the splenic artery. The superficial and the deep omental wall were each predominantly supplied by a left and a right marginal omental artery that anastomosed with each other near the caudal omental border into a superficial and a deep omental arch, respectively. Anastomoses between arteries of the superficial and the deep omental wall were weak and inconsistent, except for one anastomosis. By transposing the intact omentum, the right axilla could be reached in 3 dogs, both axillae in 1 dog and both groins in all cadavers. In all cases, the pedicled omentum reached to and beyond those main surgical regions of interest. By unfolding the pedicle walls, the width of the pedicle tip could be doubled.

It was concluded that, when lengthening of the omentum is required for extra-abdominal applications, the described pedicle technique seems to better respect the omental vascular supply than the currently applied technique.
5.2. Introduction

In the last decennia, the omentum has gained much attention in human surgery due to increasing evidence of its special features with a responsive development of new clinical applications, such as omental application to improve bone healing or to enhance survival of transplanted pluripotent stem cell-derived cardiomyocytes (Liebermann-Meffert, 1983; Collins et al., 2009; McCalinden et al., 2009; Kawamura et al., 2013). Surprisingly, veterinary surgeons have still not widely employed the omentum in their surgeries, although most of them do acknowledge its exceptional wound healing capacities and make good use of it at the end of abdominal procedures. Indeed, wrapping omentum around an intestinal anastomosis site is known to promote healing (Adams et al., 1992). Nevertheless, the use of the omentum is not imbedded in veterinary surgery to its full potential (Bright and Thacker, 1982; Hosgood, 1990). More in particular the extra-abdominal applications seem to be poorly integrated, although chronic axillary wounds (Brockman et al., 1996; Lascalles et al., 1998; Lascalles and White, 2001; Gray, 2005) and inguinal lesions (Watkins and Thomas, 1985; Williams and White, 1995; Hedlund, 2007) are well-known indications for omental flaps.

The omentum is a rich source of angiogenic and neurotrophic factors, it acts as a reservoir of peritoneal immune cells, is important for peritoneal lymphatic drainage, and it has adhesive properties, contributing to encapsulation of inflammatory processes and hemostasis (Liebermann-Meffert, 1983; De la Torre and Goldsmith, 1988; Hosgood, 1990; Logmans et al., 1996; Dujovny et al., 2004; Zhang et al., 2011b).

Given those extraordinary features and facilitated by its size and plasticity, reconstructive surgery can greatly benefit from the application of the greater omentum (Wein et al., 1980; Losken et al., 2002; Valat and Moisonnier, 2004). The omentum can be implemented as a free graft with or without microvascular anastomosis (Pap-Szekers et al., 2003; Baltzer et al., 2015) but microvascular transplantation is a complicated and difficult technique (Lascalles et al., 1998; Pap-Szekers et al., 2003). Free omental grafting is not commonly applied in veterinary surgery (Hosgood, 1990) and so far graft survival rates in dogs are poor (Roa et al., 1990). On the other hand, omental pedicled flaps are also described (Alday and Goldsmith, 1972; Ross and Pardo, 1993) and can reach remote areas. Occasional reports on the use of an omental pedicled flap in companion animals either refer to lengthening techniques reported in human medicine (Bright and Birchard, 1982; Bright and Thacker, 1982; Hosgood, 1990) or to experimental evaluation of an omental pedicle extension technique in dogs by Ross and Pardo (Ross and Pardo, 1993).
Obviously, a thorough knowledge of the vascular supply is essential to preserve the main omental vessels during surgical use of the greater omentum (Liebermann-Meffert, 2000). Extrapolation of human data is not recommended since the anatomy of the human and canine omentum shows fundamental differences (Ross and Pardo, 1993). However, the canine omental vasculature is still poorly documented. The only lengthening technique described for the canine omentum, is based on a detailed anatomical study; however, that original study (Gravenstein, 1938) was only performed in a single dog. Therefore, the aim of the present study was to expand the current knowledge on the canine omental vasculature and, based upon these results, to refine the existing omental flap technique for its practical application in dogs.
5.3. Materials and Methods

A total of 20 cadavers of dogs of different gender, age and breed, euthanized for reasons unrelated to this study, were used. All animals were positioned in dorsal recumbency. In 10 dogs, intra-arterial latex injection and subsequent vessel dissections were performed. The thoracic cavity was opened through a rectangular window (approximately 6x4 cm) in the left 4th-6th intercostal space. A 20 Gauge intravenous catheter was placed in the thoracic aorta and secured by an encircling ligature just caudal to the aortic arch, and a 3-way stopcock was connected. Subsequently, 150-700 ml of an aqueous latex solution (Polyester Demaere©, Belgium) was injected into the catheter whereafter the latex was allowed to cure for at least 2 hours. The abdominal wall was then incised along the ventral midline, and the peritoneal cavity was opened from the xiphoid cartilage to the pecten of the pubic bone to dissect and map the injected blood vessels.

In 10 additional canine cadavers, a novel lengthening technique, based on the results of the vasculature study, was performed. The abdomen was opened via a ventral midline approach; the greater omentum and spleen were exteriorized. The spleen was kept in its relative normal topographic position towards the stomach. The omentum was transposed cranially and caudally over the skin to evaluate which region could be reached without any further lengthening. When there was adequate length available to cover an anatomical region, the omentum was listed as capable to reach that region (Table 3; Fig. 12). Subsequently, a transverse incision was made through both omental walls, just caudal and parallel to the gastroepiploic arterial arch, starting from the right free omental border. After transecting 3 to 4 omental arterial branches, the incision was lengthened caudally, parallel to the omental arteries, thereby creating a pedicle flap of the omentum supplied by the splenic artery and its continuation in both omental walls (Fig. 13; Fig. 15). The operating range of the flap, with the stomach and spleen kept in their normal topographic position, was listed and compared to that of the intact omentum (Table 3; Fig. 12).
### Table 3: Measurements of the intact and pedicled omentum (through the novel technique)

<table>
<thead>
<tr>
<th>Breed/Kingdom</th>
<th>Sex</th>
<th>Weight (kg)</th>
<th>Age group</th>
<th>Height* (cm)</th>
<th>Length† (cm)</th>
<th>Length omentum‡ (cm)</th>
<th>Omentum reaches</th>
<th>Tip of the pedicle flap reaches</th>
<th>Length of the flap (cm) $\S$</th>
<th>Width of the flap (cm)</th>
<th>Width of the flap after unfolding deep and superficial wall (cm)</th>
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</thead>
<tbody>
<tr>
<td>Bordeaux Dog</td>
<td>M</td>
<td>50</td>
<td>Adult-Mature</td>
<td>67</td>
<td>77</td>
<td>35</td>
<td>thoracic inlet</td>
<td>left and right stifle</td>
<td>65</td>
<td>B:21</td>
<td>T:26</td>
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<td></td>
<td></td>
<td></td>
<td>mandible, left and right carpus</td>
<td></td>
<td>T:26</td>
<td>B:26</td>
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<td>left and right digits</td>
<td></td>
<td>T:14</td>
<td>B:12</td>
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<td>34</td>
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<td>20</td>
<td>right axilla, left: caudal to scapula</td>
<td>left and right stifle</td>
<td>thoracic inlet, left and right carpus</td>
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<td>B:10</td>
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<td>left and right digits</td>
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<td>T:12</td>
<td>B:12</td>
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<td>50</td>
<td>18</td>
<td>xiphoid</td>
<td>left stifle right groin</td>
<td>32</td>
<td>B:12</td>
<td>T:11</td>
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<td>chin, left and right digits</td>
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<td>T:20</td>
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<td>23</td>
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<td>45</td>
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<td>left and right digits</td>
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<td>T:17</td>
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<td>Staffordshire Terrier</td>
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<td>48</td>
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<td>left and right groin</td>
<td>chin, left digits, right carpus</td>
<td>57</td>
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<td></td>
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<td>left and right tarsa</td>
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<td>left groin right groin</td>
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<td>B:10</td>
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<td>left and right groin</td>
<td>mandible, left and right carpus</td>
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<td>left tarsus, right digits</td>
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<td>T:32</td>
<td>B:32</td>
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<td>Fox Terrier</td>
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<td>left and right groin</td>
<td>mandible, left and right elbow</td>
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<td>left and right tarsa</td>
<td></td>
<td>T:13</td>
<td>B:13</td>
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<td>Adult-Geriatric</td>
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<td>26</td>
<td>17</td>
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<td>left and right groin</td>
<td>nose, left carpus, beyond left and right digits</td>
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<td>left and right digits</td>
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<td>Labrador</td>
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<td>left and right groin</td>
<td>chin, left and right carpus</td>
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<td>left and right digits</td>
<td></td>
<td>T:30</td>
<td>B:30</td>
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</table>

*height measured from metacarpal pad to withers
†crown-rump length
‡length measured from halfway the greater curvature of the stomach to the most caudal point of the manually stretched omentum (straight-line measurement), mean length: 25.8 cm (range: 26-37)
§length of the flap measured from the caudal border of the spleen to the tip of the flap (straight-line measurement), mean length: 45.3 cm (range: 31-65)
B= width at flap base at the level of the caudal border of the spleen
mean width: 12.7 cm (range: 9-21), mean width after unfolding the walls of the pedicle: 19.8 cm (range: 12-32)
T= width at flap tip, mean width: 16.1 cm (range: 11-27)
mean width after unfolding the walls of the pedicle: 37.7 cm (range: 24-68)
Fig. 12: Operating range of pedicled omentum created through the novel lengthening technique, demonstrated on a canine cadaver in dorsal recumbency. The abdomen was opened in the ventral midline. Numbers (1-10) indicate the omental extent in 10 dogs cranially (A) and caudally (B).
5.4. Results

In all cadavers, adequate filling of the predominant arteries of the greater omentum with latex could be achieved. Omental arteries with smaller diameters did not or only partially fill. However, the complete bursal vasculature could be mapped by starting the dissection from the latex filled stem vessels. In all dogs, the omentum was amply vascularized. In general, the superficial wall was provided with a more dense vascular bed in comparison with the deep wall. Although some individual variation in the density of the vascular network was noted, the branching pattern of the omental arteries and their origin showed little variation. The omental arteries were located centrally in the fatty streaks. They coursed caudally and anastomosed with one another through numerous arches of varying diameter (Fig. 13). Many richly anastomosing fine vessels ran continuous with and in between the omental arteries and arcades. This system of multiple communicating arcades built up the net-like framework that renders the typical appearance of the canine omentum (Fig. 14).

In all cases, the superficial and the deep wall were each predominantly supplied by a left and a right marginal omental artery which anastomosed near the caudal omental border into a superficial and a deep omental arch, respectively (Fig. 13). In the superficial wall, the right gastroepiploic artery emitted a variable number (6-12) of omental arteries. The third or fourth of these omental branches was the superficial right marginal artery, which supplied the superficial arch from the right. The left gastroepiploic artery gave rise to a relatively smaller number (2-3) of omental arteries, which supplied a limited omental area delineated by the left gastroepiploic artery, the stomach and the spleen. From the left, the bursal portion of the omentum was predominantly supplied directly by the splenic artery. Caudal to the spleen, the splenic artery bifurcated to continue its course in the superficial and the deep omental wall as the superficial and deep left marginal artery, respectively. The deep right marginal artery was large and originated from the gastroduodenal artery. The deep omental wall was almost exclusively supplied by its marginal arteries and the communicating arcades between both vessels. Some (1-3) thinner omental arteries sprouted from the pancreatic branches of the splenic artery, but their contribution to the vascular supply of the deep wall was limited in all cases. Consequently, the area of the deep wall caudal to the left pancreatic lobe was poorly vascularized (Fig. 13).
Fig. 13: Arterial supply of the bursal portion of the canine greater omentum. A: Superficial wall (ventral view), B: Deep wall (dorsal view). The dotted line marks the incision site for the novel lengthening technique. C-D Flap technique based on insights gained by the vasculature study. C: Omental pedicle supplied by the splenic artery, D: Unfolded superficial and deep wall to extend the width of the pedicle tip, DA: deep omental arterial arch, DL: deep left marginal artery, DR: deep right marginal artery, SA: superficial omental arterial arch, SL: superficial left marginal artery, SR: superficial right marginal artery, α: anastomosis SA-DA.

1: Coeliac artery, 2: Left gastric artery, 3: Splenic artery, 4: Left gastroepiploic artery, 5: Hepatic artery, 6: Right gastric artery, 7: Gastro-duodenal artery, 8: Right gastro-epiploic artery
Anastomoses between the arteries of the superficial and the deep wall of the bursal portion of the omentum were consistently present in all cadavers, although they were neither numerous nor strong. They were more often found rounding the lateral omental margins compared to the anastomoses rounding the caudal omental border. In all cases, the slender anastomoses rounding the caudal omental border were inconsistent in location and number. However, in 8 out of 10 cases, an additional single large anastomosis between the superficial and deep arterial omental arch could be observed. It was consistently located slightly to the right of the midline, rounding the caudal omental margin (Fig. 13).

The results of the novel lengthening technique are summarized in Table 3. In 3 out of 10 canine cadavers the right axilla, in 1 case both axillae and in all cadavers both groins could be reached by transposing the intact omentum. In all cases, the lengthened omentum could easily be transposed to the aforementioned main regions of interest, and beyond (Fig. 12). By unfolding the superficial and deep wall of the omental flap, the width of the pedicle tip could be at least doubled in 9 dogs and nearly doubled in the remaining dog.

Fig. 14: Branching pattern of the omental arteries at the free caudal border of the bursal portion of the greater omentum. Notice the superficial omental arterial arch (SA), between the superficial left and right marginal arteries (SL and SR, respectively). Differentiation between the arteries of the superficial and deep walls is challenging.
Chapter 5: The omental pedicled flap in dogs revised and refined: a cadaver study

5.5. Discussion

The vascular study demonstrated that in the currently applied omental flap technique in dogs, the blood supply of the pedicle is relatively prone to be compromised. A novel omental pedicled flap, supplied by the splenic artery, is suggested.

In the first stage of the lengthening technique for the canine omentum as proposed by Ross and Pardo (1993) the deep wall is freed from its pancreatic attachment and flipped caudally. Consequently, the blood supply to the created pedicle tip solely relies on anastomoses between the superficial and the deep arches that turn around the caudal omental border. In the current study, these particular anastomosing arteries were found to be weak and inconsistent, except for one stronger anastomosis. In a subsequent lengthening step, Ross and Pardo (1993) suggested an inverse L-shaped incision, beginning from the left just caudal to the splenic portion of the omentum, across approximately one-half of the omental width, and then continuing caudally parallel to the remaining omental vessels. However, this incision could compromise that sole consistent and strong anastomosis between the superficial and deep wall, potentially jeopardizing the vascular supply of the pedicle tip. This risk of circulatory compromise has already empirically been noted in dogs (Pavletic, 2010). Although reports on the failure of these flaps are anecdotal and limited, it is not inconceivable that some of these flaps used in clinical cases do not survive completely. Furthermore, the limited width of the tip of the pedicle and the decrease in available omental tissue is an acknowledged drawback of this lengthening technique (Ross and Pardo, 1993; Roa et al., 1999; Karl and Dupre, 2012).

The canine greater omentum consists of a bursal, a splenic and a veil portion. The veil portion of the omentum is the sagittal peritoneal membrane that connects the deep wall of the greater omentum with the left surface of the descending mesocolon (Barone, 2009; Doom et al., 2014a,b). The bursal portion is remarkably large and mobile in dogs. For these reasons, this bursal portion is of particular surgical interest and is therefore in clinical literature often referred to as “the omentum” (Hosgood, 1990). It extends from the stomach to the urinary bladder, covering the intestinal coils ventrally and bilaterally (Barone, 2009; Doom et al., 2014a,b). In humans, surgical lengthening of the omentum is necessary as soon as transposition into the pelvic cavity or exteriorization beyond the peritoneal cavity is required (Williams and White, 1995), which is not the case in dogs. In one case of the present study, the intact canine omentum could even be extended as far as both axillae. Moreover, the deep and superficial bursal walls do not fuse in carnivores, which offers a wider range of
opportunities to lengthen the canine omentum in comparison to man. This demands a more thorough knowledge of the vasculature of both walls separately and of the anastomoses between both arterial systems, which was focused upon in the present study.

Fig. 15: Demonstration of the novel lengthening technique on an en bloc excised canine liver, stomach, spleen, duodenum, greater and lesser omentum. A: The dotted line marks the first incision from the right free omental border to the left, parallel to the gastroepiploic arterial arch and through both omental walls, transecting 3 to 4 omental branches. B: Spreading of the omentum after the first incision was lengthened caudally, parallel to the omental arteries, thereby creating a pedicle of the omentum supplied by the splenic artery and its branches in both omental walls; C: Unfolded superficial and deep wall of the pedicle

The omentum’s attendant potential to contribute to healing, even in the presence of infection, while maintaining suppleness make the omental pedicle graft extremely attractive for surgeons in reconstructive procedures (Wein et al., 1980; Losken et al., 2002; Valat and Moisonnier, 2004). Its malleable nature allows custom design to fit the defect (Losken et al., 2002). However, precisely its suppleness also puts the omental pedicle at risk to twist and fold on itself with resulting distal flap necrosis (Losken et al., 2002). In the present study it was opted to create an omental pedicle based on the splenic artery with an intact splenic attachment. Although dissection of the bursal portion of the omentum from its splenic attachment is claimed to result in a more mobile pedicle (Bright and Thacker, 1982), no additional need to gain mobility was perceived in the present study, as the surgical regions of interest could easily be reached. Based on the current vascular study, a comparable mirrored pedicle, supplied by the right marginal artery, might theoretically seem an equivalent alternative. However, in the latter pedicle vessels would be more prone to kinking with resulting ischemia, an actual risk for a pedicle of an organ as pliable as the omentum
(Brockman et al., 1996; Losken et al., 2002; Papachristou et al., 1977). When the pedicled flap is based on a left-sided blood supply by the splenic artery, the large omental attachment to the spleen results in a broad pedicle base providing more resistance to torsion.

The omental pedicle is transferred to the extra-abdominal site either through an opening retained from the initial celiotomy wound, or obtained through a separate transverse incision (Williams and White, 1995). The incision is kept large enough in order not to impede vascular flow. To reach the recipient place, the omentum is passed through a subcutaneous tunnel. Alternatively, in thoracic procedures, the omentum can be pulled through a substernal tunnel at the margin of the diaphragm or through a lateral diaphragmatic incision (Hosgood, 1990; Williams and Niles, 1999; Shrager, 2003). For evaluation of the operating range of the omentum, both the intact omentum and the pedicled omentum were transferred through a ventral midline incision and over the skin. Alternative abdominal exit points and the subcutaneous transfer route, which could further facilitate the access to the target tissues, were not assessed in the current study.

Although many other animal species including primates (Chaffanjon et al., 2005) pigs (Kawamura et al., 2013) and rodents (Dux et al., 1993) have been used for comparative and translational omental research, dogs in particular seem popular as model species for omental flap surgery in human medicine (Papachristou et al., 1977; Pap-Szekers, 2003; Hayari et al, 2004; Kim et al., 2004; Bigham-Sadegh et al., 2012). However, fundamental anatomical differences exist between the human and canine omentum, mainly regarding the attachment and vascular supply. In contrast to the configuration in companion animals, the deep and superficial walls of the bursal portion of the human omentum are adhered in 91% of the cases (Hoshino et al., 1979; Sompayrac et al., 1997) and the greater omentum is attached to the transverse colon (Chaffanjon et al., 2005), which is not the case in canines. Furthermore, in humans the main omental blood supply is derived from the gastroepiploic arteries. A left, right and middle omental artery originate from the left and right gastroepiploic artery and gastroepiploic arch, respectively (Casten and Alday, 1971; Alday and Goldsmith, 1972). Only exceptionally (in 0.7% of the cases), the left omental artery is derived directly from the splenic artery (Alday and Goldsmith, 1972). In contrast, as confirmed in the present study the main vascular supply in dogs is not derived from the gastroepiploic arch but from the marginal omental vessels (Gravenstein, 1938; Ross and Pardo, 1993). In dogs, the left marginal omental vessels (both in the superficial and the deep wall) are directly derived from the splenic artery and its continuation in the omental walls. The main vascular supply of the
right marginal artery is derived directly from the right gastroepiploic artery in the superficial wall, whereas in the deep wall the right marginal artery arises directly from the gastroduodenal artery. Consequently, in dogs there is no need to mobilize the gastroepiploic arch to allow incorporation in the omental pedicle, reducing the risk of hematoma formation due to ligation of the numerous gastric branches arising from the arch (Ross and Pardo, 1993). Hence, extrapolation of omental lengthening techniques from humans to dogs is not recommended (Ross and Pardo, 1993).

The most commonly cited studies on the omental vasculature, both in human and in veterinary medicine, were performed on intact, non-injected omenta (Gravenstein, 1938; Alday and Goldsmith, 1972). However, mapping of the omental vasculature based on direct observation is not reliable because of the large amount of fat surrounding the vessels and the small vascular diameter, certainly at the periphery of the omentum (Liebermann-Meffert, 1983). For the same reason, creating an omental pedicle in an individual surgical patient, based on the observed vascular supply in situ, might not be possible in all individuals, necessitating preoperative knowledge on the most common vascular pattern observed in the omentum. In a pilot study different casting techniques for the omental blood vessels were explored and compared (unpublished data). Latex, which is flexible but not corrosion resistant, proved to be a suitable casting polymer to study the omental vasculature (Doom et al., 2014a).

As our study was performed on cadavers, caution is urged when extrapolating the results to clinical and in vivo circumstances. The omental blood vessels were injected with latex to map the arterial anatomy, because casting techniques are considered the standard applied technique in cadaveric studies on vascular anatomy. However, the injections do not truly reflect natural haemodynamics. Since manual pressure was used to inject the blood vessels and not a pressure-regulated device to mimic the physiologic blood pressure, the diameters of the casted arteries might differ from the in vivo situation. An additional limitation of this study is the fact that the viability of the pedicled flaps could not be assessed. Nonetheless, this study provides objective and empirical data that do warrant further clinical trials.

Summarily, because axillary (Brockman et al., 1996; Lascalles et al., 1998; Lascalles and White, 2001; Gray, 2005) and inguinal (Watkins and Thomas, 1985; Williams and White, 1995; Hedlund, 2007) wounds are the main indications for the extra-abdominal application of
the omentum in companion animals, and taking into account that the former anatomical region could be reached with the intact omentum in some cases and the latter in all cases, the need of omental lengthening should be evaluated before any lengthening technique is even considered. If the region of interest cannot be reached merely by transposing the intact omentum, the novel pedicle technique based on the splenic arterial blood supply, as described in the current study, should be considered, with the additional benefit that the width of the pedicle tip can be extended considerably by unfolding the walls of the pedicle.
CHAPTER 6: GENERAL DISCUSSION
6.1. Search for adequate omental research techniques

The search for adequate techniques to study and illustrate the morphology of the canine omentum proved to be a real quest. The fragile and malleable nature of the omentum required a specific approach to demonstrate and map its anatomical configuration in an unambiguous way. Eventually, a new casting technique of the omental bursa facilitated the study of the omental topographic anatomy. The bursal casts and a dissection video enabled proper communication of the results (Chapters 3 and 4).

The most cited omental vasculature studies in humans (Alday and Goldsmith, 1972), in non-human primates (Chaffanjon, 2005) and in dogs (Gravenstein, 1938) were performed on intact, non-injected omenta. A large amount of fat surrounds the vessels of the omental vasculature and the vascular diameter at the periphery of the omentum is narrow. This makes mapping of the omental vasculature based on direct observation inaccurate (Lieberman-Meffert, 1983). We could confirm this issue in the vasculature studies of this thesis (Chapters 3 and 5). In a pilot study different techniques for casting the omental blood vessels were explored. It proved to be extremely difficult to produce vascular corrosion casts of the omentum. The flexible (but not corrosion resistant) latex turned out to be a suitable casting medium to study the omental vasculature (Fig. 16) (Chapter 3).
Chapter 6: General Discussion

Fig. 16: Visualization of the gastric, duodenal and omental arteries through latex injection in a canine cadaver.

The polyurethane casting technique used in this study (Chapter 4) allowed a non-destructive separation of the omental walls, which could be an asset in the omental vasculature research. Latex loaded with contrast medium was injected into the aorta just prior to the polyurethane foam injection into the omental bursa. This procedure facilitated the assessment of the main arterial omental supply on the CT images of the final casts. However, mapping smaller arteries in this setting was found to be more difficult and was in no way superior to in situ examination of the latex injected vessels without bursal casting (Fig. 17) (Chapter 4).

Fig. 17: 3D reconstruction of a polyurethane bursal cast of a dog, scanned in situ in a canine cadaver (see Chapter 5). A: Left lateral view B: Right lateral view. C: Right craniolateral view. (1) bursal cast, (2) stomach, (3) descending part of the duodenum, (4) spleen, (5) aorta and primary aortic branches
6.2. Clinical relevance

Through their eminent and meticulously detailed studies, Gravenstein (1938) and Zietzschmann (1939) delivered a thorough anatomical description of the omentum in the dog. In current morphological research, descriptive anatomy is no longer a goal on itself. Nowadays, the clinical question often precedes the anatomical one. In this regard, one might question the necessity of a detailed anatomical study and an in-depth nomenclature related to the virtual spaces of the omental bursa. The omental bursa may seem to be a purely theoretical subject reserved for anatomists. However, the investigation of the fine topographic anatomy of the canine omental bursa (Chapter 4) proved to be a prerequisite to gain insight into the omental morphology of dogs. Moreover, with advancements in medical imaging and surgical techniques, the omental bursa is certainly no longer a clinically irrelevant anatomical feature.

6.2.1. Medical imaging

Higher resolutions and better visualization of the omentum in current medical imaging techniques have led to a renewed interest in the anatomy of the omentum in human medicine. Improved CT scanning techniques allow radiologists to better evaluate the greater omentum. In recent studies, radiologists attempt to link radiologic-anatomical features of the omentum to clinical implications (Jin et al., 2008).

Current cross-sectional imaging techniques allow detailed examination of the peritoneal cavity and pathological processes affecting it. Accurate insights into the normal anatomy are evidently of high interest. Potential peritoneal spaces determine the natural flow of peritoneal fluid. They therefore also determine the spread of infection and pathways of disease processes e.g. fluid collections (Healy and Reznek, 1998). As such and although its actual space is virtual, the omental bursa has therefore greater clinical relevance than one might expect at first sight. Moreover, the anatomical location of peritoneal fluid collection, when carefully analyzed, can help to reveal its source and etiology (Churchill, 1989). Additionally, with the introduction of negative pressure techniques in the treatment of peritonitis, fluids may circulate in the peritoneal cavity in a more unpredictable manner. In humans, this may even make drainage of the omental bursa necessary in some cases (Labler, 2006). For these reasons, studies on the fine topographical layout of the omental bursa are warranted.
6.2.2. Surgery

In human medicine, the vast number of clinical applications involving mobilization of the omentum has lead to a concomitant gain in insights in the fine anatomy of this structure and its vasculature. In this framework, dogs appear in the spotlight as the most preferred animal model for translational omental research (Papachristou and Fortner, 1979; Kim et al., 2004; Pap-Szekeres, 2003; Hayari et al., 2004; Bigham-Sadegh et al., 2012). Furthermore, much of the current information on the greater omentum in companion animals, upon which veterinary surgical applications are built, is extrapolated from human medicine. However, in Chapter 5, the suitability of this animal model and the practice of sheer extrapolation of data between species were questioned because of the fundamental morphological differences that exist between the human and canine omentum. Based on the results presented in this thesis, it is arguable to reconsider the model species for omental research in human surgery and to re-evaluate the necessity and accuracy of the current techniques for omental flap lengthening and transposition in the dog.

**Translational research: the dog as best fit model?**

Apart from dogs, many animal species including primates (Chaffanjon et al., 2005), pigs (Kawamura et al., 2013) and rodents (Dux et al., 1993) have been used for comparative and translational omental research. Conversely, ruminants, due to their very specific gastrointestinal anatomy, can be excluded as models for surgical procedures involving the stomach, intestines and adnexae directed towards monogastric species such as humans.

Whilst the deep and superficial walls of the bursal portion of the human omentum are adhered in 91% of the cases (Hoshino et al., 1979; Sompayrac et al., 1997), the omental bursa remains patent in rodents, dogs, cats, pigs, horses and non-human primates (Liebermann-Meffert, 1983; Chaffanjon et al., 2005; Barone, 2009). As such, none of the potentially chosen animal models will exactly mimic the human configuration.

A wide diversity can be recorded in the dimensions of the omentum among domestic mammals. The greater omentum in rabbits and horses is relatively small and does not cover the major part of the intestinal coils like in humans. In contrast, pigs and carnivores feature a well-developed and extended greater omentum (Barone, 2009). The relative anatomical reduction of the omentum in horses could explain the fragility of the abdominal cavity of equines, in contrast to bovines that have a big and solid greater omentum (Barone, 2009).
Furthermore, as a unique feature in carnivores compared to other domestic animals, the deep omental wall inserts dorsally on the left pancreatic lobe, in contrast to the configuration in equines and pigs in which the deep wall of the greater omentum attaches to the transverse colon (Barone, 2009), similar to the situation in the human (Chaffanjon et al., 2005).

One study demonstrated that the omental anatomy of non-human primates is very similar to that of humans, apart from the shape of the omental bursa (Chaffanjon et al., 2005). Obviously, however, ethical questions rise when these species are considered as animal model.

From ethical perspective, dogs are top-ranked as animal model to be considered, because the outcome of research in this species might be of direct relevance for veterinary medicine, exemplified by the recently increasing interest in omental applications in veterinary surgery. The use of dogs rather than pigs, even if the latter might feature a more comparable omental anatomy from human perspective, is certainly justifiable and even preferable, as the clinical relevance of the omentum in the pig is currently almost non-existent. Furthermore, veterinary clinical research into the canine omentum can, in return, be beneficial to human medicine as well, provided that the anatomical differences between human and canine omenta are documented and taken into account.

**The canine omentum as an animal model: major differences compared to human anatomy**

In Chapters 3 and 4, it was confirmed that the walls of the greater omentum in the dog do not fuse and that the deep wall of the bursal portion encompasses the left pancreatic lobe craniodorsally instead of inserting on the transverse colon. In man, due to the extensive adherence of both omental walls, the omental bursa is mainly confined to the space posterior to the stomach, the lesser omentum and the caudate lobe of the liver, and only extends for a variable but limited distance between both walls of the greater omentum (Johnson, 1981; Healy and Reznek, 1998). The hourglass shaped human omental bursa is subdivided into two recesses: a small superior and a large inferior recess (Johnson, 1981; Healy and Reznek, 1998; Terminologia Anatomica, 1998). The small superior recess encloses the caudate lobe of the liver and extends superiorly between the inferior vena cava and the right crus of the diaphragm. The larger inferior recess is situated between the stomach and the visceral surface of the spleen. It is bounded inferiorly by the transverse colon and its mesentery, but can extend for a variable distance between the walls of the greater omentum. A constriction
produced by two prominent peritoneal folds containing the left gastric artery and common hepatic artery marks the boundary between both recesses (Johnson, 1981; Healy and Reznek, 1998; Terminologia Anatomica, 1998). As such, the superior recess of the omental bursa in humans seems to correspond with the vestibule of the omental bursa in dogs as described in Chapter 4, whilst the inferior recess seems to correspond with the canine caudal omental recess. However, official human anatomical nomenclature makes a clear distinction between the omental vestibule, in addition to an inferior, a superior and a splenic recess (Terminologia Anatomica, 1998). The superior recess might correspond then to the veterinary anatomical term ‘dorsal recess of the vestibule’ (Recessus dorsalis omentalis) (N.A.V., 2012), which is described as a minor dorsal diverticulum extending between the oesophagus and the caudal vena cava from the level of the liver to the right crus of the diaphragm (Habel, 2012). It is delimitated to the left and right by the gastrophrenic ligament (Ligamentum gastrophrenicum) and the coronary ligament (Ligamentum coronarium hepatis), respectively (Barone, 2001). However, no dorsal recess of the vestibule of the omental bursa was found in any of the canine cadavers of the present study (Chapter 4). On the other hand, it was demonstrated in a similar study in the horse (van Bergen et al., 2014).

A similar discussion can be held on the large number of differences related to the ligaments that constitute the omentum or are linked with it. In human anatomy, many of these ligaments, and especially those associated with the attachment of the spleen, are of clinical relevance. Malformations of the latter ligaments have been associated with an increased risk for intra-operative complications such as bleeding, torsion and “wandering” of the spleen (Skandalakis et al., 1993). Because many of these relatively short ligaments contain important vessels, surgeons are alerted for excessive traction to them, because excessive traction to the presplenic fold during upper abdominal procedures could result in a tear of the splenic capsule (Skandalakis et al., 1999).

Some ligaments, such as the gastrophrenic and phrenicosplenic ligaments, are described in man as firm structures that have a suspensory role regarding to the organs they are associated with (Skandalakis et al. 1993; Terminologia Anatomica, 1998; Feneis and Wolfgang, 2000; Barone, 2009). In dogs, no suspensory role could be ascribed to these anatomical structures, which belong to the splenic portion of the omentum (Chapter 3). It could be postulated that this weight-bearing feature is evolutionary linked with the orthograde stance of man versus quadrupeds like dogs. However, in horses such suspensory role has also been ascribed to those aforementioned ligaments as they have equal firmness as in humans.
(Barone, 2009). Furthermore, due to the loose nature of the gastrosplenic and phrenicosplenic ligaments, their margins are ill defined. In Chapter 3, we therefore used arterial landmarks to delineate the different parts of the splenic portion from one another and from the other parts of the canine omentum. The arterial landmarks associated with the superficial wall are contained in folds that protrude into the omental bursa (Plicae gastroplenicus cranialis, intermedia and caudalis). The presence of these folds results in local narrowing of the bursal compartments (Chapters 3 and 4). As such, a similar warning can be issued for the dog as in humans. Extra care should be taken when exerting traction on the omental parts that connect to the spleen.

Furthermore, not only anatomical but also nomenclatural differences regarding the omental components hamper a smooth comparison between human and canine anatomy. Of note are the pancreaticocolic and splenocolic ligaments that form one continuous, avascular plane with multiple sites of attachment in humans (Scott-Conner, 2006) and of which the latter is thought to be a remnant of the left end of the transverse mesocolon (Skandalakis et al., 1993). Anatomically, these structures correspond most closely to the component indicated as the veil portion of the greater omentum in dogs (Chapter 3). Furthermore, in veterinary reference handbooks, the term gastrosplenic ligament (Ligamentum gastroplenicum) is often considered a synonym of the entire splenic portion of the greater omentum, including its deep and superficial wall and its cranial protrusion extending beyond the dorsal extremity of the spleen (Evans, 1993; Barone, 2001; Budras, 2002; Könich and Liebich, 2004; Barone, 2009). However, based on the findings presented in Chapter 3, we do not concur with this assimilation. A definition was put forward (Chapter 3), restricting the gastrosplenic ligament to the specific part of the superficial wall of the splenic portion spanning between both organs and bordered by the cranial and caudal gastrosplenic folds.

Likewise, important differences in the vascular supply of the greater omentum can be indicated. Whilst the main omental blood supply in humans is derived from the left and right gastroepiploic arteries (Casten and Alday, 1971; Alday and Goldsmith, 1972), it was exemplified in Chapter 5 that the main vascular supply of the omentum in the dog is derived from the marginal omental vessels (Gravenstein, 1938; Ross and Pardo, 1993), which branch from the splenic artery (superficial and deep left omental branches), the gastroduodenal artery (deep right omental branch) and the right gastroepiploic artery (superficial right omental branch), respectively. These major differences in the vascular supply, combined with the aforementioned anatomical dissimilarities, urge us to revoke any sheer extrapolation of the
technique to create vascularized pedicled omental flaps between humans and dogs. Furthermore, the detailed insights gained in Chapter 5 justify the re-evaluation and re-design of the flap technique for clinical application in dogs (Ross and Pardo, 1993).

**Design of an omental pedicled flap technique in dogs as patients**

In humans, depending upon the extremity to be vascularized and the caliber of the vessel, either the left or right gastroepiploic artery is divided at one end to allow lengthening of the omentum (Casten and Alday 1972; Liebermann-Meffert, 1983; Agarwal, 2007). Based on radiological measurements the right gastroepiploic artery is reported to be larger than the left counterpart (Hannoun et al., 1984; Coulier, 2009). Consequently, the right gastroepiploic artery is generally preserved as the blood supply of the pedicle in humans (Das, 1976; Wein et al., 1980; Williams and White, 1986). Furthermore, in humans it is advised to perform the dissection of the gastrepiploic arch not too far to the right, as this may compromise the gastroduodenal artery. The omental flap may also be based on the left, but the vascular supply of the distal end of the flap is then less reliable (Petit et al., 1979).

We opted for an omental pedicle supplied by the splenic artery with preservation of the splenic attachment (Chapter 5), even though in dogs, dissection of the bursal portion of the omentum from its splenic attachment is claimed to result in a more mobilizable pedicle (Bright and Thacker, 1982). A comparable pedicle based on the right marginal branch would have been equally possible. However, it was determined that the omental attachment to the spleen results in a broader pedicle base, which provides more resistance to torsion of the base. This is especially important since kinking of vessels with resulting ischemia is a substantial risk for a pedicle of an organ as pliable as the omentum (Papachristou and Fortner, 1977). Compared to a left approach, the incision of the omentum starting from the right can be performed more closely to its cranial attachment without compromising the vascular supply of adjacent organs such as the spleen, and as such results in the creation of a larger pedicle. The malleable and plastic nature of the omentum allows custom design to fit the defect (Losken et al., 2002). Its attendant potential to contribute to healing, even in the presence of infection, while maintaining suppleness makes the omental pedicle graft most attractive for surgeons in reconstructive procedures (Wein et al., 1980). It is, however, precisely its suppleness that also puts the omental pedicle at risk to fold on itself with resulting distal flap necrosis (Losken et al., 2002). Care should be taken not to twist the omental pedicle (Brockman et al., 1996).
Design of an omental pedicled flap technique in cats as patients

The omental lengthening technique that has been described in dogs by Ross and Pardo (1993), is extrapolated in cats without any question towards anatomical differences between dogs and cats (Brockman et al., 1996; Karl and Dupré, 2012). Anatomists and surgeons are of course aware of the fact that cats are not small dogs. Each species deserves its proper anatomical studies and surgical designs. Cats are good candidates for extra-abdominal omental transposition, in particular with regard to wound care, especially since cats are prone to chronic non-healing wounds (Brockman et al., 1996; Gray, 2005) and are, maybe even more so than dogs, reluctant to long hospitalization and intensive dressing changes. Moreover, in a feline cadaver study, the technique described by Ross and Pardo (1993) for dogs seemed to be insufficient for reaching distal locations (Karl and Dupré, 2012).

Omental size and lengthening

In many clinical case reports on omental extra-abdominal transposition in dogs, the surgical lengthening is performed without assessing whether merely transposing the intact omentum could be sufficient (Smith et al., 1995; Brockman et al., 1996). However, division of the omentum to achieve lengthening should only be considered when absolutely necessary. All incisions to elongate the omentum entail the sacrifice of vascular anastomoses within the omentum and involve a risk of distal ischemia and necrosis of the pedicled flap (Petit et al., 1979; Williams and White, 1985). In the study presented in Chapter 5, the intact canine omentum reached cranially at least as far as the xiphoid, while caudally the intact omentum covered the groin bilaterally in all cases (Fig. 18). It is reported that the excessive accumulation of fat in the omentum could limit omental lengthening and mobilizing procedures (Bright and Thacker, 1982). We did not encounter this drawback (Chapter 5) but it should be mentioned that the number of animals involved was limited and the lengthening procedures were all tested on cadavers rather than on live animals in a clinical setting.

Both in humans and in dogs the size of omentum seems to be related to body weight (Das, 1981; Martin, 1985). The average length of the greater omentum appeared to be sex-related in one particular human study (Coulier, 2009), the omentum being significantly longer in females than in males. In humans, some consider it important to predict prior to surgery whether or not there is ample omentum to serve the purpose (Das, 1981), as inadequate omental volume to serve a reconstructive surgical procedure has been reported (Hultman et al., 2002). However, the accuracy of preoperative length assessment is limited and some
people show unexpected sizes at laparotomy (Liebermann-Meffert, 1983). Because of the limited number of cases in the study we presented (Chapter 5), no statistical conclusions regarding omental size and its pre-operative predictability can be made. However, in companion animals, restriction and lack of omental size seems less of an issue anyway. This is potentially due to the fact that the deep and superficial omental walls do not fuse in carnivores, creating a wider range of opportunities to lengthen the omentum than is the case in humans. In humans, lengthening of the omentum is necessary as soon as transposition into the pelvic cavity or beyond the boundaries of the peritoneal cavity is required (Williams and White, 1986). Some human surgeons even recommend liberating the omentum from its gastric attachment to place the omental flap in the proximity of the urinary bladder without tension (Petit et al., 1979). This is not the case in companion animals (Chapter 5). Because of the associated risks, designing and tailoring an omental flap technique in dogs can only be relevant and justifiable when there is an actual need of lengthening. The operating range of the intact omentum should first be evaluated (Fig. 18). Only when the surgical site of interest cannot be reached by transposing the intact omentum, lengthening can be considered.
Fig. 18: Operating range of the intact omentum, demonstrated on a canine cadaver in dorsal recumbency. The abdomen was opened in the ventral midline. Numbers (1-10) indicate omental extent cranially (A) and caudally (B) in 10 dogs (see Chapter 5).
In case lengthening is mandatory, one has to take into account that any incision designed to result in a longer graft also results in a narrower graft of which the width may become inadequate to cover large defects (Williams and White, 1985). As such, the limited width of the tip of the pedicle and the decrease in available omental tissue can be mentioned as drawbacks of the previously applied lengthening technique in dogs and cats (Ross and Pardo, 1993; Roa et al., 1999; Karl and Dupré, 2012). This concern also exists in human lengthening techniques (Das, 1976). However, in the novel lengthening technique proposed in Chapter 5, the width of the pedicle tip can be doubled by unfolding the walls of the pedicle. The tip of the pedicle can easily be unfolded whilst the vascular supply of each wall of the tip is guaranteed by a proper, major arterial branch and numerous vascular anastomoses.

Potential surgical applications in companion animals

Reporting on the first international congress on the use of the omentum in the central nervous system, Goldsmith (1995) mentioned a paper of the veterinary group of Yarrow and coworkers (London). On that congress, they presented preliminary results of omental transposition on concussive injuries to the canine thoracolumbar spinal cord. Four out of 10 dogs regained locomotion within 9 weeks after surgery. Experimental placement of a pedicled omentum onto the brain and spinal cord in dogs results in the development of blood vessels that penetrate directly in the underlying neural structures (Goldsmith, 1975 a,b). At the very least, these results deserve an attentive follow-up, certainly in veterinary medicine where these type of injuries often lead to euthanasia of the pet animal. The encouraging findings in these studies should be validated with randomized, controlled, clinical trials.

In humans, omental transposition to epileptogenic foci has been suggested for poorly controlled epileptic seizures (Rafael et al., 2002). The potential of this treatment option should be evaluated in dogs with epilepsy, especially considering the fact that a lifetime treatment with antiepileptic drugs in the end could cost more than one specialized surgery.

6.3. Hurdles in the application of omentoplasty in veterinary medicine

Research and pilot studies on novel and potential practical applications of the omentum are continuously published and support the additive value of the omentum in various fields of surgery (Regelson, 2010). In human medicine, at least in the field of plastic and reconstructive surgery, omentoplasty is already a well-established practice (Wein et al., 1980; Losken et al., 2002). However, in the veterinary environment the surgical use of the omentum, though often referred to as encouraging, has not resulted so far into routine
application in companion animals. Possible reasons for this apparent lagging are explored in the next paragraphs.

6.3.1. Scientific support

Not unimportantly, in human medicine, the surgical application of the omentum in domains other than plastic and reconstructive surgery remains controversial. The great potential of the omentum in neurosurgery and cardiac surgery is mainly promoted by a very small group of pioneering researchers such as Harry Goldsmith, Arthur Vineberg and Dorothea Liebermann-Meffert. Their omnipresence in omental literature, not being backed by their peers, only adds to the scepticism and apparent lack of credibility expressed by other scientists (Ausmann, 1996).

6.3.2. Alternative treatment options

As mentioned above, the surgical use of the omentum started making progress mainly at the end of the last century. But, as is often the case in medicine, the rise of a new technique quickly makes a prior method obsolete; sometimes the current technique is immediately disregarded as older, relatively inferior and therefore abandoned. For instance, since the emergence of coronary artery bypass grafting, the clinical experience of omental grafts or transposition to increase myocardial circulation has been lost (Schrager, 1994). Subsequently, the valid surgical concept and new ideas that might ensue from it, are also at risk of getting lost.

Although the value of the omentum in wound care is not being questioned, its use in the surgical treatment of wounds is nowadays overshadowed by negative wound pressure therapy. The advantages of the controlled use of sub-atmospheric pressure to a wound by intermittent or continuous application of a special wound dressing are impressive and include the reduction of the wound area, stimulation of granulation tissue formation, continuous removal of wound exudate and pressure-related reduction of interstitial edema with improvement of microcirculation (Ben-Amotz et al., 2007; Willy and Schmidt, 2006; Pitt and Stanley, 2014). Vacuum therapy is especially indicated in acute and subacute wounds for temporary coverage and/or wound preparation until definitive wound closure is possible (Willy, 2006), although this technique also appears to accelerate chronic wound beds into the reparative state (Pitt and Stanley, 2014).
Chapter 6: General Discussion

In well-equipped companion animal hospitals, negative wound pressure therapy has joined wet-to-dry dressing as standard-care for acute traumatic wounds (Guille et al, 2007), stabilization of skin grafts (Ben-Amotz, 2007) and chronic non-healing wounds (Pitt and Stanley, 2014). It is also used in cats for treating traumatic wounds and urine-induced skin and muscle necrosis (Owen et al., 2009). With regard to healing time and complication rate, it seems to score better in the open treatment of complex wounds as compared to conventional bandages (Nolff et al., 2015). Clinical trial data seem to support the use of negative pressure wound therapy in infected wounds. Some disagreement remains, however, as to whether this technique reduces the initial bacterial load or whether the sealed environment and decreased changes of dressing reduce the risk for nosocomial infection (Putnis et al, 2014).

It could be postulated that veterinary surgeons have neglected the omentum in wound care following the rise of vacuum therapy. Although its value is certainly demonstrated, some drawbacks remain in negative pressure wound treatment. Frequent sedation and/or anesthesia for dressing changes remain necessary. Hospitalization time is reduced in comparison to traditional treatment options but an evaluation and comparison of the financial costs is yet to be made. In addition, the head and neck regions are difficult locations to apply vacuum therapy, because obtaining a seal and maintaining integrity of the dresses is challenging in these anatomical areas. Finally, it was suggested that negative pressure wound therapy is most useful in the development of a healthy wound bed suitable for a reconstructive effort, rather than offering a long-term management option (Pitt and Stanley, 2014). Omentoplasty could be of added value in some of these cases. In plastic and reconstructive surgery in humans, the omentum has maintained its status of fixed value. Infected and ischemic wounds remain particularly amenable to reconstruction with the omentum (Hultman et al., 2002). For each patient and each case, both treatment options should be weighed against each other. Moreover, one technique should not necessary exclude the other. In a human case report, the successful combination of omentoplasty and vacuum-assisted techniques in the management of a large perineal defect has been described (Farinella et al., 2013).

6.3.3. Nomenclature issues

The omentum is often considered as a complex, almost mystic organ that is unclearly defined. It is self-evident that its anatomical complexity, and the shroud of mystery surrounding it, discourage surgeons to use it in their procedures. Nomenclature is primordial to gain control over and to define the omentum. Only a clear nomenclature can allow unambiguous communication on surgical techniques and clinical experience. Clear-cut reports
from surgeons can persuade their colleague practitioners to apply omental techniques with confidence. It is exactly this nomenclature that was lacking in literature on the canine omentum. The detailed topographic study of the canine omentum by Zietzschmann, in 1939, was a direct spin-off of the vascular study of his colleague researcher Gravenstein in 1938. Indeed, in his publication, Zietzschmann mentions that his study was initiated after Gravenstein reported to be restricted by a lack of nomenclature tools to describe in detail the course of the blood vessels. However, nomenclature introduced in Zietzschmann’s pioneer study is today no longer commonly applied and little additional research has been performed on the gross anatomy of the omentum of the dog. The main findings on the vascular supply from Gravenstein’s study, were adapted from one study to the other without questioning the fact that this study was performed in one single dog. Consequently, a pressing need for comprehensive anatomical research on the canine omentum emerged.

The findings of the studies presented in Chapters 3 and 4 lead to a number of recommendations aiming to elaborate the existing official nomenclature (N.A.V., 2012). By formulating clear definitions and by throwing light on some ambiguities in relevant literature, the primordial tools were provided to define the canine omentum in detail. Whether or not these terms should be included in the N.A.V. is another issue open for discussion. As research in gross anatomy of domestic animals is actively pursued, frequent revisions of the N.A.V. will be required. It is suggested that new terms, corroborated by adequate documentation should be submitted to the board of the International Committee on Veterinary Gross Anatomical Nomenclature (ICVGAN). Terms should have instructive and descriptive value. However, no scientific nomenclature can be considered complete and permanent as long as research in the field is ongoing (N.A.V., 2012). Hence, the N.A.V. does not strive to be definite or complete. Only when the necessity of additions or corrections is demonstrated, changes will be considered. The literature cited in this thesis clearly demonstrates the need for a detailed omental nomenclature that is specific for the various animal species. It also demonstrates the urgent nature of the need for this nomenclature.

The abundance of anatomical and species-specific terms that define the omentum, its ligaments and its bursal cavities is confusing and extremely discouraging for all who perform research on the omentum or for anyone applying it in clinical circumstances. These terms reflect the complexity and species-specificity of the embryological and fetal development of the gastrointestinal tract. A comparative morphological study on the origin and development of these anatomical structures could be a starting point to unravel this big tangle of terms.
6.3.4. Possible complications

The need for celiotomy to use the omentum for extra-abdominal indications may be considered a contraindication for the technique. It is important to realize that omentoplasty for extra-abdominal applications is a relatively invasive procedure (Petit et al., 1979; Williams and White, 1986; Hultman et al., 2002). Apart from complications that are intrinsic to abdominal procedures, specific concerns about the omental pedicle can discourage surgeons to opt for the omental approach. However, the reported incidence of significant complications remains within acceptable limits, supporting the use of the omentum in a diverse range of clinical situations (Hultman et al., 2002).

Necrosis

Partial necrosis of the pedicle is the most common complication in humans (Hosgood, 1990), but it is not necessarily of clinical significance (Petit et al., 1979; Smith et al., 1995). Most of the flap failures result from technical errors such as an inadequate subcutaneous tunneling, compression and strangulation at the site of emergence from the abdomen with resulting vascular occlusion, or excessive tension on the pedicle (Petit et al., 1979; Williams and White, 1986). Since pressure cannot be applied to the mobilized omentum without risking ischemia, meticulous hemostasis at the time of operation is mandatory (Williams and White, 1986).

Herniation

A sufficiently wide passageway is necessary to avoid strangulation of the transposed pedicled flap. Therefore, a significant incidence of incisional hernia is inevitable (Williams and White, 1986). To reduce the risk of herniation of abdominal contents through a ventral midline opening, alternatively it may be beneficial to opt for a dorsal flank exit hole (Brockman et al., 1996). Alternative abdominal exit points for application in dogs were not assessed in the study on the operating range of the pedicled omentum created through the novel lengthening technique (Chapter 5). The ventral midline defect can also be closed after healing of the wound (Brockman et al., 1996), while a few sutures between the peritoneum and the pedicle at the abdominal exit point may also reduce the frequency of post-operative herniation (Petit et al., 1979).
Seroma formation

Positioning of the pedicle in such a way that the venous and/or lymphatic circulation is compromised, can result in seroma formation (Brockman et al., 1996).

Ascending infection

Abdominal wall infection is a common complication in humans (Hultman et al., 2002). Probably owing to the fact that the omentum forms a fibrin seal at the abdominal exit wound, ascending concurrent infection is rarely if ever reported. In addition to mechanical sealing properties, the intrinsic immunological characteristics of the omentum can prevent bacteria from gaining access to the peritoneal cavity (Brockman et al., 1996).

Gastric stasis

When ligating vessels along the greater curvature of the stomach, transient gastric outlet obstruction has been reported in human medicine (Williams and White, 1986; Hultman et al., 2002). Traction on the stomach due to a pedicle that is too short may cause vague and persistent gastrointestinal symptoms (Williams and White, 1986).

Complications due to the subcutaneous tunneling over areas of motion

The need for a subcutaneous tunnel over areas of motion to reach distal sites remains a concern in the use of an omental pedicle (Brockman et al., 1996; Roa et al., 1999; McAllister et al., 2012). However, so far, no cases featuring this complication have been reported (McAllister et al., 2012). Moreover, this concern might be reduced by increasing the pedicle width with anastomosing collaterals through the technique proposed in Chapter 5.

Absence of “the abdominal policeman”

The absence of the omentum in the abdomen may aggravate and hasten the course of an intraperitoneal inflammatory process. Human patients who underwent omental transposition are recommended to be on the alert for the onset of any abdominal symptoms (Williams and White, 1986). It remains to be determined how removing an organ that has tremendous angiogenic and immunologic potential from the abdomen affects intra-abdominal physiology in the long run (Hultman et al., 2002).
6.4. Future Perspectives

Taking under consideration that veterinary surgery is rapidly evolving and that our knowledge on the omentum is vastly expanding which results in novel clinical applications, there is a continuing and increasing need for anatomical data on the canine omentum. This thesis provides only a basic but nevertheless important answer to this need, by naming, defining and delineating the fine anatomy of this too long neglected and underappreciated organ. A well-defined anatomical terminology is a prerequisite to enable researchers and clinicians to communicate their results in an unambiguous manner. As such, this thesis promotes the awareness of the clinical potential of this organ and should encourage further omental research.

The cadaver studies in this thesis provide reliable anatomical data but the number of animals studied, remains limited. To expand the anatomical findings and possibly map more variations in the arterial supply of the canine omentum, more cadavers are to be dissected. Alternatively, a retrospective analysis of CT-images of large series of patients that underwent CT-angiography is an additional approach to gather data in a faster and more efficient way. Moreover, these imaging techniques provide alternative options to perform vasculature studies in vivo. However, in carnivores the closely huddled omental walls may hinder the differentiation of the vasculature of each wall when using these imaging techniques.

The viability of the omental pedicled flap, created through the novel proposed lengthening technique, has to be evaluated in vivo. It could be postulated that the viability should first be assessed in an experimental design with laboratory animals e.g. through angiograms before the novel technique should be applied in real patients. However, the results of these cadaver studies in dogs provide objective and empirical data that warrant clinical trials with canine patients, avoiding the harm and sacrifice of laboratory animals. The novel lengthening technique should be applied in canine patients that need extra-abdominal omental transposition to document its viability in vivo.

Finally, cats are good candidates for extra-abdominal omental transposition. However, currently morphological studies on the feline omentum are completely lacking. Mere extrapolation of the anatomical data on the canine omentum is obviously fault. There is a pressing need for anatomical studies on the feline omentum, more in particular a need for research on its vascular supply with regard to surgical lengthening techniques.
SUMMARY
Although the omentum is the first organ to appear when the mammalian abdomen is opened along the ventral midline, few people seem to be aware of the existence or the unique functions of this organ. Even for those with training in medical sciences and/or morphology, the omentum often sounds only vaguely familiar. Research, however, shows increasing evidence of some extraordinary features of this organ both in human and in veterinary medicine.

The greater and lesser omentum (Omentum majus and minus) are mesenterial sheets that are attached to the stomach and contain numerous blood vessels and lymphatics. The greater omentum in dogs and cats consists of a bursal portion, a splenic portion and a veil portion. The bursal and splenic portions are folded structures composed of two walls, a superficial wall and a deep wall. In the veil portion, however, both walls fuse during prenatal development. Clinical applications mainly imply the bursal portion of the greater omentum, of which the larger part floats freely in the abdomen.

For centuries, scientists have been intrigued by the omentum. Their knowledge of its properties was for a long time merely based on empirical observations without in-depth insights. This fascinating abdominal organ only truly began to reveal its mysteries over the last decades and many more of its features are yet to be disclosed. In Chapter 1 a historical overview summarizes the searches for the true nature of the omentum over the centuries. It highlights the endeavors of scientists to explore the omental functions and the discovery of its usefulness in clinical applications, mainly in the field of surgery. Furthermore, the introduction chapter of this thesis contains a morphologic description of the canine omentum and its vascular supply with a focus on the gaps in the current knowledge. Detailed anatomical data on the canine omentum are currently lacking and information is often retrieved from human medicine. An up-to-date status on the progress in the research on omental functions is provided. The omentum contains a variable amount of fat with specific characteristics. In humans excessive stacking of fat in this depot is associated with metabolic dysfunctions such as diabetes. Recent research indicates that this is also the case in domestic animals. The omentum adheres to injured sites, contributing to the encapsulation of inflammatory processes and hemostasis in the abdomen. It contains inflammatory cells playing a key role in intraperitoneal defence mechanisms, hence its nickname “the abdominal
policeman”. Furthermore, it produces angiogenic and neurotrophic factors assigning it unique wound healing capacities. These extraordinary functions have led to clinical applications in many creative ways. The omentum can be wrapped around intestinal anastomosis sites to promote healing, but it can also be transposed to extra-peritoneal sites. To reach remote areas, the omentum can be transposed either with the preservation of its blood vessels (as a pedicled flap) or as a detached piece of tissue (graft), although the latter procedure is for now mainly applied in humans. The scientific aims of the present study are summarized in Chapter 2.

In 1939 Otto Zietzschmann meticulously described the topographical anatomy of the canine omentum. Some terminology introduced in his pioneer study is no longer commonly applied, and little to no additional research has been performed on the gross anatomy of the omentum of the dog. However, there is a need for more detailed anatomical data because dogs and cats frequently serve as animal models for omental surgical techniques in humans. The techniques used in these exploratory studies, as well as the surgical techniques used in domestic animal patients, often improperly rely on human data. Furthermore, in microscopic studies on the omentum of small animals, researchers have few anatomical landmarks to properly describe the place of sampling. In Chapter 3 of this thesis, anatomical landmarks were set to define the canine omentum and to improve unambiguous scientific communication on the omentum of the dog. In 9 cadavers of dogs, different techniques including casting of the blood vessels and dissection of embalmed cadavers were implemented to illustrate the observations. In an included dissection video, the in situ findings are demonstrated. The current nomenclature was challenged. A new and more detailed terminology was proposed that led to a number of recommendations for elaboration of the official nomenclature (Nomina Anatomica Veterinaria). Three consistent arteries were observed within the omentum, viz.; the cranial gastric branch, the caudal gastric branch and the left gastroepiploic artery. All arose directly or indirectly from the splenic artery. These arteries were contained in the cranial, the middle and the caudal gastroepiploic fold of the superficial omental wall, respectively.

The gastroepiploic artery has often been considered as a synonym of the splenic portion of the greater omentum. Based on the findings presented in this study however, both terms cannot be considered synonymous. The splenic portion was found to be an omental portion with a superficial and a deep wall, which included a cranial protrusion that extended craniodorsally beyond the cranial margin and the dorsal extremity of the spleen. In contrast, the gastroepiploic ligament, spanning between the stomach and the spleen, was a part of the
superficial wall of the splenic portion, bordered by the cranial and caudal gastrosplenic fold. On the other hand, the gastrophrenic and phrenicosplenic ligaments, which are currently listed in official nomenclature, were not observed as clearly delineated structures in any of the examined dogs.

Subsequently, in 6 canine cadavers the omental bursa was explored by means of a newly developed casting technique based on self-expanding polyurethane (Chapter 4). The omental bursa is a virtual cavity enclosed by the greater and lesser omentum. The omental vestibule, the caudal recess and the 3 compartments of the splenic recess of the omental bursa could all be clearly delineated and studied in the casts. Casting the omental bursa resulted in a hands-on, three-dimensional and reproducible study tool that showed the defining anatomical landmarks described in Chapter 3. Moreover, CT scanning of the casts resulted in grey-tone values that could be discerned from values of other surrounding air- and gas-filled structures, allowing automatic labelling and precise three-dimensional reconstruction.

In Chapter 5 the vascularization of the bursal portion of the canine omentum was mapped through intravascular latex injections and subsequent vessel dissections in 10 cadavers. The main vascularization pattern of the canine omentum varied little amongst all cadavers. Both the superficial and the deep omental walls were predominantly supplied by a left and a right marginal omental branch. Those branches anastomosed with each other near the caudal omental border into a superficial and deep omental arch, respectively. The splenic artery supplied both left marginal branches. The superficial right marginal branch arose from the right gastroepiploic artery, whereas the deep right marginal branch sprouted directly from the gastroduodenal artery. Anastomoses between the arterial systems of the superficial and deep omental walls were consistently present, although neither numerous nor strong. Most of those anastomosing vessels reflected across the lateral omental borders, not across the caudal border. However, in 8 out of 10 dogs one stronger anastomosis between the superficial and deep omental arch was observed, which did reflect across the caudal border.

The current omental surgical lengthening technique in veterinary medicine is based on a single study on the vascularization of the omentum, performed in one dog only. In that technique, however, that relatively stronger anastomosing vessel bending across the caudal border and which we observed in the majority of dogs, is potentially compromised. Consequently, the vascular supply of the pedicle tip could be jeopardized. Based on the results of the present vasculature study, a novel lengthening technique was performed in 10
additional cadavers. An incision was made through both omental walls, starting from the right free omental border, parallel to the gastroepiploic arch and transecting 3 to 4 omental arterial branches. The incision was then continued caudally parallel to the omental branches, creating a pedicle supplied by the splenic artery and its continuation in both omental walls. By unfolding the walls of the pedicle, the width of the pedicle tip could be at least doubled in 9 dogs and almost doubled in the 10th dog.

The main surgical regions of interest for omental transposition in companion animals are the axillary and inguinal regions. In 10 cadavers, the operating range of the intact omentum was studied to verify the necessity to surgically lengthen the omentum in extraperitoneal applications (Chapter 5). In 3 out of 10 dogs the intact omentum could reach the right axilla, and in 1 dog the omentum could even be transposed as far as the thoracic inlet. The groin was covered bilaterally in all cases. Determining the operating range of the pedicle created through the novel technique, we found that the pedicle could reach the digits of the forelimb in more than half of the cases and the hindlimb digits in most cases.

The general conclusion of the present dissertation is that the omentum is indeed a complex and an intriguing abdominal organ which demands creative solutions to gain accurate insights into its anatomical lay-out. The bursal cast created through the polyurethane casting technique is an adequate tool to study both the omental bursa and the enveloping omentum. The recommendations for a more elaborate nomenclature of the canine omentum, that were presented in this thesis, can ameliorate unambiguous scientific communication. When lengthening of the omentum is required for extra-abdominal applications, the novel pedicle technique supplied by the splenic artery seems to better respect the omental vascular supply than the currently applied technique. Moreover, pedicle tip width is no longer a limitation in this new technique because it can be doubled by unfolding the superficial and deep walls of the pedicle.
SAMENVATTING
Wanneer het abdomen van zoogdieren via een incisie in de ventrale middellijn wordt geopend, is het omentum het eerste orgaan dat men tegenkomt. Toch lijken weinigen zich bewust van het bestaan van dit orgaan, laat staan van zijn unieke functies. Zelfs voor wetenschappers die getraind zijn in de (dier)geneeskunde en/of morfologie doet het omentum vaak maar vaag een belletje rinkelen. Nochtans wijst recent onderzoek steeds meer op enkele buitengewone eigenschappen van dit orgaan, zowel in de humane geneeskunde als in de diergeneeskunde.


Reeds eeuwenlang zijn wetenschappers geïntrigeerd door het omentum. Hun kennis van de eigenschappen van het omentum was lang uitsluitend gebaseerd op empirische bevindingen zonder diepgaande inzichten. Dit fascinerende orgaan begon pas echt zijn mysteries prijs te geven in de laatste decennia en heeft nog veel meer eigenschappen te onthullen. In Hoofdstuk 1 wordt een historisch overzicht gegeven van de zoektocht naar de ware aard van het omentum tijdens de afgelopen eeuwen. De inspanningen van wetenschappers om de functies van het omentum te exploreren, worden eveneens belicht in het eerste hoofdstuk, alsook de ontdekking van het nut van het gebruik van het omentum in klinische toepassingen en wel voornamelijk in de chirurgie. Verder wordt in de inleiding van deze thesis een beschrijving gegeven van de morfologie van het omentum en zijn bloedvoorziening, met een focus op de hiaten in de huidige kennis. Momenteel ontbreken gedetailleerde anatomische data over het omentum van de hond en informatie wordt vaak geëxtrapolieerd uit de menselijke geneeskunde. Er wordt een up-to-date status van het onderzoek naar het omentum en zijn functies gegeven. Het omentum bevat een variabele hoeveelheid vet met specifieke eigenschappen. Bij de mens is een overmatige opstapeling van vet in dit depot geassocieerd met metabole disfuncties zoals diabetes. Recent onderzoek geeft

In 1939 beschreef Otto Zietzschmann nauwgezet de topografische anatomie van het omentum van de hond. De nomenclatuur die hij introduceerde in deze pionierstudie wordt niet langer algemeen gebruikt en over de macroscopische anatomie van het omentum van de hond werd sindsdien weinig tot geen onderzoek uitgevoerd. Toch is er nood aan meer gedetailleerde anatomische data. Honden en katten dienen vaak als proefdiermodel voor chirurgische technieken van het omentum bij de mens. De technieken die in deze explorerende studies worden toegepast, en de chirurgische technieken die worden aangewend bij de hond en kat als patiënt, zijn vaak ten onrechte gebaseerd op humane data. Verder beschikken onderzoekers in de microscopische morfologie van het omentum van hond en kat slechts over een beperkt arsenaal aan anatomische bakens om de plaats van staalname correct te beschrijven. In Hoofdstuk 3 van deze thesis worden een aantal anatomische bakens bepaald die ondubbelzinnige communicatie tussen wetenschappers over het omentum van de hond moeten bevorderen. Er werden 9 hondenkadavers ingezet in deze studie. Verschillende technieken, waaronder afgietseltechnieken van de bloedvaten en dissecties van gebalsemde kadavers, werden toegepast om de observaties te illustreren. In een bijgesloten dissectievideo worden de in situ bevindingen gedemonstreerd. De huidige nomenclatuur werd kritisch doorgelicht. Een nieuwe en meer gedetailleerde terminologie werd voorgesteld wat leidde tot een aantal aanbevelingen voor bewerkingen van de officiële nomenclatuur (Nomina Anatomica Veterinaria). Drie constante arteriën werden waargenomen, nl. de craniale maagtak, de caudale maagtak en de linker gastroëpiploïsche arterie. Allen werden direct of indirect afgegeven door de miltarterie. Deze arteriën waren ingesloten in respectievelijk de
craniale, de middelste en de caudale maag-miltploi van het oppervlakkige blad van het omentum.

De maag-miltband wordt vaak beschouwd als synoniem voor het miltnet. Voortgaand op de bevindingen uit de huidige studie, kunnen we dit echter betwisten. In Hoofdstuk 3 werd het miltnet beschreven als een onderdeel van het grote net, dat bestaat uit een oppervlakkig en diep blad. Het bevat een craniale protrusie die voorbij de craniale rand en de dorsale pool van de milt reikte. De maag-miltband daarentegen, die zich uitspreidt tussen de maag en de milt, is een onderdeel van het oppervlakkige blad van het miltnet en wordt begrensd door de craniale en caudale maag-miltploi. De maag-middenrifband en de middenrif-miltband, die vermeld zijn in de officiële nomenclatuur, werden daarentegen bij geen enkele onderzochte hond waargenomen als duidelijk afgelijnde structuren.

Vervolgens werd de bursa omentalis geëxplorieerd in 6 kadavers van honden met behulp van een nieuwe daartoe ontwikkelde polyurethaanafgietseltechniek (Hoofdstuk 4). De bursa omentalis is een virtuele ruimte tussen de bladen van het grote en kleine net. Het vestibulum van de bursa, haar caudale blindzak en de 3 compartimenten van de milt-blindzak konden allen duidelijk in de afgietsels worden afgelijnd en bestudeerd. Het afgieten van de bursa resulteerde in een handig, driedimensionaal en reproduceerbaar studiemodel waarop de anatomische bakens (zoals omschreven in Hoofdstuk 3) zich duidelijk aftekenen. Daarenboven resulteerden de CT scans van deze afgietsels in toonwaarden die gemakkelijk konden gedifferentieerd worden van de waarden van naburige lucht- en gashoudende structuren. Dit liet een automatische identificatie van de structuren en een nauwkeurige driedimensionale reconstructie toe.

In Hoofdstuk 5 werd de vascularisatie van het buidelnet onderzocht door middel van intravasculaire latexinjecties en daaropvolgende dissecties van de bloedvaten in 10 kadavers. Het patroon van bloedvoorziening varieerde weinig tussen de kadavers onderling. Zowel het oppervlakkige als het diepe blad werden in hoofdzaak van bloed voorzien via een linker en rechter randarterie. Deze randarteriën anastomoseerden met elkaar nabij de caudale omslagrand in een oppervlakkige en diepe omentale boog. De miltarterie bracht beide linker randarteriën voort. De oppervlakkige rechter randarterie kwam voort uit de rechter a. gastroepiploica, terwijl de diepe rechter randarterie direct ontsprong uit de a. gastroduodenalis. Anastomoses tussen het arterieel systeem van het oppervlakkige en diepe blad waren weliswaar constant aanwezig, doch ze waren noch talrijk, noch zwaar. De meeste
van deze anastomoses sloegen om de vrije laterale randen van het omentum heen en niet omheen de caudale omslagrand. Bij 8 van de 10 honden werd echter één enkele en zware anastomose tussen de oppervlakkige en diepe omentale boog teruggevonden die wel om de caudale omslagrand heen sloeg.

De chirurgische verlengtechniek van het omentum die momenteel in de diergeneeskunde toegepast wordt, is gebaseerd op één enkele vasculaire studie die werd uitgevoerd op slechts één hond. In die techniek elimineert men echter potentieel de ene zwaardere anastomose die aan de caudale omentumrand omzlaat en die werd gevonden in het merendeel van de honden. Bijgevolg komt de bloedvoorziening van de tip van deze gesteelde flap mogelijk in het gedrang. Op basis van de resultaten van het bloedvatonderzoek uit de gepresenteerde studie, werd een nieuwe verlengtechniek gecreëerd in 10 extra kadavers. Er werd een incisie gemaakt door beide bladen van het omentum, beginnend bij de rechter vrije rand, parallel aan de gastroëpiploïsche boog en doorheen 3 tot 4 omentale arterietakken. De incisie werd vervolgens caudaal verlengd, parallel aan de omentale arteries waardoor een gesteelde flap werd gecreëerd die van bloed werd voorzien door de miltarterie en haar verderzetting in beide omentumbladen. Door de bladen van deze flap open te vouwen, kon de breedte van de tip van de flap op zijn minst verdubbeld worden bij 9 honden en bijna verdubbeld bij de 10de hond.

De oksel- en liesstreek zijn de voornaamste regio’s met chirurgische indicaties voor omentumtransplantatie bij kleine huisdieren. Om te onderzoeken of het omentum chirurgisch moet verlengd worden bij extraperitoneale toepassingen, werd in 10 honden de reikwijdte van het intact omentum bestudeerd. In 3 van de 10 honden kon het intact omentum de rechter oksel bereiken en in 1 hond kon het omentum zelfs tot aan de borstingang worden getransponeerd. De liesstreek kon in alle gevallen beiderzijds worden bedekt. De reikwijdte van de flap gecreëerd via de nieuwe techniek werd nagegaan. De tenen van het voor- en achterbeen konden bereikt worden, bij meer dan de helft respectievelijk bijna alle honden.

Algemeen kan besloten worden dat het omentum inderdaad een intrigerend abdominaal orgaan is met een complexe anatomische organisatie. De afgietsels van de bursa omentalis, gecreëerd met behulp van de polyurethaanafgietseltechniek, zijn adequate studiemodellen voor het bestuderen van zowel de bursa als het omhullende omentum. De reeks aanbevelingen in nieuwe nomenclatuur van het omentum van de hond, die in deze thesis werden voorgesteld, kunnen onduidelijke wetschappelijke communicatie bevorderen.
Wanneer verlenging van het omentum nodig blijkt bij extra-abdominale toepassingen, lijkt de nieuwe flaptechniek bevloeid door de miltarterie, de bloedvoorziening beter te respecteren dan de huidig toegepaste verlengtechniek. Daarenboven kan bij deze nieuwe techniek de breedte van de tip van de flap verdubbeld worden door beide bladen van de flap open te vouwen.
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DANKWOORD
wat volgt is onvermijdelijk onderhevig aan clichés en sentiment. Mijn verwoede zoektocht naar andere vernieuwende invalshoeken bracht weinig revelatie. Laat ik me dan maar onderwerpen aan het cliché en openen met een citaat, en nog wel ééntje van mijn eigen vader.

“Ik wil onderstrepen dat ik me niet verzet tegen een constante stroom van peer-reviewed artikelen, wetenschapsblogs, specialisaties en diversificatie, maar in de lijn van wat ‘Slow Science Manifesto’ beklemtuont, vind ik dat een mens – en ook een onderzoeker – soms de tijd moet nemen om te denken, om vooruit en achteruit te kijken.” (Doom R., Omzien in verwarring, Academia Press, 2012)

Misschien nog meer dan met deze thesis als tastbaar eindproduct van het doctoraat, ben ik blij met de weg die ik voorbije jaren heb mogen afleggen in de wonderbaarlijke wereld van wetenschap en haar omkadering. Het is een tocht gebleken vol verwondering, plezier, enthousiasme en creativiteit, maar bijtijds even goed van desillusie en frustratie. Het is een weg die ik gelukkig niet alleen heb moeten bewandelen. Mijn dank gaat dan ook in de eerste plaats uit naar mijn promotoren die me gegidst hebben, me hebben bijgestaan met raad en daad, zijn meegegaan in mijn enthousiasme en me bij mekaar geraapt hebben na geïncasseerde teleurstellingen.

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Dankwoord

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CURRICULUM VITAE

Geboeid door het wetenschappelijk onderzoek en de academische wereld keerde ze in oktober 2008 terug naar de Faculteit Diergeneeskunde. In oktober 2008 trad ze halftijds in dienst als museumconservator van het Museum Morfologie verbonden aan de Vakgroep Morfologie. Als conservator van de collectie participeert ze in het uitzetten van een museumbeleid van de Universiteit Gent (publiekswerking, acquisitie, strategie van registratie en ontsluiting,…) en de conceptontwikkeling van het nieuw Universiteitsmuseum. Ze zet zich tevens actief in in wetenschapscommunicatie- en popularisatieprojecten (tentoonstellingen, Kinderuniversiteit, Durf Denken blog,…).


Marjan is sinds enkele jaren lid van de ethische commissie van de Faculteit Diergeneeskunde en sinds 2014 ook van de ethische commissie van Ablynx NV. Ze behaalde het diploma van Master of Laboratory Animal Science in 2013. Ze is auteur en co-auteur van meerdere publicaties in nationale en internationale tijdschriften en van een hoofdstuk in een internationaal handboek voor chirurgie van de kleine huisdieren. Ze nam actief deel aan verschillende nationale en internationale congressen en was tweemaal lid van het organiserend comité.
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