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Visualization of Equine Colic

from Ultrasound Diagnosis to Surgery

Master Scientific Illustration 2023 Maastricht, The Netherlands

Visualization of Equine Colic

From Ultrasound Diagnosis to Surgery

Thesis presented for the degree of
Master of Arts in Scientific Illustration

by Eungyeol Lee

Zuyd University of Applied Sciences and
Maastricht University
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COLOPHON

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TABLE OF CONTENTS

PREFACE

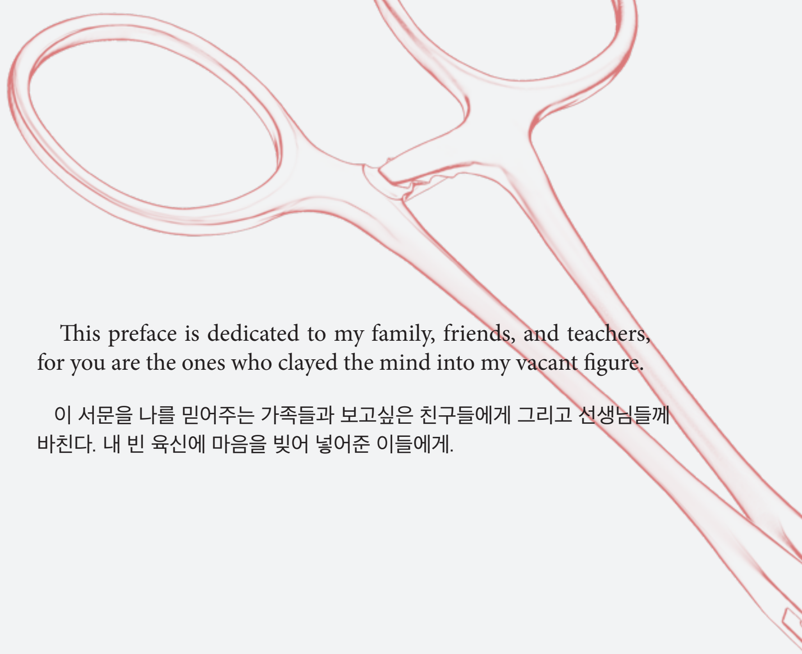
Horses are majestic animals. The reason they especially interest me is that they occupy a rather special and unique place in relationships with people. Horses were traditional vehicles for transportation before man invented machines. A significant amount of historical evidence supports the hypothesis that horses became domesticated in approximately 3500 BCE.[1] They were one of the very first domesticated animals bigger than a human. Though domestication of cattle occurred much earlier around 9000 BCE,[2] cattle were mainly used as a food source and for farming. Horses brought humans the gift of speed and long-distance traveling. They were the extensions of the human body in terms of speed and distance.

Civilization took place over time, and machines were made. Horses no longer occupy a significant role in transportation anymore. Descartes in the 17th CE internalized, within man, the Cartesian dualism (or mind-body dualism) implicit in the human relation to animals.[3] He thought the universe contained two different substances — the 'mind' defined as thinking, and the 'body (matter)' under the law of physics and mechanics, unthinking.[4] And since he deemed animals were soulless, animals were reduced to the model of a machine. So in this sense, horse surgeons are car engineers.

I thought during dissection classes that the body may seem like an elaborate machine. Every organ, muscle, bone, and vessel has a function and structure. Because there lies a brain attached at the end of all nerves, we move, think, talk, and feel. And because of that, we have minds which make us who we are. This is why I am keen on the idea of surgeries. Surgery may seem like when a body is treated like a machine. The body is cut, sewed, conjoined, and closed back. Every step of it is a goal-oriented, problem-solving process. And surgical illustrations are like IKEA assembly instructions but of a live body.

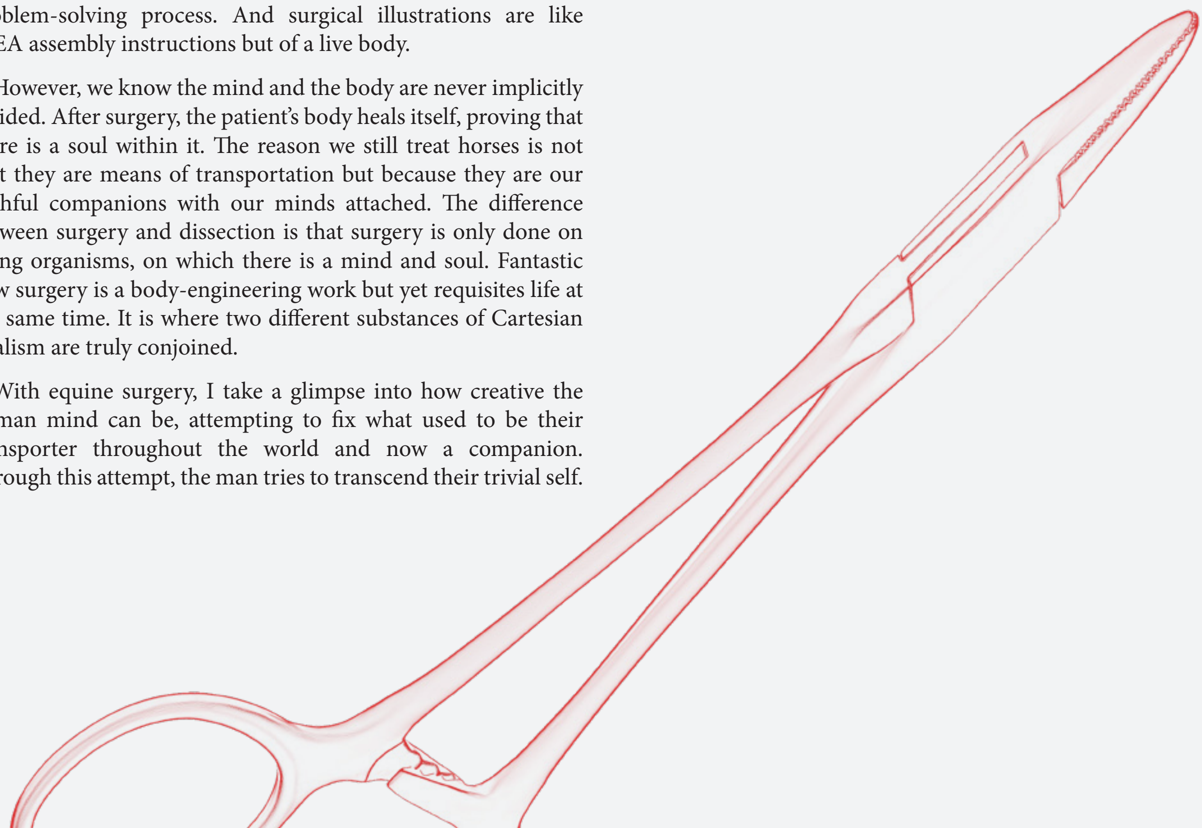
However, we know the mind and the body are never implicitly divided. After surgery, the patient's body heals itself, proving that there is a soul within it. The reason we still treat horses is not that they are means of transportation but because they are our faithful companions with our minds attached. The difference between surgery and dissection is that surgery is only done on living organisms, on which there is a mind and soul. Fantastic how surgery is a body-engineering work but yet requisites life at the same time. It is where two different substances of Cartesian dualism are truly conjoined.

With equine surgery, I take a glimpse into how creative the human mind can be, attempting to fix what used to be their transporter throughout the world and now a companion. Through this attempt, the man tries to transcend their trivial self.



This preface is dedicated to my family, friends, and teachers, for you are the ones who clayed the mind into my vacant figure.

이 서문을 나를 믿어주는 가족들과 보고싶은 친구들에게 그리고 선생님들께 바친다. 내 빈 육신에 마음을 빚어 넣어준 이들에게.



INTRODUCTION

Despite being mostly raised in urban areas that lack horses, horses were often the inspiration for my artworks. When first deciding the topic for this thesis, I knew I wanted a research topic related to surgery. Surgical illustrations are what I enjoyed working on the most during my first year in MSI. And in the future, I hope to specialize in surgical illustration and 3D imaging. Neurosurgery was another choice of topics I considered since neurosurgery seemed more practical for a future career. But I hated to miss the chance to work on large ungulates. Eventually, my love for horses and interest in surgical illustration melted down as the topic of equine surgery.

I reached out to several veterinary universities near The Netherlands and eventually got in contact with two researchers; Dr. Gabriel Manso-Díaz of the Department of Animal Medicine and Surgery, Veterinary School, Universidad Madrid, Spain, and Dr. Harold Brommer of the Department of Clinical Sciences, Utrecht University, The Netherlands. At the time, Dr. Manso-Díaz was looking for an illustrator to make diagrams for his publication. He is specialized in diagnostic imaging of large animals which was another topic I was interested in, but I still wished to include surgical illustrations in the thesis. Eventually, I reached out to Dr. Brommer to ask if he is interested in advising on the part regarding equine colic surgery. He did not need an illustrator at the moment but was very kind to find the surgery that would suit the topic and to invite me to a surgery excursion.

This thesis consists of two parts. Part A is regarding the ultrasonography of Nephrosplenic Entrapment, a kind of equine colic, advised by Dr. Gabriel Manso-Díaz. Part B contains surgical procedures of jejunocecostomy, and was advised by Dr. Harold Brommer.

Research Question:
How can scientific illustration benefit from 3D?

The research question of this thesis, from a scientific illustrator's point of view, may differ from that of the external advisor. The former lies in the field of art and visuals, and the latter lies in that of science and medicine. My initial research question was; How can scientific illustration benefit from technology? And this question was followed by a few more questions; How can we utilize technology to improve our work? What are the advantages that traditional methods have over relatively newer methods? The word 'technology' in this thesis refers to 3D and diagnostic imaging. The meaning of this word could also be extended to other fields of technology for broader discussions. But in this thesis project, I want to concentrate on how 3D imaging can be used in scientific illustration. The goal is to explore the advantages of 3D imaging and to find ways to improve 2D illustration workflow by utilizing 3D.

Today we live in a world of Computer Science, Artificial Intelligence (AI), and images produced by deep learning machines. Will man-drawn illustrations gradually cease to exist? Or will it survive just because human labor costs less than machines do? My apologies if the questions sound overly pessimistic. I have a fine art background, and in fine art when seeking answers, I start with denying and questioning.

These insecurities root partially in my national background. South Korea, geographically, gains very few natural resources. Mineral resources are meager, no fuel energy and the land is not large enough for mass factory farming. Therefore, the country made its profit within industries such as electrical and electronic devices, IT, steel and car manufacturing, semiconductor production, and shipbuilding. It did bring a huge leap in economic growth in a short period, changing so much over just two or three generations. The rapid growth engraved a certain national mindset; if one falls behind state-of-the-art techniques, one will not succeed in making a living. I always have been living in constant fear of computer technology replacing my job. I certainly still have that anxiousness in me. This insecurity motivates me sometimes, to learn more and grow.

Slowly I am seeing that technology is not against us. Thirty years ago from now, most scientific illustration work was drawn with ink and watercolor. Now, most illustrators work digitally. When 3D imaging was first introduced to the scientific visualization world, it replaced some traditional illustration works. But eventually, scientific illustrators became the ones who build these models. Even traditional illustrators benefit from 3D, utilizing them as references. And because there are advantages of classical illustration that 3D imaging does not have, both 2D and 3D images continue to exist in the scientific visualization world, specializing deeply in each of the two fields. Continuous learning is what matters, and this applies not only to the scientific visualization field but to every profession present.

Technology and traditional illustrations, machines and man, body (matter) and mind — these elements seem to be in isolation from each other or a conflicting relation, but they are not as distant as we might think. We ourselves are fusions of body and mind. Hardware reshapes software, and software runs the hardware. I find this relationship rather interesting to think of.

RESEARCH TOPIC

Equine Colic: What is equine colic? Why is it so common?

The term 'Colic' in equine veterinary refers to all abdominal pain in horses rather than a specific diagnosis. The source of colic may originate from any part of the horse's abdomen, from gastrointestinal tracts to non-gastrointestinal such as reproductive, nervous, and muscular systems. The most common forms of colic are gastrointestinal and are frequently related to colonic disorders. Common causes of colic include accumulation of gas in the intestines, impaction of food or sand, and displacement and volvulus of gastrointestinal tracts. Annually the frequency of colic is reported to be 4-10% of horses, with great variation between farms, ranging from 0% to 30% of horses per year. [5,6,7,8,12]

Colic, by its nature, is often unpredictable and can rapidly progress to its fatal phase. It is the most common cause of death in horses, as shown in its epithet 'Number one equine killer'. Why are horses so prone to colic? This question has multiple answers. The equine gastrointestinal tracts differ from human anatomy and are much more susceptible to impaction. A horse's digestive system consists of the esophagus, stomach, small intestine, cecum, large colon, small colon, rectum, and anus. After food and water intake pass through the esophagus, stomach, and small intestine, it enters the cecum where bacterial action takes place. Because horses consume a large amount of cellulose in their diets, their cecum and large colon are relatively bigger than those of other mammals, giving bacteria enough time to decompose cellulose into absorbable substances.[9] After being digested inside the cecum, the food and water contents travel through the large intestine and travel around in the abdomen twice. After passing the transverse colon, the very last portion of the large colon, the contents enter the small colon and finally pass the rectum. Due to this structure, it is very easy for gas to build up at certain locations in the abdomen as the left ventral and left dorsal colon (LVC and LDC) and right dorsal colon (RDC). Impaction of food and sand often takes place at locations such as pelvic flexure, ileum, and cecum. For the schematized diagram of the equine digestive system, see Fig.1.

In addition, horses have very well-developed cardiac sphincters. The cardiac sphincter is a muscular ring that connects the esophagus and the stomach at an oblique angle. It acts like a valve and allows food, water, and gas into the stomach, but not in a reverse direction. This mechanism disables the horse to vomit or burp, enhancing the possibility of gas buildups inside the gastrointestinal tracts when most of its diet is fiber as grass and hay.[16]

Many cases of colic can be treated non-surgically. Approximately 80% of horses with colic suffer from gas colic or colic of unknown cause that can be healed with no treatment or a single treatment.[10,11,12] 5% of horses with colic suffer large colon impactions that are mild in most cases and are treatable with medicine.[11] Fewer than 7% percent of colic requires surgery.[10,11,12]

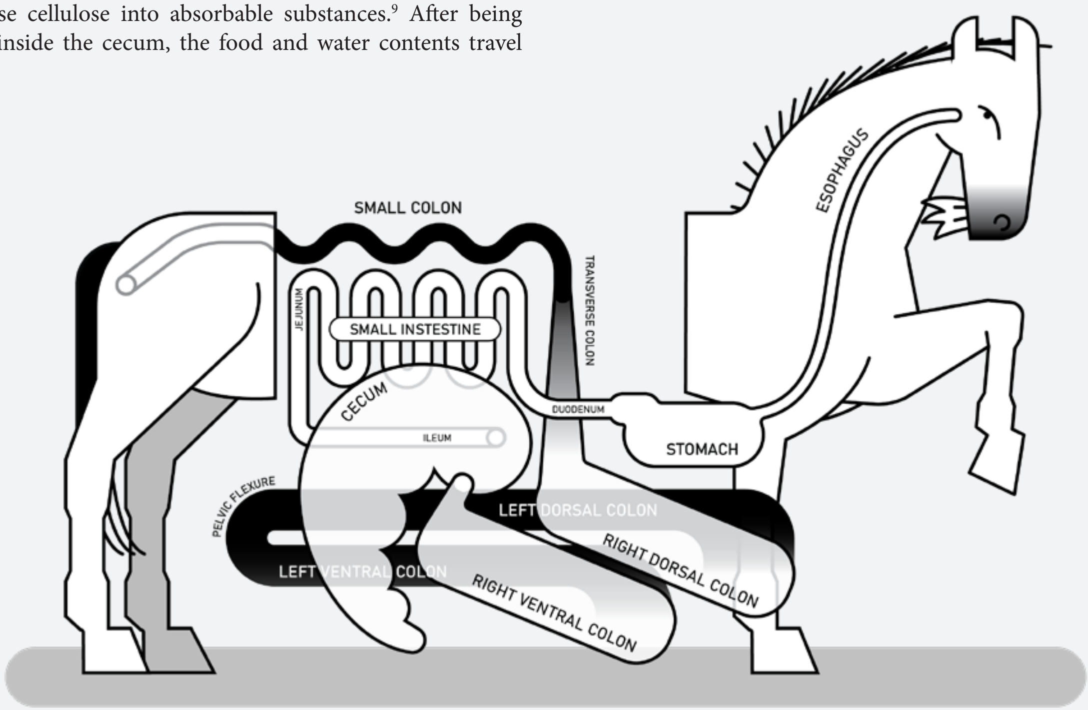


Fig.1 Schematized diagram of equine digestive system.

PART A
:ULTRASOUND DIAGNOSIS OF NEPHROSPLENIC ENTRAPMENT(NSE)

External advisor:
Dr. Gabriel Manso-Díaz

Introduction

Diagnostic Imaging (MRI, CT, Ultrasonography, etc.) may have partly replaced what used to be the role of scientific illustration in the past. But fundamentally, scientific illustration and diagnostic imaging gain different purposes. As its name says, diagnostic imaging is used to diagnose symptoms and diseases of individual patients quickly and immediately, while scientific illustration processes more refined information. As diagnostic images are challenging to read for most of the general public, scientific illustrators can provide a bridge between the general public and specialists by translating the raw data into a more comprehensible and refined form. And often, scientific illustrators also benefit from diagnostic imaging when researching and learning about certain topics.

Why is 3D imaging an effective way to explain and visualize ultrasonography? 3D imaging has its benefits compared to 2D illustration. It provides visuals of an object from different views. It can be cut and rearranged. Parts of the model can be separated, removed, reshaped, or altered of its transparency.

Understanding ultrasonography requires a sense of 3D dimensionality. 2D ultrasonography provides flat, cross-sectional images that can be difficult for some to read, especially when the clinicians are untrained in medicine or diagnostic imaging. When performing the ultrasound, the clinician builds the 3D picture in their mind by moving the transducer. Building the 3D image by watching the performances of others requires a high level of experience. Looking at and understanding a single 2D slice requires a thorough understanding of the topic. Therefore, using a 3D model generating virtual 3D views can be the most effective way to explain 2D ultrasonography as it allows a more intuitive understanding of the structure.

Explaining ultrasonography with visuals often requires images of the same topic from various points of view. It was also the case with Dr. Gabriel Manso-Díaz. The pictures he needed for his publications were images of a horse with Nephrosplenic Entrapment(NSE) from four diverse angles. Thus it was a reasonable choice to build a 3D reconstruction of a horse's abdomen and derive multiple renders from the model.

ULTRASONOGRAPHIC TRAITS OF NEPHROSPLENIC ENTRAPMENT

In his publication (Manso-Díaz, G., et al., 2023, Ultrasonographic features of left dorsal displacement of the large colon in horses), the research goal of Dr. Gabriel Manso-Díaz is to analyze the ultrasonographic traits of Nephrosplenic Entrapment (NSE). Since ultrasonography findings of NSE are not well described in textbooks. Nephrosplenic Entrapment, also referred to as left dorsal displacement of the large colon (LDDLC), is a common cause of equine colic that accounts for 2.5-9% of colic cases.[15] NSE is a condition in which the left large colon gets entrapped in the nephrosplenic space, which is the place between the left kidney and the spleen. Though the direct cause of NSE is unclear, it is hypothesized that the accumulation of gas or ingesta allows the colon to travel dorsally between the spleen and the body wall.[13]

When compared to the normal horse abdomen (Fig.2), a few characteristics can be found in the abdomen with NSE (Fig.3). Most noticeably, the left large colon had traveled dorsally and is trapped in the nephrosplenic space. Another noticeable trait is that the spleen is caudoventrally displaced and far more enlarged than the normal spleen. This trait is due to the large colon pressing down the nephrosplenic ligament, pushing the spleen towards the caudoventral direction and blocking the blood flow in the splenic vein, only allowing the blood to travel into the spleen but not out from the spleen. What is often overlooked is that the stomach is also ventrally displaced from its normal location. Because the gastrosplenic ligament connecting the stomach and the spleen forces the two viscera to move together.

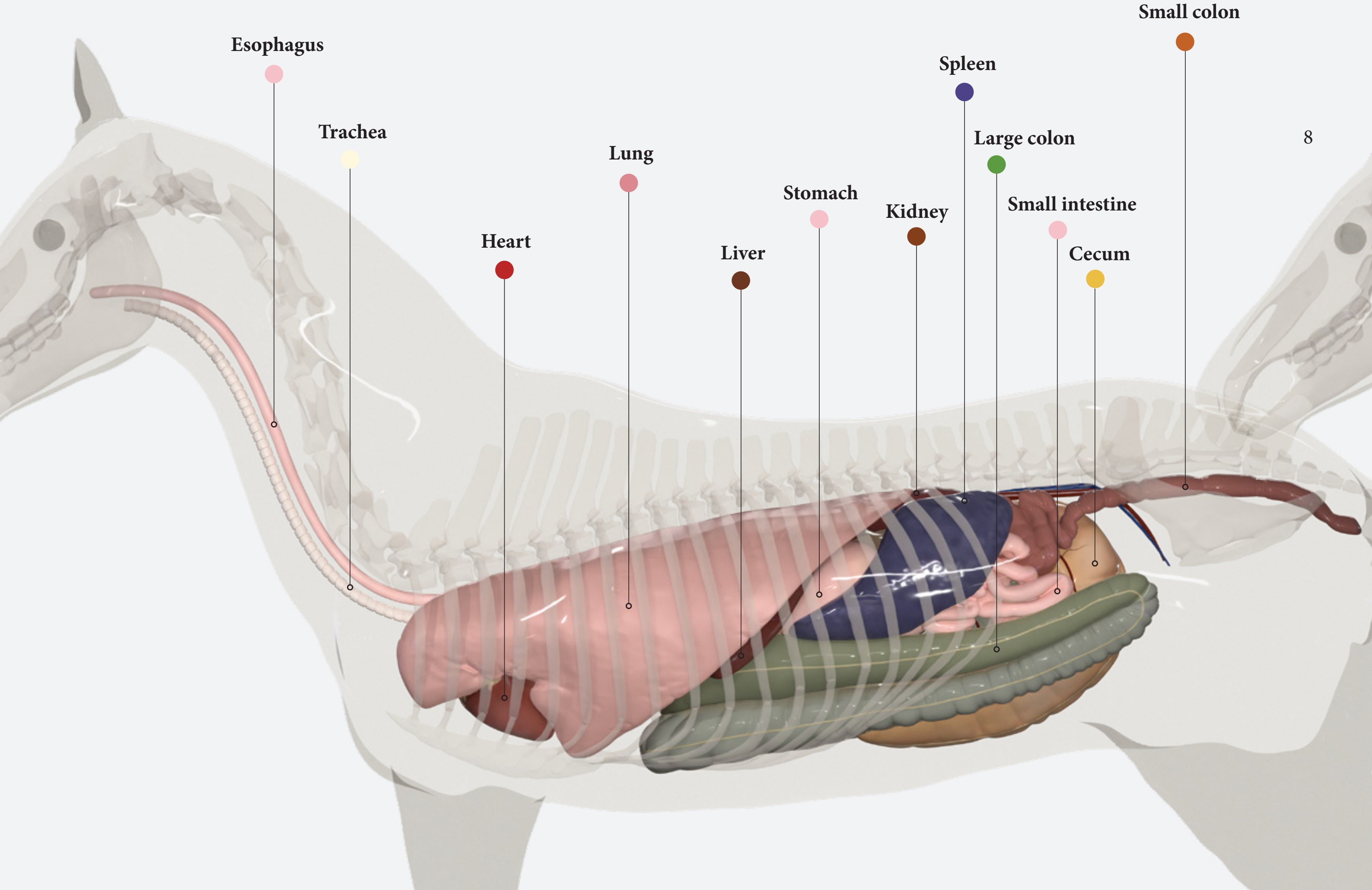
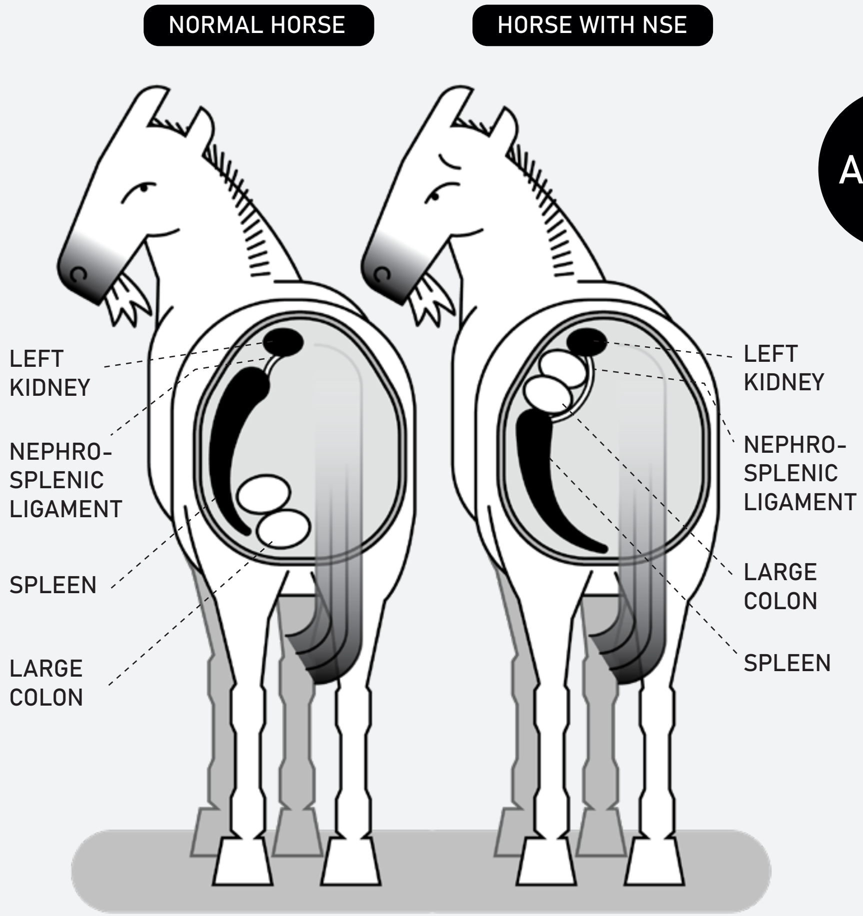
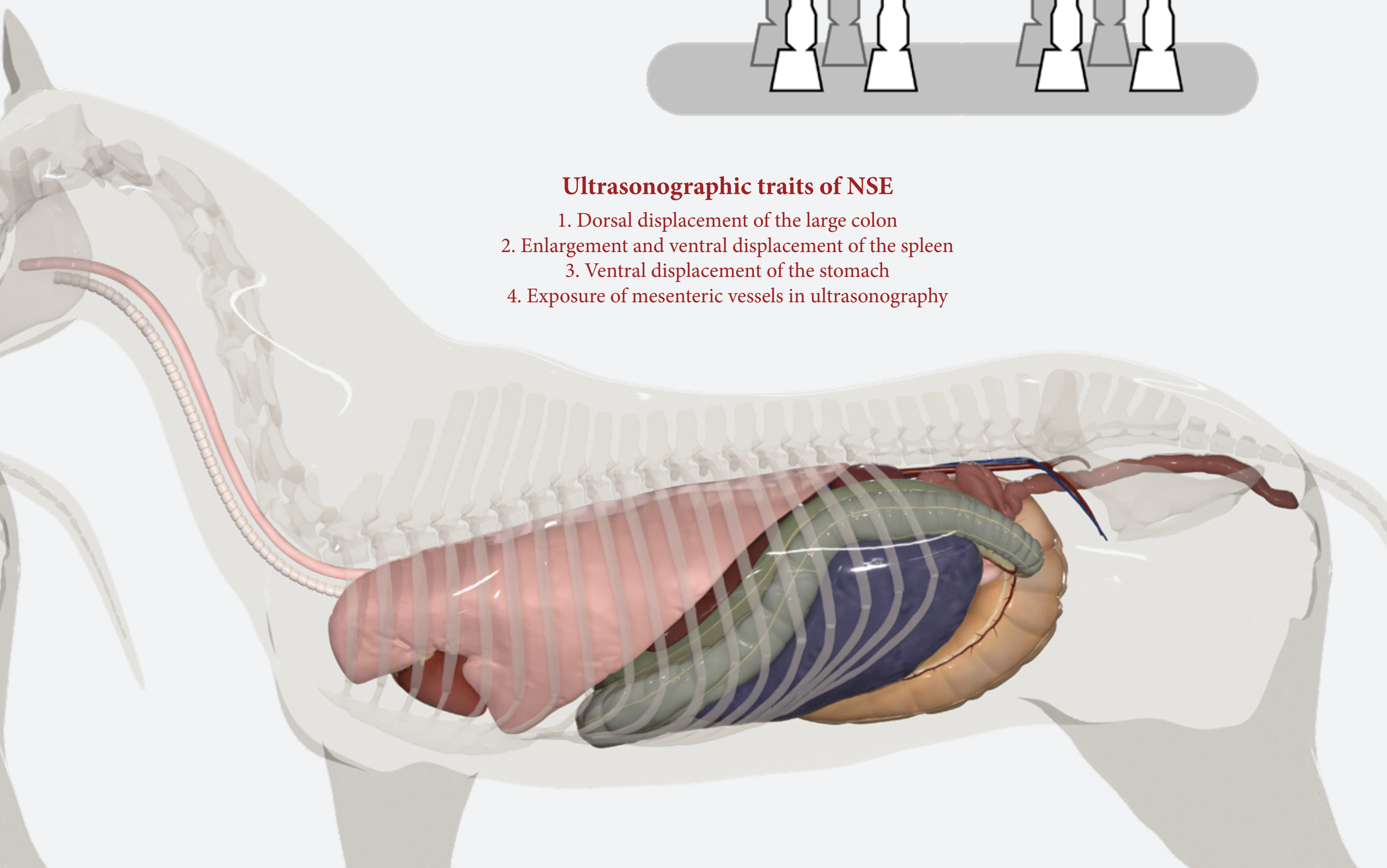


Fig.2 Left lateral view of a normal horse abdomen.

Displacement of the large colon is challenging to diagnose with ultrasonography as there are no sonographic characteristics to detect different parts of the large colon. What is already well known as the ultrasonographic trait of NSE is that the large colon casts an 'acoustic shadow' and locates on the dorsal side of the spleen.[17] The gas accumulated inside the large colon absorbs sound waves and does not reflect any sound waves to the transducer. This trait can be found from the 10th - 12th intercostal spaces up to the paralumbar fossa.[14] Another common finding is that the left kidney and dorsal portions of the spleen are undetectable due to the large colon standing in front.[17] But this should not be the sole reason for NSE diagnosis because lack of visualization of the left kidney is an unspecific finding that can be found in other diseases as well. For this reason, NSE should be diagnosed based on the lack of visualization of the kidney together with the findings of the abnormal location of other organs such as the spleen, stomach, or mesenteric vessels.





Ultrasonographic traits of NSE

1. Dorsal displacement of the large colon
2. Enlargement and ventral displacement of the spleen
3. Ventral displacement of the stomach
4. Exposure of mesenteric vessels in ultrasonography

Fig.3 Left lateral view of a horse abdomen with Nephrosplenic Entrapment.

SHORT INTRODUCTION TO ULTRASONOGRAPHY

[19] Ultrasonography, or ultrasound, is the most inexpensive and harmless modality in diagnostic imaging. For that, clinicians of various specialties use ultrasonography. It is a modality used at the point of care by the bedside, providing real-time sonographic images of the patient.

Ultrasound by definition is the audio frequency above human hearing (16 Hz – 18 kHz). The sound wave frequency used in diagnostic medical ultrasound is 1 MHz – 20 (+) MHz, thus inaudible to human ears. The ultrasound transducer generates sound waves from its piezoelectric crystals. When electric signals of a certain frequency are applied, these crystals vibrate and generate sound pressure waves ("ultrasounds") of that same frequency. This mechanism also works in reverse, meaning the piezoelectric crystals can convert sound waves into electric signals.

Because the ultrasound waves do not travel well through the air, the ultrasound gel is used to reduce the air between the patient and the transducer. The gel allows the transducer to produce a clearer image. When ultrasound waves enter the body, they reach tissues with different densities, which absorb, scatter, or reflect the sound waves. And depending on how strong the tissues reflect the soundwaves, they are described in a spectrum of **hyperechoic** (very echoic), **hypoechoic** (not much echoic), and **anechoic** (not echoic). The more echoic the tissue is, the brighter it appears in the ultrasonographic images. Bones, stones, and calcifications absorb the waves completely. As no soundwave gets past through some tissues such as minerals or bone, they create an '**acoustic shadow**' behind them. In ultrasonography, the acoustic shadow is an area where sound waves fail to reach due to certain types of tissues. Acoustic shadows appear very dark in ultrasound images, so tissues like bones, stones, and calcifications appear dark with a bright border. Fluid-filled viscera such as vessels and cysts absorb very little soundwaves, enhancing the soundwave behind them. Organs such as the kidney, liver, and spleen each have their particular echogenicity and characteristics. A clinician may detect abnormality in a patient when certain tissues appear hyperechoic (more echogenic) or hypoechoic (less echogenic) than their normal state.

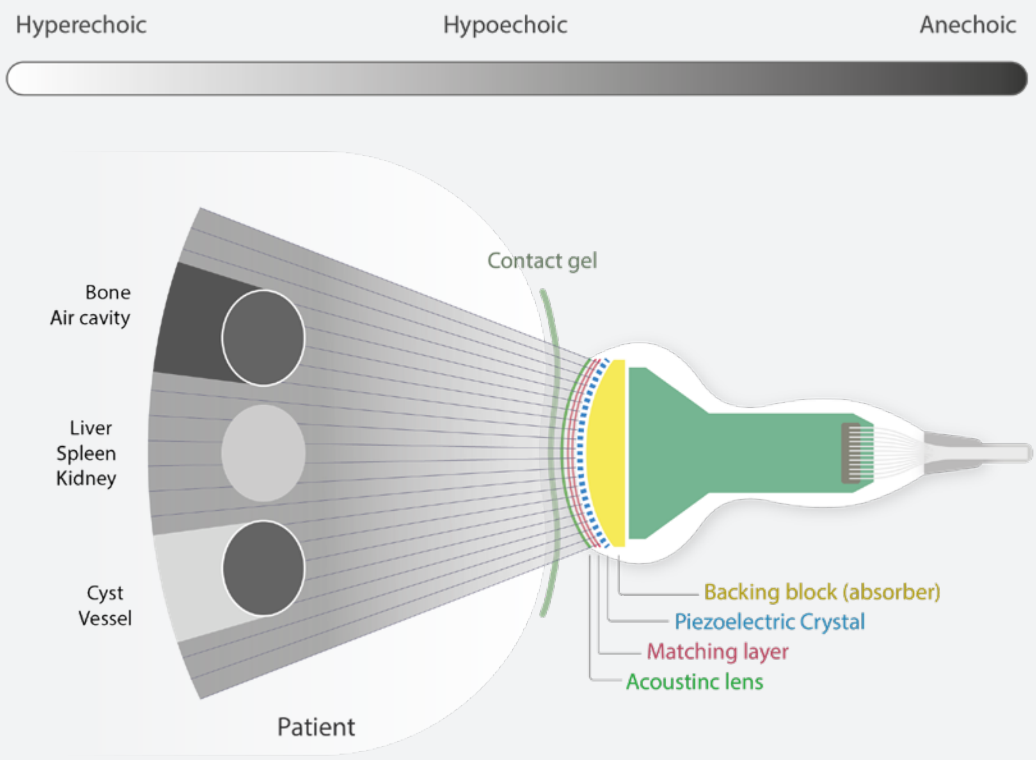


Fig.4 Working principal of ultrasound and structure of ultrasound transducer.

MAKING OF 'GHOST HORSE'

A

No matter how complex it gets at the end, every 3d sculpture starts with a basic shape like a sphere, cube, or cylinder. Organic figures often begin with a sphere. The 'Ghost Horse', as I call it with keen affection, also started from a sphere. Building the horse's outer shape came beforehand sculpting its skeletal structure and inner organs. I find it easier to have a mold in advance to place the objects inside, but this process also could have been the other way around, by using the landmarks of the skeleton to build the skin. As the idea was to create a model that may represent various warmblood horse breeds, the outer shape is based on the features of a Thoroughbred horse. This sculpting process was entirely done in ZBrush.

When sculpting a 3D object, there is a big difference between having and not having the actual reference in presence. It was a privilege to have access to a foal skull as a reference from the specimen library of MSI studio. Owing to it, sculpting the skull was quick and easy. However, it was relatively much more difficult to comprehend the shape of the vertebrae and the ribs in the absence of actual skeletal specimens. Each vertebrate animal has its characteristic shapes of vertebrae. Supposed that the object is symmetrical on its left and right like a vertebrate ideally is, the sculptor at least needs reference images from five different views (from the top, bottom, one lateral side, front, and rear) to be able to sculpt the precise shape. Books and online research did not provide enough of these references. Therefore, observing a horse skeletal specimen in real-life was in desperate need. The closest museum with a complete horse skeleton specimen, Zoölogisch Museum Luik (Quai Edouard Van Beneden 22, 4020 Liège, Belgium), was unfortunately closed due to renovation during the time. But when I was traveling in Paris during the Christmas holidays, I encountered a horse skeleton at Muséum National d'Histoire Naturelle (Paris National Museum of Natural History, 57 Rue Cuvier, 75005 Paris, France) by sheer chance. There complete skeleton specimen of a thoroughbred horse was displaced, and some vertebrae and limbs were displayed in addition apart from the complete skeleton. I was able to collect enough information and apply it to the model. It was worth being yelled at in French for standing too close to the specimen. Later on, under the supervision of Dr. Gabriel Manso-Díaz, a few more refinements were made to complete the skeletal structure of 'Ghost Horse'.

Because I did not have access to wet specimens or dissections of a horse, much of the reconstruction of inner organs had to be dependent on textbook references. The aim of 'Ghost Horse' was to build an ideal, refined, comprehensible reconstruction of the equine abdomen, and therefore much of realistic depictions had to be yielded. It is not impossible to create realistic recreation of anatomy in 3D. But to achieve that takes a considerable amount of time, budget, and research data. On account of limited time and resources, and of the ultimate purpose of the model, I decided it is best to keep the reconstructions of the organs ideal and schematized, which is sometimes even better for educational purposes. Each organ is coded with unrealistic colors so that they are easily distinguishable. Ligaments and tenias are schematized into simpler shapes and thus more recognizable. My understanding of equine anatomy comes from several textbooks, atlases, and photography references. The two publications I mostly referred to are An Atlas of Animal Anatomy for Artists (W. Ellenberger et al. 1949) and Atlas der Anatomie des Pferdes (Budras et al. 1991).

The 'Ghost Horse' includes the skeletal system (excluding limbs as they are not part of the discussed topic), digestive system, kidneys, spleen, heart, aorta, vena cava, and vessels and ligaments concerning ultrasonographic traits of NSE. What is unincluded are the muscular system, urogenital system, brain and nervous system, and vasculature and ligaments unrelated to NSE.

Fig.5 Skeleton of a (from left) Thoroughbred Horse, Percheron Horse, Kulan Horse displayed in Muséum national d'Histoire Naturelle, Paris, France

Fig.6 Overview of Ghost Horse.

1. Esophagus **2.** Trachea **3.** Lung
4. Heart **5.** Liver **6.** Stomach
7. Kidney **8.** Spleen **9.** Small intestine
10. Cecum **11.** Right ventral colon
12. Left ventral colon **13.** Left dorsal colon
14. Right dorsal colon **15.** Small colon

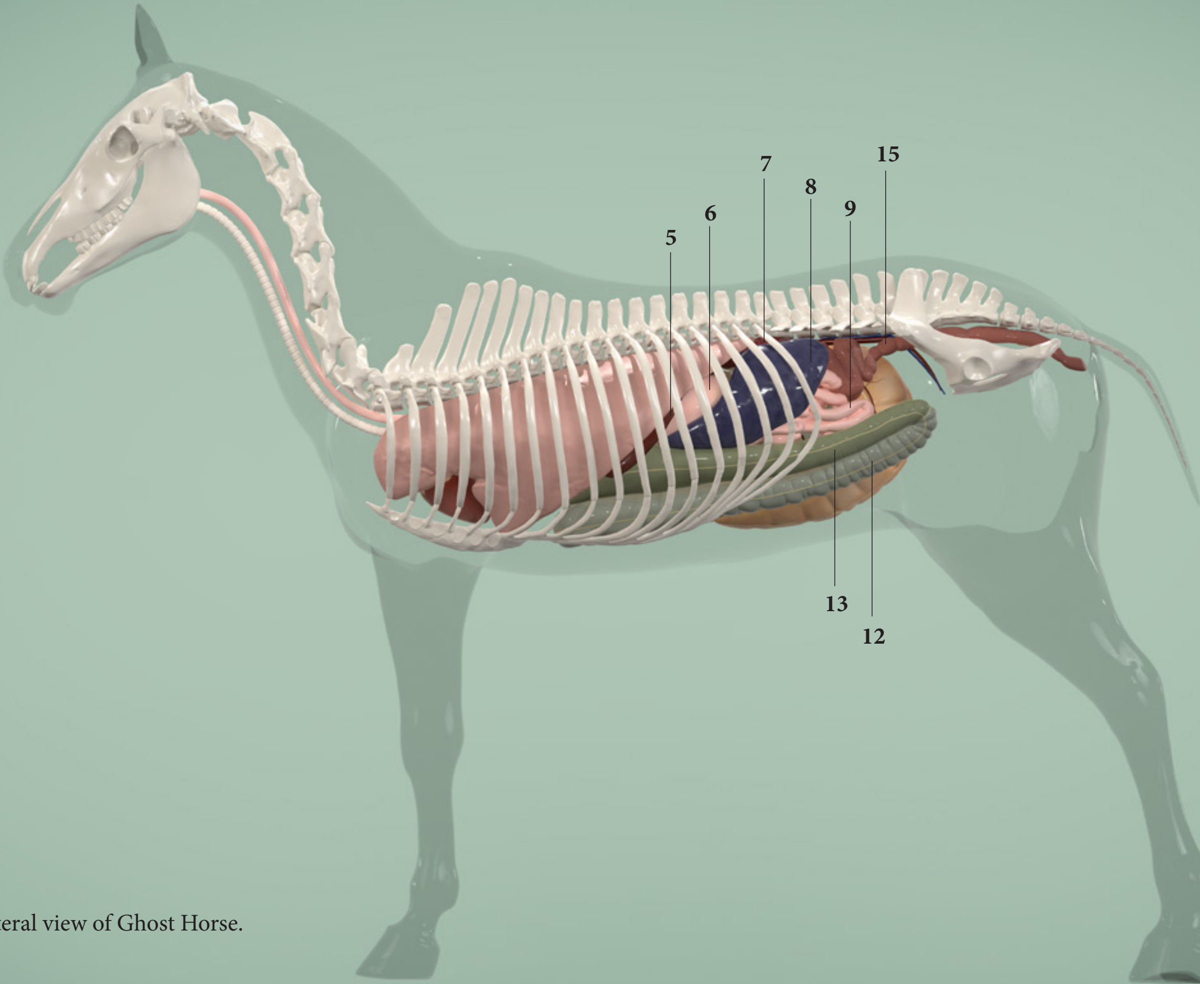
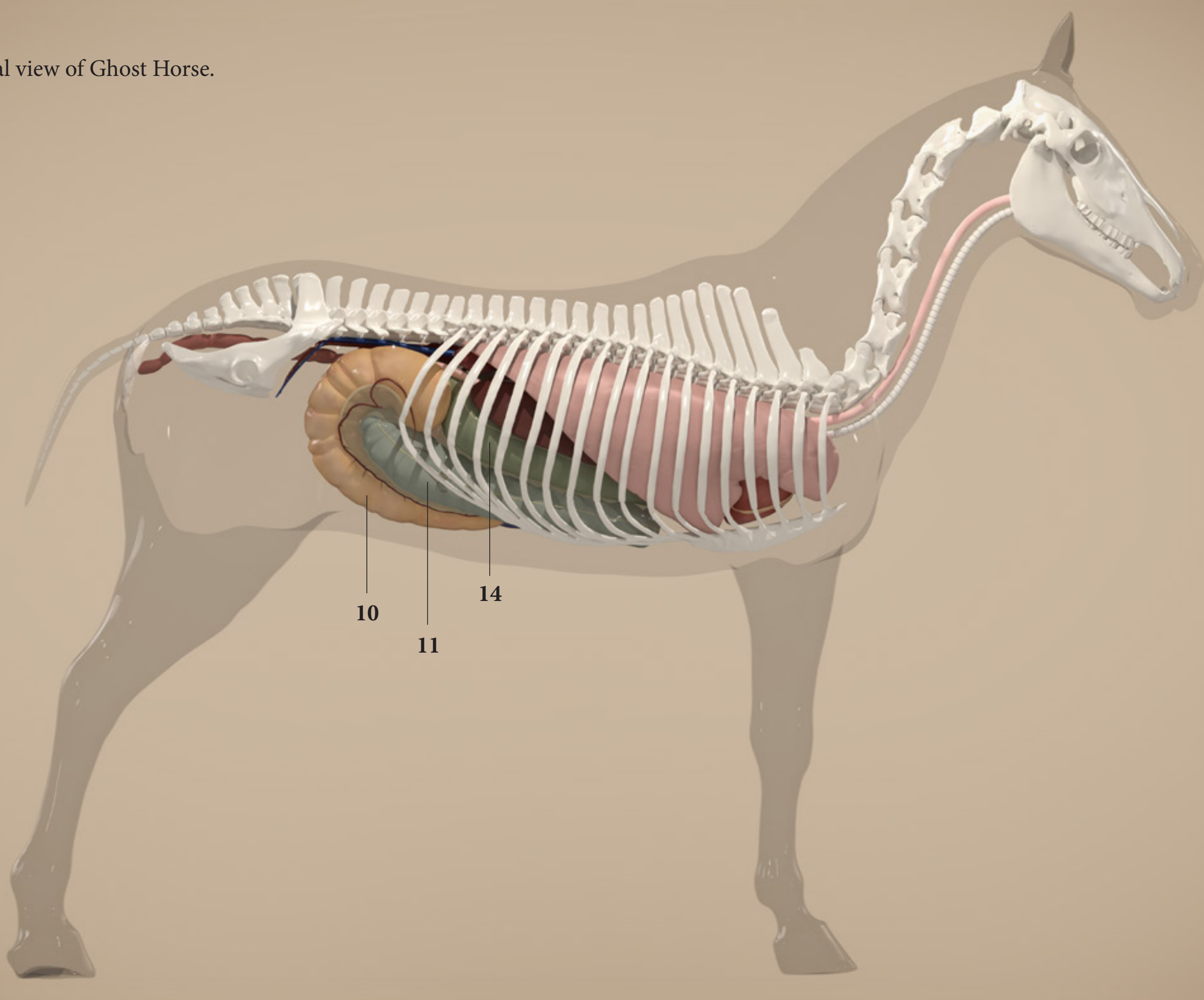


Fig.7 Left lateral view of Ghost Horse.

Fig.8 Right lateral view of Ghost Horse.



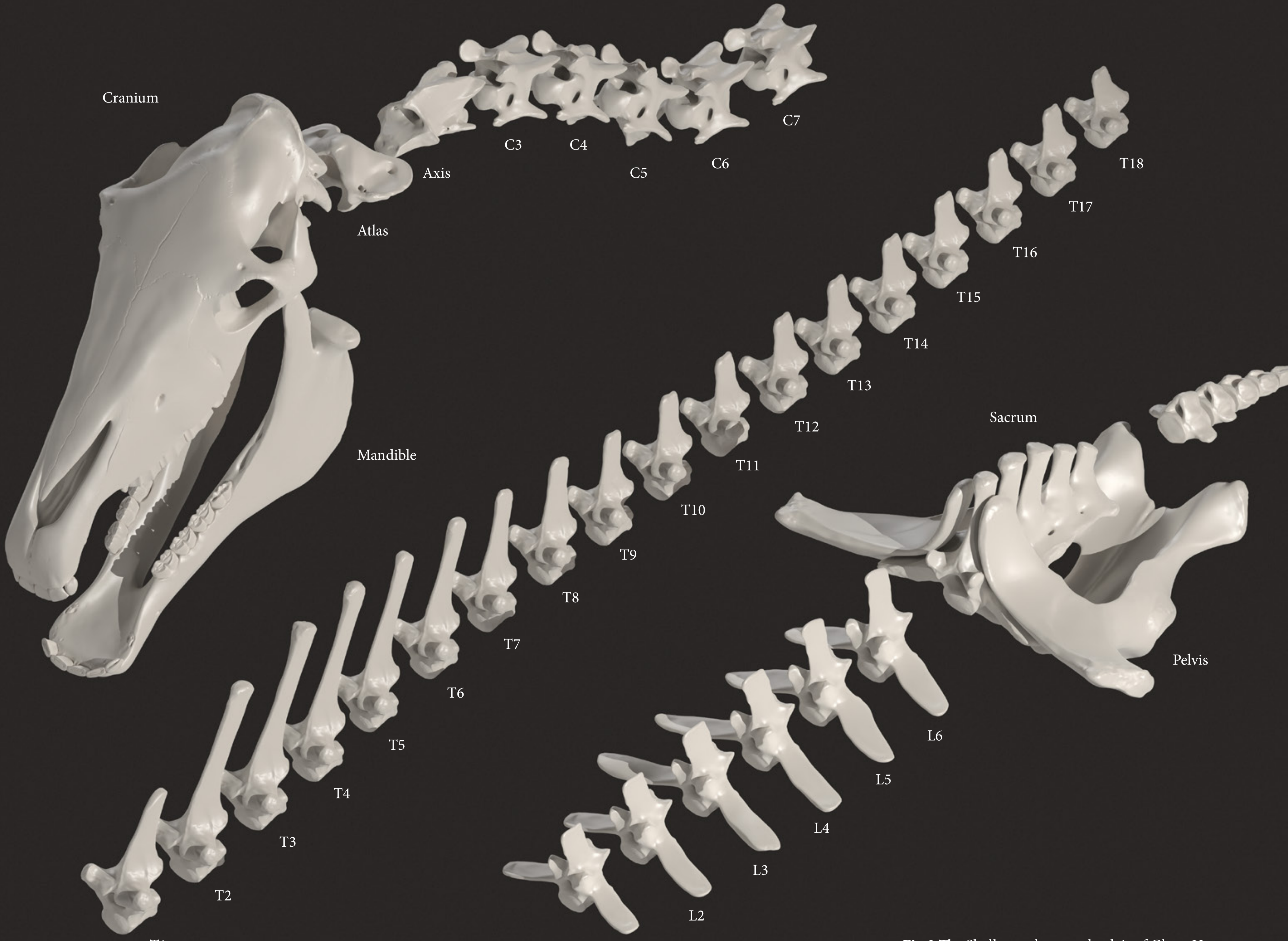


Fig.9 The Skull, vertebrae, and pelvis of Ghost Horse.

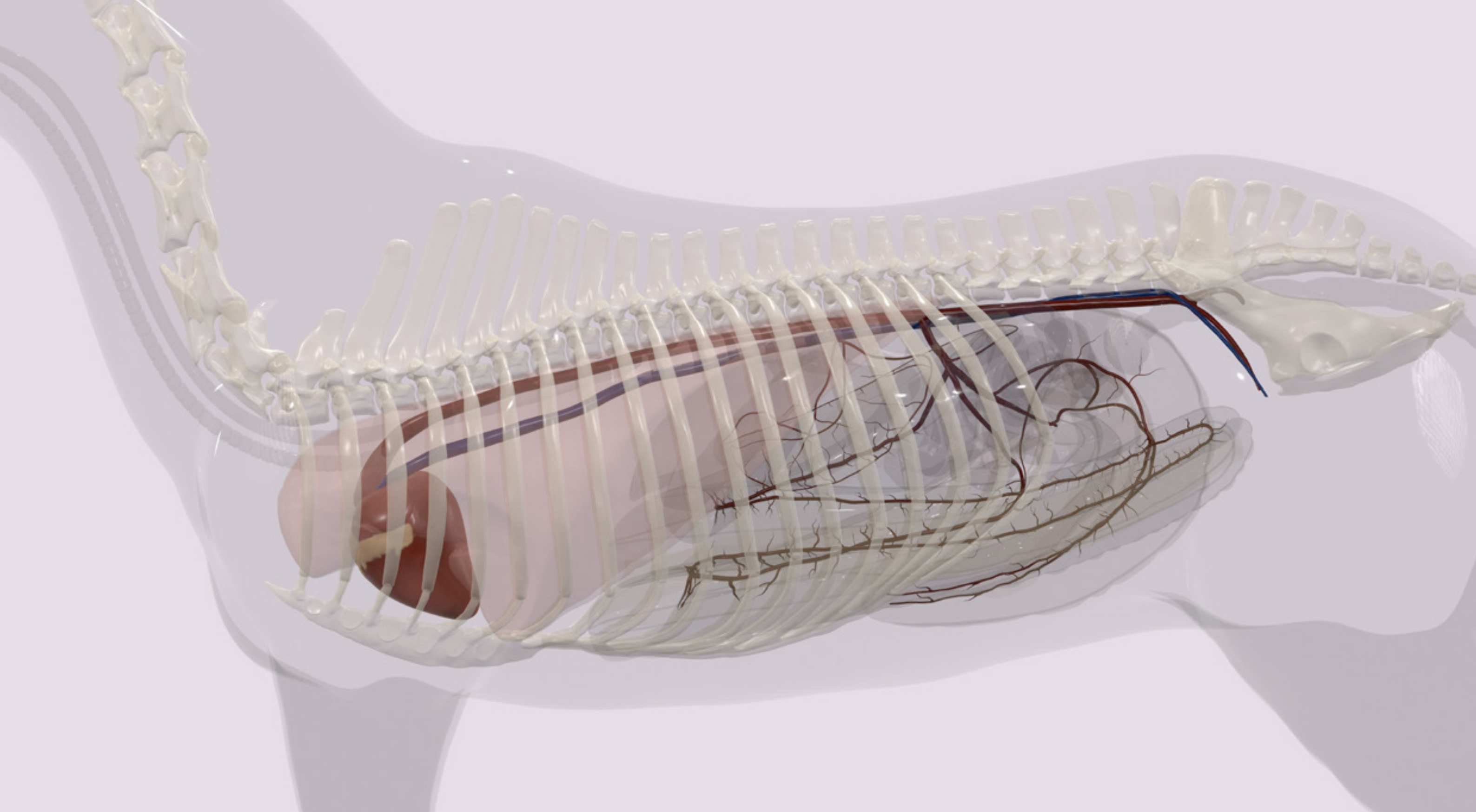


Fig.10 Circulatory system of Ghost Horse related to NSE, left lateral view.

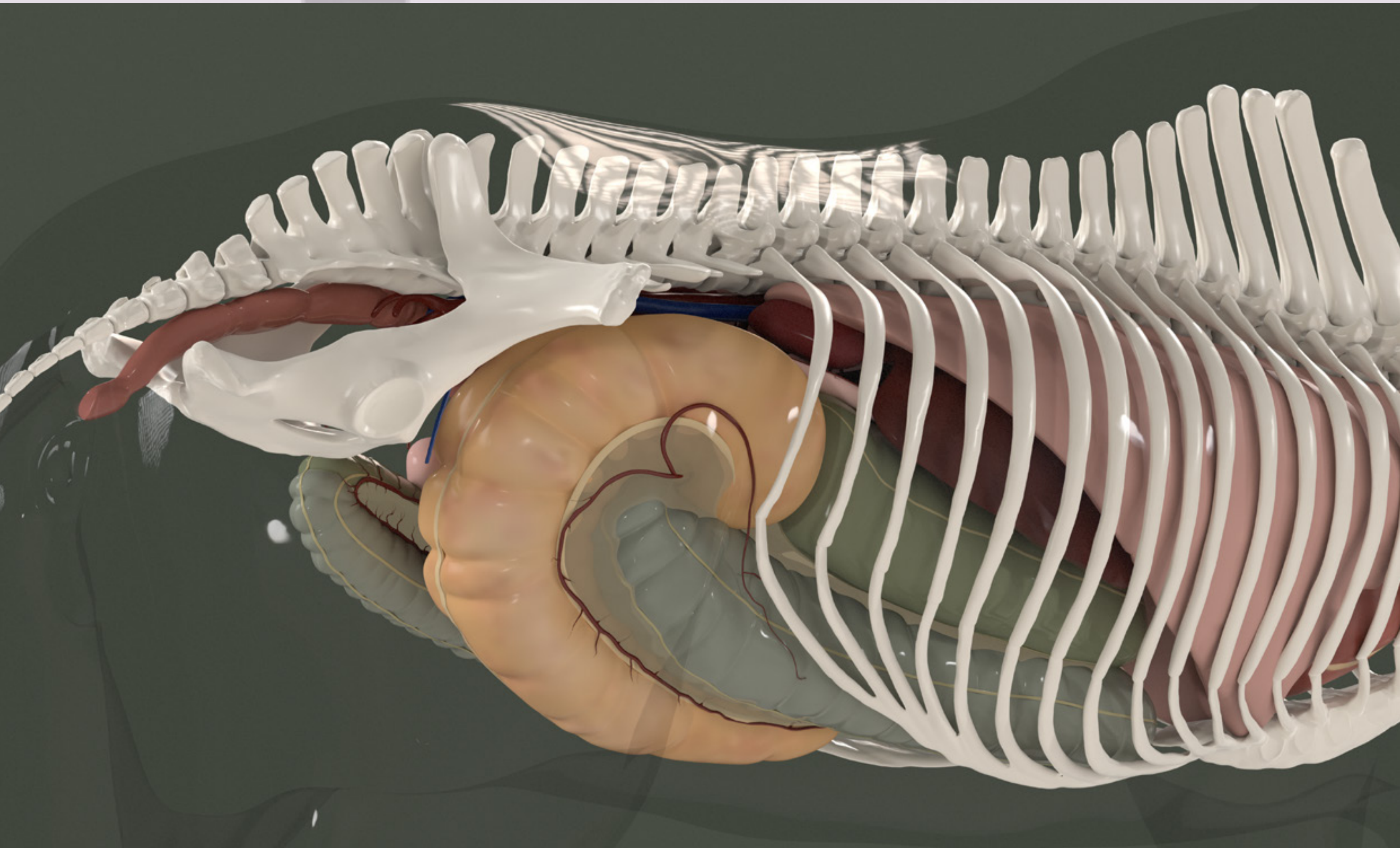


Fig.11 Close up of Ghost Horse, right lateral-caudal view.

RESULT IMAGES

The following four images rendered from the 'Ghost Horse' are the images requested by Dr. Gabriel Manso-Díaz, for use in his publication. Fig.13 and Fig.14 was modified in Adobe Photoshop after 3D rendering for better storytelling. Marmoset Toolbag 4 was used for the render of these images.

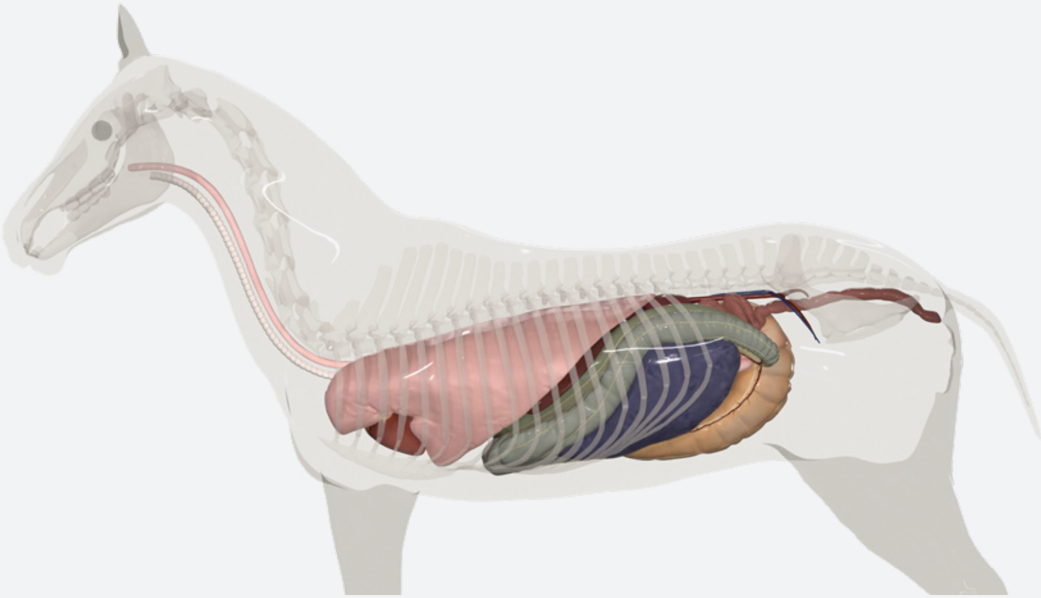


Fig.12 Overview of Nephrosplenic Entrapment

Image showing the Nephrosplenic Entrapment from the left lateral side. The large colon has traveled dorsally and is trapped in the nephrosplenic space. Ventral displacement and enlargement of the spleen are also noticeable. The opacity of the bones was lowered for a better view of the organs.

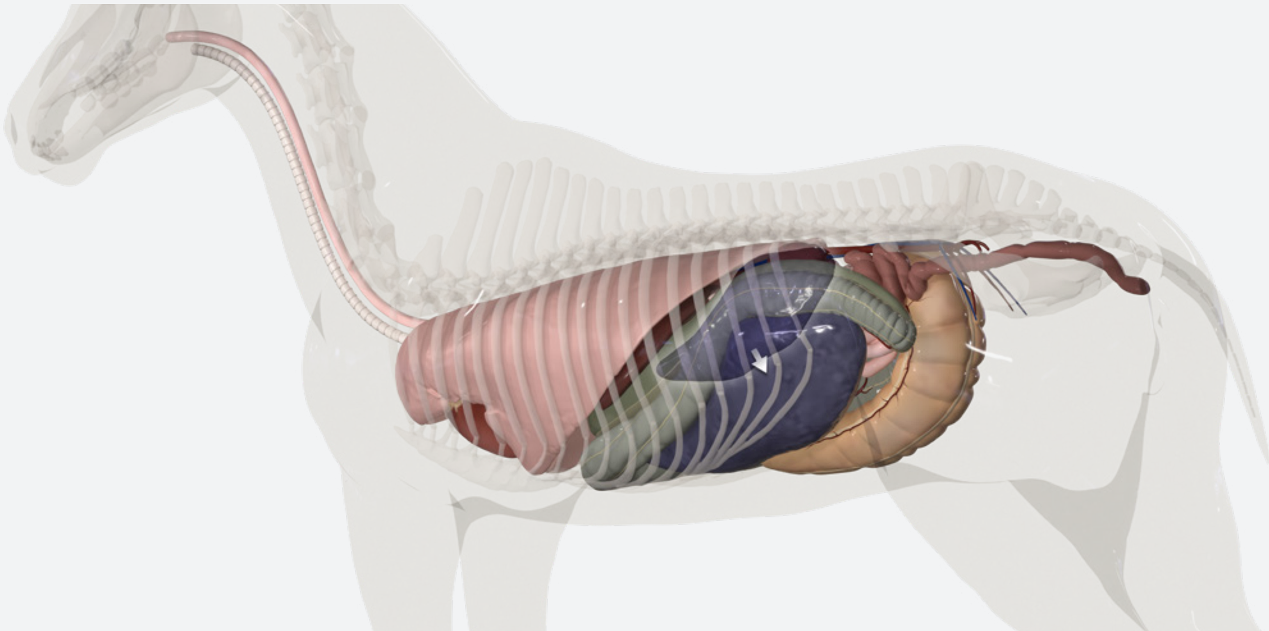


Fig.13 Ventral displacement of the spleen

Image with more emphasis on the ventral displacement of the spleen. The normal spleen is portrayed more transparent than other organs. Its location is highlightened by a bright glow around it. An arrow is indicating the direction of displacement.

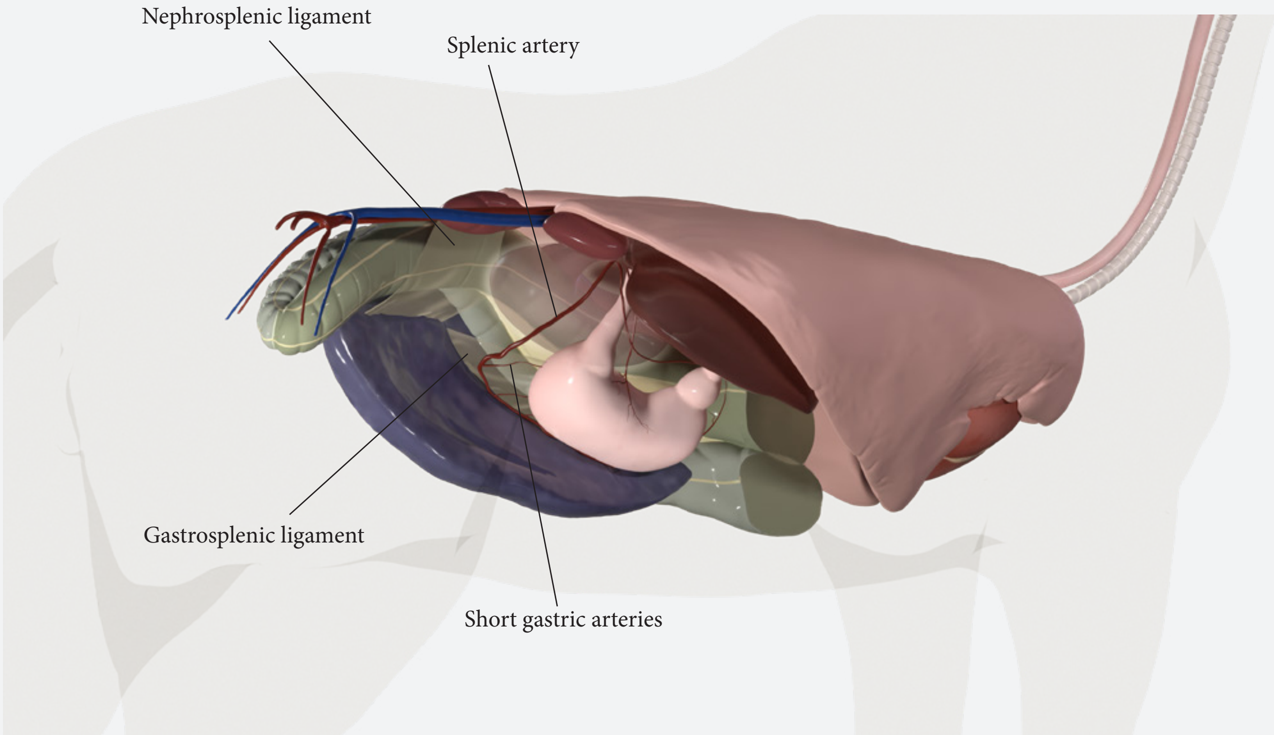


Fig.14 Ventral displacement of the stomach

The ventrally displaced stomach is not visible from the left side because of the large colon. It is clearer from the right side that the stomach and the spleen have moved together due to the gastrosplenic ligament attaching two organs. The splenic artery and short gastric arteries are also visible in the image. The skeleton, cecum, small intestine, right ventral colon, and right dorsal colon were withdrawn for a better view of the stomach.

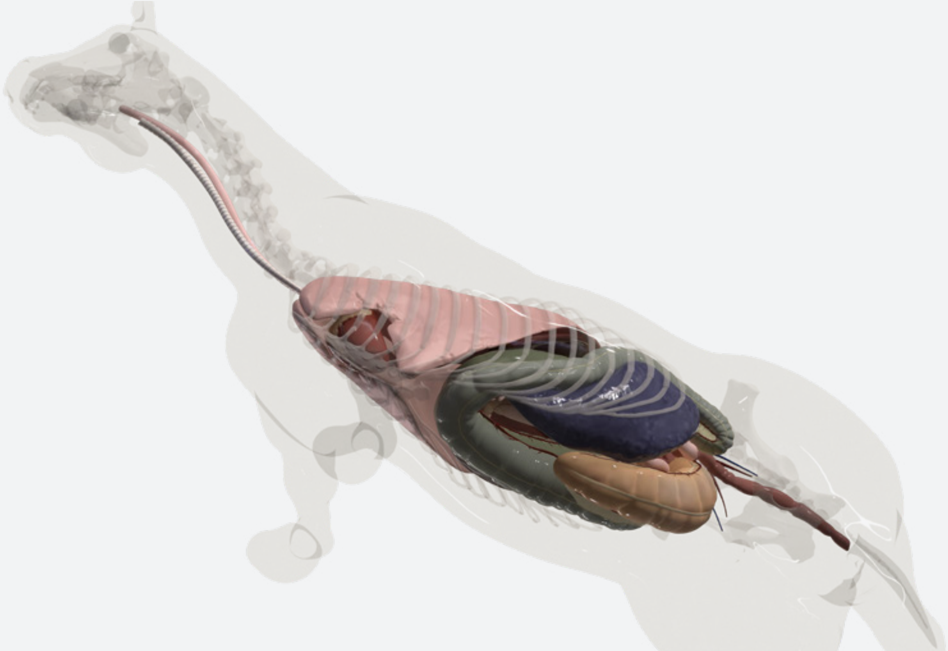


Fig.15 Nephrosplenic Entrapment viewed from underneath

View of the lesion from the lateral-ventral side, showing the relation between the stomach, large colon, spleen, and cecum. One of the advantages of a 3D model is that it can render images even from unusual and unconventional angles very quickly.

ULTRASONOGRAPHIC FEATURES OF NSE
with corresponding ultrasound images

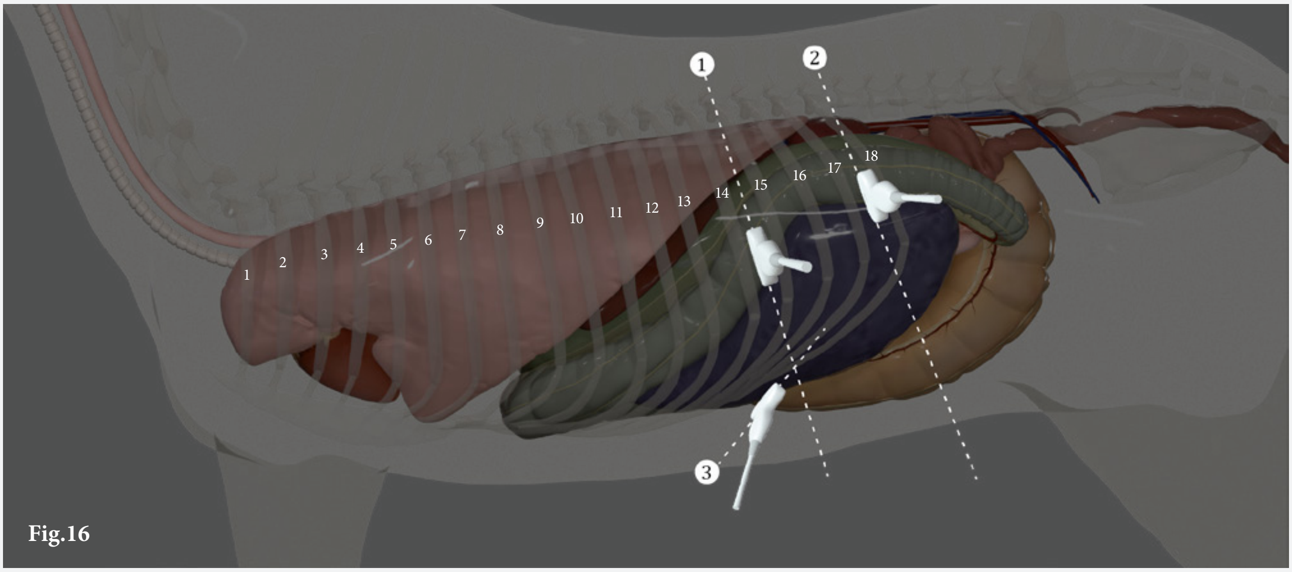


Fig.16

This chapter describes three major ultrasonographic traits of NSE, with cross-sections of 3D models with corresponding ultrasound images. In Fig.16, the ultrasound transducers are numbered to the corresponding location where these traits can be found. Although ultrasonography is in most cases greyscale, the major organs are color-coded (spleen: blue, large colon: green, stomach: pink) here for better understanding. The dorsal is to the left of the ultrasound images, where it is marked with a red dot.

- **Spleen**
- **Large colon**
- **Small intestine**


Fig.17

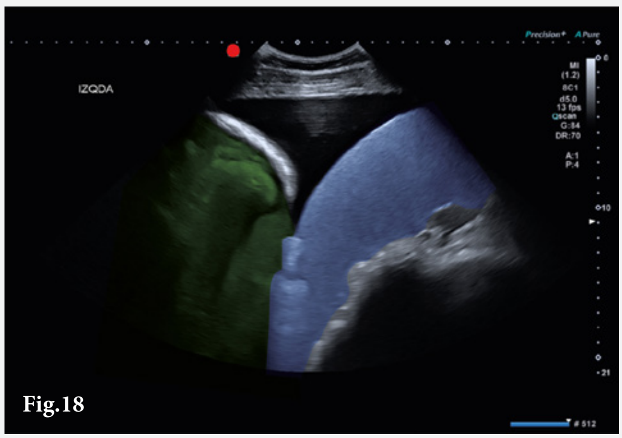


Fig.18

1. Large colon dorsal to the spleen
(Fig.17 - Fig.18)

The large colon (green) is located at the dorsal side of the spleen (blue), which is abnormal in horses. This trait can be found from the 10th - 12th intercostal spaces up to the paralumbar fossa. The left kidney is not visible in the image due to the gas-inflated large colon blocking the vision.

A

2. Colonic mesenteric vessels

(Fig.19 - Fig.21)

When the large colon gets dorsally displaced, the colon becomes twisted horizontally, revealing the mesenteric vessels which are not visible in the ultrasound of normal horses. Findings of the mesenteric vessels in ultrasound are one of the significant key traits when diagnosing NSE. The mesenteric artery (colic branch) is marked with a white dot in Fig.20. In Fig.21, The mesenteric arteries and veins are shown in red and blue colors because the Doppler color ultrasound* was used.

3. Ventral displacement of the spleen and stomach

(Fig.22 - Fig.23)

The spleen and the stomach (pink) are not visible in this region in a normal horse. The finding of the spleen and the stomach in this ventral area may indicate the occurrence of NSE since this is extremely uncommon in other large colon diseases. The splenic artery behind the spleen is also a key trait when diagnosing NSE. The splenic artery is marked in Fig.23 with an alphabet A.

Fig.19

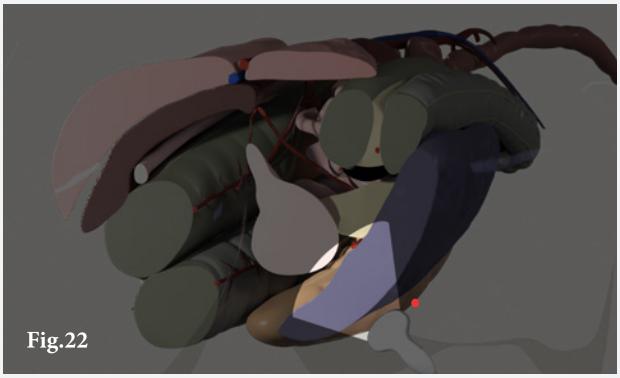


Fig.22

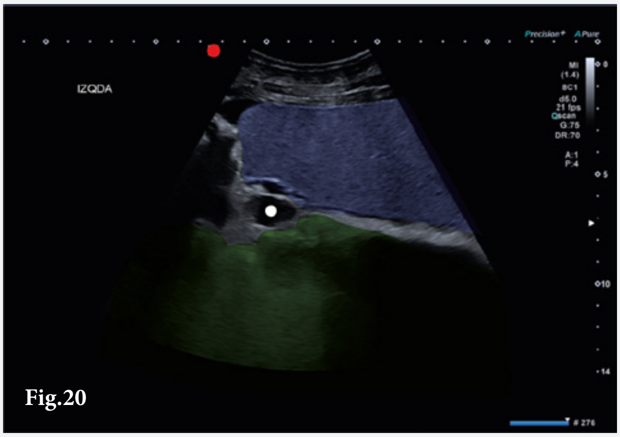


Fig.20

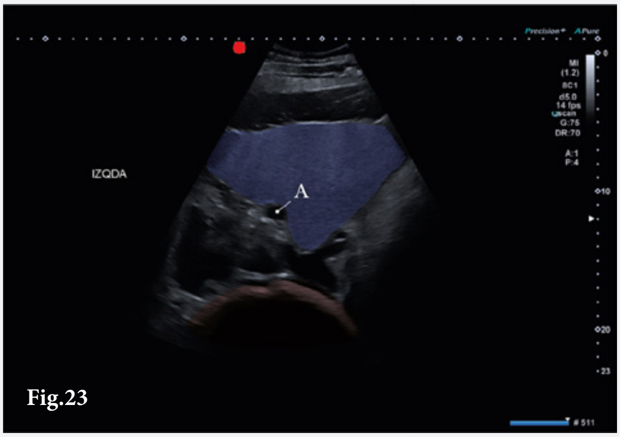


Fig.23

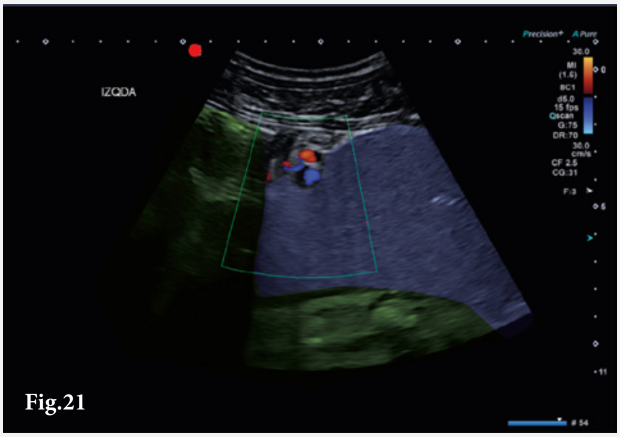


Fig.21

Fig.21 *Doppler Color Ultrasound

When we hear a train, we know if it is going or coming by the volume of the sound we hear. When ultrasound waves encounter erythrocytes in running blood at an angle of 10-60°, the same Doppler effect happens (the Doppler effect: the change in wave frequency during the relative motion between a wave source and its observer). The transducer detects the speed and direction of the blood flow and color codes this information. Usually, the veins are coded as blue and the arteries as red.

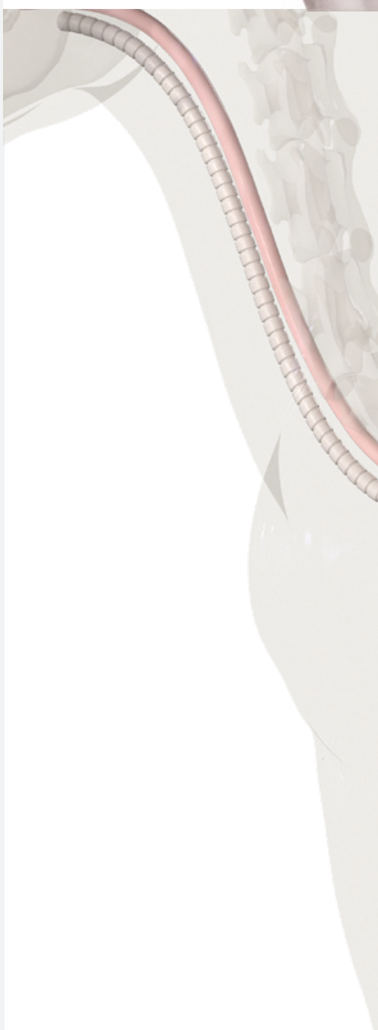
COMPARISON OF 2D ILLUSTRATION AND 3D IMAGING

To compare the advantages of 2D illustration and 3D imaging, I recreated one of the 3D rendered images (Fig.13) made for the client into a 2D illustration. Both images share an identical topic and objective. The shared objective of these images is to show how much the spleen of a horse with NSE becomes enlarged and caudoventrally displaced compared to that of a normal horse.

For the 2D illustration, watercolor was chosen among various traditional mediums of illustration because watercolor is the customary medium of scientific illustration along with the ink. Watercolor was favored by many scientific illustrators of the past such as the artists of the medical atlas of Eduard Pernkopf (Topographische Anatomie des Menschen, 1937-1960), Maria Sibylla Merian, and John James Audubon, due to its transparent colors and ability to depict very delicate details. Because the goal of this chapter is to compare 2D and 3D imaging, I thought it was unnecessary to proceed and finish every element with watercolor when digital painting technology is available, despite the fact watercolor is solely adequate for elaborate depiction. Therefore, the completion and depiction of details in this illustration were done digitally in Adobe Photoshop.

The two resulting images are noticeably different in two ways. Firstly, the texture and tissue behaviors of organs seem more natural in watercolor. Watercolor can easily recreate the texture of actual objects, as it is faster to draw details than to sculpt 3D. It is possible to give a 3D model a life-like texture and detail, but it usually takes more time and work. In some cases of 3D reconstruction, photo images are mapped on the surface of 3D shapes to recreate a realistic look. Because of its texture, 2D illustration often feels more natural, soft, and classical. On the other hand, the 3D image feels relatively sharper and cutting-edge.

What is also noticeable is the different logic in transparency. In scientific illustration, it is customary to show transparency by mixing overlapping colors and leaving a slite space where two objects meet. This technique is seen repeatedly in the medical atlas of Eduard Pernkopf, where it was significant to show the overlapping anatomical structures behind one another. In Fig.24, this technique was applied to the ribs and partly to the organs. On the other hand, transparency can be put into 3D imaging in two different ways. One way is to give the object a transparent material such as glass, and the other is to lower the opacity of the object. For the 'Ghost Horse', the outer shape of the horse was designated glass material. The glass material exhibits the inner objects without blurring or distorting them (this level of blur and distortion can be controlled in the material settings). The skeletal structure of 'Ghost Horse' was initially given an opaque material with boney colors, and the opacity of the bone was lowered during the rendering process for better storytelling.



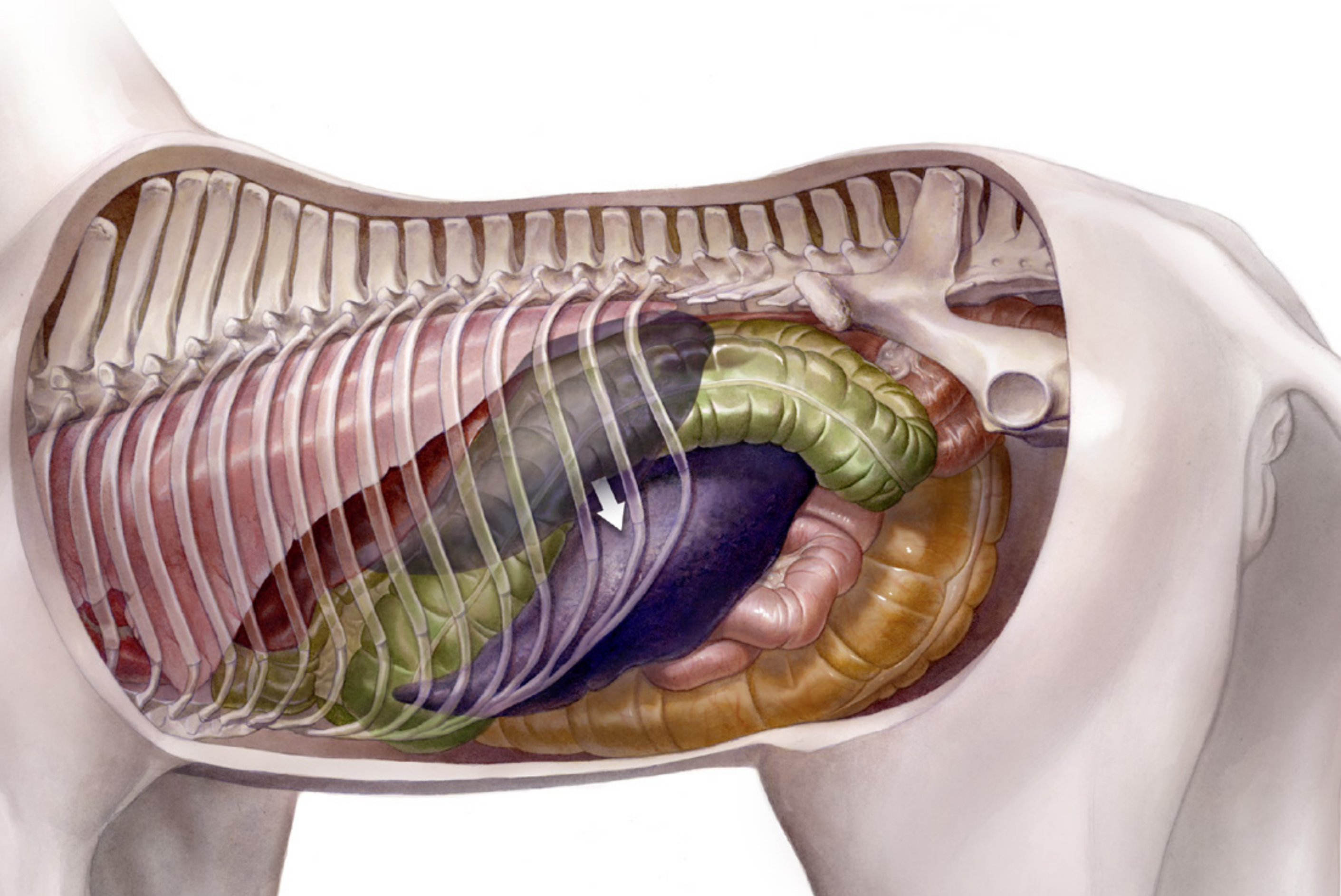


Fig.24 Watercolor recreation of Fig.13, showing the displacement of the spleen.

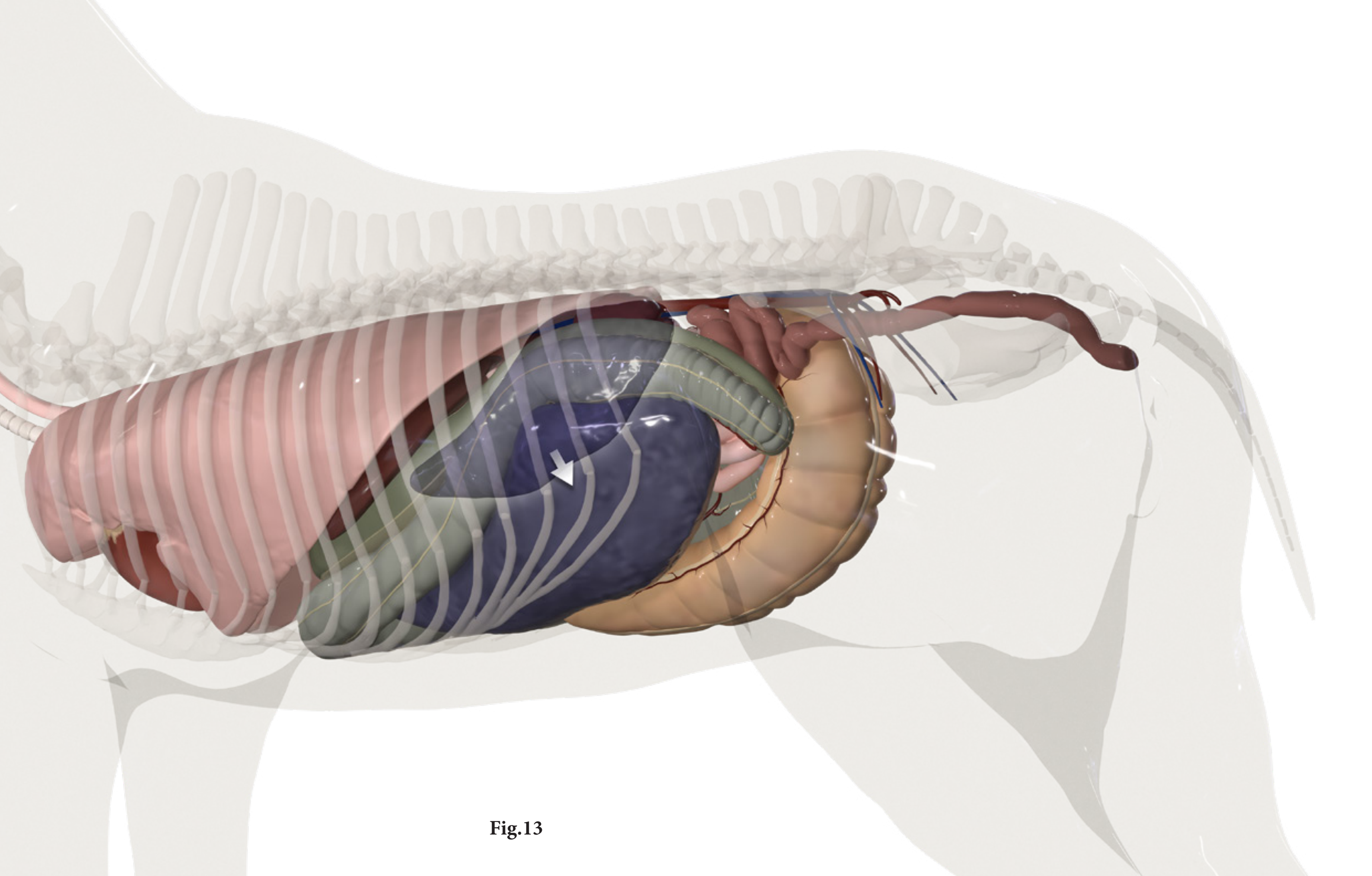


Fig.13

COMPARISON OF 3D RECONSTRUCTION FROM SCANS AND 3D MODELING

To compare the 'Ghost Horse' to computer-generated 3D reconstruction, an array of CT scans of a Shetland pony torso was reconstructed in 3D through Vesalius 3D. Vesalius 3D is a software application for 3D visualization of medication data, that reconstructs an array of 2D scanned images (CT, MRI, Ultrasound, etc.) into a virtual 3D model. The CT scan research data is of Dr. S. Veraa of Utrecht University Department of Clinical Sciences, Division of Diagnostic Imaging. These DICOM format data were processed in the Vasalius3D program on the lab computer at Maastricht University, FHML, Anatomy & Embryology Department.

The Vesalius3D binds grayscale CT cross-section 2D images and reconstructs them in a virtual 3D shape. The denser the scans are, the better the 3D reconstruction is. Skeletal parts are clearly distinguished from other structures, for the reason the bones appear very bright and distinguishable in the CT scans. But because the program does not clearly distinguish different soft tissues, which appear in similar gray tones, it is difficult to separate the muscles from inner organs. The organs often appear fuzzy and unclear. This can be partly improved by manipulating the contrast in 2D images and designating different colors to each grayscale level. However, it is difficult to acquire the clean shape of individual organs as in a sculpted 3D model.

Although the 3D reconstruction from CT scans may not be clear as a sculpted 3D model, the scanned reconstruction has its own advantages and usages. Because a scanned reconstruction is from the actual patient, it can instantly show the specific anatomy of each individual patient. It means that scanned reconstruction can help diagnose a disease and help the patient to understand their circumstances better. It is also effective in educating what is realistic in actual anatomy. These differences between scanned reconstruction and sculpted model are similar to the differences between diagnostic imaging and scientific illustration, as already mentioned in the introduction of this chapter. What is important is that we scientific illustrators can transfer what we learn from diagnostic imaging into a more refined form. Not only that illustrators can learn anatomy from diagnostic imaging, but also find the defects of the technology and acknowledge the advantages of their work.

To acquire a better 3D reconstructional result for educational purposes, we can imagine using the two means of 3D reconstruction in conjunction. For instance, scanning the form of each organ individually and combining the results manually may bring out a clearer result, maintaining the organic shape derived from the actual specimen but rearranging the structure for better storytelling. Or, a 3D artist may improve the scanned model or add what cannot be caught on scanners, reflecting their knowledge to create a more precise reconstruction.

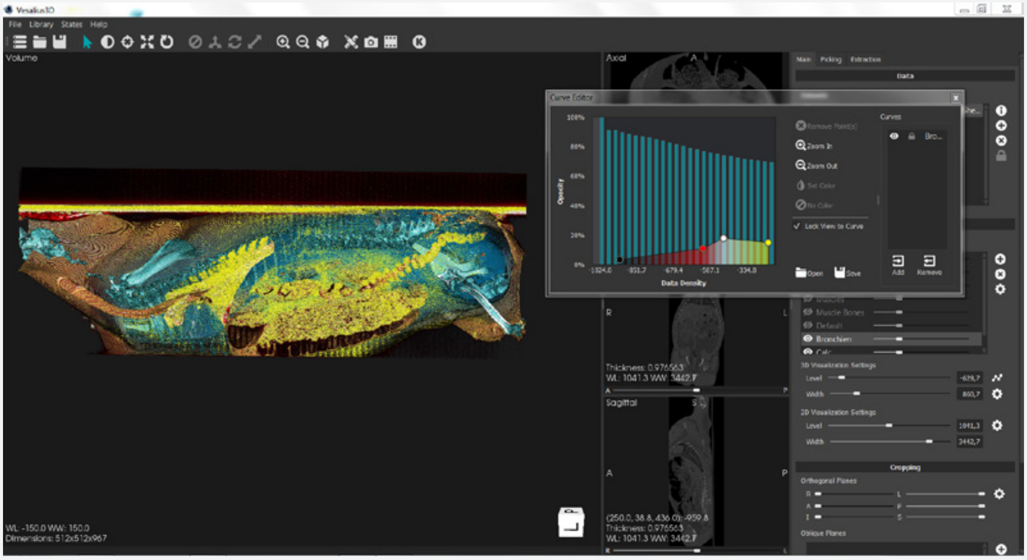
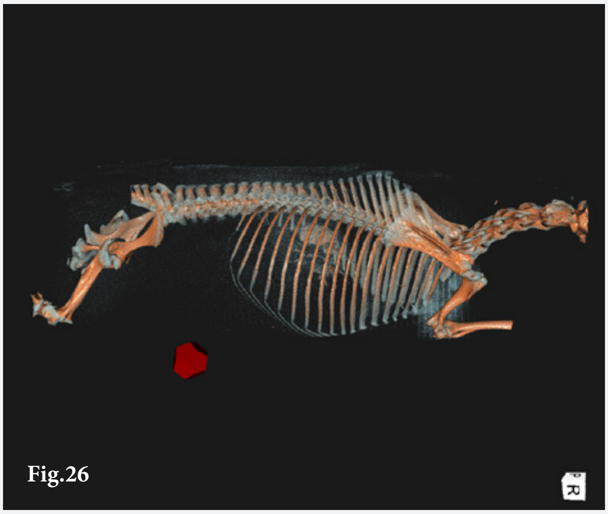


Fig.25 Screenshot of Vesalius3D work window display. The level and width of both 2D scans and 3D visualization can be modified. The colors and curve value can be controlled as well.



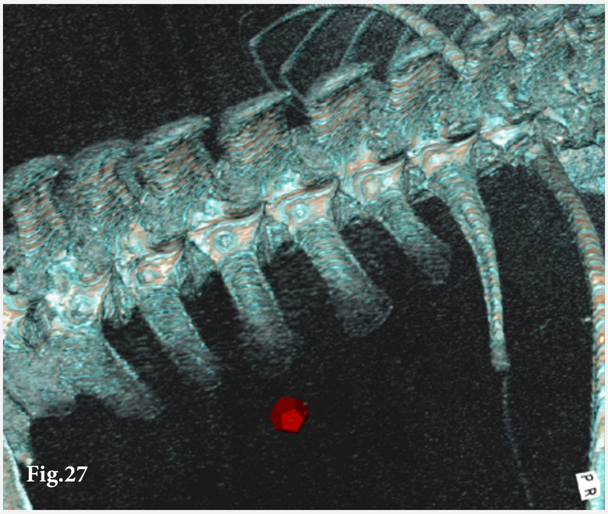


Fig.26 / Fig.27 Virtual 3D reconstruction of skeletal stucture of Shetland pony.

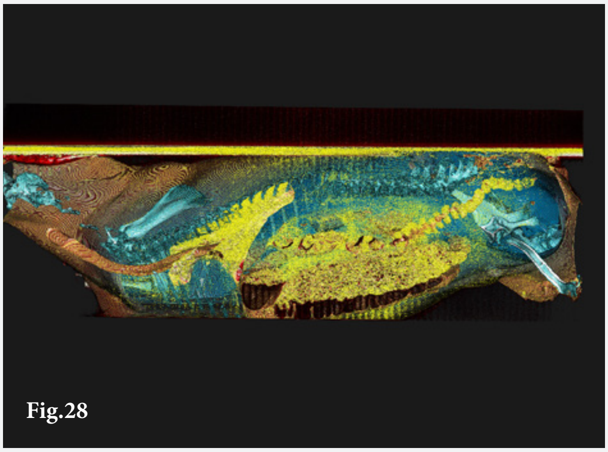


Fig.28 Left lateral view cross-section of Shetland pony abdomen, 3D reconstructed out of CT scans in Versalius3D.

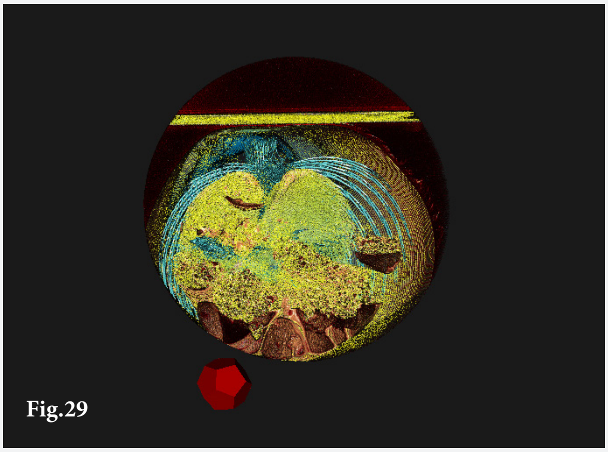


Fig.29 Caudal view cross-section of Shetland pony abdomen, 3D reconstructed out of CT scans in Versalius3D.

In Fig.25, Fig.28, and Fig.29, bones are drawn as light blue, and organs are designated yellow. These color codes and contrast levels can be altered in the settings of Vesalius3D. Because the pony was lying on its back during the scanning process, the contents inside the large intestines sit on the dorsal side, leaving empty space in the colon which appears dark brown in the reconstruction.

It would be difficult for learners to distinguish every different part of the intestines from this image. Because the CT scans include the contents in the intestines, the compact vowels tend to appear fuzzy and less distinguishable. Therefore 3D scan reconstructions may not be ideal for general educational purposes. But this would be useful for clinicians who are trying to diagnose patients with problems in their digestive system, or for those wanting to see the status of contents inside.

CONCLUSION

Ultrasound is a useful tool in diagnosing equine colic. It is a fast, real-time modality that does not harm the patient. But its results may be difficult to read for those not specialized in reading ultrasonography. 3D imaging is a powerful tool in explaining ultrasonography given its ability to show the subject from various angles.

Among preexisting 3D horse anatomy models in the market, the most used and renowned is the Glass horse (Science in 3D Inc., Dr. Jim Moore). Glass horse is extremely helpful in educating veterinarians and students as it features not only equine anatomical structures but also animation series of 28 different colic and their diagnosis. The Glass Horse project received Dr. Frank Netter Award twice (Award for Special Contributions to Medical Education in 1999, and Certificate of Excellence in 2009) and proved that, with sufficient time and resources, 3D can be immensely helpful in medical education. The 3D technique's scalability is even greater than before, now combined with VR, games, 3D printing, and 3D scanning. Also, its compatibility has significantly increased over the past decade as a result of massive technological advances in electronic devices. 3D viewer programs can now easily run on mobile devices and personal computers. Indisputably, 3D imaging is a growing market field in medical education and scientific visualization.

However, there are significant advantages that traditional 2D illustration holds against 3D. A 2D illustration can be faster when it comes to creating images on a fixed angle. Creating an entire 3D model for every topic may not be time efficient if the task only requires a few still pictures. An illustration also can be more effective in delivering realistic depictions. A well-trained artist can give hyper-realistic textures and details to the drawing, and these depictions are sometimes even more life-like and clear than photography. Although a 3D model can render a realistic visual style very quickly, the distinctive characteristics of 3D rendering often show. It takes a lot of time, effort, and budget to make it look more natural. The realistic render is also where the risk of 3D imaging lies. Because it is rendered to seem realistic, the viewers tend to conceive it as the definite truth even though it is an interpretation of an artist.

Also, traditional techniques deliver a more aesthetic impression and easily convey each artist's style. This factor is not something to be overlooked. 3D rendering technique has developed significantly over the past decade and is bringing more artistic and friendly impressions to 3D imaging. But up to this day, the beauty of traditional techniques and the human touch of individual artists still hold the power to appeal to a great number of the public.

In conclusion, it is important to know the different advantages and characteristics of 2D illustrations, 3D models, and computer-generated images. The choice of imaging technique shall depend on factors such as function, timeframe, budget, and audience.

PART B
:SURGERY

External advisor:
Prof. Dr. Harold Brommer

Introduction

Surgical illustrations provide a clear and accurate depiction of anatomical structures and surgical procedures, which is immensely helpful for medical students, residents, and surgeons to understand and learn about the surgery. When someone imagines an object, the brain simulates it. For surgeons, this simulation is an important preparation before the actual surgery. For the desirable result, the procedures in surgery have to be refined and efficient. This factor makes planning a significant element in surgery. By image-simulating, in other words, by visualizing surgical plans, the surgeon reduces the chance of committing mistakes and enhances the efficiency of surgery. A good series of surgical illustrations is a highly refined blueprint that delivers visuals directly to the surgeon's imagination. With them, a surgeon is guided from the start to the end of the surgery and therefore becomes better prepared for the actual performance. This preparation leads to a better surgical outcome and thus influences the patient's postoperative life.

Surgical illustrations also can be used to communicate with patients (or the owner of the patient in the case of veterinary medicine) about their surgical procedure. They can help the medical staff to explain the surgical procedure in simple terms and provide a visual reference for the patient to understand what will happen during the surgery. Sometimes, because patients are not fully aware of what will happen during the surgery, they fear undergoing it. Surgical illustration can play a key role in communicating with the patient and diminishing these fears. In these situations, 'friendly-looking' images of the procedure can be more effective in comforting the patient than realistic images. This case reflects that the art style choices should depend on the purposes of the illustration.

Every day, new procedures are studied in every field of surgery. Without a doubt, surgical illustration is a field with abundant opportunities. The general public and the young generation were exposed to media substantially more than the older generation over the past decade. And as a result, more and more people learn from images rather than solely from texts. This phenomenon is not necessarily negative but a change of direction in human conditions. Surgical illustration can provide the foundation of understanding for the new power generation. Every day, images matter more and more.

PREPARATION

Before visiting Utrecht University for the surgery excursion, I made a few preparations that may help the workflow of main surgical illustrations. 3D modeling of a few commonly used surgical instruments was the first part. Hard surface modeling (the modeling process of objects that has smooth, static surfaces such as cars, robots, industrial products, etc.) starts differently from organic modeling. If organic modeling begins with pulling a sphere, hard edge modeling starts with a much more simplified shape of the final object, constructed of very few polygon meshes. Mesh is the elementary structural build of a 3D model consisting of polygons. A basic cube with six meshes is expanded and carved into a shape as close as possible to the final object. Then it is dynameshed and given more meshes to manipulate. After the dynamesh, the model is refined to its precise shape and sculpted for more details.

Most commonly used surgical tools such as artery forceps, scalpels, towel forceps, and scissors were made. The objective of this process was to save time when illustrating surgery and to put more precision in where challenging and diverse angles come into play. These models can be used repeatedly in further works as well. I expect this preparation process will enhance my work efficiency throughout my future career.

What is convenient about 3D models is that they can be rendered into various art styles depending on the illustration they will be in. For example, the instruments may gain a realistic look with metallic texture (Fig.32) or render into a line style (toon shading) fit for line art drawings (Fig.33).

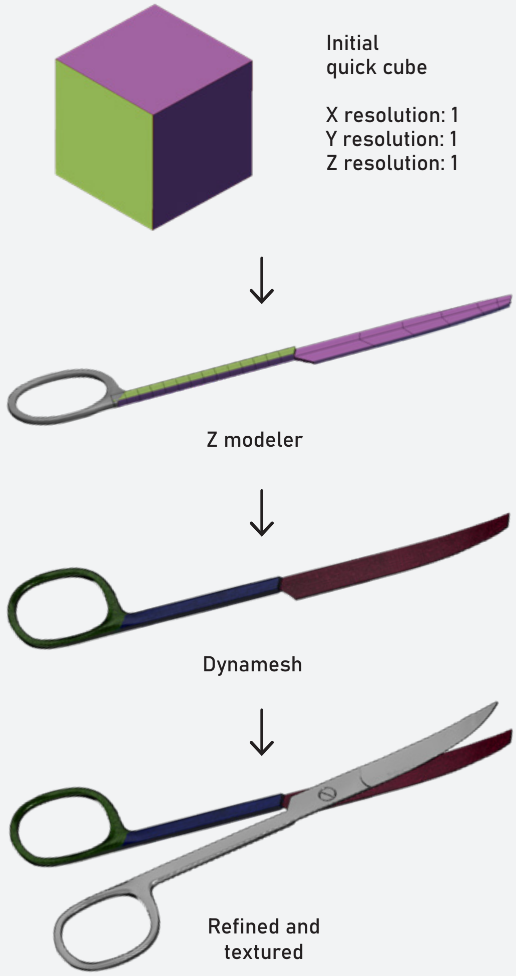


Fig.30 Gradual process of hard surface modeling in ZBrush.

Fig.31 3D reconstruction of surgical linear stapler. Modeled in ZBrush, rendered in Marmoset Toolbar 4.

Fig.32

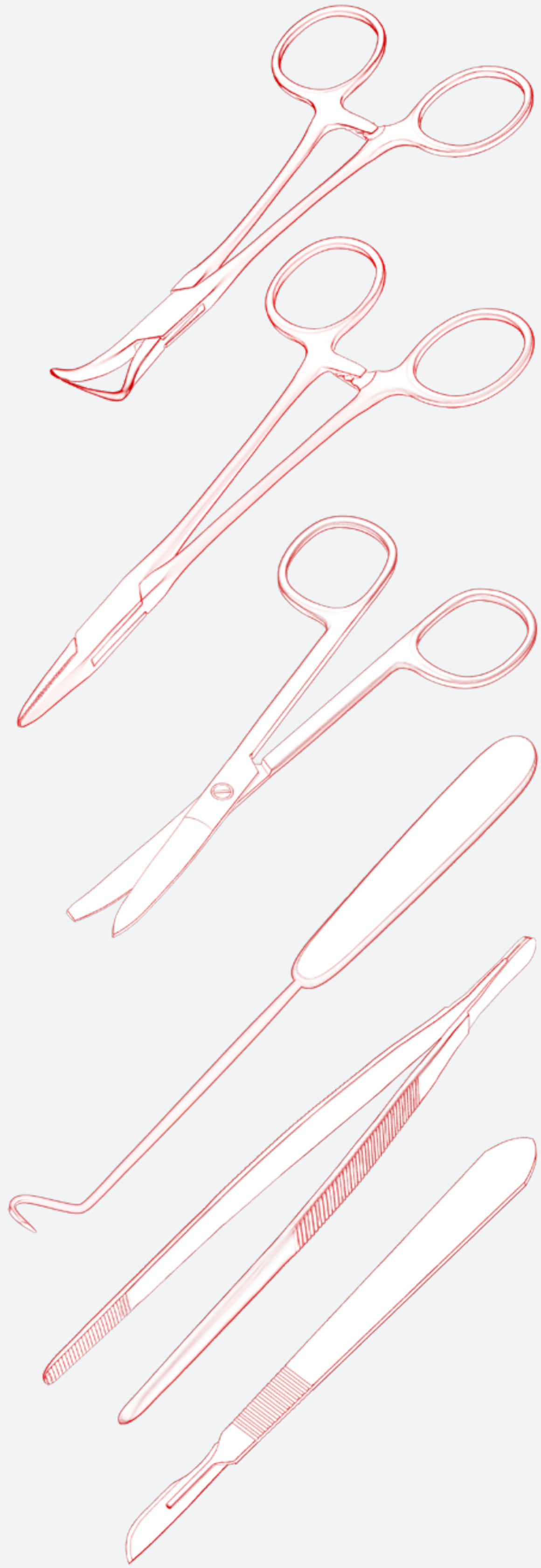


Fig.33

Fig.32 3D reconstruction of various surgical instruments with realistic metal texture. Modeled in ZBrush, rendered in Marmoset Toolbar 4.
Fig.33 3D reconstruction of various surgical instruments with toon shading render. Modeled and rendered in ZBrush.

Another preparation I did was to pose the horse model in a surgical position. In frequent cases of equine abdomen surgeries, the patient is positioned on their back (dorsal recumbency). Therefore the anatomical orientation seen in a horse on its feet is completely flipped over. This model of a horse in a surgical position helps understand the location of organs when the horse is lying on its back. In addition, this model can be traced over in surgical drawings to convey the correct anatomical orientation.

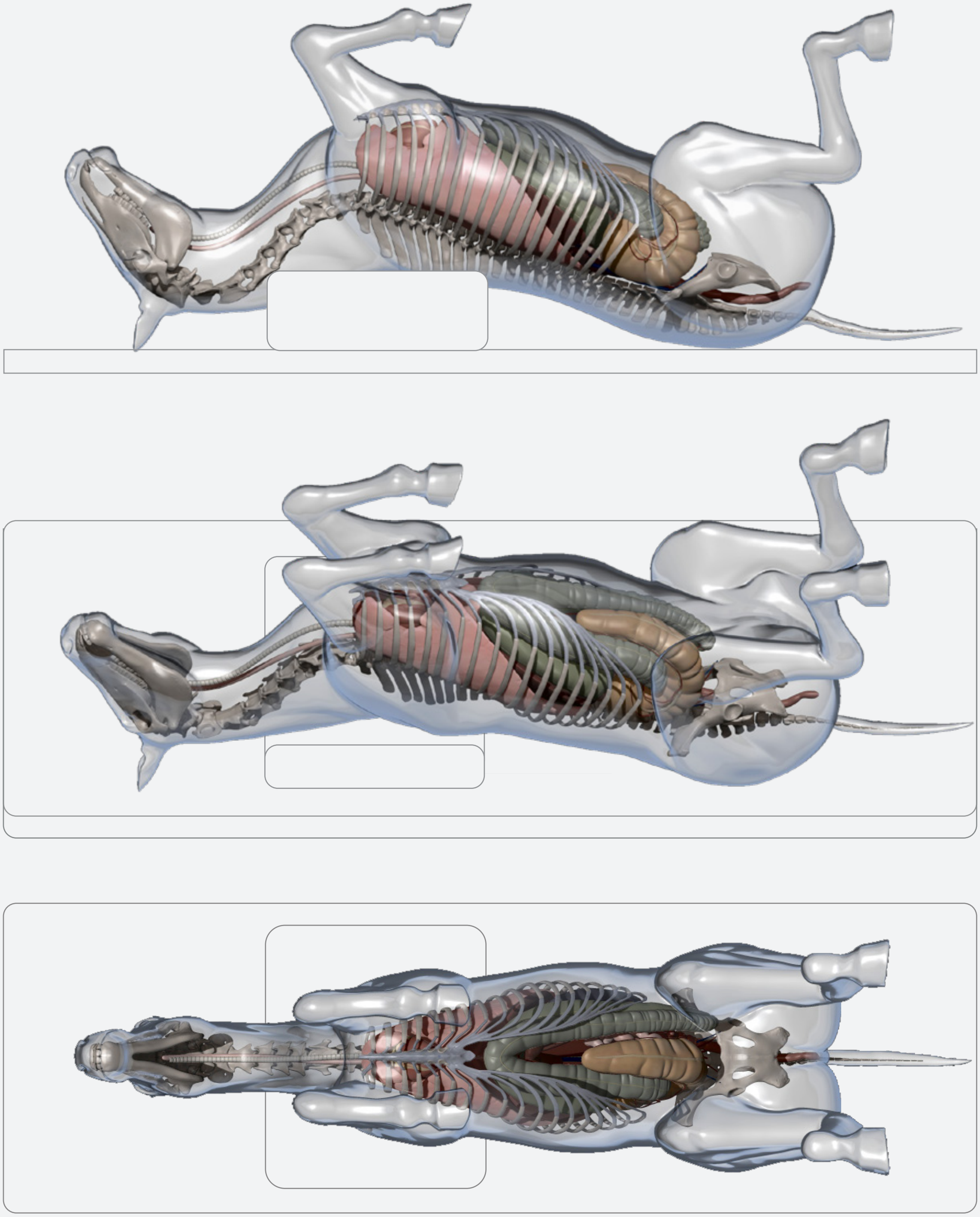


Fig.34 3D reconstruction of horse put to dorsal recumbency position. Specific settings and facilities may differ from hospitals. Modeled and rendered in ZBrush.

JEJUNOCECOSTOMY

Jejunocecostomy is the anastomosis procedure of the jejunum and cecum. This type of surgery is performed when much of the ileum has undergone necrosis due to colic and thus in a condition where jejunoileostomy (anastomosis of jejunum and ileum) cannot be performed. This procedure will significantly alter the inner anatomy, creating the stoma on the cecal body much more distal from its original location. Also, the inner wall of the jejunum is less muscular than that of the ileum, resulting in difficulties in the propulsion of intestinal contents.[20] In three studies, the survival rate of jejunocecostomy on horses until hospital discharge ranged between 71% to 76%. [21, 22, 23]

Jejunocecostomy can be performed in two ways; End-to-Side (E2S) or Side-to-Side (S2S). A Side-to-Side jejunocecostomy may allow the creation of a wider stoma less likely to be associated with problems resulting from stomal swelling and obstruction.[24] This chapter of the thesis contains a series of illustrated steps of Side-to-Side jejunocecostomy, using a linear stapling instrument.

The surgery itself is not new or rare. But the reason this surgery was selected as the topic of this thesis was because according to Dr. Brommer, even though the procedure is challenging to comprehend without image references, there has not been a good series of illustrations in textbooks that depicts this surgery thoroughly. He stated that the illustrations would be helpful in teaching residents or veterinary students at the university.

SURGERY EXCURSION & PROCESS OF SURGICAL ILLUSTRATION

Every two or three months, equine surgical training takes place at the Utrecht University Department of Equine Sciences. Under the supervision of Dr. Brommer, I was invited to the training session twice, once on 22nd November and once more on 21st February. On the first visit in November, I mainly observed and made sketches of general equine surgery procedures. I could make several sketches of the surgeons in operation and see the differences between equine and human surgery. On my second visit in February, Dr. Brommer demonstrated the jejunocecostomy surgery for me to record and take notes on. The surgery took a little over an hour. It was a rare and valuable experience observing a surgery from the view of the main surgeon, asking questions whenever necessary.

Every time shortly after getting back from a surgery excursion, I write down the surgical report of that surgery. A 'surgical report' is the documentation of the surgery written as meticulously as possible and therefore needs to be done without delay. After the surgical report, rough sketches of the surgical illustrations are made based on the recordings and notes. The surgical procedure is planned out on multiple sequences. Various visual languages are considered in this process for a clear comprehension of the surgical procedures. Because this project was not for a specific purpose other than educational purposes inside the university, many elements were up to my choice. But usually, elements like the target group, art style, and the goal and structure of illustrations are discussed with the client during this phase.

On some occasions, the rough sketches need to get refined for clients to read. These sketches are simple but must be clear about how the final illustrations will be. These are sent to the client for confirmation and may be revised. After the sketches are confirmed, I start working on the final illustrations. The final outcome varies in styles and degrees of elaboration.

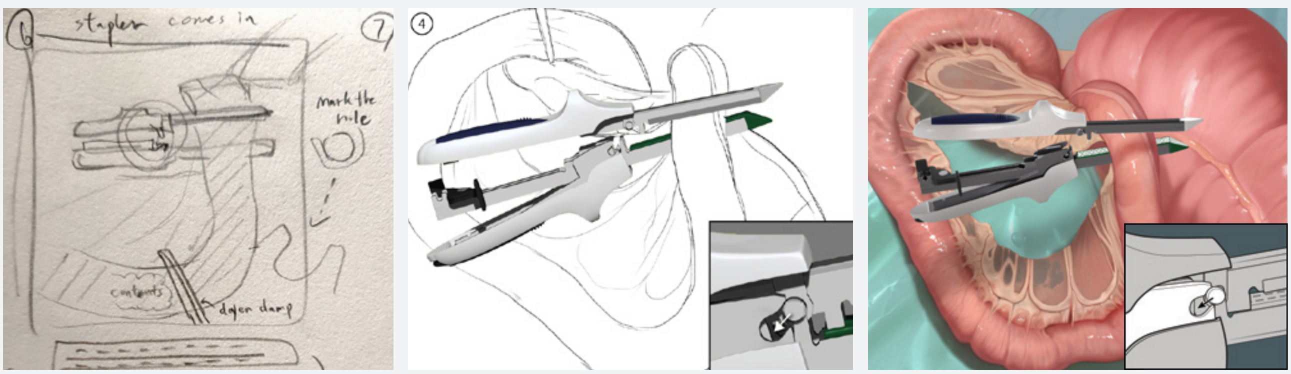


Fig.35 Gradual process of surgical illustration. (From left) The rough sketch, clean sketch, and final result.

LEVELS OF ELABORATION IN SURGICAL ILLUSTRATION

Surgical illustrations come in various levels of elaboration. The level depends on several factors like the subject of the surgery, time frame, and budget. The lowest time-consuming and least elaborated level of surgical illustration is the line art. Line art style delivers the structure of anatomical parts and surgical elements in simple line graphics, commonly with line width profiles. This style is suitable for simple diagrams or textbooks with numerous illustrations. (Fig.36)

The next level of elaboration is line art together with color flat-fills. This illustration style maintains the lines from the line art style but conveys more information with flat fills. Often, the flat fills come with colors and basic shading. This degree of elaboration is usually informative enough to deliver the content of the surgery to the audience, as it shows the orientation of the surgical area clearer than pictures but still delivers enough depiction with fills. (Fig.37)

The furthest level of elaboration is full elaboration. This style depicts the surgery as lifelike as possible but is easier to understand than photography as it removes unnecessary elements such as blood. This style can convey realistic tissue behavior and texture. Precautions of fully elaborated images are that they may deliver unnecessary information, depriving focus of the main topic of the scene. This problem can be partly resolved by cropping or blurring portions of the less significant image. (Fig.38)

For this thesis project, a series of fully elaborated illustrations were made. The procedure of jejunocecostomy is divided into three chapters in this thesis; ligation of mesenteric vessels, anastomosis of the jejunum and the cecum, and mesenteric closure. Many sequences are moderately morphed from their beforehand scene for efficiency and consistency. Organic objects such as organs and the hands of the surgeon were digitally painted in Adobe Photoshop. Surgical instruments were sculpted in ZBrush and later rendered with Marmoset Toolbag 4. Photography was partly used on less significant objects like sterile drapes.

Fig.36 Surgical illustration in line and greyscale flat fill.

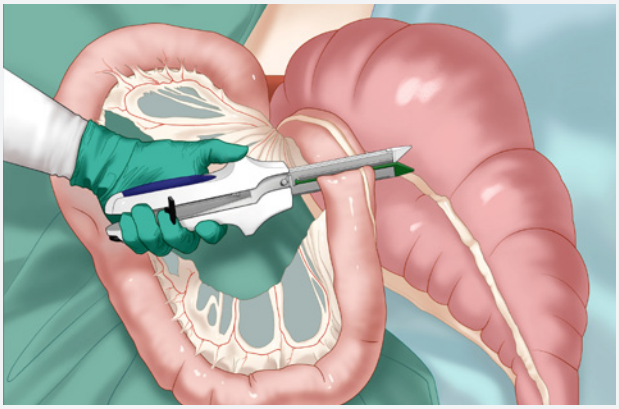


Fig.37 Surgical illustration in colored line and color fill, with simple shadows.

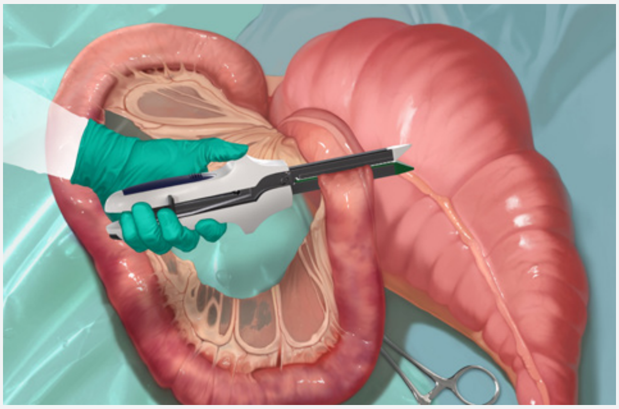


Fig.38 Surgical illustration in fully elaborated style.

ILLUSTRATED STEPS OF EQUINE JEJUNOCECOSTOMY
(Side-to-Side)

B

Surgical Setting

31

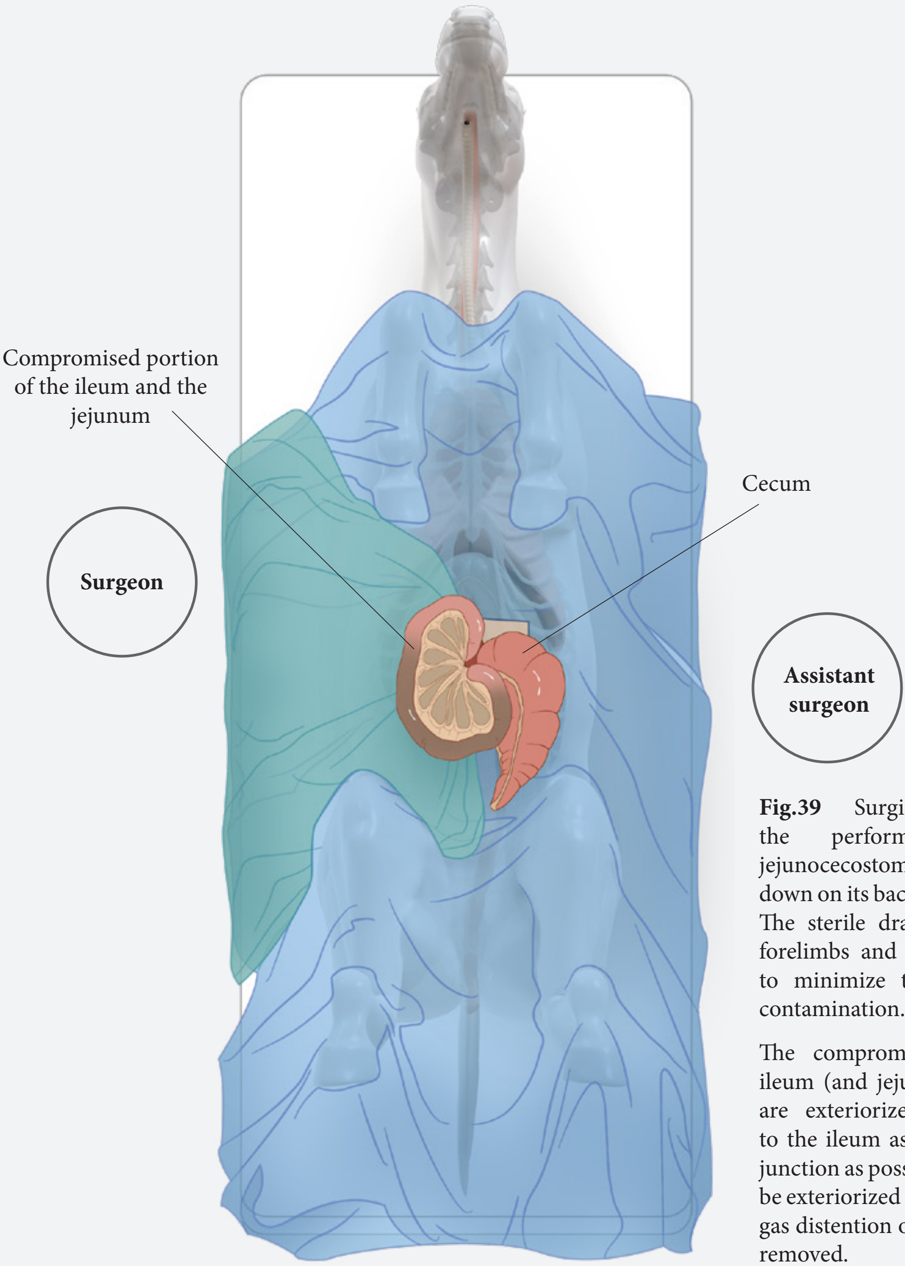


Fig.39 Surgical setting before the performance of equine jejunocecostomy. The horse is lying down on its back(dorsal recumbency). The sterile drapes are covering the forelimbs and hindlimbs completely to minimize the risk of abdomen contamination.

The compromised portion of the ileum (and jejunum) and the cecum are exteriorized. To obtain access to the ileum as close to the ileocecal junction as possible, the cecum should be exteriorized as far as possible.[20] Any gas distention of the cecum should be removed.

Fig.39

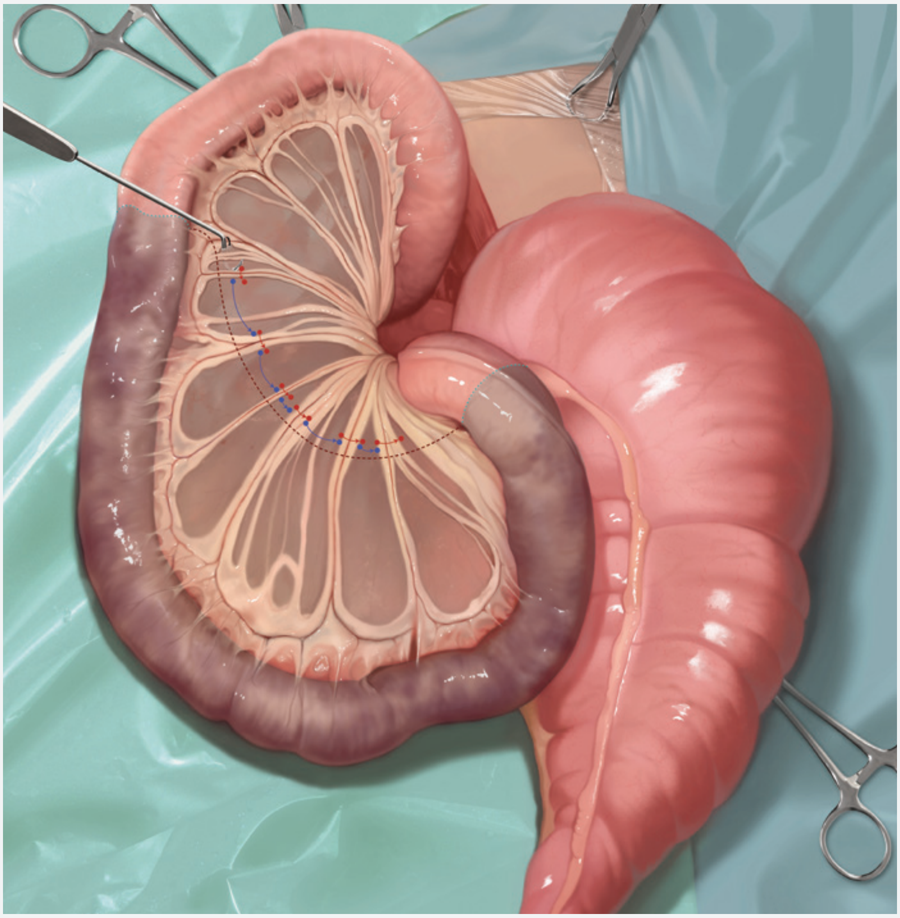


Fig.40 Before removing the compromised portion of the intestine from the body, concerning mesenteric vessels must be ligated. In Fig.40, the compromised portion is marked with dark grey color. Use a curved ligature needle to grasp and ligate a major branch of the mesentery, and then repeat the action to ligate the in-between region up until the next major branch. The locations of major branch ligatures are indicated in red, and the locations of in-between region ligatures are indicated in blue. In this surgery, every suture is built out of four single knots.

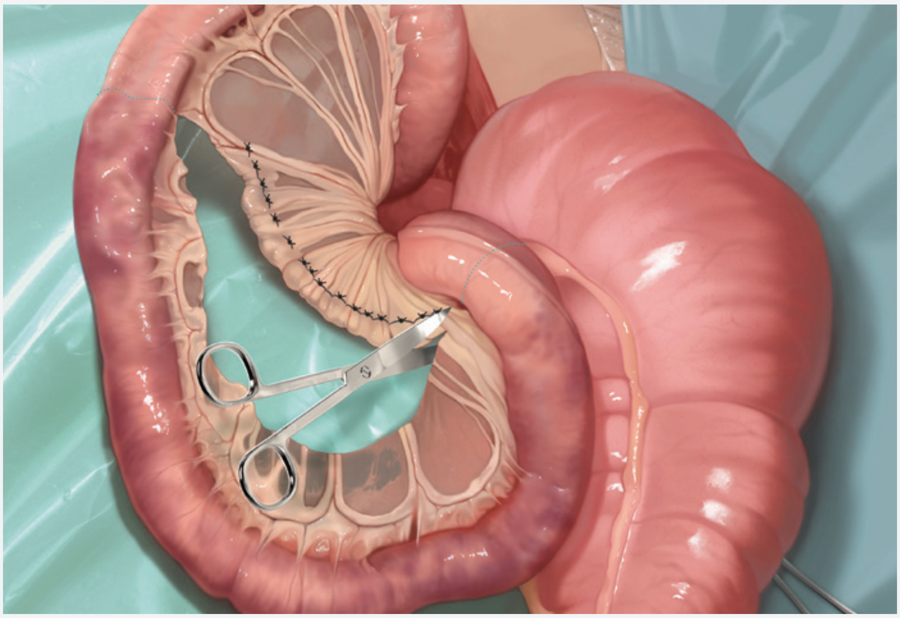


Fig.41 When every mesenteric vessel concerning the resection area is ligated, use scissors to transect the mesentery along the ligated line.

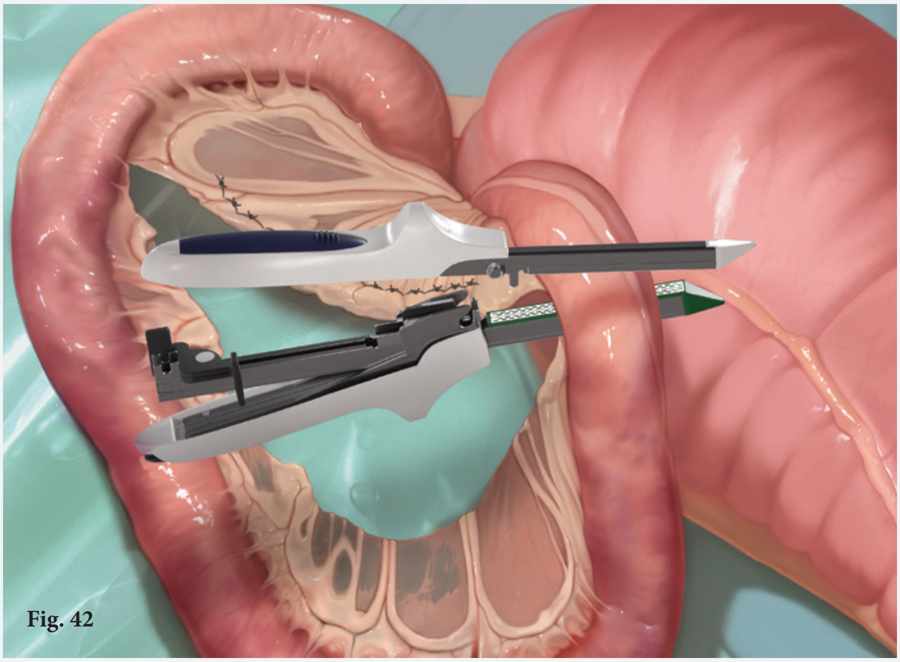


Fig.42 Assemble the surgical stapler at the distal part of the intestine that has to be resected. Two parts of the stapler should be parallel.

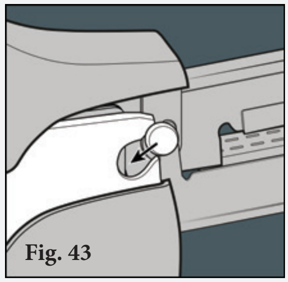


Fig. 43 The round bolt should slide into the socket on the other side.

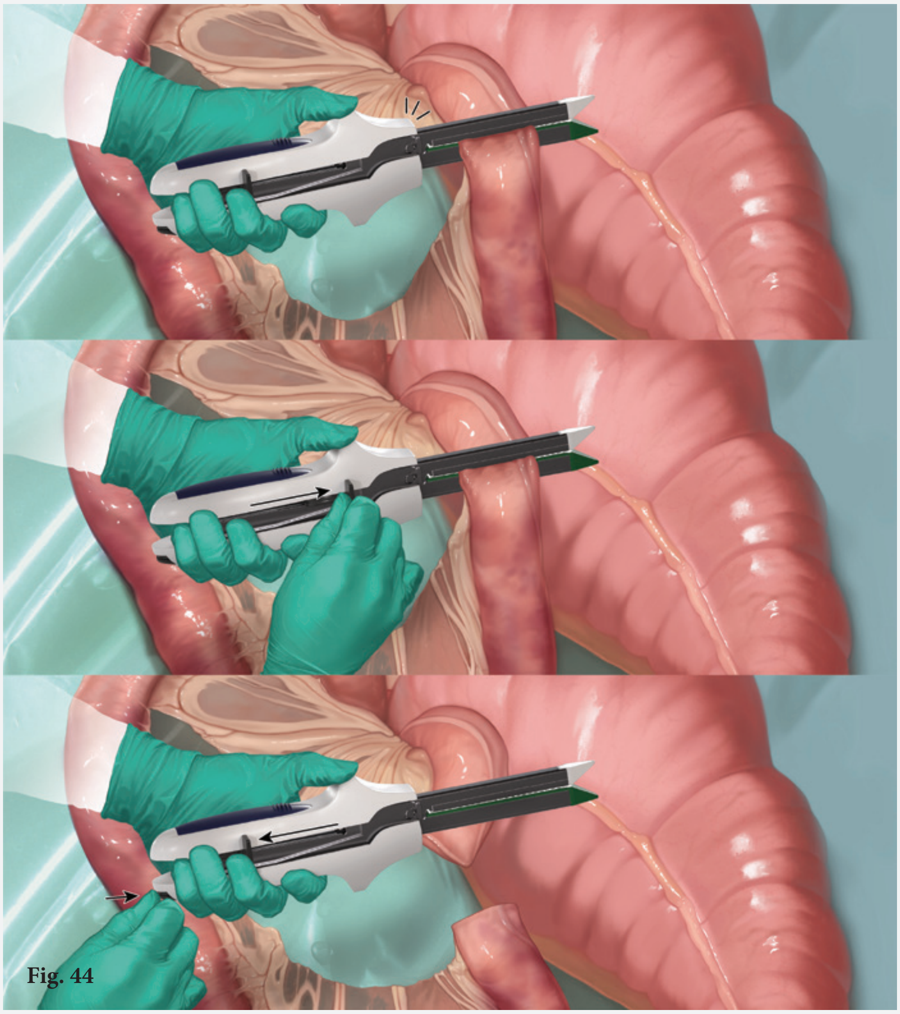


Fig.44 Push the bolt into the socket until you hear a clicking sound. Push the lever forward to fire the stapler. Pull the lever back to its original place and press the button to release the locked stapler.

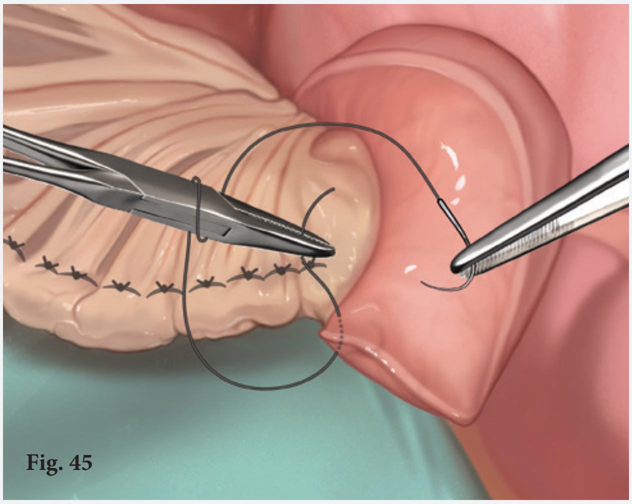


Fig. 45

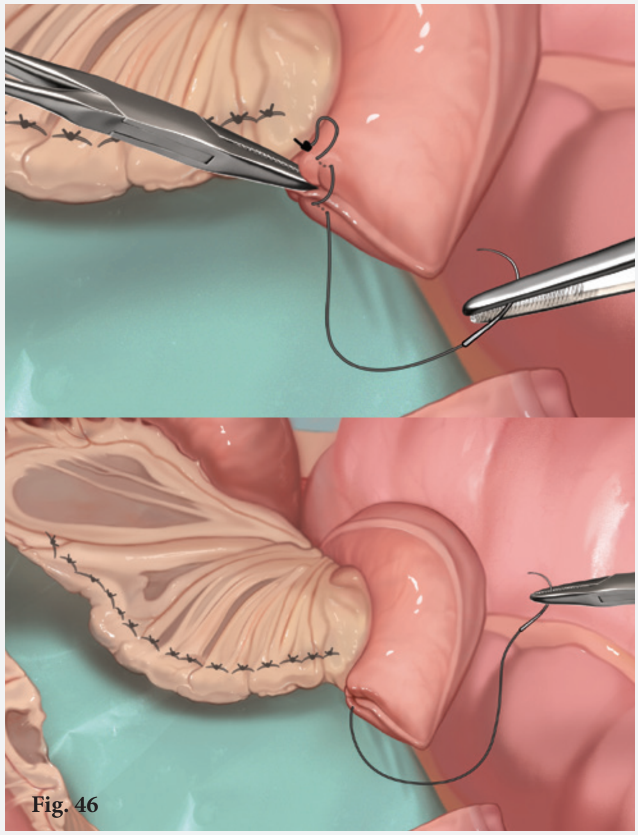


Fig. 46

Fig.45 / Fig.46 The remaining stump of the ileum should be as short as possible and need to be oversewed at its end to prevent the stump from becoming a cause of another colic. Start with making a knot at one pointy end of the stump. Push in the protruding end and sew over.

Fig.47 / Fig.48 Oversew the blind end with Lembert or Cushing pattern. The two sides of the wall are closed together so that there are no mucosa or stapled lines visible from the serosal side.

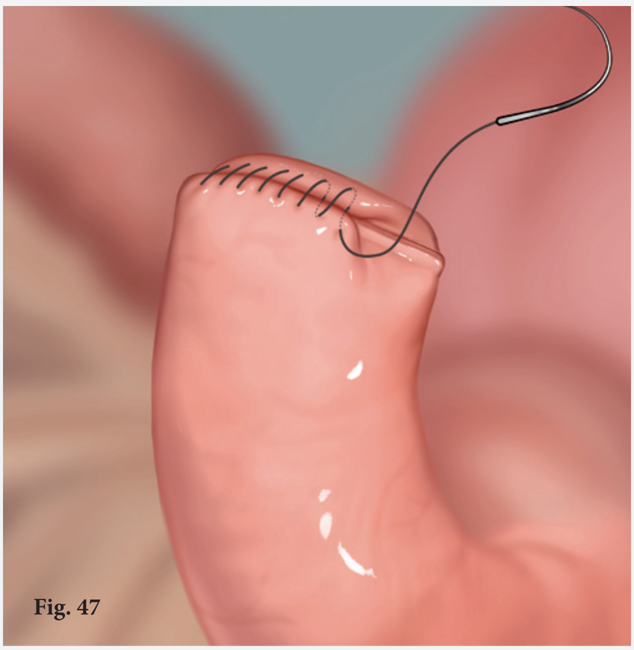


Fig. 47

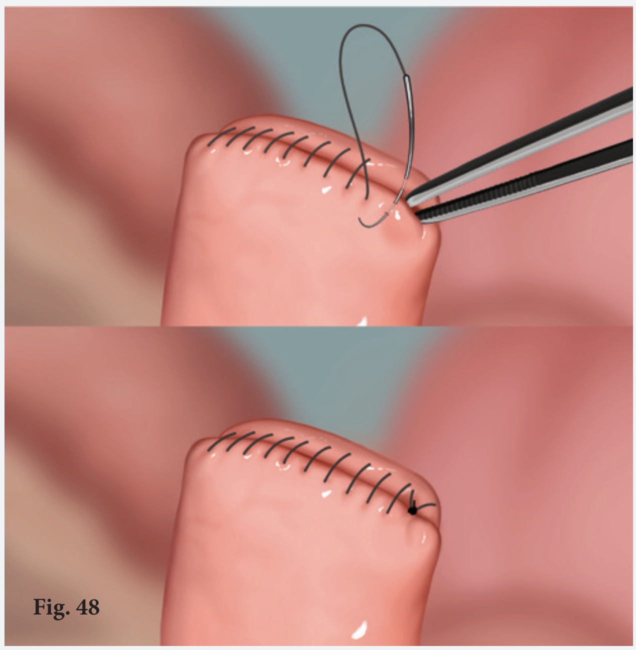


Fig. 48

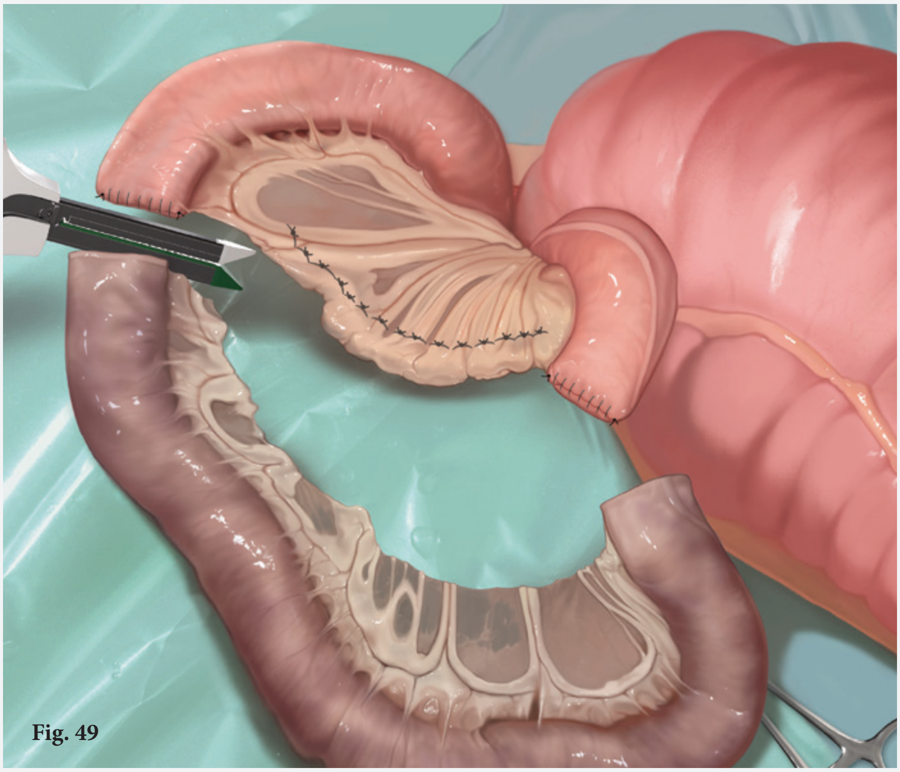


Fig. 49

Fig.49 Use the linear stapler again to detach the compromised area completely from the jejunum. After the compromised proportion is removed from the body, oversew the remaining blind end of the jejunum with the same technique used to suture the stump of the ileum.

Anastamosis of the Jejunum and Cecum

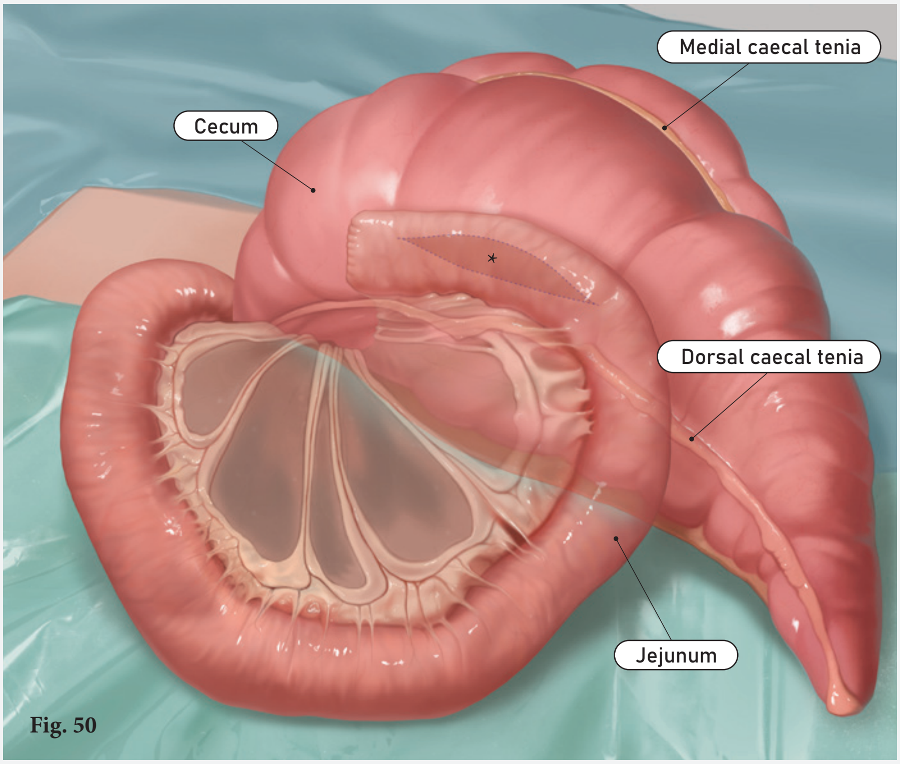


Fig. 50

Fig.50 Surgical plan showing where the stoma between the jejunum and the cecum should be made(*). The blind end of the jejunum should be heading in the direction towards the base of the cecum, therefore heading to the cranial direction of the horse. The stoma should be made between the dorsal caecal tenia and medial caecal tenia, as proximal as possible and as close to the dorsal tenia of the cecum as possible.

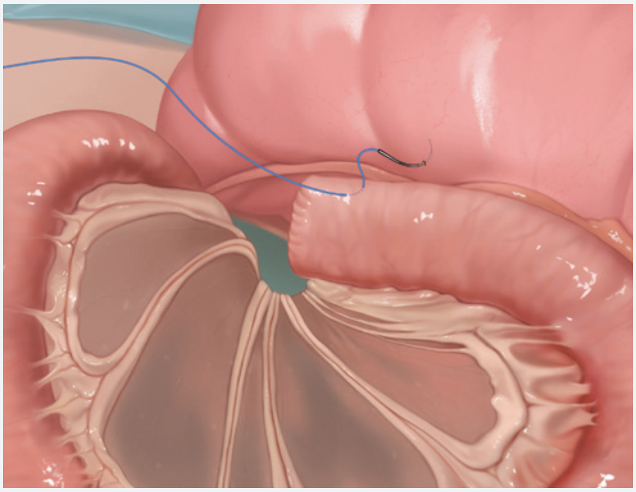


Fig.51 The first outer suture starts from the antimesenteric side of the jejunum, directly at the medial side of the dorsal caecal tenia, as proximally as possible.

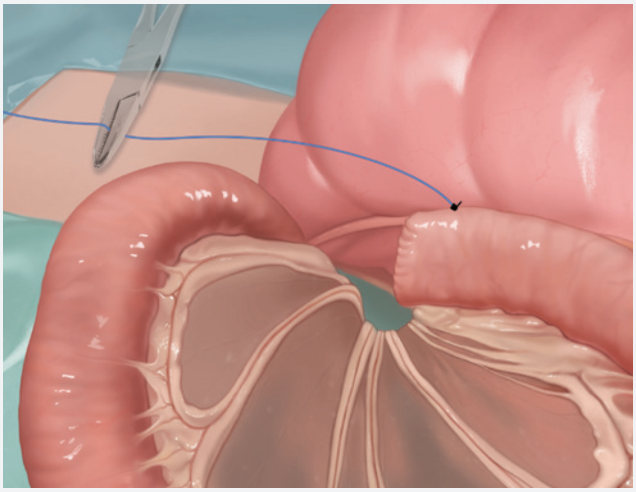


Fig.52 Leave one long end of the first knot as an end to knot the final knot onto it.

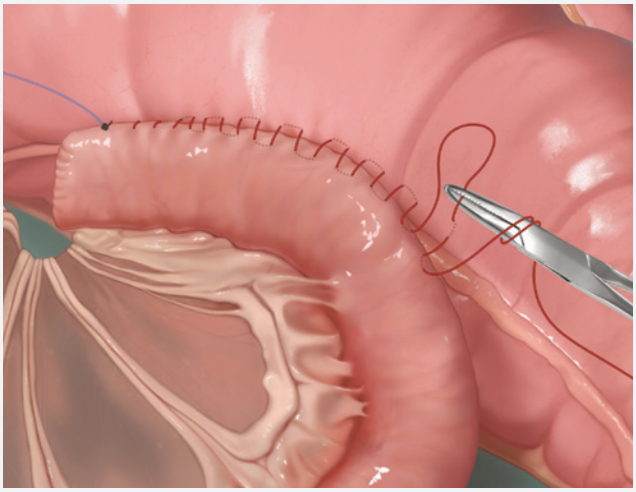


Fig.53 With a running Cushing pattern, suture the antimesenteric side of the jejunum to the caecal wall medial to the dorsal caecal tenia. The length of the suture should approximately be three times the diameter of the jejunum.

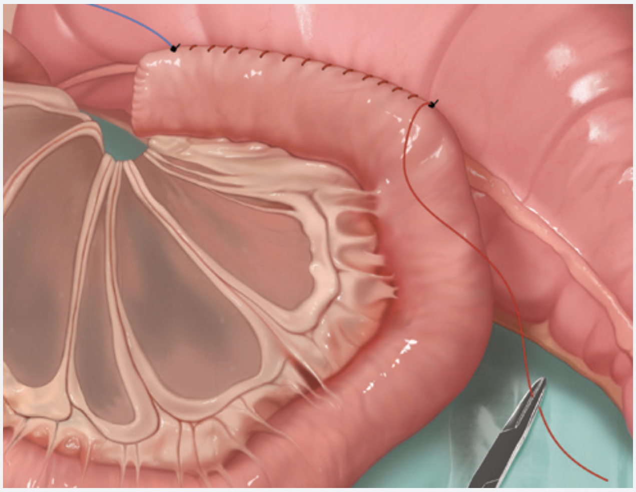


Fig.54 After reaching the proper length, leave one long end of the final knot.

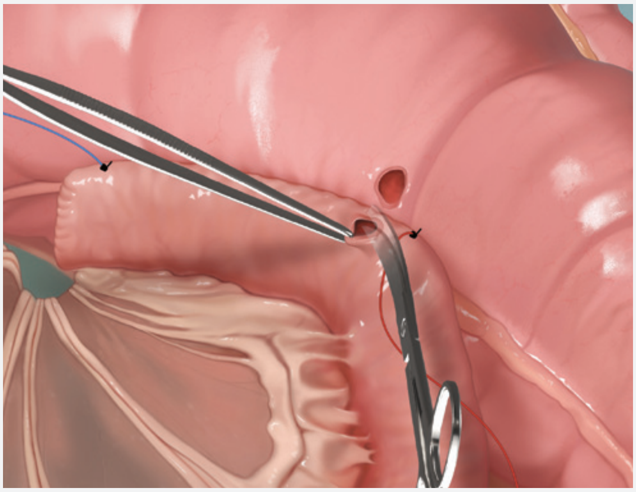


Fig.55 Make two small incisions near the knot. One incision should be on the jejunum and one should be made on the cecal wall.

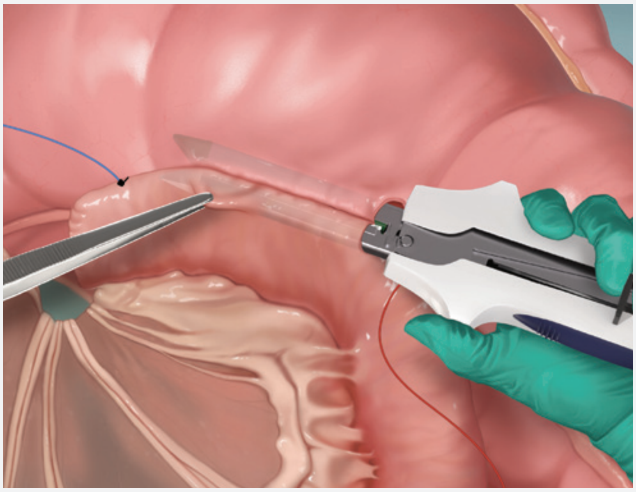


Fig.56 Place each side of the stapler into each incision and staple the jejunum and the cecum together. Before stapling, check if the first outer suture is not kinked between the two parts of the stapler.

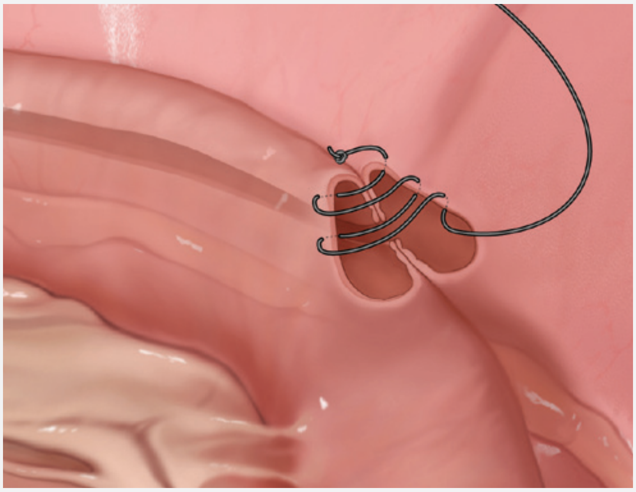


Fig.57 Completely suture the incision used for the insertion of the stapler. This suture is a continuation of inner stapled lines.

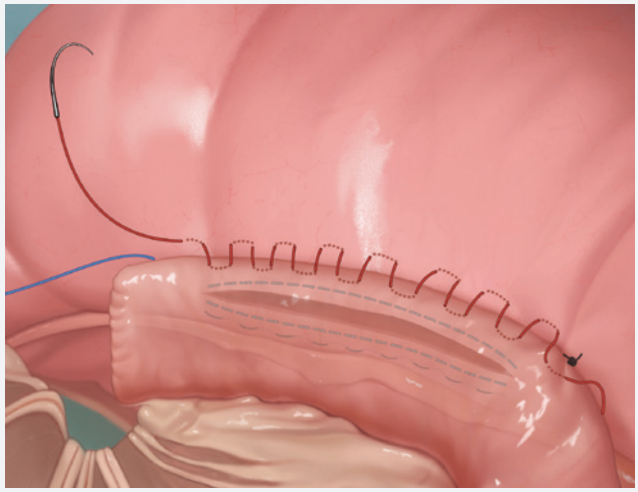


Fig.58 Grab the suture remaining uncut from Fig.54 (red), and make the second outer suture with a Cushing pattern above the stapled line. The suture thread is marked red.

37

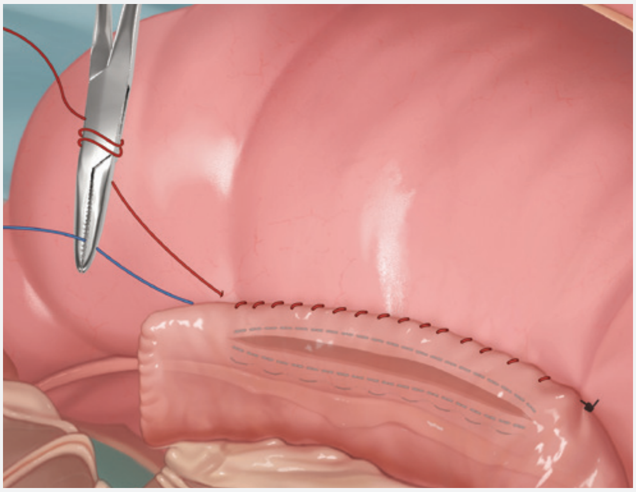


Fig.59 After reaching the point where the start of creating the stoma was located, grab the suture that remains uncut from Fig.52 (blue) and tie it together with the second outer suture(red).

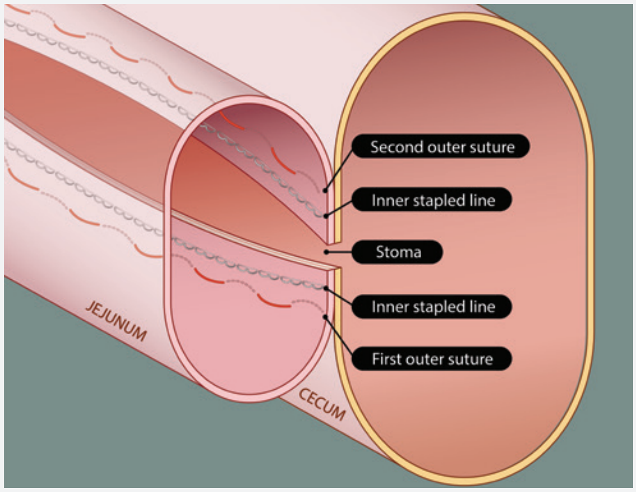


Fig.60 Transverse cross-section of the area around the stoma. This is a double-layer suture. The two inner layers are stapled, and the two outer layers are hand sutured. Both inner and outer lines run circularly around the stoma.

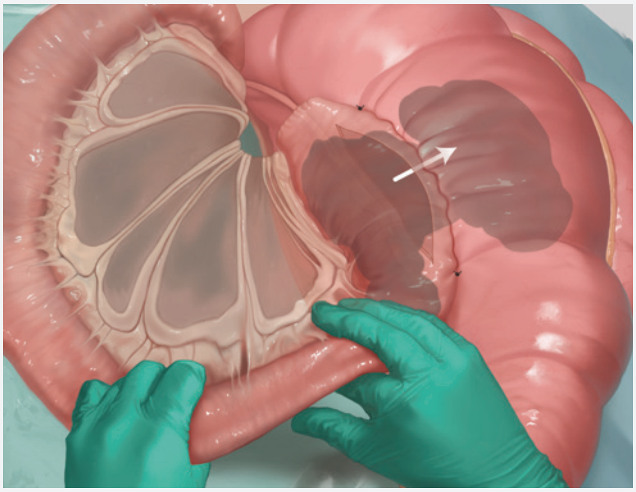


Fig.61 Push the contents of the jejunum to check if the contents pass through the stoma and enter the cecum.

B

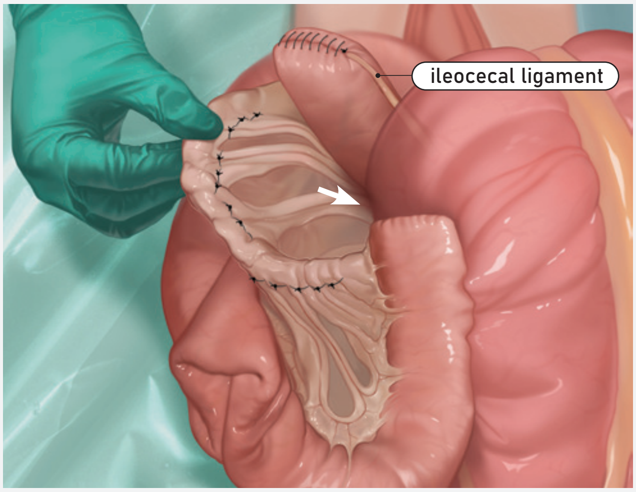


Fig.62 To prevent strangulation due to the mesenteric defect(arrow), the ligated mesentery needs to be sutured along the ileocecal ligament. This should result in complete closure of the mesentery without any remaining gaps.[20]

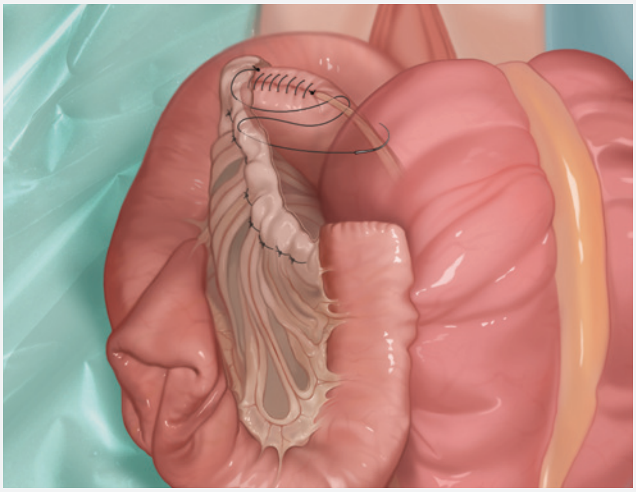


Fig.63 The first knot starts from the end of the mesenteric flap, holding the stump of the ileum together with the flap. The suture continues along the edge of the mesenteric flap and the ileocecal ligament.

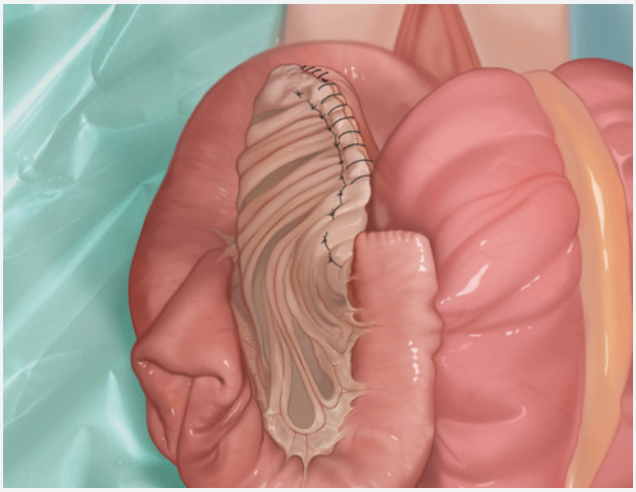


Fig.64 The mesenteric gap and the remaining stump of ileum is completely covered by the mesenteric flap.

Fig.65 Place the cecum and jejunum back into the abdomen and close the incision. The apex of the cecum should head in the cranial direction.

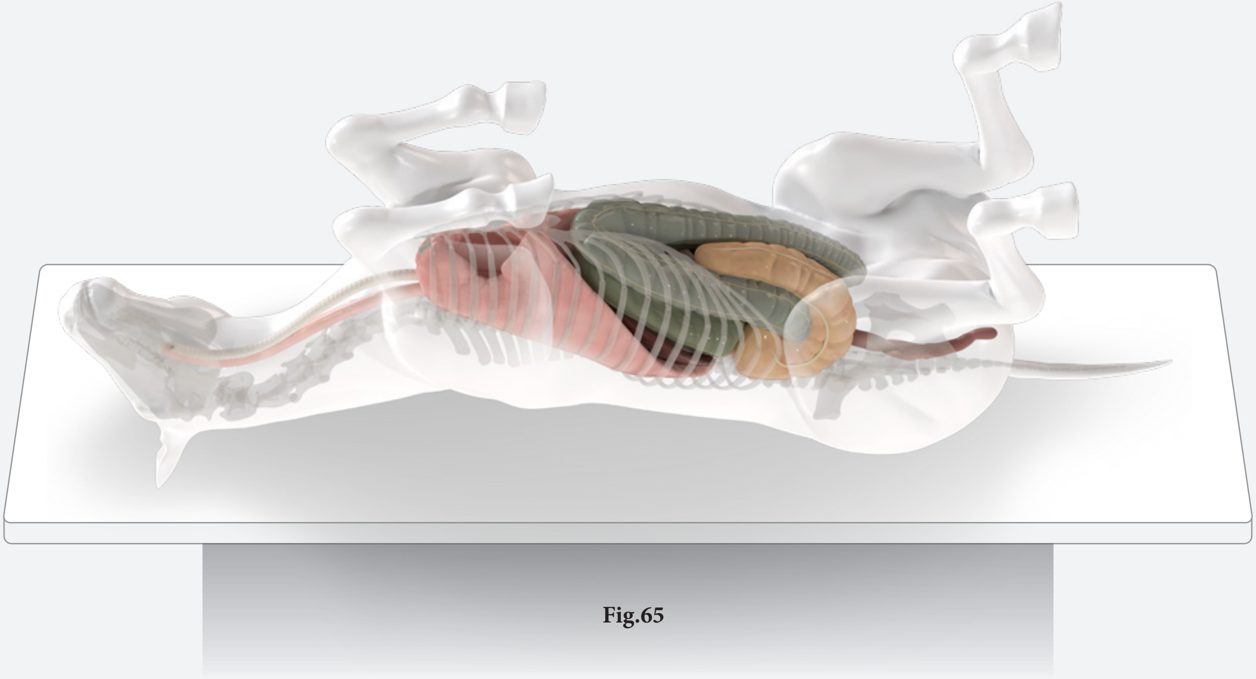


Fig.65

CONCLUSION

Utilizing 3D as a tool of science visualization and education can be very beneficial, as it allows for more accurate visualization of complex structures from different angles. By providing a 3D representation, scientists and researchers can better understand the relationship between various structures and their spatial orientation.

From the artist's point of view, 3D is efficient and helpful, especially in the long term. When a scientific illustrator continues to build 3D reconstructions for different assignments, the stock of models becomes the artist's library of intellectual properties. Those models can be used repeatedly in other works, hence increasing the time efficiency of the workflow. This also indicates working with 3D is, even more, beneficial for scientific illustrators who specialize in certain research fields. The 'Ghost Horse' can be used not only for visualizing other equine colics but also for other projects regarding different horse anatomy. If I were to get more assignments on equine science, more anatomical parts would be added to the 'Ghost Horse', eventually resulting in a whole reconstruction of the horse anatomy with high accuracy.

Another reason 3D imaging is beneficial is that it can also be utilized to enhance the accuracy of 2D imaging. It allows for precise measurements and representations of objects from different angles. Some illustrators use 3D objects to confirm the accuracy of their drawings. And some improve work efficiency by actively including 3D render images in their 2D illustrations.

Arguably, a 3D graphic artist in subcultural fields such as games, movies, and animations may be more proficient in 3D imaging than a scientific illustrator with 3D skills. It may be partially true in terms of graphics. But to create accurate visualization, the artist must comprehend the contents of the research and be capable of communicating efficiently with researchers. The deeper the artist understands, the more representative of the subject and accurate the visualization can be. Scientific illustrators possess a deep understanding of tissue behavior, texture, and structures of anatomy, filling the gap in comprehension and communication between the art and science fields.

Traditional 2D illustration and 3D imaging each hold different advantages and strengths. It is ideally the artist's judgment to decide which method would function well with each assigned work. The visual elements can be tuned not only for their efficiency and function but also for their aesthetics. My art bachelor's background allows me the ability to utilize traditional drawing, digital drawing, and 3D imaging techniques. They are various tools in the shed the artist can choose from.

Horses once were an extension of human ability in terms of speed and distance. Horses wake up a sense in us, a feeling that we can reach anywhere. Perhaps it is why horses remain an affectionate companion to people to this day. Because horses granted people the ability to go somewhere out of reach, people started to explore, encounter others, and became who we are now. Like so, technology is an extension of human ability. They are developed in response to our needs, and also in reverse affect the way we live and think. In my opinion, artists will have more and more opportunities to work together with technology, not against them. They will be our new tools in the shed.

I do not in any way mean that technology is almighty or superior to traditional illustration. Although new technologies such as 3D imaging or computer-generated images and reconstructions are useful, they have their own defects. It is important to know the pros and cons of each tool and use them where necessary. I am excited to see how these new tools would broaden the role of scientific illustrators. I am more than excited to see the new beauty of works to come, and to see how they would benefit scientific research and help communicate with the masses.

In my future career, I wish to specialize in 3D imaging and surgical illustration, especially in the veterinary field. It had been a wonderful experience working with specialists in equine science and seeing their passions run like horses. I thank again to teachers, external advisors, and researchers who helped me throughout this horseback ride.

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