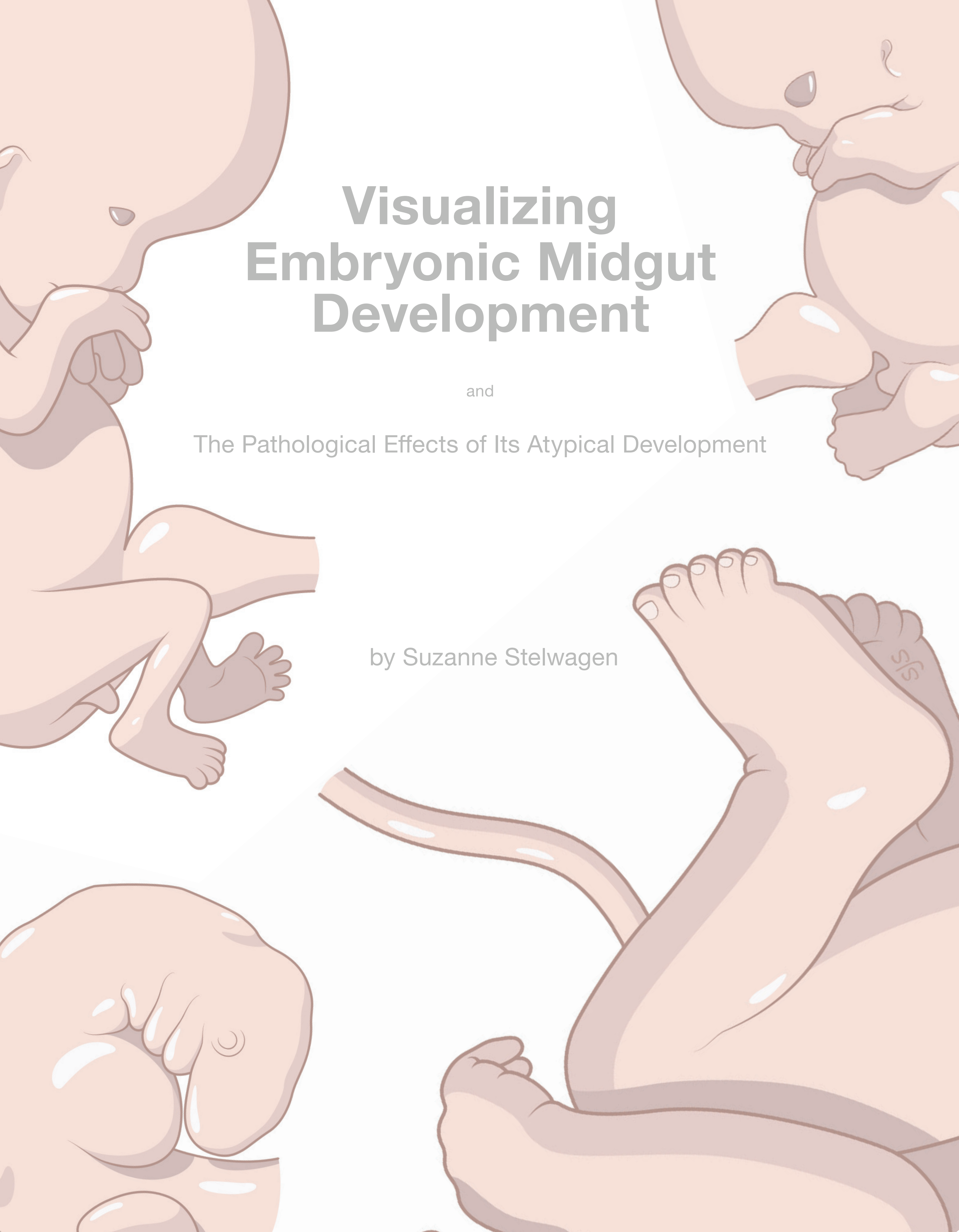


Visualizing Embryonic Midgut Development

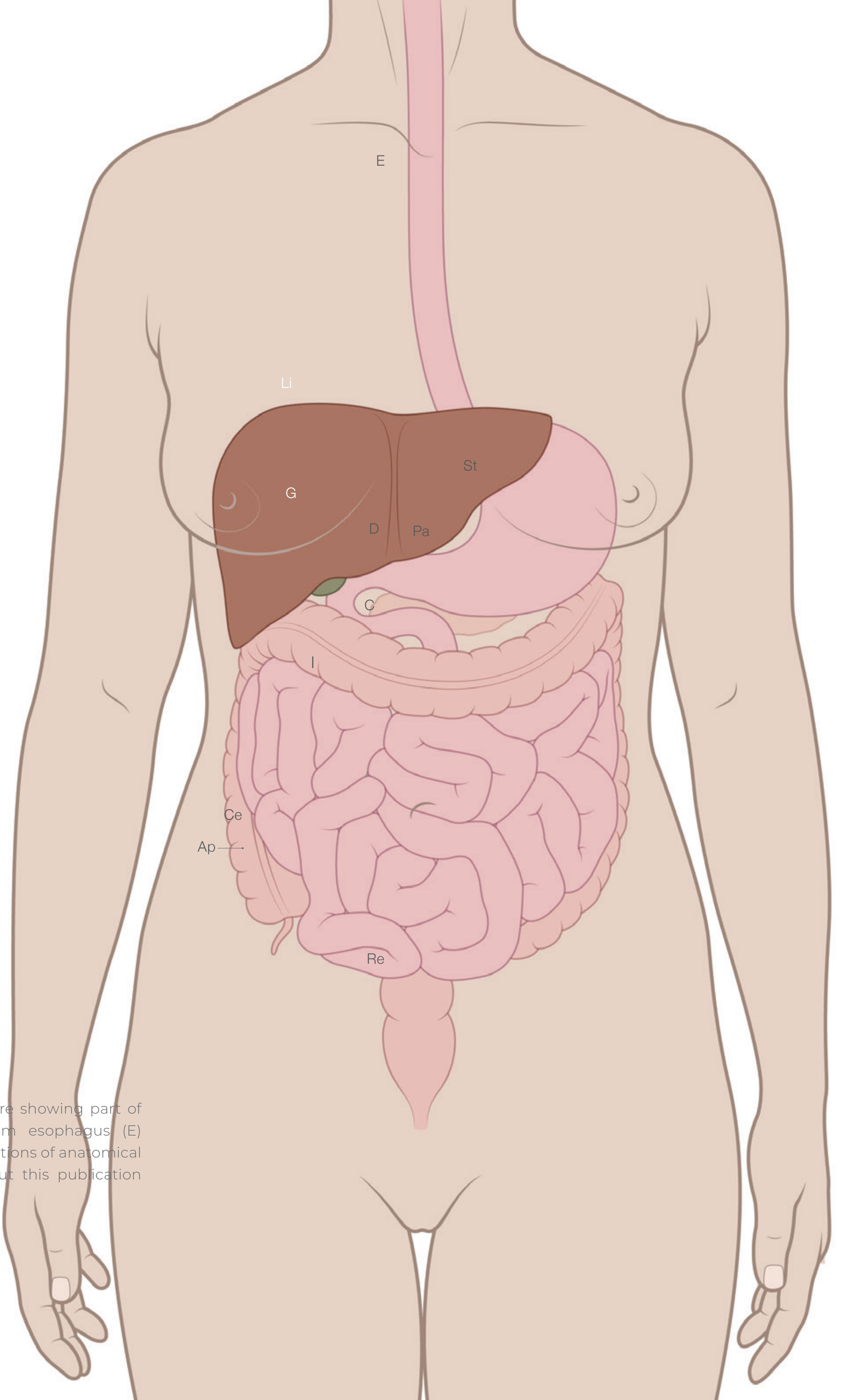
and

The Pathological Effects of Its Atypical Development

by Suzanne Stelwagen

Abbreviations

A	Aorta
Ab	Abdominal cavity
Ap	Appendix
C	Colon
Ce	Cecum
CS	Carnegie Stage
D	Duodenum
E	Esophagus
F	Fat
G	Galbladder
I	Small intestines
K	Kidney
Li	Liver
M	Muscle
Me	Mesentery
Mra	M. rectus abdominis
P	Portal vein
Pa	Pancreas
Re	Rectum
S	Skin
St	Stomach
Um	Umbilical cord
V	Vertebra



► Figure 1 An adult figure showing part of the digestive system from esophagus (E) untill rectum (Re). Abbreviations of anatomical structures used throughout this publication can be found above.

Visualizing Embryonic Midgut Development

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The Pathological Effects of Its Atypical Development

by
Suzanne Stelwagen

A Thesis
presented for the degree of

Master of Arts in

SCIENTIFIC ILLUSTRATION

ZUYD University of Applied Sciences and Maastricht University

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2023

Maastricht University

Zuyd University
of Applied Sciences

Colophon

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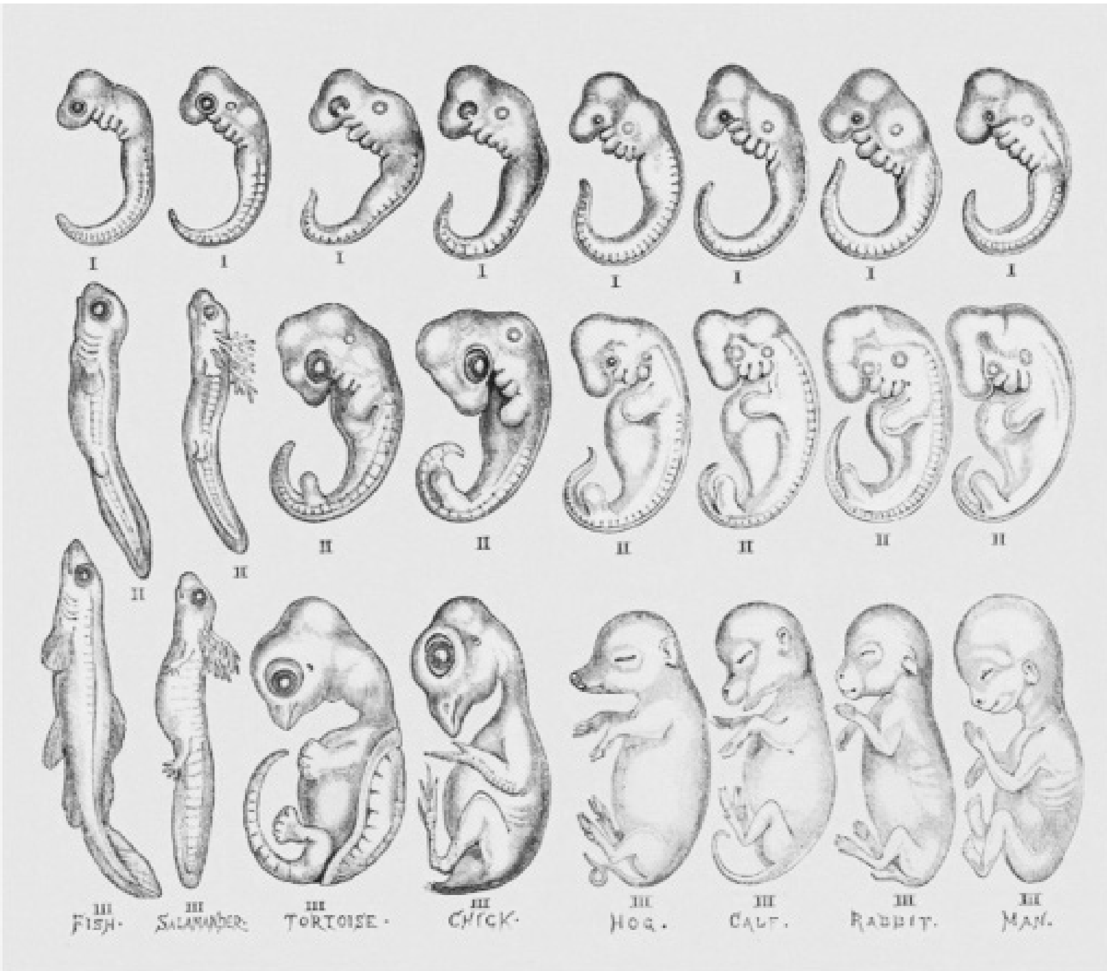


▲ Figure 2 Haeckel's bespoke 1874 illustrations showing three stages of embryonal development of a (left to right) fish, salamender, turtle, chick, pig, cow, rabbit and human.

Preface

One cannot write about scientific illustration and embryological research without spending a few words on the influential biologist, philosopher and artist Ernst Haeckel (1834-1919).

Haeckel popularized the ideas of evolution, advocated for the conservation of natural resources and developed the concept of the phylogenetic tree to represent evolutionary relationships between organisms. However, as he was accused of falsification of data, his work on embryological research has been a subject of controversy. His theory of recapitulation proposes that the development of an organism from embryo to adult reflects the evolutionary history of its species. The similarities between embryos of different species in his drawings (fig. 2) are thought to have been exaggerated to match his theory. While this theory and supporting drawings are largely discredited, it is also important to note that his work has taught millions of people and contributed significantly to the progress in the fields of developmental biology and evolution. [1]

With his artwork he had a significant influence on the art styles of his time, particularly the Art Nouveau movement, which is characterized by its use of flowing, curved forms inspired by nature.

Also for me personally Haeckel's art has long been a source of aesthetic inspiration and as such has been decorating the wall above my desk for many years.

To me the use of symmetry and style of composition in much of his work [2] represents man's desire to create order from the chaos, and in doing so his work not only has educational and aesthetic value, but also raises an important question:

"How?"

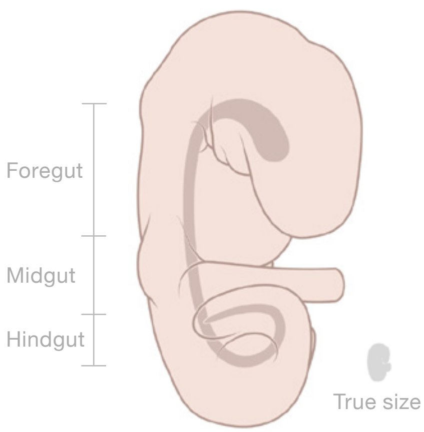
As it is not my wish to scare off the reader with seemingly philosophical questions, I will quickly state that in scientific illustration, this is actually a very practical dilemma.

Teaching, which is the essence of scientific illustration, asks us to simplify, distil and order the variety and chaos that is inherent to nature. It is the most important skill I have learned during my time at the Master Scientific Illustration in Maastricht, and will continue to develop afterwards.

In this thesis I present to the reader my take on creating order from the chaos.

1 Introduction

The curriculum of certain courses at Maastricht University, faculty of Health, Medicine and Life Sciences (FHML) covers the development of the embryonic midgut. The term “midgut” refers to the middle part of the embryonic gut (fig. 3), which eventually gives rise to part of the duodenum, small intestines and first part of the colon, including the cecum and appendix. [3]



▲ Figure 3 Simplified image of the embryonic gut in a 28 days old (post-ovulatory) embryo. It is divided into three parts (from cranial to caudal): foregut, midgut and hindgut.

As a lecturer at Maastricht University, J.P.J.M. Hikspoors PhD – external supervisor to this thesis project – experiences that some processes during midgut development are often difficult to grasp for students, due to outdated terminology and illustrations.
A main event in midgut development, during which the midgut undergoes a dramatic change in shape and position, is consistently described in the established literature as “the turning of the midgut” [4][5]. By describing this change as “turning”, it is implied that the midgut alters its shape and position by itself. However, recent research has given more insight into the driving forces behind this event and has concluded that this change in shape and position is a result of passive movement of the midgut, driven by growth and configuration differences between the midgut and surrounding tissues [6]. More information on this process can be found on page 16. Another process, concerning the part of the midgut that gives rise to the colon, is described as “the descending of the cecum” and similar misrepresentation as described above is present here as well. Changes in colon configuration, their driving forces and consequent changes in cecum location are not accurately described by existing literature [6]. More information on this event can be found on page 19.

Furthermore, it was discussed that students miss a clear overview and have difficulty linking events of typical and atypical midgut development to the appropriate stage of embryonic development. This is best demonstrated by two specimens displayed during practicals. Despite their considerable size difference, both specimens are labelled as 8 weeks old (post-ovulatory). Among the students this does not seem to spark questions, possibly due to uncertainty on general embryonal development and growth; “which external features are to be expected at which stage?”.
The size of the biggest specimen (fig. 3) corresponds to a 12 weeks old fetus. However, the stage of gut development corresponds to an 8 weeks old embryo (CS23, fig. 24.6, page 17). In combination with additional atypical characteristics, it is concluded that this embryo is 12 weeks old and is showing atypical development that would probably have resulted in a newborn with omphalocele, if development

had continued. Omphalocele is a birth defect in which the intestines or other organs protrude out of the belly via the umbilical opening (fig. 42, page 31). It is desired that students recognize main developmental characteristics and be able to identify at what moment atypical development could start for birth defects like omphalocele. The differences between omphalocele and gastroschisis, another birth defect showing protruding intestines (fig. 46, page 33), students should be able to identify as well. Additionally, variation in colon configuration among adults (fig. 30, page 19) has a basis in variable midgut development [6]. This link should be made clear in the course material, as variation in appendix location is relevant for diagnosing and operating on appendicitis.

To conclude, illustrations currently used in education on midgut development have become misleading and inaccurate according to recent research, hence there is a need for up-to-date illustrations to clear up misconceptions about the mechanisms behind midgut development. Additional illustrations on pathological consequences of atypical development complete an overview on midgut development that highlights its most important aspects in a way that is suitable for bachelor students in the biomedical field. The experimentation and decision making described in the next chapters was done with this particular target group in mind.

During this project I am aided by my mentor Andreas Herrler, Lecturer Anatomy and Embryology, Maastricht University FHML, and the aforementioned J.P.J.M Hikspoors PhD, Lecturer Anatomy and Embryology, Maastricht University FHML.

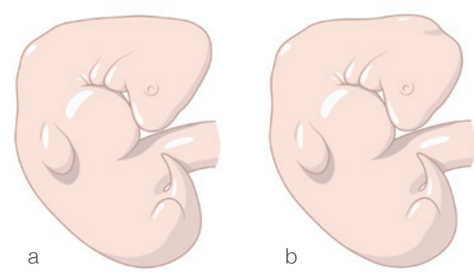
Figure 55 on the inside of the back cover flap explains the anatomical terminology used throughout the text.

▲ Figure 4 Twelve weeks old specimen showing atypical development. Photo: Maastricht University FHML.

2 Carnegie Stages

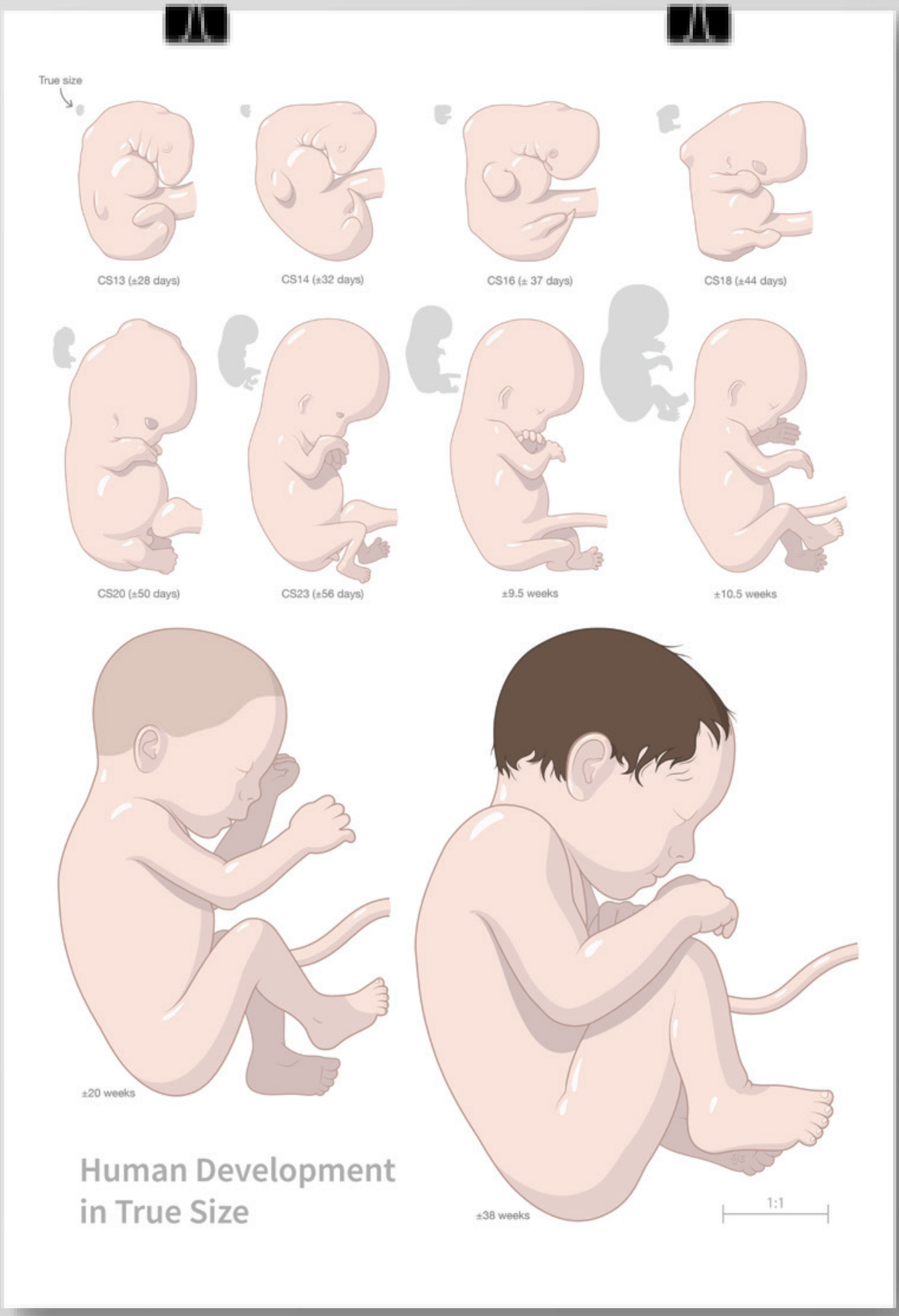
Carnegie stages (CS) are a widely used system to describe and organize the different stages of embryonic development. It was developed by the Carnegie Institution for Science (Washington D.C., US) in the early 20th century.
This classification system puts emphasis on external and internal characteristics of embryos, instead of age and size. This is done to accurately describe and compare the development of embryos across different studies and species. It facillitates consistent communication on embryonic development, the identification of abnormalities, and provides insights into the timing and sequence of key developmental events. The different stages range from 1 to 23 and represent different developmental milestones from the start of development to approximately 8 weeks after ovulation. After 8 weeks (CS23), the embryonic phase (focussed on organogenisis) ends and the fetal phase (focussing on growth) starts. From then on the embryo is referred to as fetus. For the purpose of this project I added four timepoints during fetal development (fig. 23.9-12, pages 18-19), as these coinside with key events in midgut development (fig. 24.9-24.12, pages 18-19).
Features of six for midgut development relevant relevant Carnegie stages and the four abovementioned additional fetal stages are described by a series of simplified illustrations (fig. 6; fig. 7-16, page 10-12). The purpose of these illustrations is to provide an understanding of the general development of the embryo/fetus in relation to the timing of various steps in midgut development. As such, these illustrations were initially intended to only feature in a poster on midgut development (fig. 22, page 15). A request by Natuurmuseum Brabant to provide artwork for the exhibition “Pencil to Pixel” prompted the idea to show the embryos/fetuses in a separate poster (fig. 6). To make it more engaging for the museum visitors the ±20 and ±38 weeks old fetuses are shown in their true size. The true sizes of the other stages are conveyed by grey silhouettes next to the corresponding stages. This way the viewer can get a general idea of growth speed during development without having to read any size charts.
Age approximations are given to provide the reader with an understanding of time passed between stages. These ages are post-ovulatory (meaning “counted from ovulation”) and can easily be confused with gestational age, commonly used to discuss pregnancy, for which counting starts from the beginning of the last menstrual cycle (two weeks before ovulation). As post-ovulatory age is preferred in research, this will be used here as well.

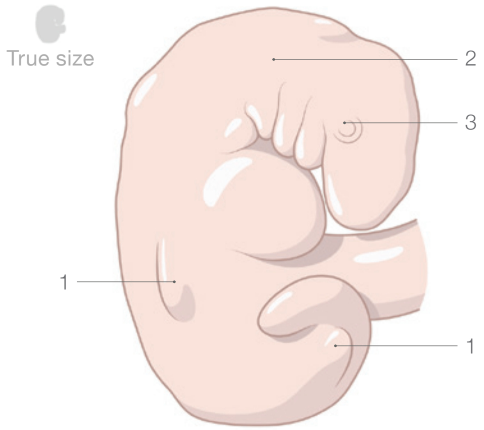
3D models of some of the stages were available and proved usefull references, but since these are subject to individuality (n=1 [6, table 1]), additional sources were used to create more representative images, as demonstrated by figure 5. As Carnegie stages are widely documented, more than enough reference material was available [7][8][9]. References on fetal stages (with exeption of ±38 weeks) were less abundant, but still sufficient.



▲ Figure 5 Due to individual variation and/or handling of the embryo (CS14), the head shape according to the 3D model (a) is different from the commonly seen head shape (b).

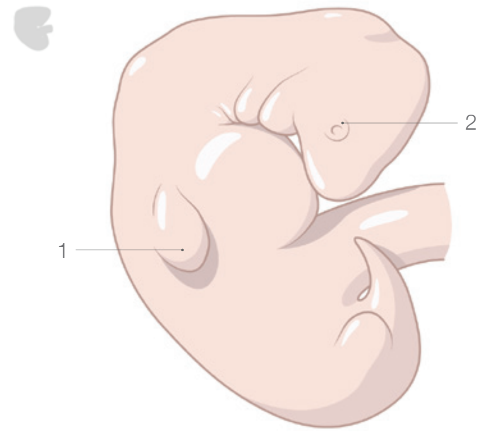
▶ Figure 6 Poster (A2 size) displaying stages in real size.


True size
CS13 (±28 days)
CS14 (±32 days)
CS16 (± 37 days)
CS18 (±44 days)
CS20 (±50 days)
CS23 (±56 days)
±9.5 weeks
±10.5 weeks
±20 weeks
Human Development
in True Size
±38 weeks
1:1



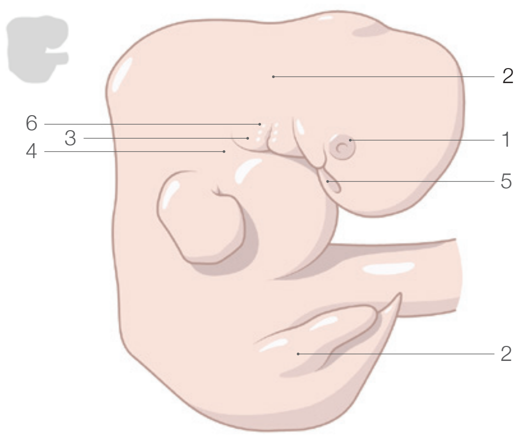
CS13 (±28 days)

▲ Figure 7 All four limb buds are visible (1); the otic vesicle (structure that will give rise to most celltypes of the adult inner ear) is closed; the lens disc is not indented (3).



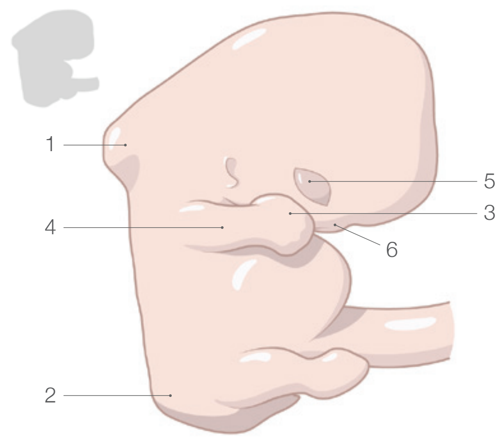
CS14 (±32 days)

▲ Figure 8 The upper limb buds are elongated and tapering (1); the lens disc is invaginated and no ectoderm (giving rise to e.g. the skin) is covering this lens pit (2).



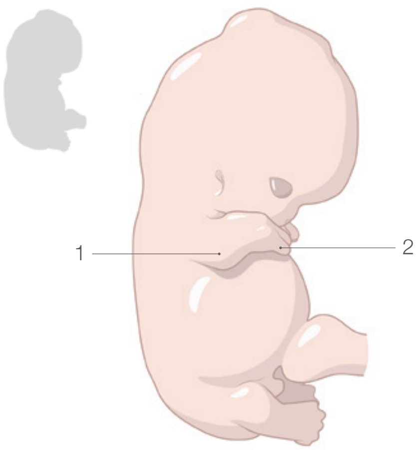
CS16 (±37 days)

▲ Figure 9 Retinal pigment is becoming visible (1); the thigh, leg and foot are becoming distinguishable (2); pharyngeal arch 2 has become more massive and prominent (3); whereas arch 3 is receding from the surface (4); the nasal pits face ventrally (5); auricular hillocks (precursors of the auricle) emerge (6).



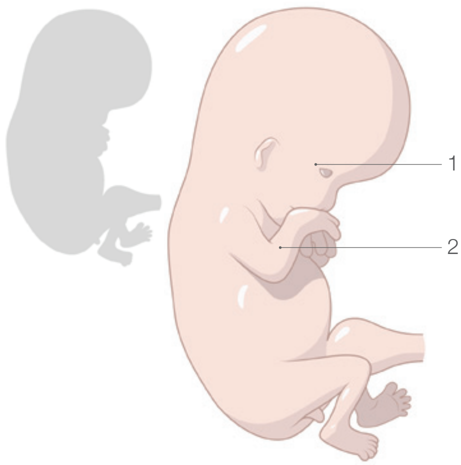
CS18 (±44 days)

▲ Figure 10 The body is more of a unified cuboidal mass; both cervical (1) and lumbar (2) flexures are indicated; the plate of the hand shows hints of digit formation (3); the elbow region is discernable (4); eyelid folds can be seen (5); the tip of the nose is distinguishable in profile (6).



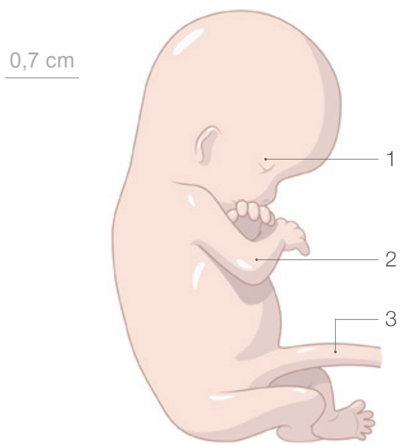
CS20 (±50 days)

▲ Figure 11 The upper limbs are slightly bent at the elbows (1); the hands have a little distance between them and short, stubby fingers are present (2).



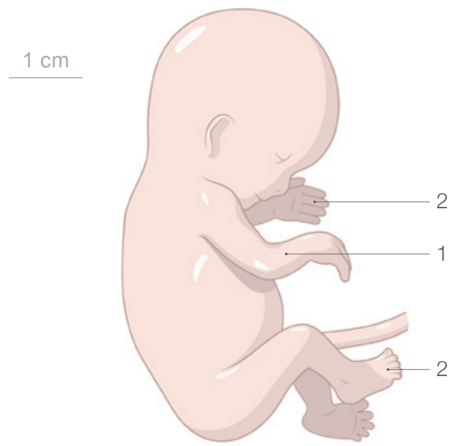
CS23 (±56 days)

▲ Figure 12 The eyelids are starting to fuse at the margins (1); the limbs have increased in length and show more advanced differentiation of their subdivisions (2).



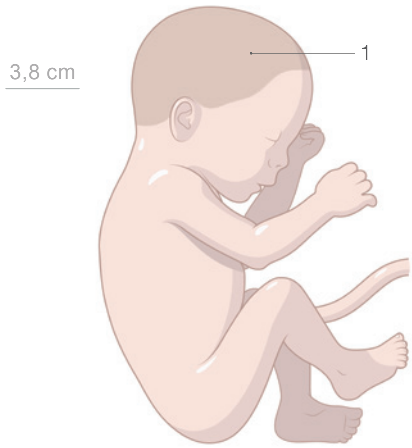
±9.5 weeks

▲ Figure 13 The eyelids are fully formed and fused (1); limb length is increasing (2); the head-to-body ratio has notably decreased; the widening of the umbilical cord, as seen in CS20 (fig. 11) and CS23 (fig. 12), is no longer present (3), since the herniation of the midgut has resolved (fig. 24.9, page 18).



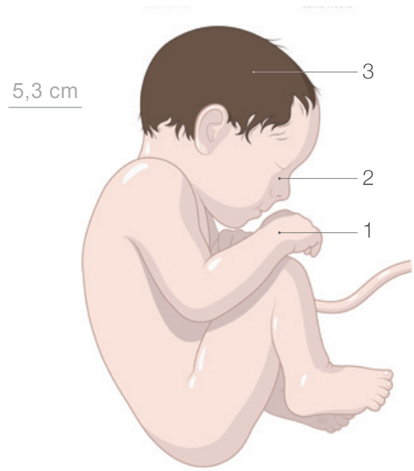
±10.5 weeks

▲ Figure 14 Limb length continues to increase (1); fingers and toes are further developed (2); the head-to-body ratio continues to decrease.



±20 weeks

▲ Figure 15 The fetus is growing; the head-to-body ratio has notably decreased; hair follicles have developed and fine hairs start to emerge (1).



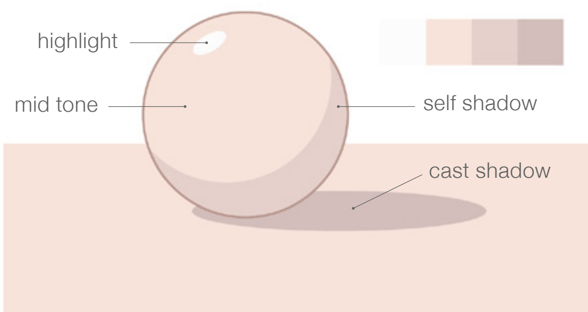
±38 weeks

▲ Figure 16 The body mass has significantly increased; the limbs (1) and facial features (2) have fully developed; hairs are usually clearly visible (3).

Artistic Choices and Techniques

Initially I planned on keeping the figures just as lines with flatfills (fig. 18). Having done this, I found that the shape was not conveyed clear enough without any shading. Hence, cel shading was added (fig. 19).

Besides wanting to experiment with a style that was new to me, the choice for cel shading was also based on the amount of time available. As there are 10 figures (fig. 7-16) in this series, it would have taken significantly more time to employ a higher elaborated style like smooth digital shading (fig. 20) or pencil shading (fig. 21), while the information could also be conveyed by using a less elaborated, much quicker style like cel shading.
I made a distinction between self shadows, cast shadows, mid tones and highlights (fig. 17).



▲ Figure 17 Colorpalette for the cel shading of the embryos and fetuses. Cast shadows are slightly darker and cooler toned than self shadows, as this is usually the case in reality.

Lines & flatfills

▲ Figure 18 This style is often seen in educational textbooks as it is quick, which is usefull when the quantity of illustrations needed is high or the budget is small. However, complex shapes may be difficult to convey without any shading.

Cel shading

▲ Figure 19 By strategically placing shadows as different colored shapes in certain areas of the figure, a sense of shape can be created. This technique is fast, but can be limiting in conveying details or complex shapes.

Smooth digital shading

▲ Figure 20 Working digitally with software such as Adobe Photoshop has many conveniences: layers, ctrl-z, various tools, endless color adjusting, etc. It is quite fast, however the aesthetic of traditional (meaning non-digital) techniques is difficult to recreate.

Smooth pencil shading

▲ Figure 21 Traditional techniques, such as pencil, give an image a certain aestetic. Often the paper texture is slightly visible. This technique takes significantly more time, but this can be worth it for projects that require this kind of look. Color can be added digitally or by working with colored pencils.

3 Midgut Development

This thesis subject was first suggested to me as a 3D animation project. However, a few meeting later it became clear that software and data limitations postponed the 3D animation far beyond the time available for this thesis project.

Initially it seemed suitable to present the information in 2D animation, as an alternative for 3D animation. The first few weeks were spent on learning how to animate in 2D and exploring the possibilities for this project. Unfortunately the medium proved suboptimal. I concluded that, in this case, a series of illustrations (fig. 24, page 16-19) would have a higher educational value than 2D animation (box 1).

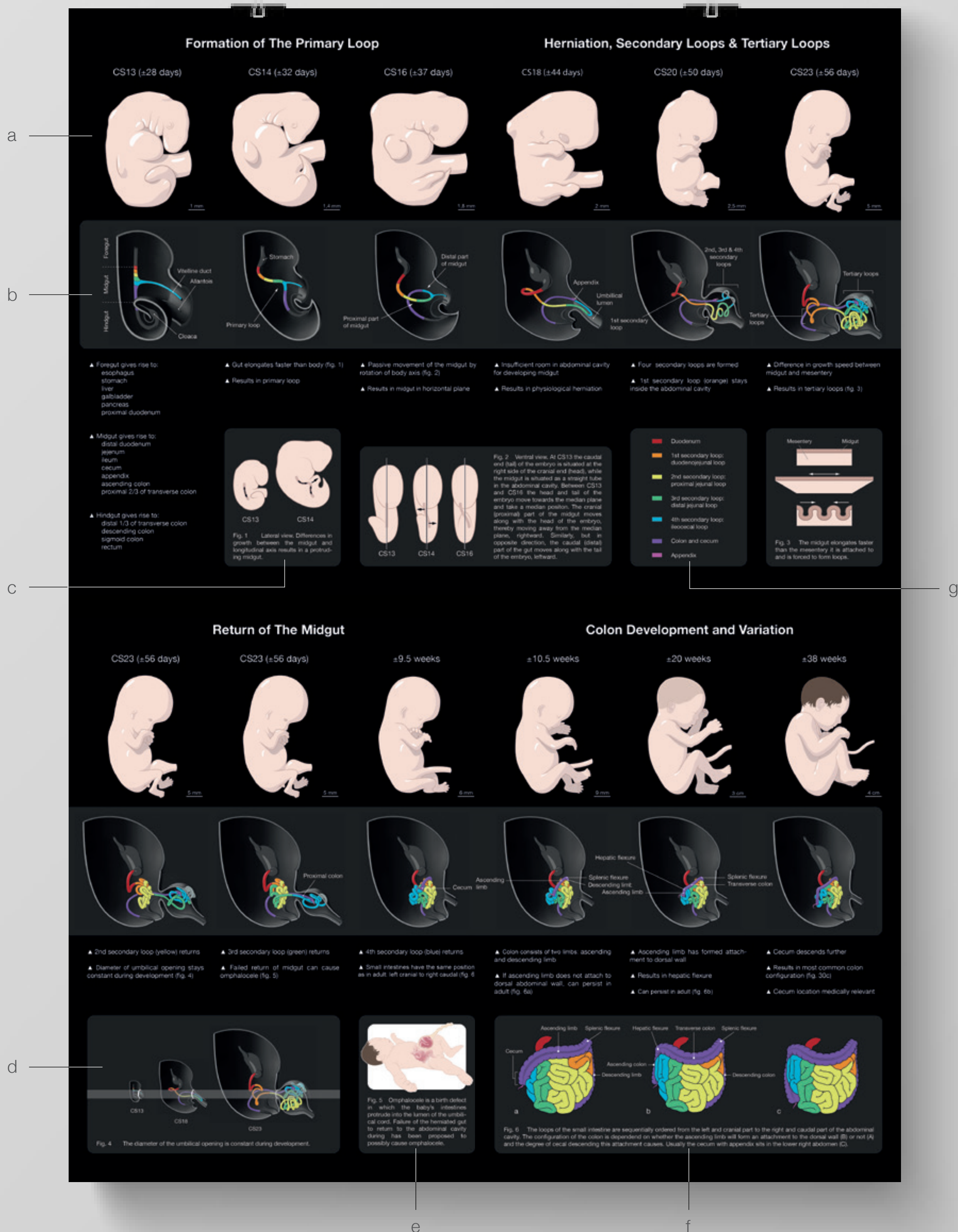
BOX 1

Additional value of illustrations with respect to animation

- Stages are easier to compare to each other when shown next to each other, compared to a changing image in which the previous step has disappeared.
- The quality and educational value that can be delivered in the available time is much higher for illustrations than for animations.
- Static illustrations accomodate self-directed learning: the viewer can process the information in their own pace.

To aid the students during their practicals, the information on midgut development is presented as an educational poster. Students can compare specimens to the embryos/fetuses in the top row (fig. 22a) and find information on the corresponding stage of midgut development in the second row (fig. 22b). Mechanisms behind midgut development are explained separately in additional schematic illustrations below the relevant stages (fig. 22c).
To visualise the constancy of the diameter of the umbilical opening clearly, the illustrations are put next to each other behind a transparant line which has a width equal to the umbilical openings (fig. 22d). This way their relative size is made clear while focussing on the constant umbilical diameter.
A figure showing a newborn with omphalocele (fig. 22e) is placed below the stage of a fully to the abdominal cavity returned midgut. Here its connection to these stages is emphasizes, as this birth defect is thought to be the result of incomplete return of the midgut.
The illustrations on colon variation in adults (fig. 22f) are placed under the specific stage in midgut development that would give rise to that particular colon variation if development did not continue normally from that point onwards.
A legend (fig. 22g) minimises the amount of labels in the illustrations, in order to not overwhelm the viewer with anatomical terms. To keep the attention to the most important structures, most are only labelled when they are explicitly mentioned in the text or upon first appearance.
The information summed up in the bullet points on the poster is written out more elaborately on pages 16-19, where the poster is shown in a readable size.

▶ Figure 22 Poster on midgut development showing embryos/fetuses (a), midgut development stages (b), schematic illustrations (c), a constant umbilical opening size (d), omphalocele (e), colon variation (f) and a legend (g).


Formation of The Primary Loop
Herniation, Secondary Loops & Tertiary Loops
CS13 (±28 days)
CS14 (±32 days)
CS16 (±37 days)
CS18 (±44 days)
CS20 (±50 days)
CS23 (±56 days)
Return of The Midgut
Colon Development and Variation
CS23 (±56 days)
CS23 (±56 days)
±9.5 weeks
±10.5 weeks
±20 weeks
±38 weeks
a
b
c
d
e
f
g

Formation of The Primary Loop

CS13 (±28 days)

Fig. 23.1

CS14 (±32 days)

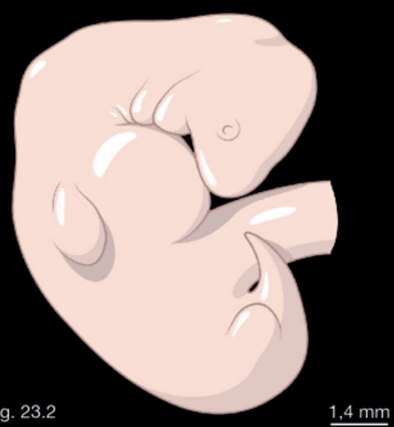


Fig. 23.2

CS16 (±37 days)

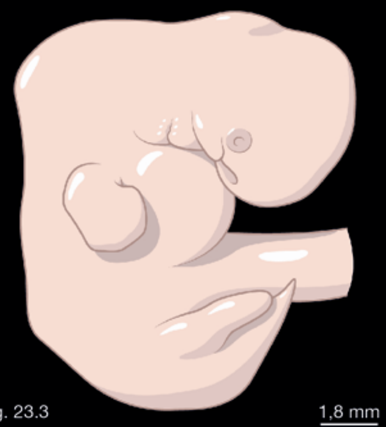


Fig. 23.3

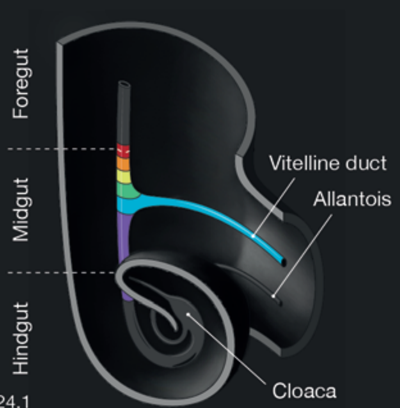


Fig. 24.1

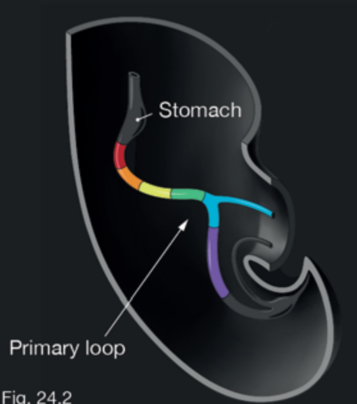


Fig. 24.2

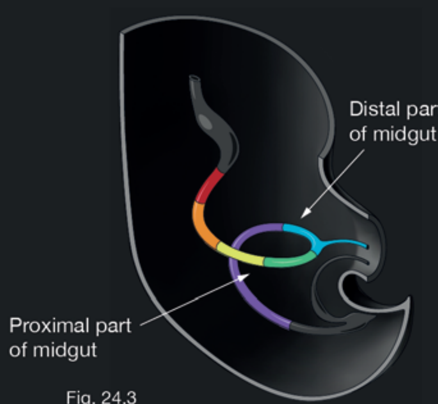


Fig. 24.3

▲ The primitive gut starts out as a more or less straight tube extending cranio-caudally in the median plane of the embryo. It is divided into 3 sections: foregut (partially shown here, extending cranially, giving rise to the esophagus, stomach, liver, galbladder, pancreas and proximal duodenum), midgut (giving rise to the distal duodenum, jejenum, ileum, cecum, appendix, ascending colon and proximal two-third of the transverse colon) and hindgut (giving rise to the distal one-third of the transverse colon, descending colon, sigmoid colon and rectum). [3]
The vitelline duct connects the yolk sac to the midgut lumen [10]. Amongst other functions, the yolk sac and surrounding blood vessels play an important role in early embryonic blood supply [11], delivering nutrients to the embryo, untill the placenta is sufficiently matured [12].
The distal allantois gives rise to the fetal urachus, a canal which drains the fetal urinary bladder [5].

▲ Between week 4 and 5 after fertilization the midgut starts to elongate faster than the longitudinal body axis of the embryo. This causes the midgut to protrude ventrally (fig. 25).
The loop that is formed by this process is refered to as the primary loop.

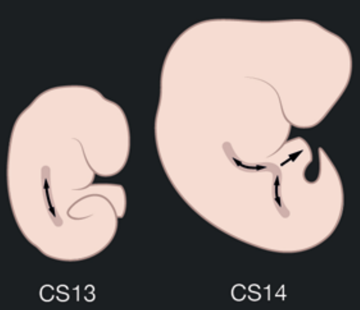
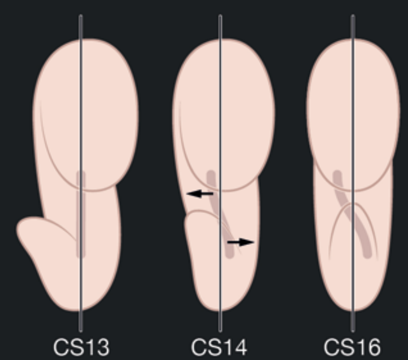


Fig. 25 Lateral view. Differences in growth between the midgut and longitudinal axis results in a protruding midgut.

▲ The primary loop continues to protrude ventrally and orients itself in a transverse plane in which the proximal half of the loop is situated on the right and the distal half of the loop on the left of the abdominal cavity. This is a result of passive movement of the midgut, driven by the descent of ventral structures and rotation of the body axis of the embryo (fig. 26).



Herniation, Secondary Loops & Tertiary Loops

CS18 (±44 days)

Fig. 23.4

CS20 (±50 days)

Fig. 23.5

CS23 (±56 days)

Fig. 23.6

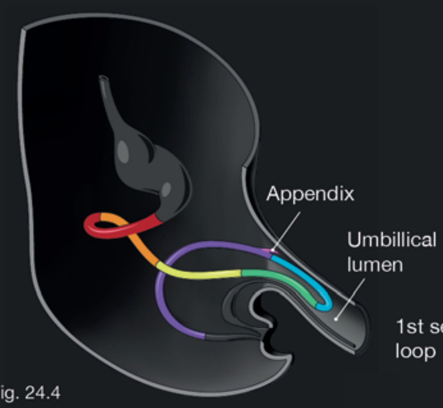


Fig. 24.4

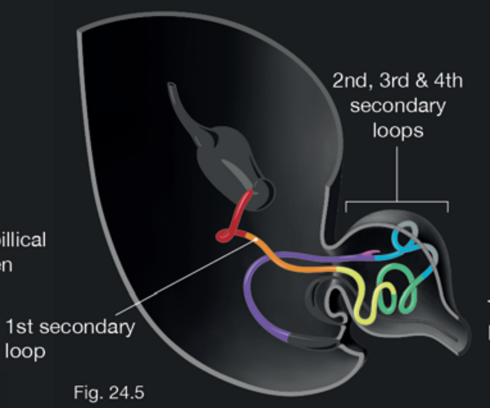


Fig. 24.5

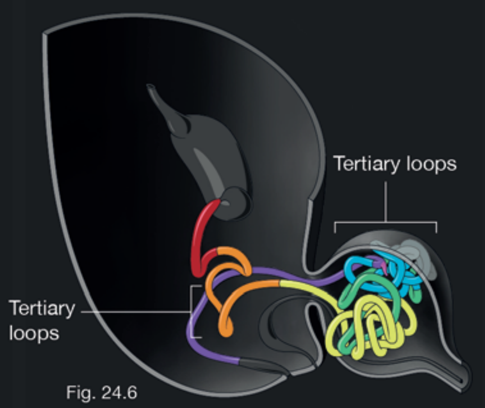


Fig. 24.6

▲ Around the end of week 5 after fertilization the abdominal cavity has insufficient room for the developing midgut. The primary loop protrudes out of the abdominal cavity, into the lumen of the umbilical cord. This phenomenon is referred to as the physiological herniation of the gut. At this stage the vitelline duct has narrowed and disappeared. The appendix has appeared.

Fig. 26 Ventral view. At CS13 the caudal end (tail) of the embryo is situated at the right side of the cranial end (head), while the midgut is situated as a straight tube in the abdominal cavity. Between CS13 and CS16 the head and tail of the embryo move towards the median plane and take a median positon. The cranial (proximal) part of the midgut moves along with the head of the embryo, thereby moving away from the median plane, rightward. Similarly, but in opposite direction, the caudal (distal) part of the gut moves along with the tail of the embryo, leftward.

▲ The midgut is still elongating and the four secondary loops are forming. The 1st secondary loop (orange, legend below) developes inside the abdominal cavity. The others will undergo extra-abdominal development inside the umbillical lumen.

- Duodenum
- 1st secondary loop: duodenojejunal loop
- 2nd secondary loop: proximal jejunal loop
- 3rd secondary loop: distal jejunal loop
- 4th secondary loop: ileocecal loop
- Colon and cecum
- Appendix

▲ A difference in growth speed between the midgut and mesentery forces the midgut to form additional loops (fig. 27). These loops are referred to as tertiary loops. Since the colon grows with half the velocity of the small intestine, no loops are formed here.

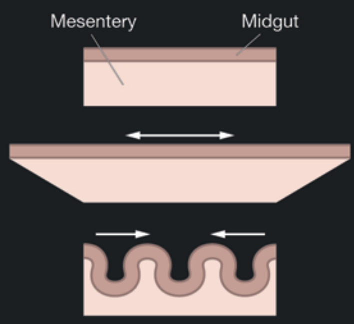


Fig. 27 The midgut elongates faster than the mesentery it is attached to and is forced to form loops.

Return of The Midgut

CS23 (±56 days)

Fig. 23.7

CS23 (±56 days)

Fig. 23.8

±9.5 weeks

Fig. 23.9

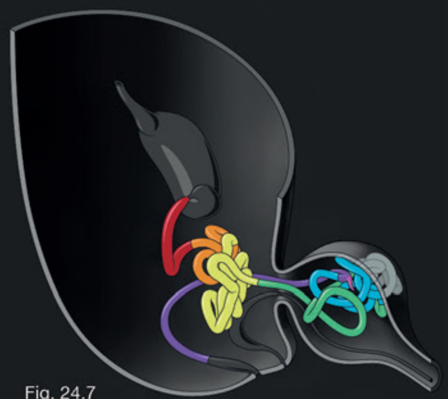


Fig. 24.7

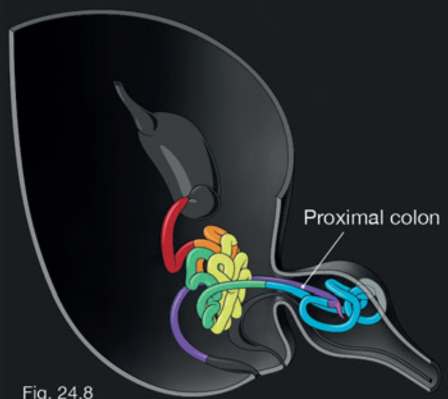


Fig. 24.8

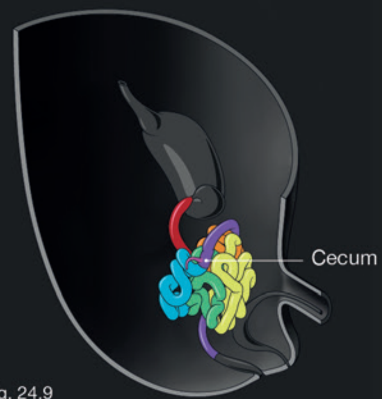


Fig. 24.9

▲ The abdominal cavity has increased sufficiently in size for the herniated gut to return. The 1st secondary loop (orange, legend on page 17) is positioned on the left in the abdominal cavity. The 2nd secondary loop (yellow) follows into the abdomen.

▲ The 3rd secondary loop (green) has returned. Next the proximal colon will return to the abdominal cavity, before the 4th secondary loop (blue) returns. During this development, the opening from the abdominal cavity to the umbilical lumen is constant in size (fig. 28).

▲ When the 4th secondary loop (blue) has returned, the small-intestines have already aquired their definite position in the abdominal cavity: from leftsided cranial to rightsided caudal (fig. 30). Failed return of the midgut is thought to cause omphalocele (fig. 29).

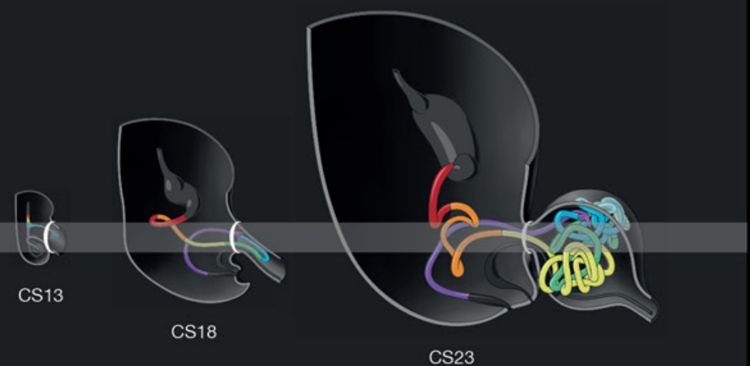


Fig. 28 The diameter of the umbilical opening is constant during development.

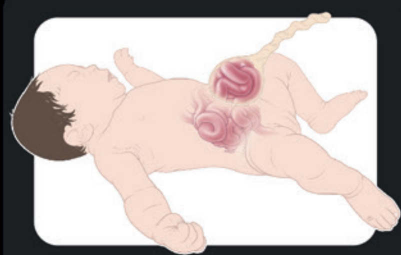


Fig. 29 Omphalocele is a birth defect in which the baby's intestines protrude into the lumen of the umbilical cord (fig. x). Failure of the herniated gut to return to the abdominal cavity during has been proposed to possibly cause omphalocele.

Colon Development and Variation

±10.5 weeks

Fig. 23.10 9 mm

±20 weeks

Fig. 23.11 3 cm

±38 weeks

Fig. 23.12 4 cm

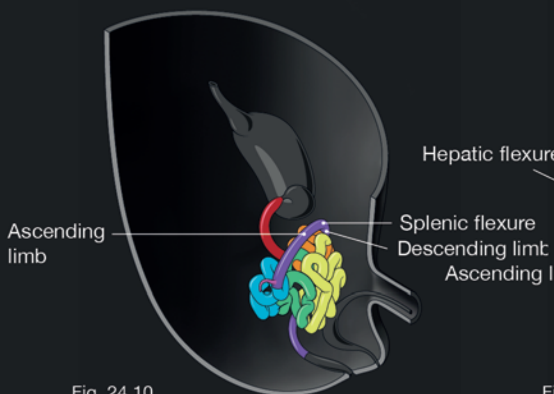


Fig. 24.10

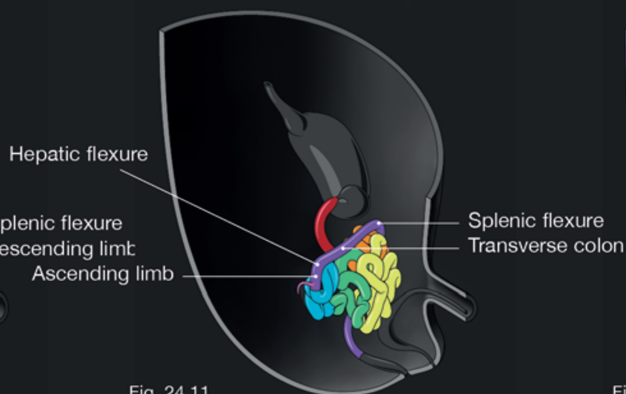


Fig. 24.11

Fig. 24.12

▲ The cecum has moved more rightward and has descended slightly. It consists of an ascending and descending limb. When the ascending limb forms no attachment to the dorsal abdominal wall, this configuration persists in the adult (fig. 30a).

▲ The ascending limb has formed an attachment to the dorsal wall. This has resulted in the formation of the hepatic flexure and transverse colon.
When the cecum does not descend, this configuration persists in the adult (fig. 30b).

▲ The attachement of the colon to the dorsal wall has caused the cecum to further descend, eventually resulting in the most common colon configuration (fig. 30c). Colon variation is relevant in diagnosing various conditions, such as appendicitis (fig. 36, page 26). [3-16]

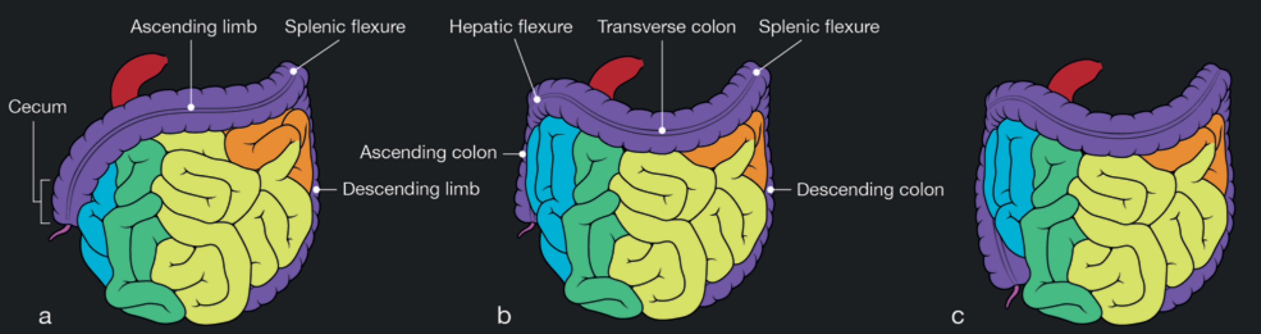


Fig. 30 The loops of the small intestine are sequentially ordered from the left and cranial part to the right and caudal part of the abdominal cavity. The configuration of the colon is dependend on whether the ascending limb will form an attachment to the dorsal wall (B) or not (A) and the degree of cecal descending this attachment causes. Usually the cecum with appendix sits in the lower right abdomen (C).

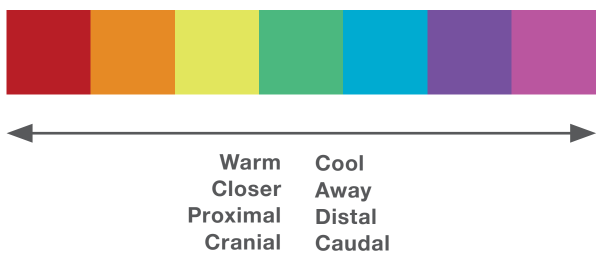
Artistic Choices and Techniques

When choosing which stages to illustrate, I thought it best to keep the amount of illustrations as low as possible, to not overwhelm the viewer. For the return of the gut to the abdominal cavity, I chose to include the stages represented in figures 24.7 and 24.8 (page 18), as only these specific stages were mentioned in the literature to have been observed. The return of the 4th secondary loop could have been included as well (leaving only the proximal colon herniated), but this stage was not fully described. Leaving out this step did not disturb the storyline of the return of the gut, so I decided to combine this step with the return of the proximal colon (fig. 24.9, page 18), in order to avoid making visual statements without ample literary backup.

As the existing figures on colon development during the fetal stage were in need of updating (see box 2 for the added value of the illustrations presented in this chapter), most existing material could not be used as reference and only literature was available on the position and configuration of the colon. It proved a challenge to convert this to a visual representation. In text a position or shape can be described quite generally without giving much detail on exact location or shape, sometimes by a lack of exact data, while every line in a drawing makes a statement on the position and shape of a structure. A simplified, schematic style avoids giving the impression of an exact representation of nature and was therefore chosen for this series. On the flipside of this, in schematic illustrations the placements of the lines must be done very convincingly, because without tonal rendering and details, these lines get all attention. A little distortion or disproportion immediately shows.

Of the embryo/fetus bodies presented in figure 24 (page 16-19) only the left half of the lower body is shown, in order to have a clear view on the midgut. Initially the bodies and the guts were all smoothly shaded (digitally). Unfortunately this resulted in much less vibrant colors for the midgut. To let the colors stand out more, all guts were converted to cel shading. However, the shapes of the bodies are difficult to convey clearly with only cel shading. Keeping the bodies smoothly shaded would therefore be better. Having done the full series in both styles, a combination of both could easily be made and proved to be the best solution.

As warm colors are perceived as closer to the viewer than cool colors, the colors used to label different parts of the midgut correspond to the terms proximal and distal, meaning closer and further away from the centre of the body (fig. 55, inside back cover flap), here used to describe more cranial (proximal) and more caudal (distal) parts of the midgut (fig. 31).
Since this sequence is well known by everyone as the order of the rainbow, it is very intuitive for the viewer to place different parts of the midgut in the right order. This is especially usefull in later steps were different loops overlap and the gut is too long and curved to follow the structure by eye (fig. 24.6-24.12, page 17-19). In addition, labelling different structures by color gives the viewer more information on their length, growth speed and their precursory parts of the midgut, compared to only a label pointing at a spot within this loop.



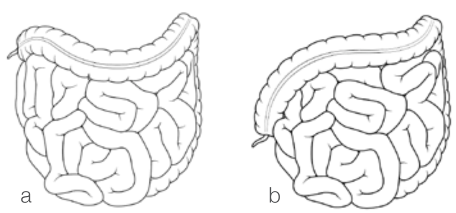
▲ Figure 31 Warm colors seem closer than cool colors.

The different parts of the adult guts were also given the same color-coding (fig. 30, page 19), to make it as easy as possible to see the connection between the adult structures and their corresponding embryonal/fetal structures at first glance.

The borders of anatomical structures do not align with the actual borders of the midgut. The midgut starts halfway the duodenum and ends after two-thirds of the colon. Hence, when talking about midgut development, only the parts between its border should be regarded and colored. However, the exact borders of the midgut are not of great importance to understand its development and when looking at a structure with a different color, the most intuitive thought for most viewers would be to assume that it represents another anatomical structure. In order to enhance the readability of the illustrations and to avoid causing confusion, I chose to disregard the midgut borders and keep colorcoding specific to anatomical structures. For accuracy, the actual borders of the midgut are shown in the first illustration by dashed lines (fig. 24.1, page 16).

The label of the tertiary loops within the 1st secondary loop (fig. 24.6, page 17) only points to its distal part. This was purposely done, as the proximal part has formed a connection to surrounding tissues and as a result does not form tertiary loops. These kinds of details are not important for bachelor students and are therefore not pointed out in the poster.

After reading more on the subject, I realized that one of the colon variation illustrations I had proposed (fig. 32a) was not correct. Upon return of the midgut to the abdominal cavity, the location of the cecum is already notably caudal and rightward. As this position is not as high as shown in figure 32a, this adult configuration would not (or rarely) occur. The figure was adjusted and replaced by figure 32b.



a b

▲ Figure 32 Version a was adjusted and replaced by b.

BOX 2

Additional value of illustrations with respect to existing figures

- The illustrations are up-to-date, as they are based on recent research and 3D models.
- Existing figures show only part of the development shown in these illustrations, often in less steps.
- The perspective and depth has been elaborated with a higher quality than in most existing figures.
- These new figures are highly simplified in order to not distract students with irrelevant structures in the embryo.
- In some existing figures the body of the embryo is not shown, which makes is more difficult for the viewer to orient themselves.

Schematic illustrations (fig. 25, 26, 27, page 16-17) were kept as simple as possible to focus on the mechanisms they explain. To clearly show the process by which the primary loop positions itself in a horizontal plane (fig. 26, page 16), I decided on a ventral view, including an isolated midgut. This way the changes in midgut position can easily be linked to the rotation of the longitudinal body axis.

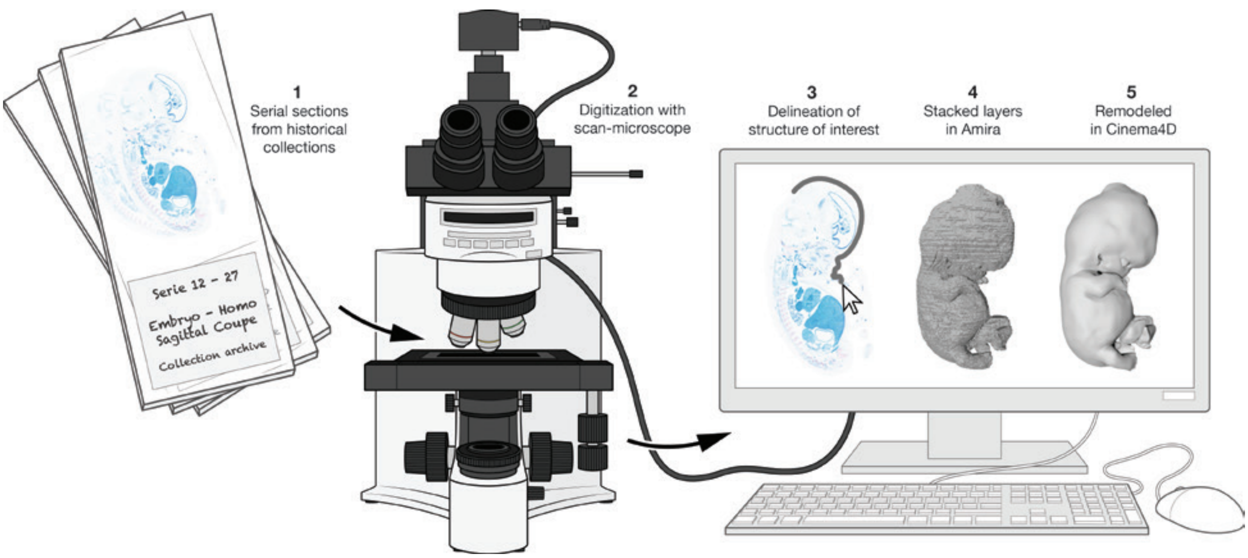
Upon reflecting it seems inevitable that the research for this series of illustrations took the most time (even excluding the research on animation), as the development of every structure needed to be researched and adjusted for 12 different stages, while making sure all relative sizes were correct.

4 On 3D Models

J.P.J.M. Hikspoors research is mainly based on 3D models of embryos at different stages of development. These are made by her and her team by generating anatomical data from histological slides of embryos and using software to model this (fig. 33) [6]. When loaded into Cinema4D (3D animation software), these models can be viewed from all angles. The software gives the option to display certain structures transparant or not at all, making it possible to look through, for example, the outermost layer of the skin and see various internal structures such as the heart, lungs and the gut.

These models were a valuable source in creating the series of illustrations on midgut development presented in the previous chapter (pages 16-19), especially in determining the position of the midgut and other organs within the embryo at a few stages of development (fig. 24.1-6, page 16-17).

As usefull as these 3D models are for research, they are not optimal (yet) for all educational purposes. By using them as references, the information that these models contain is translated to a specific audience. Thereby their educational value is enhanced (box 3).



▲ Figure 33 The process of making the 3D models starts with historical histology collections of embryos (1). These are digitized by a scan-microscope (2). By hand the anatomical structures of interest are delineated in the software Amira (3). These delineated structures of multiple slides are stacked and turned into a rough model by Amira (4). This model is remodeled and smoothed out by hand in the 3D animation software Cinema4D (5). Histology photo & 3D models: Maastricht University FHML.

Artistic Choices and Techniques

To explain the making of these 3D models I first proposed an illustration which focussed on the making and stacking of the slides. Later it was brought to my attention that it may not be necessary to illustrate these steps as images of the actual models and coupes could also be used. To create one cohesive figure of the process, the second version (fig. 33) focusses more on the setup and workflow. I edited images of the models and histology slides in Photoshop and placed them into the figure. The making of the slides was skipped as most people with a basic scientific background (the target audience for this image) know what a slide is and how it is made.

The slides are made to look transparant by using thinner lines that discontinue before they disappear under overlying structures (fig. 33.1).
Illustrating the microscopes and computer setup took more time than anticipated, as it is easier to spot poor perspective or other inperfections in geometrical structures than in organic sturctures.

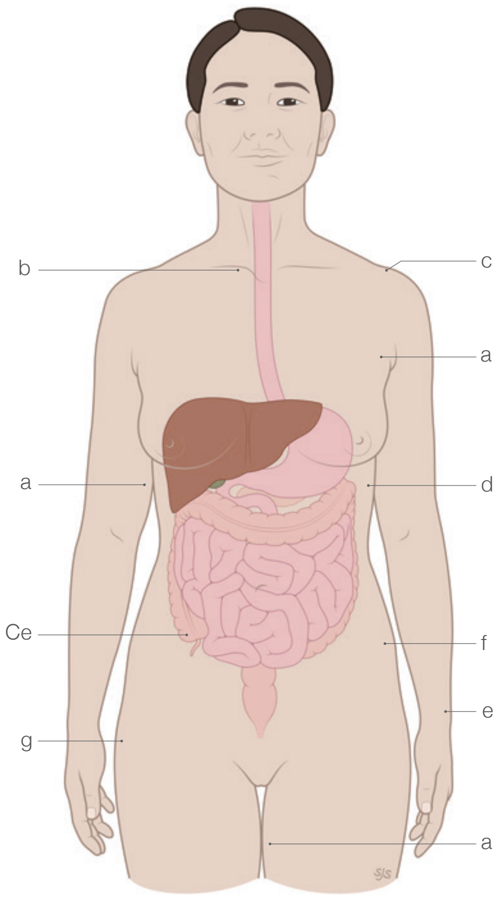
BOX 3

Additional value of illustrations with respect to 3D models

- Completion of series: fig 24.7-12 (24.9 partly) are not available as 3D model and had to be reconstructed from the literature.
- The whole series is displayed in the same style. This way anatomical structures are more easily recognizable and comparable.
- The scale is disregarded and the figures are shown in the same size, making changes in midgut anatomy more notable.
- The individual variation of the specimens, which the 3D models are reconstructed from (n=1 [6, table 1]), can be confusing to the viewer and is therefore eliminated in the illustrations.
- The constancy of the diameter of the umbilical opening is emphasized in the illustrations.
- The shading in 3D models is computer generated and is therefore often not the most optimal shading to convey the shape. In the illustrations this is fully controlled.
- Colorcoding of the midgut is consistent throughout the series.
- Additional schematic illustrations add educational value by explaining mechanisms behind the changes of the midgut, this way the whole story of development is complete and made understandable to a non-specialist audience.

5 Colon Variation

In this and the following chapters I elaborate on the possible clinical implications of atypical midgut development. To keep with the target audience of biomedical bachelor students, the illustrations are also presented in a bookpage design often seen in educational textbooks (fig. 35).



▲ Figure 34 Figure showing the location of the cecum (Ce), a few fatpads (a) and bony landmarks (b-f).
► Figure 35 Figures presented in an educational textbook.

When discussing atypical anatomy, it is useful to have a representation of the normal anatomy (fig. 1, inside front cover) at hand to be able to properly discuss and compare any variations. Here the normal digestive system is shown in an adult figure.

Artistic Choices and Techniques

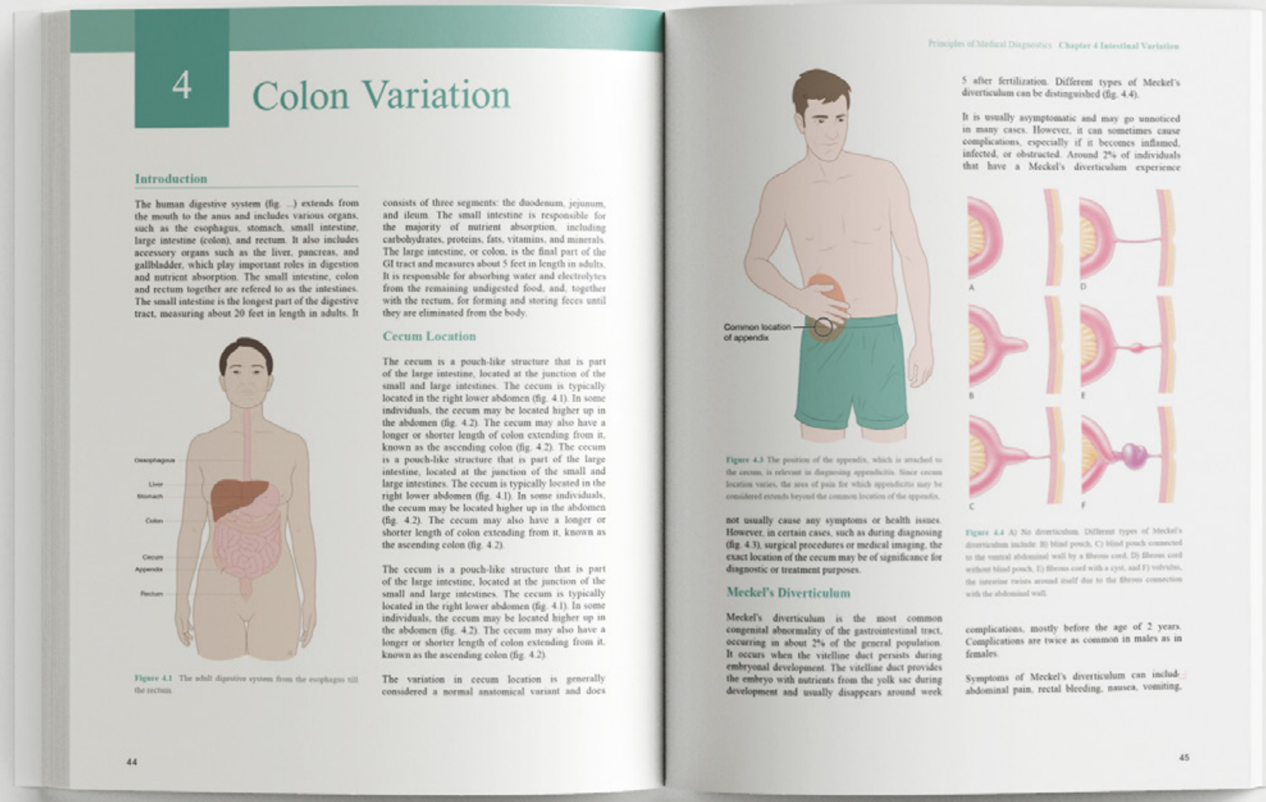
The figure drawing classes with live models during the first year at MSI were of great value to learn how to draw human figures. In the human figures presented in this thesis I have tried to pay attention to fat pads (fig. 34a) and bony landmarks (bone structures visible on the surface), such as the clavicles (fig. 34b), acromion (fig. 34c), ribs (fig. 34d), wristbones (fig. 34e), iliac crest of the hip (fig. 34f) and greater trochanter of the femur (fig. 34g).

To add more realism, the inner thighs are touching, the face shows some smile lines/wrinkels and the arms are hanging naturally next to the body.

The position of the stomach with respect to the transverse colon and liver is less realistic, as it is moved to a slightly more cranial position to include a view on the duodenum and pancreas. Otherwise not all organs of the digestive system in the abdomen could be shown in one image. Using transparancy would have been a less optimal solution, as the lines would have become too crowded in certain places, resulting in an unclear image.

Clinical Relevance

Colon variations are generally considered normal anatomical variants and do usually not cause any symptoms or health issues. However, the exact location of the cecum and/or appendix can be important in some diagnostic procedures, surgical



4 Colon Variation

Introduction

The human digestive system (fig. ...) extends from the mouth to the anus and includes various organs, such as the esophagus, stomach, small intestine, large intestine (colon), and rectum. It also includes accessory organs such as the liver, pancreas, and gallbladder, which play important roles in digestion and nutrient absorption. The small intestine, colon and rectum together are refered to as the intestines. The small intestine is the longest part of the digestive tract, measuring about 20 feet in length in adults. It consists of three segments: the duodenum, jejunum, and ileum. The small intestine is responsible for the majority of nutrient absorption, including carbohydrates, proteins, fats, vitamins, and minerals. The large intestine, or colon, is the final part of the GI tract and measures about 5 feet in length in adults. It is responsible for absorbing water and electrolytes from the remaining undigested food, and, together with the rectum, for forming and storing feces until they are eliminated from the body.

Figure 4.1 The adult digestive system from the esophagus till the rectum.

Cecum Location

The cecum is a pouch-like structure that is part of the large intestine, located at the junction of the small and large intestines. The cecum is typically located in the right lower abdomen (fig. 4.1). In some individuals, the cecum may be located higher up in the abdomen (fig. 4.2). The cecum may also have a longer or shorter length of colon extending from it, known as the ascending colon (fig. 4.2). The cecum is a pouch-like structure that is part of the large intestine, located at the junction of the small and large intestines. The cecum is typically located in the right lower abdomen (fig. 4.1). In some individuals, the cecum may be located higher up in the abdomen (fig. 4.2). The cecum may also have a longer or shorter length of colon extending from it, known as the ascending colon (fig. 4.2).

The cecum is a pouch-like structure that is part of the large intestine, located at the junction of the small and large intestines. The cecum is typically located in the right lower abdomen (fig. 4.1). In some individuals, the cecum may be located higher up in the abdomen (fig. 4.2). The cecum may also have a longer or shorter length of colon extending from it, known as the ascending colon (fig. 4.2).

The variation in cecum location is generally considered a normal anatomical variant and does

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Figure 4.3 The position of the appendix, which is attached to the cecum, is relevant in diagnosing appendicitis. Since cecum location varies, the area of pain for which appendicitis may be considered extends beyond the common location of the appendix.

not usually cause any symptoms or health issues. However, in certain cases, such as during diagnosing (fig. 4.3), surgical procedures or medical imaging, the exact location of the cecum may be of significance for diagnostic or treatment purposes.

Meckel's Diverticulum

Meckel's diverticulum is the most common congenital abnormality of the gastrointestinal tract, occurring in about 2% of the general population. It occurs when the vitelline duct persists during embryonal development. The vitelline duct provides the embryo with nutrients from the yolk sac during development and usually disappears around week 5 after fertilization. Different types of Meckel's diverticulum can be distinguished (fig. 4.4).

It is usually asymptomatic and may go unnoticed in many cases. However, it can sometimes cause complications, especially if it becomes inflamed, infected, or obstructed. Around 2% of individuals that have a Meckel's diverticulum experience

Figure 4.4 A) No diverticulum. Different types of Meckel's diverticulum include: B) blind pouch, C) blind pouch connected to the ventral abdominal wall by a fibrous cord, D) fibrous cord without blind pouch, E) fibrous cord with a cyst, and F) volvulus, the intestine twists around itself due to the fibrous connection with the abdominal wall.

complications, mostly before the age of 2 years. Complications are twice as common in males as in females.

Symptoms of Meckel's diverticulum can includ abdominal pain, rectal bleeding, nausea, vomiting,

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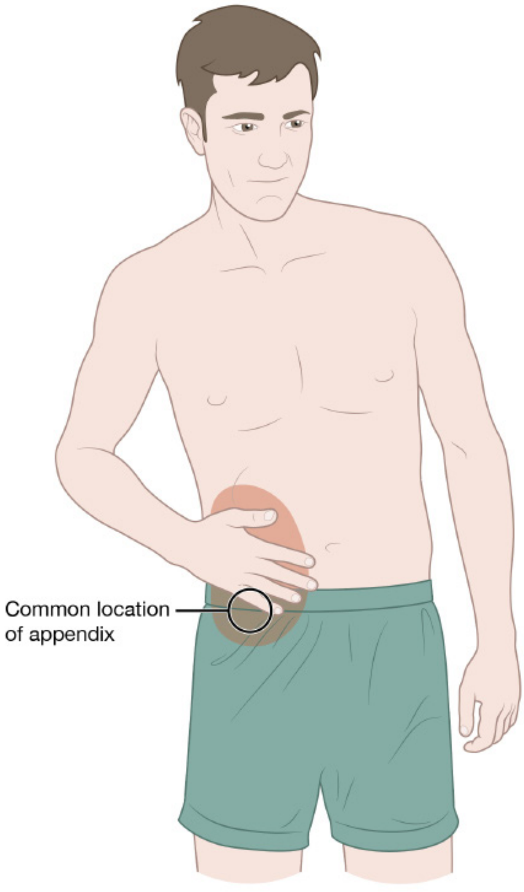
procedures or medical imaging. For example, when diagnosing (fig. 36, page 26) or operating on appendicitis, the location of the appendix is relevant. The appendix is attached to the cecum, a pouch-like structure that is part of the colon. It is typically located in the right lower abdomen (fig. 60, folded flap of the back cover), but in some individuals, the cecum is located higher up in the abdomen (fig. 34, Ce). As the location of the cecum, and therefore the location of the appendix varies among individuals, the area in wich pain (caused by appendicitis) can be experienced extends beyond the common location of the appendix. Figure 36 was made to clearly show this to an audience of (bio)medical students. However, the friendly colors and style make this figure also suitable for patient education.

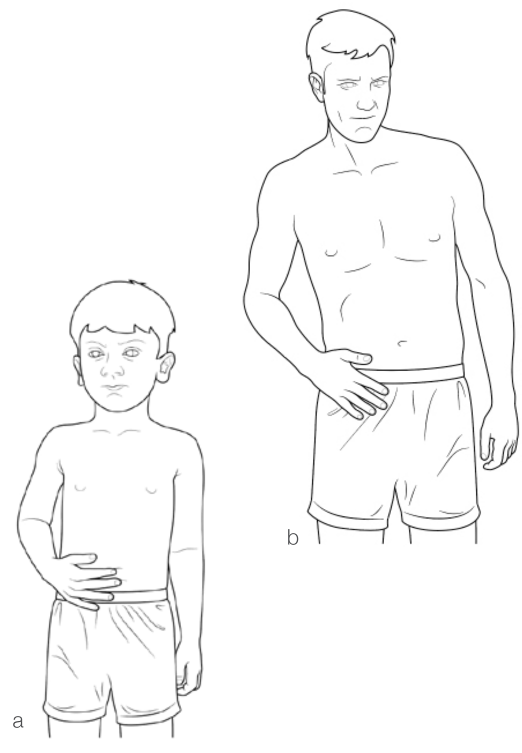
Artistic Choices and Techniques

Initially I planned on showing this phenomenon in a young boy (fig. 37a). However, the typical demographic for appendicitis is actually males of adolescent age. To include this information in the illustration the figure was updated to a young male (fig 37b). It was an important learning point for me to keep in mind the demographic of certain medical conditions, as it could be misleading to show a condition in a figure that is representative of a group of people in which the condition rarely occurs.

I experimented with colors and different elements to get an optimal image that clearly conveys the information on cecum variation and its possible effect on pain location. For example, initially the hand was placed on the common location of the appendix (fig. 38a), but since the figure should demonstrate the possibility of a patient experiencing pain elsewhere I

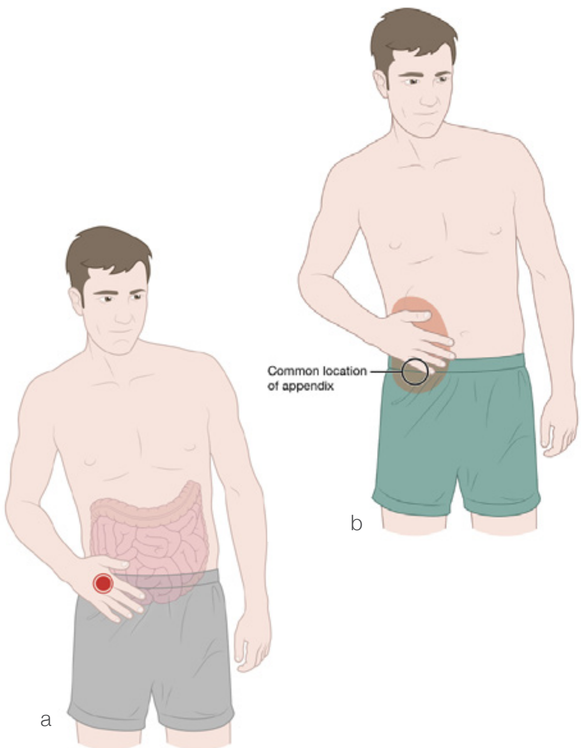


▲ Figure 36 The position of the appendix is relevant in diagnosing appendicitis. Since cecum location varies, the area of pain for which appendicitis may be considered extends beyond the common location of the appendix.



▲ Figure 37 The initial figure of a boy showing abdominal pain (a) was later updated to a male adolecent (b). Note that the lines of the shorts are reused in the updated figure, to be as time efficient as possible.

decided to move the hand upwards (fig. 28b). The lines of the arm were adjusted accordingly to the new position of the arm, as a higher hand means a smaller angle at the elbow. Since the cecum area is covered by the hand, the intestines were left out. This also resulted in a less crowded figure in which the attention of the viewer is directed to the area of pain, instead of internal structures.
As red is the universal color for “not good”, this color choice for the area of pain is obvious. The color of the pants is in a shade of teal that is associated with anything medical.



▲ Figure 38 The first version (a) looks quite different from the last version (b). In the updated version the whole area of pain for which appendicitis may be considered is shown, alongside the common location of the appendix.

Dissections as References

I was given the opportunity to attend an abdominal dissection demonstration at Maastricht University FHML. Unfortunately no intestinal abnormality could be seen in that demonstration. After the class I was permitted to study the tissues a bit longer. Studying anatomy from cadavers during my bachelor and especially during this master has benefitted my understanding of human anatomy tremendously, as structures can be looked at from any angle and tissue behaviour can be observed and felt.
Observing anatomy first hand also gives me a chance to translate the information from real life to illustration myself, instead of fully relying references made by other people.
On the other hand, it is good to keep in mind that the proces of decay has started from the moment of death and the “as-in-life situation” can not with certainty be extrapolated from dissections.
In general, attending dissections definitely gives a better understanding of the anatomical variation among individuals, which is very usefull for studying and illustrating anatomy.

6 Meckel's Diverticulum

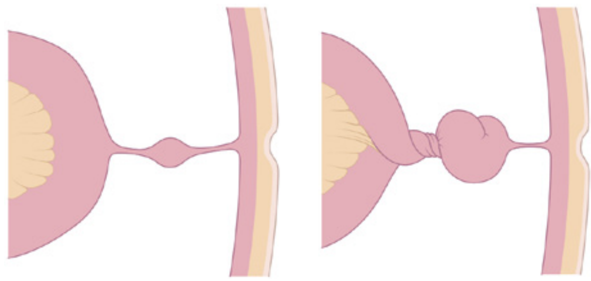
Meckel's diverticulum is the most common abnormality of the gastrointestinal tract, occurring in about 2% of the general population. Usually the vitelline duct disappears around week 5, but different types of Meckel's diverticulum can be found (fig. 40) when it or its surrounding blood vessels persist. [14] This abnormality is usually asymptomatic and goes unnoticed in most cases. Around 2% of individuals that have a Meckel's diverticulum experience complications, mostly before the age of two. Complications are twice as common in males as in females and can be the result of inflammation, infection or obstruction.
Symptoms of Meckel's diverticulum can include abdominal pain, rectal bleeding, nausea, vomiting, and changes in bowel habits. In some cases, it may mimic appendicitis, leading to misdiagnosis. Diagnosis is typically made using imaging techniques such as CT scans, barium studies, or scintigraphy.

As this is a common abnormality, ample references and photo's were available. There seemed to be a high variety in shape and size of Meckel's diverticulum within the different types. Therefore the figures presented here (fig. 40) are simplified approximations of average sizes and shapes, from which a wide variety of cases can be recognized and classified.

Artistic Choices and Techniques

In order to give a clear overview of a few types of Meckel's diverticulum I decided to show them all in the same lateral view, including a median section of part of the ventral abdominal wall. At first I planned to show the median plane of the intestine as well, but for the cyst (fig. 40d) and volvulus (fig. 40f) this could lead to confusion. To make the series consistent, none of the intestines are shown in a median plane.

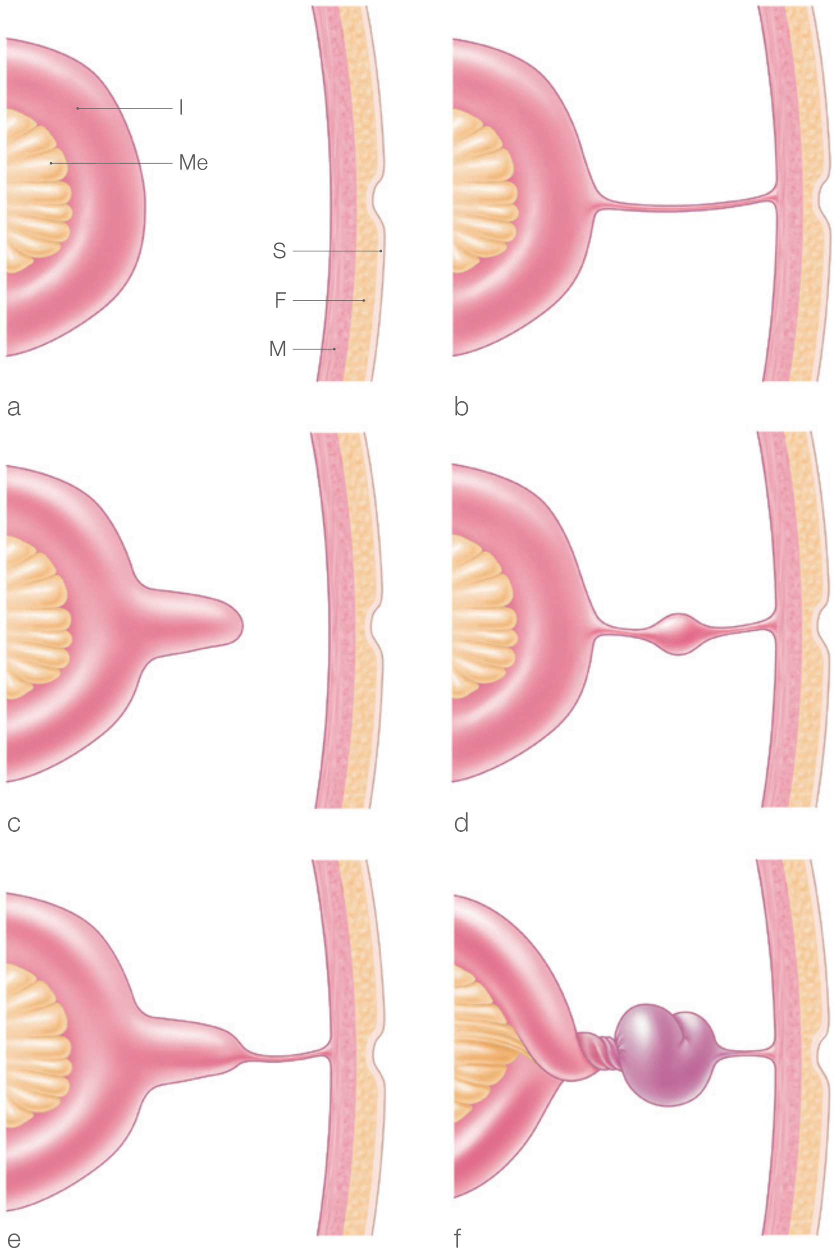
Linework alone was not sufficient to convey the shape of the different diverticula clearly (fig. 39). I chose to do these figures in smooth digital shading in Photoshop. Although this proces takes more time than cel shading, it was still time efficient, as parts of these figures could be reused in order to save time. This is a method that has been mentioned multiple times at MSI, but which I had not yet been able to apply.



▲ Figure 39 Linework and flatfills are not sufficient to clearly convey the shape of the gut and Meckel's diverticulum.

The figures are kept simplified without details, to keep the focus on the general differences between types. Although some fat and muscle texture was added to the tissues in the abdominal wall, to make them more recognizable. The different fiber directions of the deeper and superficial abdominal muscle layers are lightly indicated as well, by longitudinal strokes for the rectus abdominis muscle and a more dotted texture for the crossections of muscle fibers of the internal and external oblique muscles.

The purple color of the distal part of the intestine showing a volvulus Meckel's diverticulum (fig. 40f) indicates poor blood flow due to strangulation of the intestine by twisting around itself.



▲ Figure 40 Small intestines (I), mesentery (Me), skin (S), fat (F) and muscles (M) of the ventral abdominal wall are shown (a). Different types of Meckel's diverticulum include: blind pouch (b), blind pouch connected to the ventral abdominal wall (c), fibrous cord (d), fibrous cord with a cyst (e), and volvulus (f): the intestine twists around itself.

7 Omphalocele

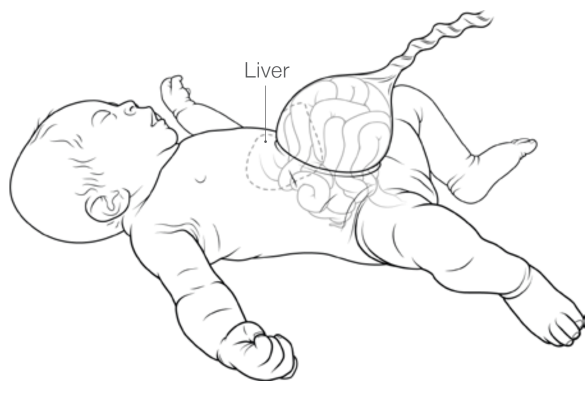
The aforementioned atypical specimen shown during anatomy classes at Maastricht University (fig. 4, page 7) would likely have developed into a newborn showing omphalocele (fig. 42), had development not been arrested. This specimen prompted the idea to elaborate more on this topic. Including omphalocele in the project makes another connection between midgut development and possible pathological effects of its atypical development. These illustrations also provided an opportunity for me to explore a few visual storytelling strategies, such as the use of transparency and the functionality of different views.

When looking at the existing visual material on the subject of omphalocele (and it's comparison to gastroschisis, another birth defect showing herniated abdominal organs), it was apparent that the variation among the illustrations is low. The information is mostly limited to the outer appearance of the newborn showing the birth defect. Therefore questions on for example the nature and location of the opening through which the organs protrude and the organization of the organs in and outside of the abdominal cavity remain largely unanswered. A direct one to one comparison to a healthy newborn was seen only a number of times.
To add educational value to the existing material, in the illustrations presented in this chapter, a view on the intestines inside the abdominal cavity is added to the newborn figure (fig. 42). For comparison, a healthy newborn is also shown (fig. 44, page 32), as well as a newborn with gastroschisis (fig. 46, page 33). Three illustrations of cross sections at umbilical level (fig. 43, 45, 47) complement the abovementioned illustrations and provide more information on the anatomy of the ventral abdominal wall for each case.

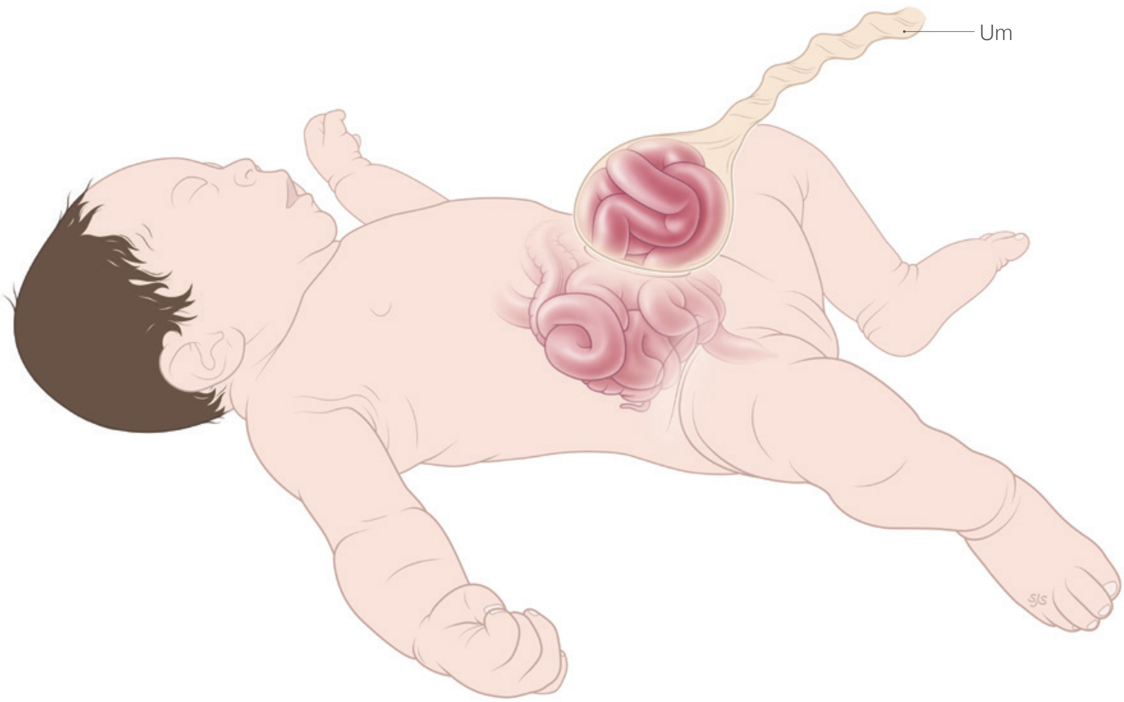
Initially, a distinction would be made between minor omphalocele (fig. 42) and major omphalocele (fig. 41), as the developmental causes for these two types are thought to be different. The main diagnostic distinction seems to be made on the basis of the amount of organs protruding through the abdominal wall. Generally, minor omphalocele is restricted to displaying only a partly protruding small intestine, whereas in case of major omphalocele also the liver and other organs may protrude.

A lack of information on the atypical embryonal development causing major omphalocele lead to the decision to exclude this type from the project. This does not affect the connection to the main topic of midgut development, as minor omphalocele is thought to have a stronger connection to atypical physiological herniation of the midgut than major omphalocele.

Minor omphalocele will be further referred to here as simply "omphalocele". Pages 31-33 present the illustrations, accompanied by a short explanatory text on the shown conditions.



▲ Figure 41 Newborn showing major omphalocele. A partly protruding liver is shown in a dashed line.



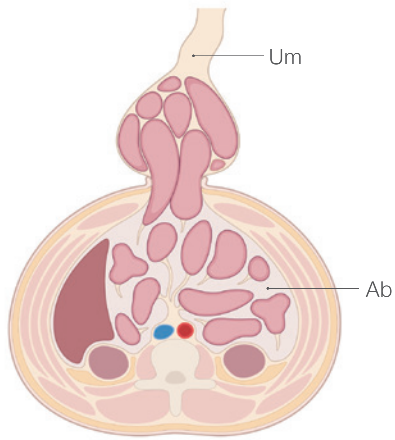
▲ Figure 42 Newborn showing minor omphalocele. The intestines protrude into the umbilical cord (Um).

Omphalocele

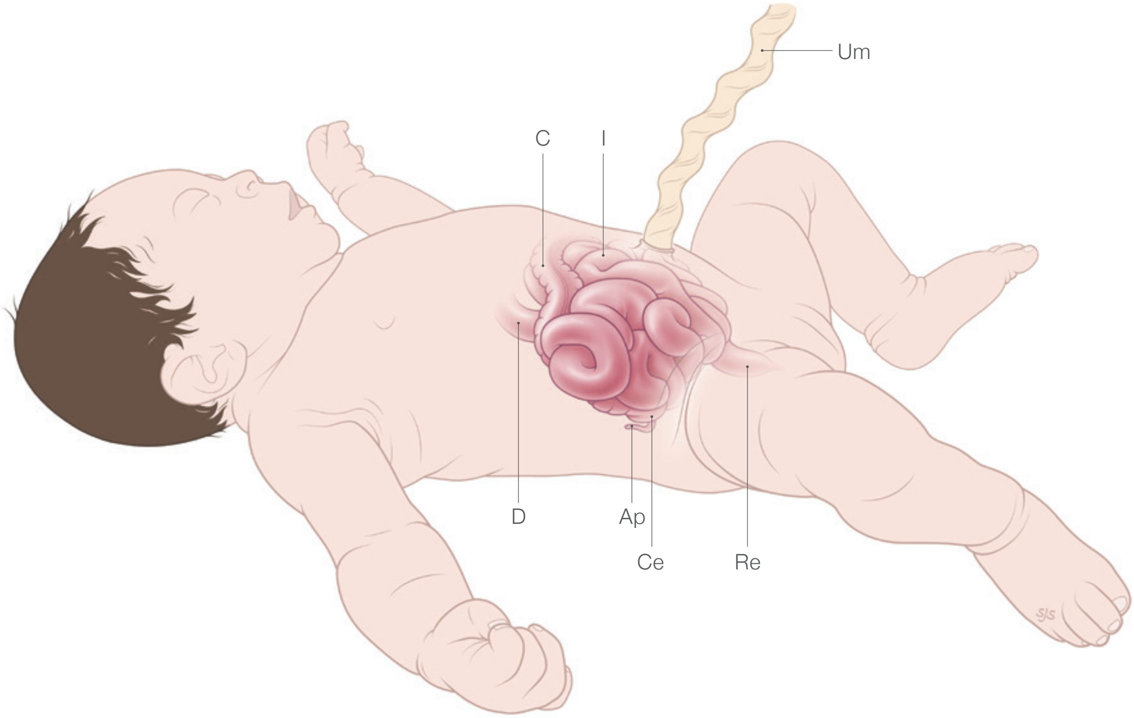
Omphalocele (fig. 42) is a birth defect in which the baby's intestines protrude through the umbilical opening, into the lumen of the umbilical cord (Um). The exact cause of this condition is unknown.

During early development, part of the embryonic midgut protrudes into the lumen of the umbilical cord to undergo development outside of the abdominal cavity (page 17).

Around week 8 this herniated part of the midgut returns to the abdominal cavity (page 18). Failure of the herniated midgut to return to the abdominal cavity (Ab, fig. 43) has been proposed to be among the multiple atypical developmental pathways that could cause omphalocele.



▲ Figure 43 Cross section of omphalocele. Um: umbilical cord; Ab: abdominal cavity.

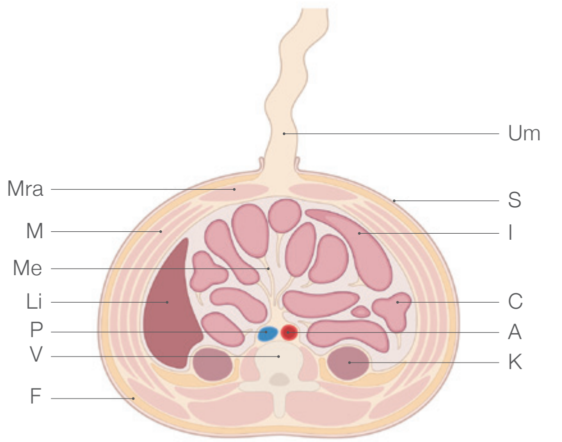


▲ Figure 44 Healthy newborn. Abbreviations can be found on the inside of the frontal cover flap.

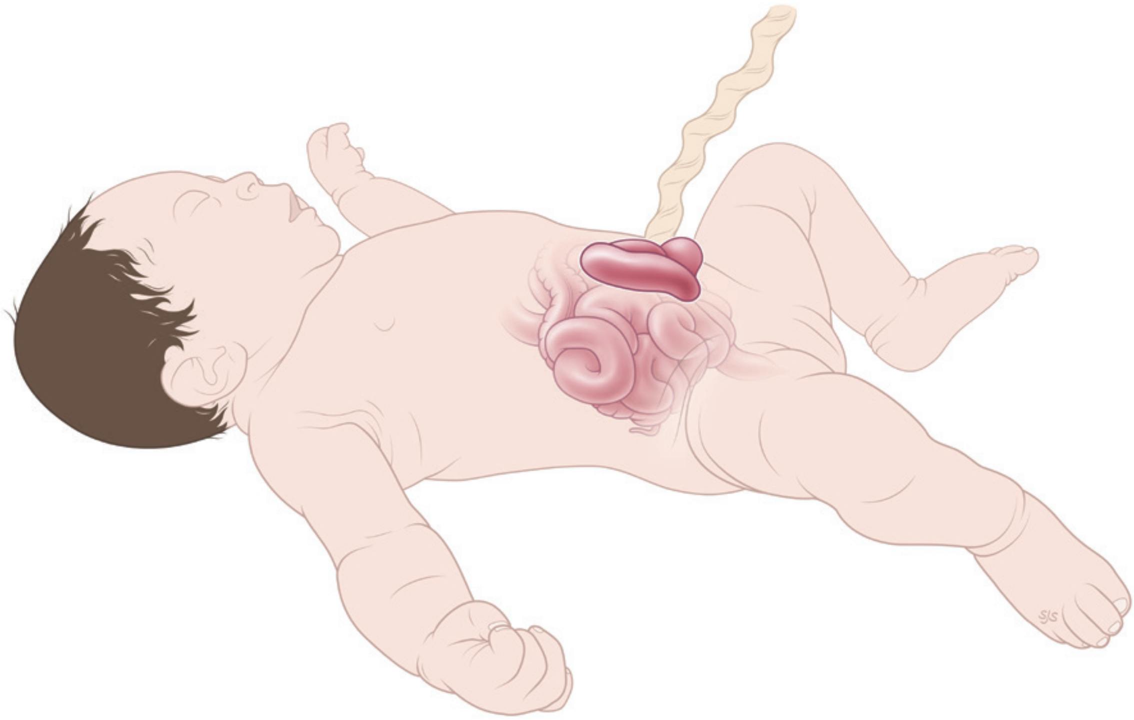
Healthy newborn

When the physiological herniation of the midgut resolves during embryonal development, the herniated midgut returns to the abdominal cavity and takes its almost definite position (pages 18-19).

In figures 44 and 45 the following structures are distinguishable: the small intestines (I), in figure x also the colon (C) rectum (Re), cecum (Ce), appendix (Ap), duodenum (D) and umbilical cord (Um). In addition, the cross section in figure 45 shows the position of the liver (Li), mesenterium (Me), aorta (A), portal vein (P), kidneys (K), vertebra (V), m. rectus abdominis (Mra), other muscles of the abdominal wall (M), subcutaneous fat layer (F) and skin (S).



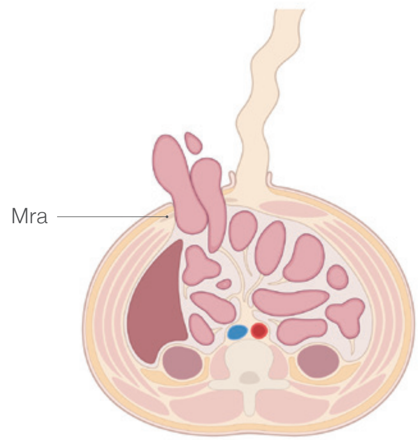
▲ Figure 45 Cross section of a healthy newborn. Abbreviations can be found inside the frontal cover flap.



▲ Figure 46 Newborn showing gastroschisis. Intestines protrude through a hole in the abdominal wall, usually on the right side.

Gastroschisis

Like omphalocele, gastroschisis is a birth defect in which the baby's intestines protrude out of the abdominal cavity. Unlike omphalocele, there is no tissue covering the protruding intestines (fig. 46). The defect is usually located to the right of the umbilical cord. Other organs may also protrude along through the abdominal wall. The exact cause of gastroschisis is unknown. Suboptimal development of the right side of the abdominal wall and the right rectus abdominis muscle (Mra, fig. 47), due to the disappearance of the right umbilical vein (possibly causing local insufficient blood supply), has been proposed as an underlying factor for gastroschisis. Midgut development is not associated with this condition.

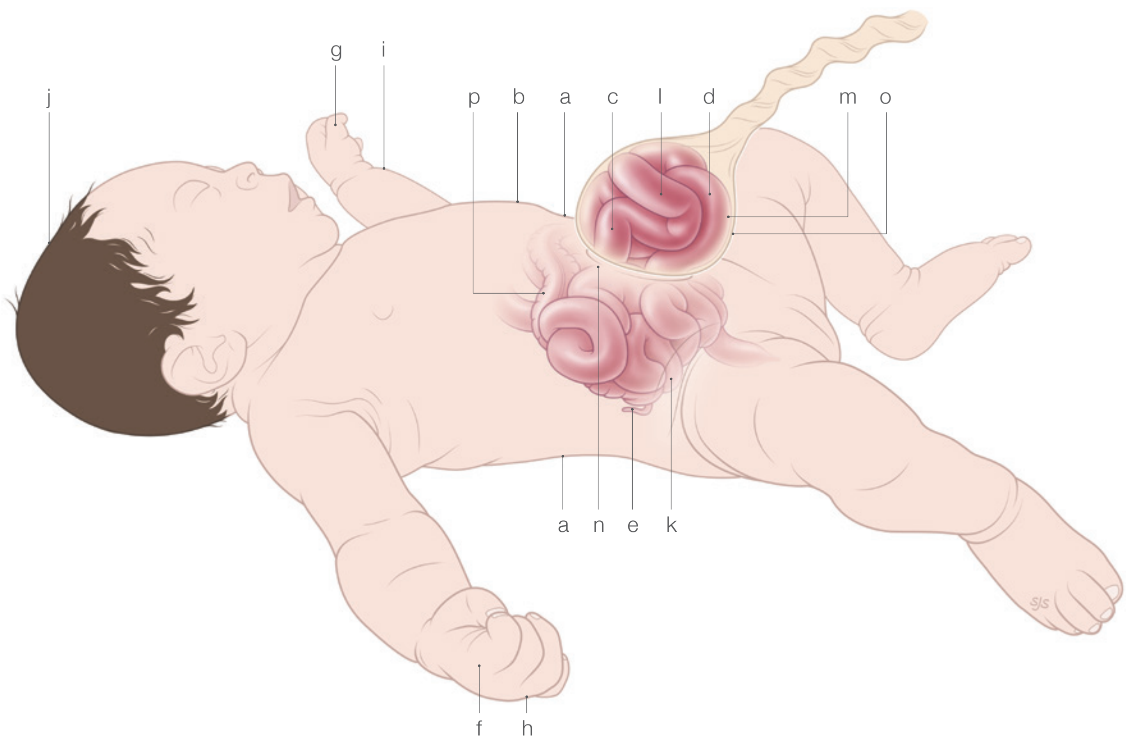


▲ Figure 47 Cross section of gastroschisis. Mra: rectus abdominis muscle.

Artistic Choices and Techniques

In newborns with herniated abdominal organs, the diameter of the abdomen is slightly decreased by lack of internal pressure. They also seem to display a less overall bodyweight and size. To indicate this, the diameter of the cross sections (fig. 43, 47, page 31, 33, respectively) and the outline of the abdomen in the newborn figures is adjusted accordingly in the cases of omphalocele (fig. 48a) and gastroschisis. Additionally, the ribs are slightly more pronounced in these newborn figures (fig. 48b). There were no sources stating lower body weight as a rule for these birth defects, therefore the adjustments were kept minimal, to avoid false representation.

To work efficiently, the healthy guts were reused for the omphalocele and gastroschisis cases. These guts are placed higher in the abdominal cavity and a few intestinal loops are removed to account for the protruding intestines. As no specific reoccuring composition of the protruding intestines in the umbilical cord seemed to be described in either photo's, illustrations or literature, the chosen composition shows the intestines protruding as a loop, with one outgoing intestinal limb (fig. 48c) and one inward going intestinal limb (fig. 48d). This composition makes it easier for students to make the connection between the omphalocele and its proposed developmental cause: the herniated midgut (fig. 24.6-8, page 17-18).



▲ Figure 48 Newborn showing omphalocele, with indications of artistic choices and techniques referenced in the text.

The direction of the appendix is variable among individuals. It is illustrated here in posterior cranial direction (fig. 48e). This is done to avoid the lines of the appendix crossing over with the lines of the newborn's skin in the groing area. When multiple lines cross over or get too close to each other, they draw attention away from the more important parts of the illustration and lower the aesthetic value of the image.

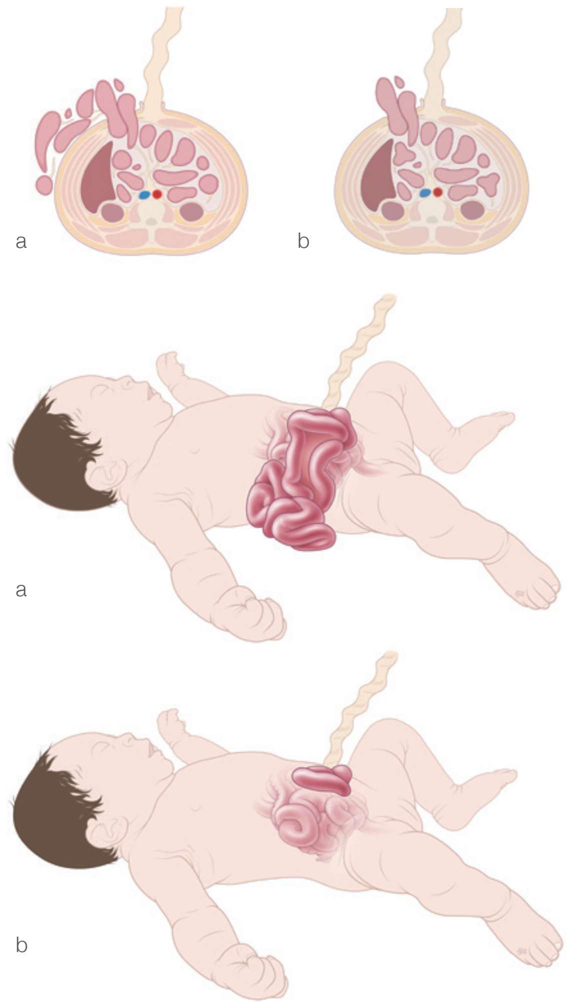
Depth is created by drawing bodyparts that are closer to the viewer bigger (fig. 48f) than parts that are turned away from the viewer (fig. 48g).
Besides this, also difference in line thickness is used to further enhance the field of depth of the image. Thicker lines (fig. 48h) suggest an object to be closer than an object with thinner lines (fig. 48i).

The newborn's head is illustrated slightly longitudinal and flat on top (fig. 48j). This shape is characteristic for newborns as the bones of the skull are not yet fused together, in order to aid the baby through the birth canal.

The intestines completely inside the abdominal cavity were given a lower saturation (fig. 48k) than the protruding intestines (fig. 48l), to convey their position ínside the body.

The area around the edges of the umbilical cord (fig. 48m) and around the umbilical opening (fig. 48n) are less transparant to clearly show these tissues and to further emphasize that the intestines are located ínside the body and umbillical cord.
To make the umbilical cord and the protruding intestines of gastroschisis stand out and come slightly forward from the newborn's body, a thin white line was put around these structures (fig. 48o). The same can be seen for the umbilical cord and protruding intestines in the newborn showing gastroschisis (fig. 46, page 33).

These illustrations have gone through multiple changes. For example, it was requested to decrease the amount of protruding small intestine for the gastroschisis (fig. 49). Although the elaboration in Photoshop had already been done, the change could be made relatively easily by simply reusing a part. Haustra (characteristic bumps of the colon, fig. 48p) were also added to the figures at a later stage.



▲ Figure 49 The initial versions of gastroschisis show a severe case in which a high amount of intestines protrude through the abdominal wall (a). The newest versions (b) represent a more common, less severe case of gastroschisis.

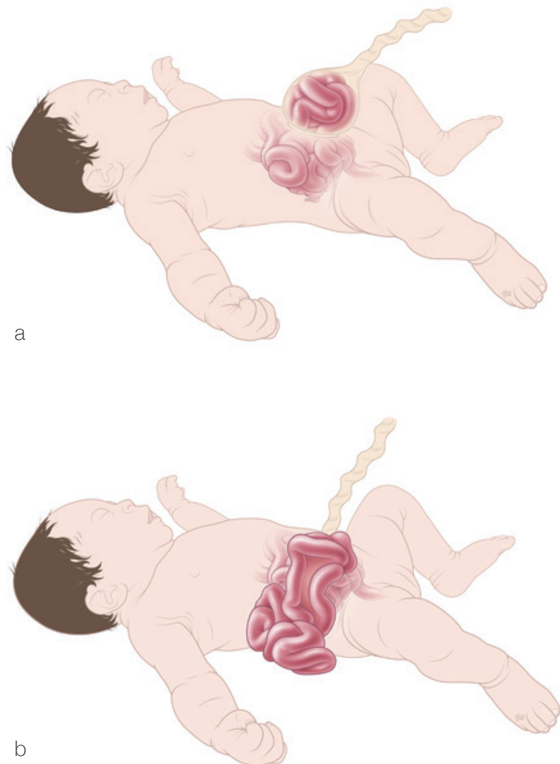
Together is Better

MRI scans, x-rays and ultrasounds were useful references for the illustrations on omphalocele and gastroschisis. In turn, these educational illustrations are help making MRI scans, x-rays and ultrasounds more readable. For example, when looking at ultrasounds of omphalocele and gastroschisis (fig. 50), it may not be directly clear to the viewer what anatomical structures the shapes are representing. When they are displayed next to educational illustrations (fig. 51) the grey shapes become more recognizable and understandable.

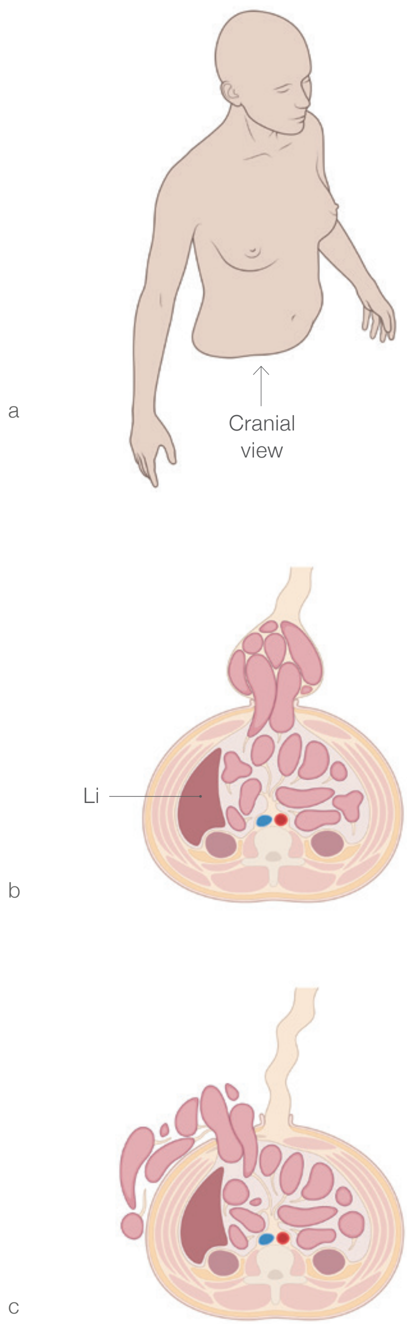
Cranial and Caudal View

Cross sections can be shown in a cranial (fig. 52) or caudal view (fig. 53). I asked around what view people would expect to see in a cross section figure. Interestingly, contrary to the intuition of most people, a cranial view is most common, as it is the standard for MRI. It was decided to display the cross sections in a cranial view as well, for easy comparison to MRI. The location of the liver (Li, fig. 52b), either left or right sided, can indicate in which view a cross section is presented, as it is normally located on the right side in the abdominal cavity.

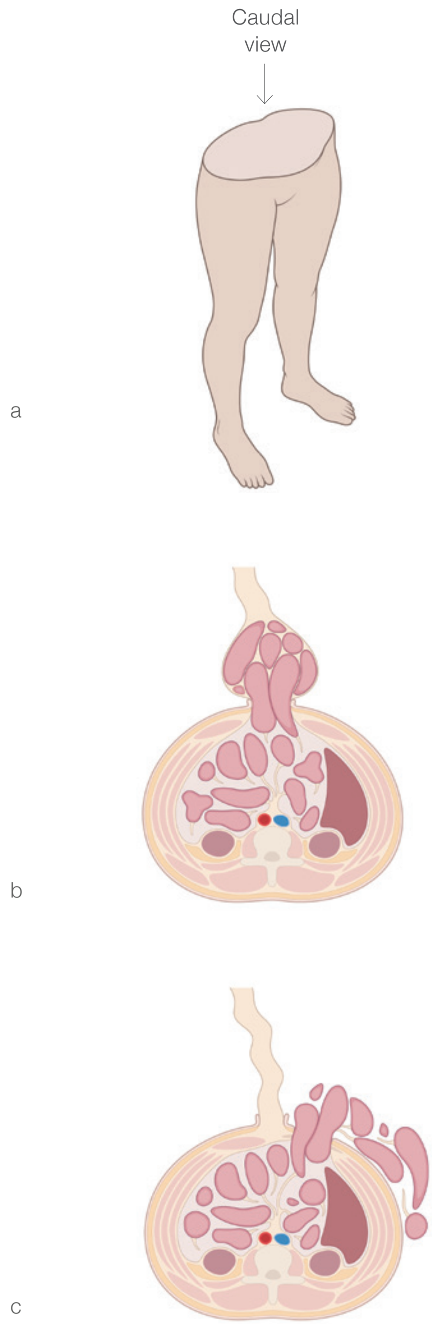
▲ Figure 50 Ultrasounds of omphalocele (a) and a severe case of gastroschisis (b). [17]



▲ Figure 51 Educational figures of newborns showing omphalocele (a) and severe gastroschisis (b).



▲ Figure 52 A cranial view (a) of a cross section of omphalocele (b) and gastroschisis (c).



▲ Figure 53 A caudal view (a) of a cross section of omphalocele (b) and gastroschisis (c).

Epilogue

I struggled with my drawing speed in the earlier parts of the curriculum at MSI, due to lack of experience and time management skills that could be improved upon. Creating an efficient workflow was an important learning goal for me. Although there is still enough to improve on, I am satisfied with the progress I made regarding this.

Most of all I am satisfied with my progress in Adobe Illustrator, in which I feel very comfortable now. My digital workflow has improved by learning how to properly use masks, layers and other tricks and techniques available in this software. My general speed has gone up by simply having more experience with digital illustration at this point.

It was a challenge to estimate how much time certain parts of the project would take me. It surprised me that the vast majority of the time was taken up by research. This did not bother me, as I enjoy learning about new topics, although in future projects, I will leave a bigger part of this for the client, in order to keep an efficient workflow for myself. However, towards the end of the project I surprised myself by quickly becoming faster and making more work than anticipated. I imagine that my understanding of my own working speed will improve over time and as a result I can continue to improve my time management skills. Other important points I want to improve on are general art and design skills. I would especially like to improve my digital shading technique.

I was given a lot of freedom in the ways the information would be visualized. This gave me a great opportunity to work on my storytelling skills and conceptual thinking. Unfortunately, the drawback of having freedom is the extra time and effort it takes to come up with, suggest and discuss ideas. To avoid unnecessary loss of time and energy on both sides of the collaboration between client and scientific illustrator, in future projects I will spend more time on discussing specific goals of the project.

Despite ending up not delivering any animations for this project, by experimenting with it, I now have a much better understanding of animation in general, its possibilities and limitations.

I have missed working with pencil on paper, but producing digital illustrations at a fast pace outweighs much pros of traditional techniques, despite the limitations and challenges to create similar aesthetic results digitally. I have found that artistic satisfaction does not necessarily have to come from using traditional (non-digital) techniques and making highly elaborated work. For me it can also come from coming up with ideas and creating graphic illustrations, which is equally challenging. Especially doing linework has caught my attention and in many cases I preferred it over elaborating the work.

In general I greatly value the personal growth that has been the result of the nourishing and stimulating learning environment that is set up by this program. As it is “the artists’s curse” to never be satisfied with their own work, myself and many of my classmates can relate to feelings of self doubt and overthinking one’s own work. Discussing this with my peers and teachers has given me many helpful insights. It is now easier to not let it get in the way of producing work, but also to truly enjoy the artistic process.

There are many more topics related to embryology and I hope to revisit this field again soon. I hope the information and the work that has been presented here has interested the reader, as well as given some insight in my work process as scientific illustrator.

Acknowledgements

Firstly, ofcourse, I would like to thank all my teachers and advisors at MSI; Rogier Trompert, Dirk Traufelder, Andreas Herrler, Alex Vent, Jacques Spee, Arno Lataster and Greet Mommen for their guidance. It is a great pleasure and privilege to be taught by people whose work and knowledge is so aspirational to me. I am deeply grateful for this experience.

I thank J.P.J.M. Hikspoors and, again, Andreas Herrler for providing such an interesting thesis topic, for sharing their knowledge with me and for setting me on an exploratory path during this project.

My grattitude also goes out to Rob Delsing for introducing me to animation and answering all my questions with enthusiasm.

I want to thank my classmates for sharing their knowledge, skills, phone-chargers and snacks with me during the past two years.

Last but not least I would like to thank my friends, partner and family for their continued support.

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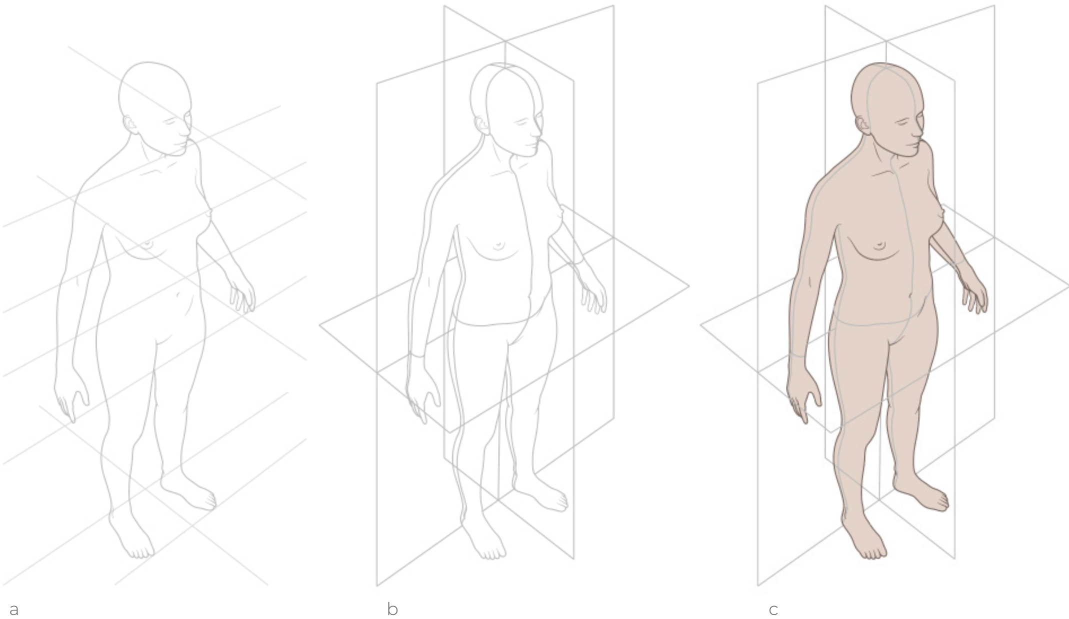
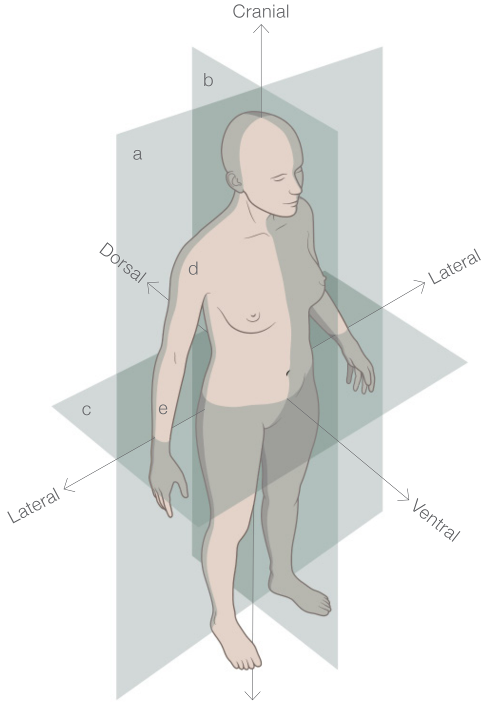


▲ Figure 54 When illustrating the body, help lines were a useful tool to make sense of the angle and visual shortening of the body, due to a high viewing point (a). These help lines were also used to put the anatomical planes in place (b). The image was then colored (c). Different colors were used to convey the transparancy of the anatomical planes (fig. 55). The figure was kept hairless to clearly show were the planes are placed within the body.

Anatomical Terminology

a Frontal plane
b Median plane
c Transverse plane
d Proximal (closer to the center of the body)
e Distal (further away from the center of the body)



▲ Figure 55 Commonly used anatomical planes are the frontal (a), median (b) and transverse plane (c). The shoulder (d) is more proximal (closer to the body) than the underarm (e), which is more distal (away from the body).

After studying biology, focussing on organismal development and adaptation, at Wageningen University and Research (The Netherlands), Suzanne continued her studies at the Master Scientific Illustration in Maastricht (The Netherlands), were an interest in medical education was sparked.

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