

ORIGINAL COMMUNICATION

Detailed Anatomy of the Abdomen and Pelvis of the Visible Human Female

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We report on a virtual anatomical preparation of the abdomen and pelvis of the Visible Human Female (VHF) for laparoscopic surgery training. The detailed cross-sectional image data set from the U.S. National Library of Medicine was used as the basis to build an exemplary model of the female abdomen and pelvis. Segmentation software was developed to delineate organ outlines and more than 300 structures of interest, including organs, blood vessels, bones, muscles, and ligaments, have been segmented and three-dimensionally reconstructed. Analyzing the normal anatomy we found several variations and pathologies of the VHF, such as missing muscles (gemellus superior, psoas minor), additional veins as well as spondylophytes (vertebral column, pubic bone), and colon diverticula. The complete data set may be viewed on the home page of the project (<http://www.vision.ee.ethz.ch/projects/Lasso/start.html>). Clin. Anat. 17:252–260, 2004. © 2004 Wiley-Liss, Inc.

Key words: laparoscopic surgery training; segmentation; virtual anatomy

INTRODUCTION

Increasing computational power, as well as current achievements in the field of interactive computer graphics and virtual reality, have led to the rapid development of tools in medicine, e.g., for education in anatomy or for surgical training. The Laparoscopic Surgery Simulator Project (Lasso-project) (<http://www.vision.ee.ethz.ch/projects/Lasso/start.html>, Székely), which started in Zurich in 1996, uses these innovative techniques to develop new approaches toward photo-realistic simulation in anatomy running in real-time and realistic laparoscopic surgery simulation.

Sophisticated simulation of any operation depends, however, on a correct and detailed anatomical model. In 1989, the U.S. National Library of Medicine (NLM) started the Visible Human Project (VHP) to create the digital data base for models of human anatomy (http://www.nlm.nih.gov/research/visible/visible_human.html, Ackerman). To provide a male and female data set, NLM collaborated with the Center for Human Simulation (CHS) at the University of Colorado in Denver. Both data sets were prepared as a compilation of very detailed digital images from cryosections of human cadavers collected by a specially developed dissection procedure, documented in the

comprehensive technical report on the Visible Human Male (VHM) (Spitzer et al., 1996). It took 10 months to dissect the 59-year-old Visible Human Female (VHF), completed in 1996, with its total of 40 GB of digital information resulting in a much more detailed data set than the corresponding male data set of 15 GB, completed 2 years before in 1994. This is due to the fact that the female cadaver was sliced in 0.33 mm intervals, three times thinner than the 1.0 mm intervals on the male cadaver. The VHF data set provided a high level of contrast and resolution of anatomical details.

The visible human data sets were first used for improving medical imaging modality data (Kerr et al., 2000), for bio-animation of the human musculoskeletal system (Hollon, 2000; Kang et al., 2000), for clarifying the anatomy of the human lumbar erector spinae muscles (Daggfeldt et al., 2000) and for simulation of

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Received 17 April 2002; Revised 22 June 2003

Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/ca.10215

a virtual arthroscopy of the temporomandibular joint (Ishimaru et al., 1999). This report describes the results of our segmentation efforts using the VHF's data set of the abdomen and pelvis, whereby anatomical variations and pathologies were especially investigated.

MATERIALS AND METHODS

For ease of handling, the image data set of the VHF was installed at the ETH Zurich and adapted for storage volume reduction. A limited number of images were chosen, containing the entire 6 GB stack of slices forming the abdominal cavity and the pelvis, starting at slice *avf1432a* at the level of the cranial border of the diaphragm and ending with slice *avf1909c* at the caudal border of the vulva, a total of 1434 slices. Then, all images were reduced to a close-fitting rectangle tightly bounding the body's surface. We also decided to restrict the resolution of $1,300 \times 870$ pixels to half, saving nearly 50% of storage capacity. For that purpose, a low pass filter was applied to each image and a sub-sampling was carried out. To preserve isotropy (pixel as cube with identical length, width and depth), every second slice was excluded, saving another 50 percent of storage capacity, resulting in 717 images with a resolution of 650×435 pixels. For easier access, a proprietary numbering system was introduced: image 1–717.

All these adaptations resulted in a 10-fold reduction of storage capacity with a total volume of 0.608 GB. Zooming in on details allowed an unrestricted macroscopic inspection without losing any critical anatomical information. An intuitive user interface was built to facilitate the image segmentation and to support the powers of imagination in 3D. This was mainly achieved by simultaneous presentation of the actual VHF image and calculated images of the two other cardinal planes.

The segmentation approach used in the Lasso-project has been described previously (Snedeker et al., 2002). We relied completely on the approved 2D contour-based concept, manually defining object outlines on the stack of 2D images of the VHF data set.

Organs and structures from the abdomen and pelvis that are important for endoscopic surgical interventions in gynecology were grouped into 18 smaller projects, each containing a list of anatomical items, relying on *Terminologia Anatomica* (1998). Segmentation was then carried out by 11 medical students who had completed their anatomical education under the guidance of experienced anatomists. All available anatomical information sources were consulted during the ongoing segmentation work. Direct comparison of

the VHF data set and female cadavers in the dissection room was an integral part of image analysis.

RESULTS

A total of 302 anatomical items on 220 structures, including organs and parts of organs, blood vessels, bones, muscles, and ligaments of the abdomen and pelvis of the VHF data set, were identified, segmented, and reconstructed. The accompanying figures represent a selection of the images that may be viewed on the project's website (<http://www.vision.ee.ethz.ch/projects/Lasso/start.html>). The simplest structure to be segmented was the body surface, traced on the outer border of the skin. The high color contrast between the light beige skin and the surrounding blue gelatin easily allowed an achievable reconstruction of the body shape. The abnormal flattening of the buttocks and the dorsal thorax may have been caused by placing the cadaver on the back for a prolonged time before freezing. The thickness of the subcutaneous fat layer in the abdominal wall varied between 24–35 mm, indicating an increased body mass index of the VHF.

Major problems for segmentation arose from the separation of ligaments and connecting tissue from bones and muscles, because structures merge directly into one another; for example, from the obturator membrane to the pelvic bone, and from the sacrospinous and sacrotuberous ligaments to the sacrum. In these cases, borders had to be defined in the best possible way. In general, the findings on the segmented vertebrae, ribs, pelvis and femurs indicated a normal skeleton. The thoracic vertebrae presented a small but continuous increase in height of approximately 2 mm from vertebra to vertebra in the cranio-caudal direction; however, thoracic vertebra 10 broke the rule: it appeared higher than expected.

Some interesting pathologies were observed. Spondylophytes were found on lumbar vertebrae 1, 2, and 3, particularly on the ventrolateral side of the body (*avf1604a–avf1618b*) (Fig. 1). Ribs 4 and 5 on the right side showed a craniocaudal straight fracture line without any macroscopically recognizable reaction of the periosteum (rib 4: *avf1434b–avf1454a*, rib 5: *avf1456b–avf1472a*). The xiphoid process of the sternum was bifurcated. An exostotic ossification of 9 mm was observed at the superior border of the left pubic bone, near the symphysis, that slightly indented the urinary bladder on its ventral side (*avf1863c–avf1872a*). This bony growth may be a spondylophyte or it may have resulted from an old fracture. Another exostosis 4.6 mm in length was detected on the left sacrum (*avf1772a–avf1785c*).

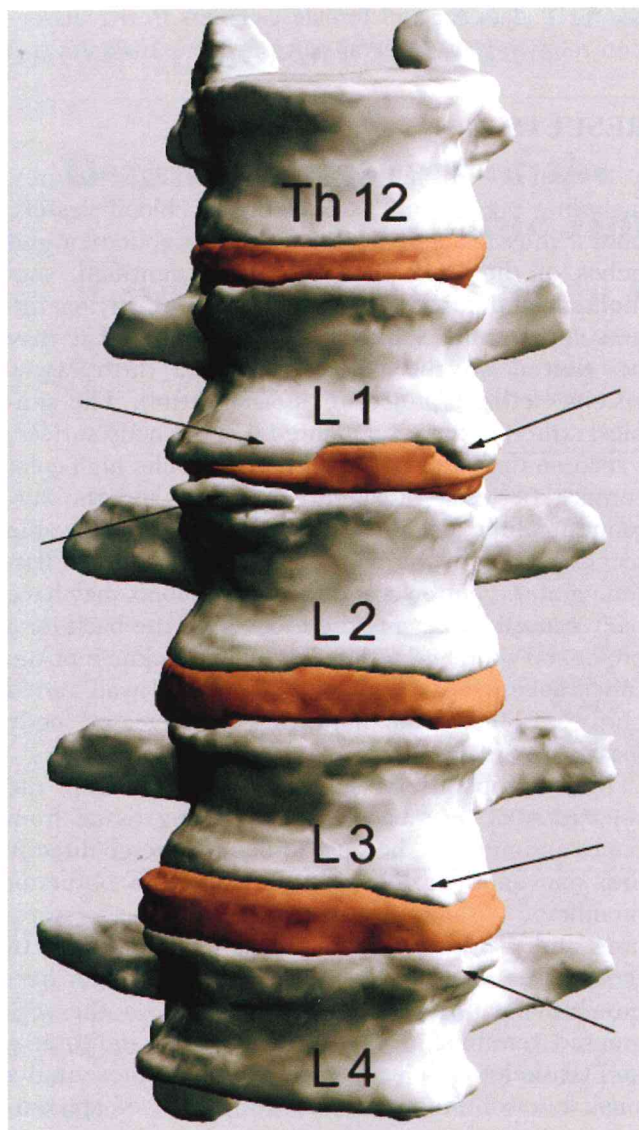


Fig. 1. Vertebral column. In lumbar region of vertebral column note spondylophytes (arrows) between adjacent vertebrae.

Fifty-eight muscles could be segmented on the VHF data set. They were of normal appearance, size, origin, and insertion, especially in the abdominal wall, which contained all layers of muscles and aponeuroses expected; however, the gemellus superior and the psoas minor muscles were absent on both sides.

For segmentation of the arterial system, the abdominal aorta as well as the iliac and ovarian arteries were followed (Fig. 2). At bifurcations, the first section that did not contain any part of the "mother vessel" was described as the beginning of the "daughter vessel." Regarding the venous system, segmentation was carried out, starting at the inferior vena cava, moving against the direction of the flow of blood (Fig. 3). Only this procedure allowed a reliable analysis of the complex venous

system. The uterine, obturator and vesical veins could be segmented to only a certain slice before their diameters dropped below image resolution.

The following arteries had to be partially reconstructed because of missing links on several slices: left ovarian artery, right and left uterine artery, right and left umbilical artery, left lateral sacral artery and right middle rectal artery. The following blood vessels could not be definitively identified over their entire length and were rebuilt completely on educated guesses: right ovarian artery, right and left superior vesical artery, helicine branch of the right and left uterine artery, ovarian branch of the right and left uterine artery, right and left tubal branch of the uterine artery and left middle rectal artery.

Some variants of the vascular system were observed: the left obturator artery arose from the left external iliac artery and a middle iliac vein on both sides was formed by the joining of the uterine and vesical veins.

Segmentation of the kidneys revealed slightly oversized organs (left kidney: 122 x 55 x 53 mm, right kidney: 99 x 60 x 55 mm). Both renal arteries arose from the abdominal aorta; both renal veins joined the inferior vena cava at the level of the first lumbar vertebra. Polar arteries, which rose from the renal artery and passed superior of the hilum to the kidney, were observed on both sides. The hilum of the left kidney was oriented more ventromedially than that of the right kidney. The renal pelvis demonstrated two major calyces on the right and four on the left side. Five subcapsular cysts with a diameter of 3–6 mm were found on the left kidney and one with a diameter of 5 mm on the right kidney. The ureters were not congested. They were calculated to be 222 mm long on the right side and 212 mm on the left side, slightly less than normal values (280–340 mm). Segmentation of the urinary bladder revealed on the anterior surface an impression caused by a 9 mm long exostosis on the left superior border of the pubis; it projected in a dorsal, cranial and medial direction. The actual volume of the urinary bladder was estimated to be 31 ml. The 42 mm long urethra was in a normal retrosymphyseal position and was not enlarged. It ended in the vestibule of the vagina.

The VHF uterus (Fig. 4) was calculated to be 55 mm long (cranio-caudal extent), 42 mm wide (left-right), and 27 mm thick (anterior-posterior), which is in the range of standard sonographic values for over 5 years postmenopausal uterus (normal sonographic mean values: length 56 mm, width 36 mm, thickness 25 mm) (Merz et al., 1996). The shape of the anteverted and anteflexed uterus was pear-like. The consistently reddish-brownish uterus could be clearly distinguished from adjacent structures, such as yellow fat

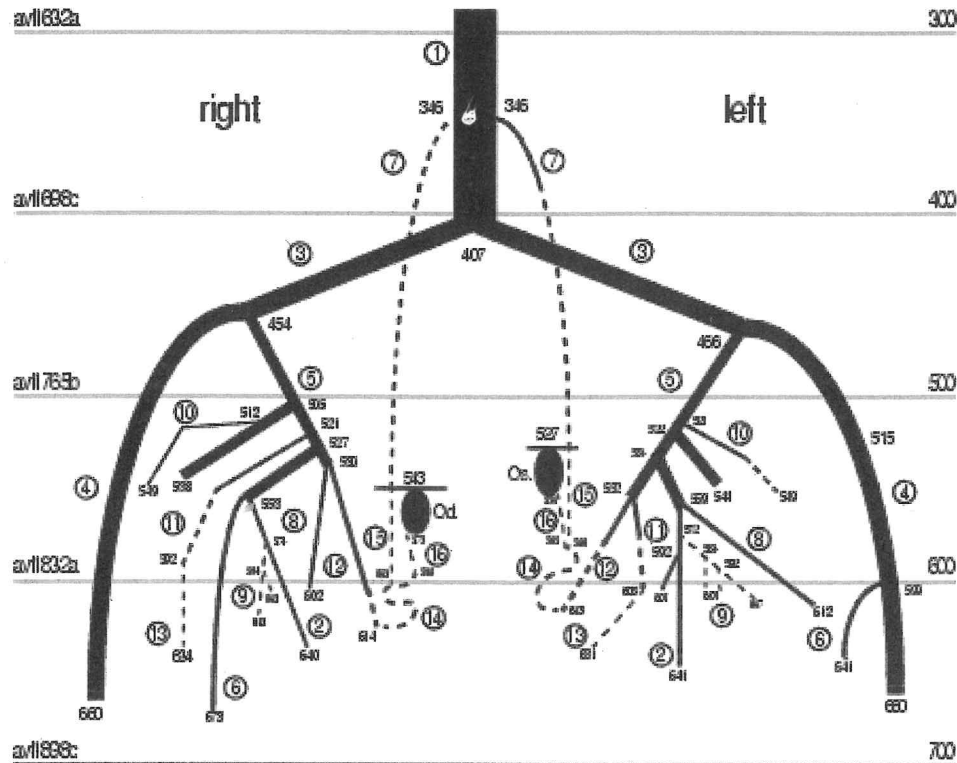


Fig. 2. System of arteries. The original numbering in the VHF data set is presented on the left side, the proprietary numbering system on the right side. Triple-digit numbers in the figure belong to the proprietary numbering system. Encircled numbers see legend. Special findings were the left obturator artery (6) arising from the left external iliac artery (4). Numbers in circles are the names of arteries (see legend). The numbers without circles correspond to the slice the

vessels could not be recognized anymore, following the blood flow. 1, Aorta abdominalis; 2, A. glutealis inferior; 3, A. iliaca communis; 4, A. iliaca externa; 5, A. iliaca interna; 6, A. obturatoria; 7, A. ovarica; 8, A. pudenda interna; 9, A. renalis; 10, A. rectalis media; 11, Aa. sacrales laterales; 12, A. umbilicalis; 13, A. uterina; 14, Aa. vesicales superiores; 15, R. helicinus; 16, R. ovaricus; 17, R. tubarius; O.d., right ovary; O.s., left ovary.

and brown ileum. The superolateral ends led to the intramural parts of the uterine tubes. The border between cervix and body was assumed to be at the clearly recognizable point of narrowing of the pear-shaped organ. The cervix was estimated to be one-third of the total length of the uterus. No myomas were recognized in the myometrium, and the endometrium did not reveal any pathology.

Both ovaries (Fig. 4) could be identified by their beige to dark yellow color (the surrounding fatty tissue was light yellow). They were oval in shape and their sizes (right ovary: $20 \times 10 \times 7$ mm, left ovary: $25 \times 11 \times 9$ mm) corresponded to typical postmenopausal ovaries. The VHF uterine tubes (Fig. 4) were calculated to be approximately 60–85 mm long with two-thirds belonging to the ampulla and one-third to the isthmus. The wide range of the estimated lengths is the consequence of the high tortuosity. The complete 3D reconstruction of the tubes was limited by the resolution capabilities of the data set, especially in the case of the fimbriae. Tubal borders could be followed cranially up to image *avf1795c* (right tube) and

avf1788b (left tube). Even with the segmentation tools, tubal elements cranial to these images could not be confirmed; therefore, in our reconstruction, the VHF uterine tubes are horizontally cut at the lateral ends because of the missing fimbriae.

Segmentation of the major ligaments of the uterus and its adnexa (Fig. 4) was important for accurate descriptions of the interconnections between the uterus and pelvis. It was a challenge to distinguish between the very similar elements of connective tissue, lying very close together next to the anteflexed uterus. We were able to identify and reconstruct the broad ligament, mesometrium, mesosalpinx, mesovarium, parametrium, paracervix, recto-uterine ligament, round ligament, ligament of the ovary, and the suspensory ligament of ovary on both sides.

The vagina and its fornices and ostium could be segmented completely. A surprise finding was a muscular structure in the lowest part of the vagina, which protruded from the dorsal wall into the vaginal lumen. This may be a posterior ruga and a part of the deep transverse perineal muscle protruding into the vagina.

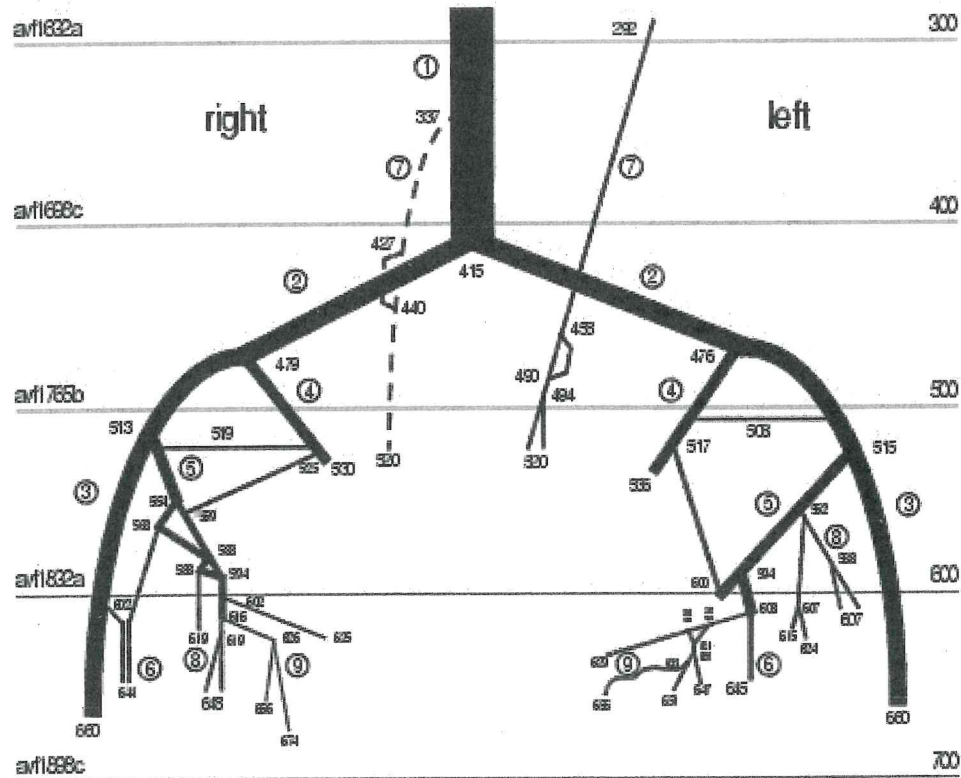


Fig. 3. System of veins. The original numbering in the VHF data set is presented on the left side, the proprietary numbering system on the right side. Triple-digit numbers in the figure belong to the proprietary numbering system. Encircled numbers see legend. Special findings were a middle iliac vein (5) on both sides formed by the joining of the uterine veins (8) and the vesical veins (9). Numbers in circles are

the names of veins (see legend). The numbers without circles correspond to the slice the vessels could not be recognized anymore, following the blood flow. 1, V. cava inferior; 2, V. iliaca communis; 3, V. iliaca externa; 4, V. iliaca interna; 5, V. iliaca media; 6, Vv. obturatoriae; 7, Vv. ovaricae; 8, Vv. uterinae; 9, Vv. vesicales.

The vestibule of the vagina as well as the clitoris were not completely included in our data set; therefore, segmentation of these structures could not be completed in their most caudal parts.

The image segmentation of the liver (Fig. 5) allowed the reconstruction of all lobes, margins, fissures, impressions and ligaments. It also included the gallbladder (Fig. 6), with the common hepatic (49 mm), cystic (94 mm), and bile ducts (163 mm). Problems arose from slices that were lacking due to the horizontal body cut; therefore, this information had to be reconstructed as an educated guess, directed towards an optimally curved surface in the 3D reconstruction. The liver was calculated to enclose 7,799,106 voxels (smallest elements of spatial extent), corresponding to a volume of 2,311 mm³.

The spleen, located in the left upper abdomen, was about 91 mm long, 83 mm broad and 40 mm thick. Its volume was estimated to be 1,860 mm³. The hilum of the spleen was L-shaped with a serrated edge. As in the case of the liver, the reconstruction of the spleen was affected by the cutting line.

The pancreas (Fig. 6) was found to be 151 mm long, 53 mm wide, maximally 27 mm thick, with an estimated volume of 929 mm³. It appeared S-shaped, crossing the vertebral column between lumbar vertebrae 1 and 2 and slanting superiorly to the left toward the spleen hilum without actually being in contact with it. The approximately 180 mm long pancreatic duct with the bile duct formed the hepatopancreatic ampulla, which at the major duodenal papilla opened into the duodenum. The accessory pancreatic duct was connected to the pancreatic duct within the head of the pancreas but opened separately into the duodenum on the minor duodenal papilla. On the pancreas, no major pathology was detected.

The greater omentum (Fig. 5) had a length of 150 mm, a width of over 250 mm and a thickness of 25–30 mm caudally and just 5 mm cranially. Its cranial part covered the caudal margin of the liver, the stomach and the spleen, which may be the result of an unusual folding. The omentum was expanded over the entire intestine down to the lesser pelvis. The most important problem during segmentation was the definition

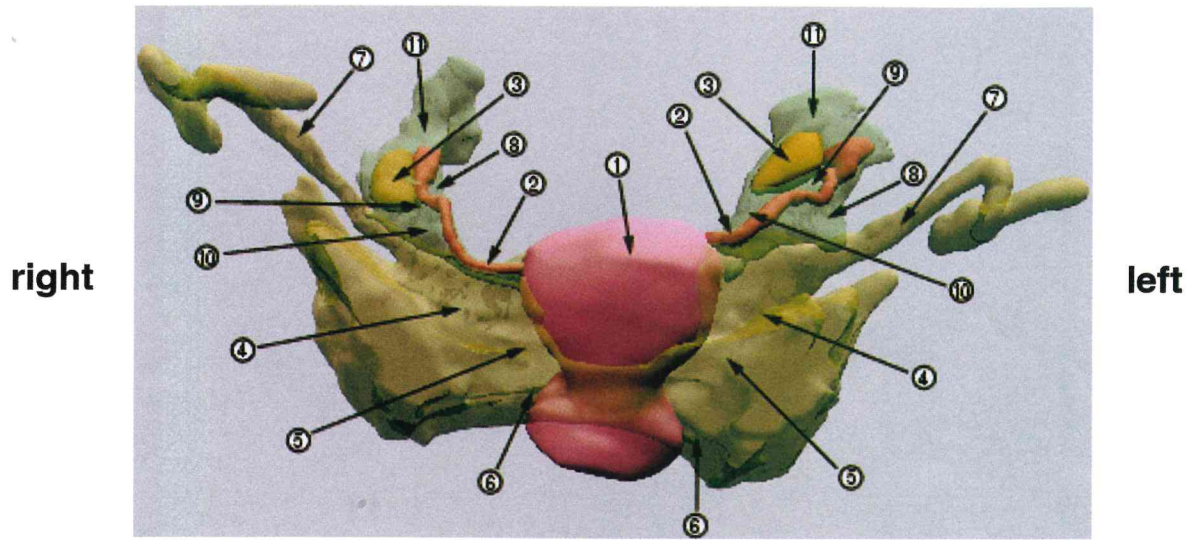


Figure 4.

of the borders. A special finding was a solitary "hole" of approximately 150 mm² in size caudal to the right colic flexure. Because there was no evidence of traumatic lesion, this "hole" may be a lack of adipose tissue between the layers of the transparent serosa (Fredet, 1914; Liebermann-Meffert and White, 1983).

In the segmented block of the abdomen, the esophagus started at the 7th thoracic vertebra, crossed the diaphragm diagonally and ended at the 11th thoracic vertebra.

For the J-shaped stomach, the cardia, fundus, body, antrum and pylorus could easily be separated. The stomach had a volume of approximately one liter (1,069 mm³) with very different pultaceous components. The mean length was calculated to be 275 mm. The wall was approximately 3 mm thick except in the region of the pylorus, where it was 7 mm thick. On its ventral wall, an impression of a few millimeters produced by the inferior border of the left lobe of the liver, was found, resulting in an artificial sharp elevation on the "free" left side.

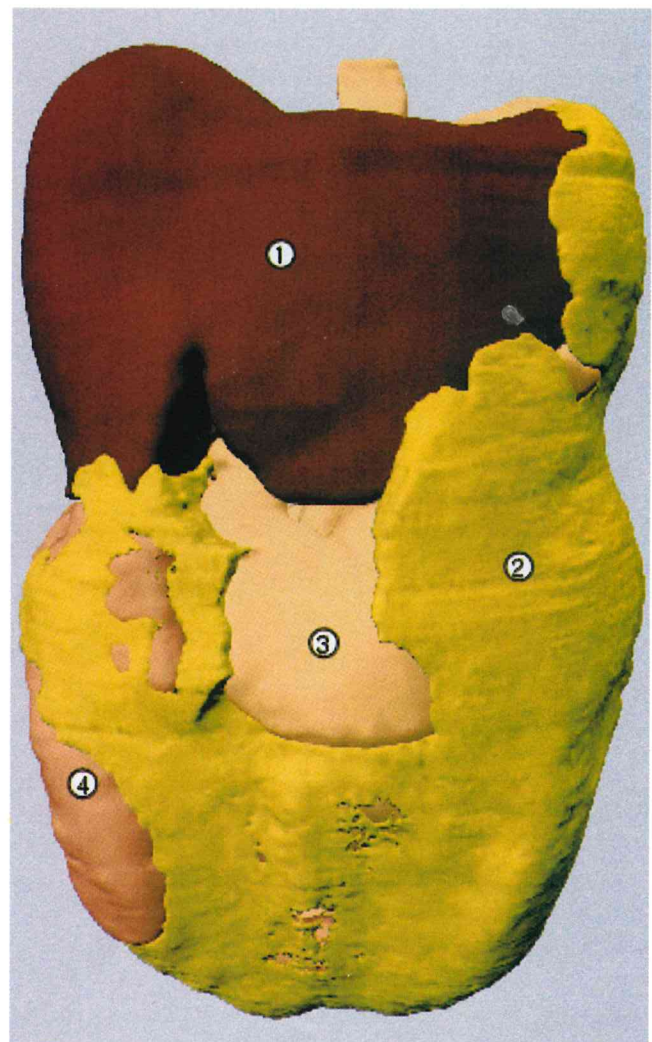


Figure 5.

Fig. 4. Internal genital organs with ligaments. Ventral view of the uterus (pink), uterine tubes (red), ovaries (yellow). The ligaments with their insertions on the uterus are marked in semi-transparent yellow (mesometrium, parametrium, paracervix, round ligament). The ligaments predominantly inserting in the uterine tubes and ovaries are marked in semi-transparent green (mesosalpinx, mesovarium, ovarian ligament and suspensory ligament of ovary). 1, uterus; 2, uterine tubes; 3, ovary; 4, mesometrium; 5, parametrium; 6, paracervix; 7, round ligament; 8, mesosalpinx; 9, mesovarium; 10, ovarian ligament; 11, suspensory ligament of ovary.

Fig. 5. Ventral view of liver, intestine and greater omentum. This "laparoscopic view" shows that the intestine of the VHF is mostly covered by the greater omentum presenting transparent areas. 1, liver; 2, greater omentum; 3, stomach; 4, ascending colon.

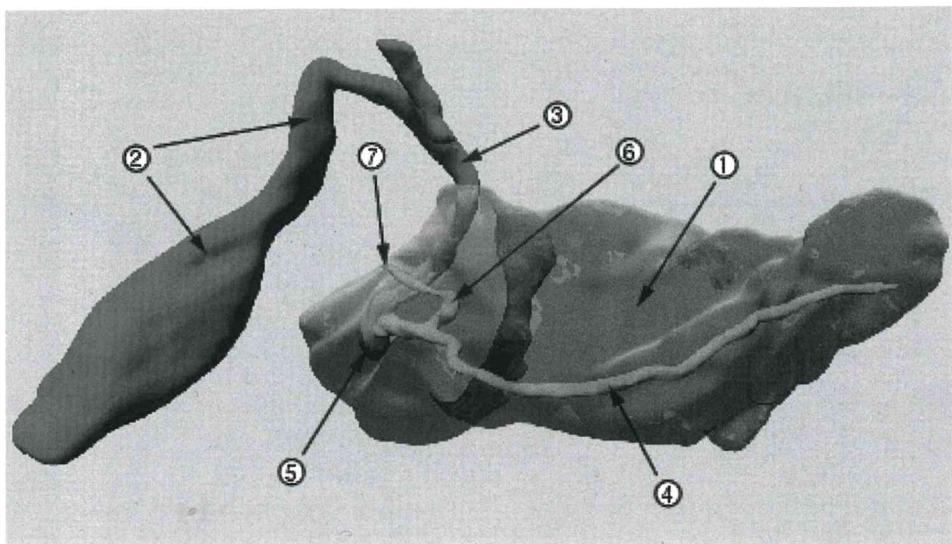


Fig. 6. Pancreas, gallbladder and biliary duct system. Ventral view of pancreas, gallbladder with cystic duct and the biliary duct system. 1, pancreas; 2, gallbladder with cystic duct; 3, bile duct; 4, accessory pancreatic duct; 5, major duodenal papilla; 6, pancreatic duct; 7, minor duodenal papilla.

The duodenum of the VHF consisted of a superior part (75 mm in length), a descending part (70 mm), a horizontal part (20 mm), and an ascending part (70 mm) with a volume of 1,735 mm³. The head of the pancreas was in close contact with the duodenum, and it was difficult to distinguish between duodenum and pancreas because of their similar color; however, the structure of the wall of the intestine with its characteristic mucous coat and the characteristic lobular structure of the pancreas was helpful.

The duodenojejunal flexure was observed at the second lumbar vertebra on the left of the midline. The jejunum and ileum forming 25 loops were found to be approximately 8,500 mm long, with a mean diameter of 20–25 mm. The distended cecum and ascending colon displaced the small intestine to the left side of the abdomen.

The colon (Fig. 7) was approximately 1,400 mm long. The curved cecum and the ascending colon appeared markedly voluminous due to a vast quantity of feces. The 65 mm-long vermiform appendix was caudal in position, extending inferiorly into the lesser pelvis. The U-shaped transverse colon descended steeply into the lesser pelvis, and turned superiorly to the left colic flexure. The left colic flexure was positioned more superiorly than the right colic flexure. The first half of the S-shaped sigmoid colon had 30 authentic diverticula, located mainly at the posterolateral wall. The diameters of the diverticula varied between 5–20 mm. No perforation of any diverticula was observed. The ampulla of both the rectum (125 mm long) and of the anal canal (15 mm long) were normal in appearance.

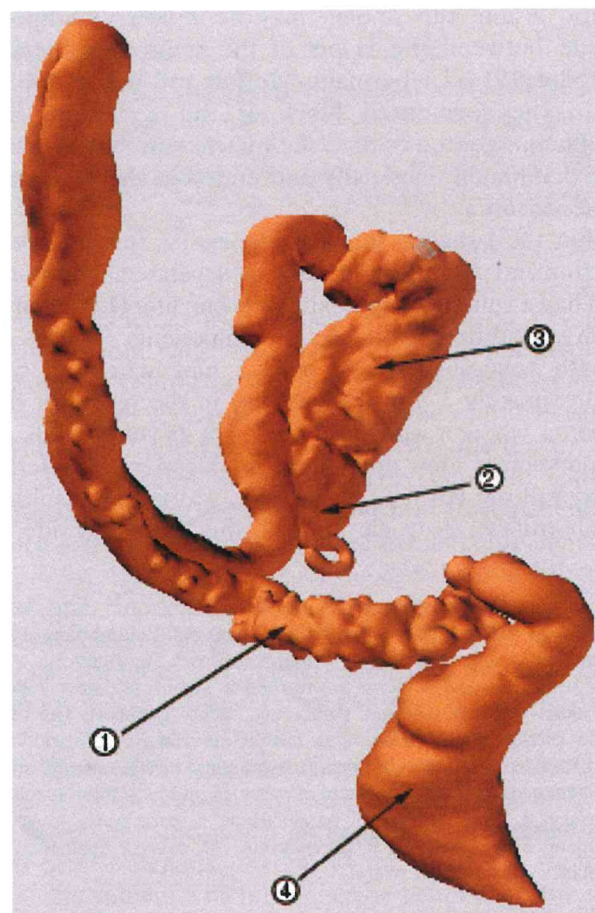


Fig. 7. Colon and rectum. Left lateral view. The sigmoid colon (1) exhibits 30 diverticula. The cecum (2) and ascending colon (3), as well as the rectum (4), are remarkably enlarged due to feces.

DISCUSSION

To understand some specific characteristics of the reconstructed structures, it is important to have a closer look at the technical problems and peculiarities of the VHF's anatomy we were confronted with during segmentation of the cryosections. The anatomy found corresponds to an untouched frozen cadaver. Several structures, such as ligaments, could not be analyzed by holding, pulling or stretching as is possible in conventional cadaver dissection. Therefore, to determine certain borders we were aided by intense study of the literature, explorations on cadavers, and several digital tools offered by the segmentation software, especially the possibility to superimpose borders already segmented on a neighboring slice.

The digital image capture modality with its high resolution and contrast gives excellent macroscopic documentation of the cadaver up to spatial resolution of approximately 1 mm. But during segmentation we were confronted with objects, in particular with blood vessels, that could not be identified on all images, resulting in missing parts. Whenever possible, interpolation of missing parts was carried out through educated guess anatomy. But in some cases, there was little evidence that some organs, for example, the fimbriae of the uterine tubes, or vessels, such as the right ovarian artery, really did exist. Whether these objects were reconstructed or not was decided on an individual basis. In the case of the right ovarian artery, we could identify both ends, i.e., at the abdominal aorta and on the right ovary; therefore, we decided to reconstruct this artery throughout its entire length. The missing fimbrial ends of the uterine tubes were not reconstructed because closer inspection of the peritoneal opening of the tubes revealed funneling towards the inner oviduct giving enough ampullar appearance to the free tubal ends. Therefore, it seemed suitable to achieve simulation of the fimbriae by graphic representation on the surface of the reconstructed tubes rather than as volumetric elements.

The cutting procedure was executed in strict transversal planes. Therefore, many winding or curved objects were tangentially cut, e.g., the bowel loops and the diaphragm. This led to some trails on the soft tissue, especially on the stomach and its contents and fissures on the walls of the bowel. It also raised the question as to on which slice an object really first or last appeared. We decided to mark the highest and lowest clearly detectable appearance of an object as their cranial and caudal end, respectively.

The most challenging aspect of the VHF preparation resulted from the dissection of the cadaver into four blocks. The size of missing layers due to the dissection procedure was estimated to be 1.5 mm (Spitzer et al.,

1996), the equivalent of approximately five layers. But 15 layers (*avf1492a-avf1496c*) had been introduced by the CHS/NLM, resulting in an unnecessarily tripled height of the block to 4.5 mm, or 3 mm too much, i.e., 10 slices. This striking peculiarity attracts attention when the height of the thoracic vertebrae are studied in the craniocaudal dimension. Usually, the thoracic vertebrae show a small but continuous increase in height of approximately 2 mm, but in the VHF data set, the dividing line containing the tenth thoracic vertebra breaks the rule. We calculated that its height should be approximately 21 mm not 24 mm; i.e., its reconstruction was 3 mm too high, corresponding to 10 extra slices. This is in perfect correspondence with the 10 slices that were added artificially by the CHS/NLM.

The well-developed subcutaneous tissue of the VHF supports the argument for a slightly overweight body. The liver was calculated to enclose 7,799,106 voxels, corresponding to a volume of 2,311 mm³. Following the equation of Leung (1986), this liver volume would correspond to a body weight of 123.7–130.7 kg. Because the body weight of the VHF was not determined before embalming, the exact weight is not available. Therefore, the liver might have been abnormally enlarged, although no pathologies were detectable macroscopically.

A number of anatomical variants and pathologies were found on the VHF data set (Table 1): Ribs 4 and 5 on the right side showed a craniocaudal straight fracture line without any macroscopically recognizable reaction of the periosteum, indicating that the fracture occurred immediately before the embalming or cutting procedure. A surprise finding was the lack of the gemellus superior and the psoas minor muscles on both sides. Particular findings of the vessels concerned the left obturator artery arising from the left external iliac artery as well as a middle iliac vein on both sides formed by the uterine and vesical veins, a rare variation described by Charpy (1920). Protruding ossifications were found at the superior border of the body of the left pubic bone producing a slight impression in the ventral wall of the bladder. Spondylophytes were detected on lumbar vertebrae 1–3, partially enclosing the corresponding intervertebral discs. We found several subcapsular cysts on the kidneys with diameters varying between 3–6 mm. The reconstruction of the 30 authentic diverticula on the sigmoid colon gave a very impressive view of one of the few true pathologies on the data set (Fig. 7).

No perfusion of the VHF was done before the embalming procedure; therefore, the arterial and venous systems could not serve as landmarks through the entire abdomen and lesser pelvis. Furthermore, autolysis became a serious limiting factor for image documentation before deep freezing. Structural

TABLE 1. Variants and Pathologies Found on the Visible Human Female Data Set

Variant or location	Description
Spondylophytes	On lumbar vertebrae 1–3, most impressive on the ventrolateral side of the intervertebral disc of lumbar vertebrae 1 and 2 (<i>avf1604a–avf1618b</i>), partially enclosing the corresponding intervertebral disc
Ossifications	At the superior border of the left pubic bone (9 mm in length), near the pubic symphysis, producing a slight impression of the ventral wall of the bladder (<i>avf1863c–avf1872a</i>); on the sacral bone on the left (<i>avf1772a–avf1785c</i>) (4.6 mm in length)
Ribs four and five on the right side	Craniocaudal straight fracture line without any macroscopically recognizable reaction of the periosteum (rib 4 <i>avf1434b–avf1454a</i> , rib 5 <i>avf1456b–avf1472a</i>)
Missing muscles	Gemellus superior on both sides; psoas minor on both sides
Vessels	The left obturator artery arose from the left external iliac artery; a middle iliac vein was formed by the union of the uterine and vesical veins on both sides
Kidneys	Five simple subcapsular cysts with a diameter of 3–6 mm on the left kidney, one with a diameter of 5 mm on the right kidney
Liver	Increased volume
Pancreas	Autolysis
Sigmoid colon	Approximately 30 diverticula

changes found in the pancreas, its color, its surface, and the difficulties when looking for the ducts and the pancreatic islets, suggest postmortem changes, as indicated in the technical report (Spitzer et al., 1996).

Our project's entire reconstruction of the abdomen represents a coherent model with the exemplary anatomy of the VHF data set, and the expected richness of detail. We believe that the requirements for a macroscopically correct anatomical presentation of a female abdomen and pelvis have been fulfilled. No major pathologies or variations of any structures were found that prevent further processing as needed for constructing a laparoscopic surgery simulator.

ACKNOWLEDGMENT

The EMDO Foundation, Zurich, is acknowledged for their most generous financial support.

REFERENCES

- Ackerman MJ. The visible human project. http://www.nlm.nih.gov/research/visible/visible_human.html
- Charpy A. 1920. Systeme veineux. In: Poirier P, Charpy A. *Traité d'anatomie humaine*. Tome II. Fasc. III. Paris: Masson. p 203.
- Daggfeldt K, Huang Q-M, Thorstensson A. 2000. The visible human anatomy of the lumbar erector spinae. *Spine* 25: 2719–2725.
- Federative Committee on Anatomical Terminology. 1998. *Terminologia anatomica*. Stuttgart: Thieme. p 1–292.
- Fredet P. 1914. Le péritoine. In: Poirier P, Charpy A, Nicolas A. *Traité d'anatomie humaine*. Tome IV. Fasc. III. Paris: Masson. p 385–395.
- Hollon T. 2000. A double life for a very visible human. *Scientist* 14:8.
- Ishimaru T, Lew D, Haller J, Vannier MW. 1999. Virtual arthroscopy of the visible human female temporomandibular joint. *J Oral Maxillofac Surg* 57:807–811.
- Kang HS, Kim BH, Ryu JW, Hong SH, Chung HW, Cho SY, Kim YH, Hwang SI, Jeong DK, Shin YG. 2000. The visible man: three-dimensional interactive musculo-skeletal anatomic atlas of the lower extremity. *Radiographics* 20:279–286.
- Kerr JP, Knapp D, Frake B, Sellberg M. 2000. "True" color surface anatomy: mapping the Visible Human to patient-specific CT data. *Comput Med Imaging Graph* 24:153–164.
- Leung NW, Farrant P, Peters TJ. 1986. Liver volume measurement by ultrasonography in normal subjects and alcoholic patients. *J Hepatol* 2:157–164.
- Liebermann-Meffert D, White H. 1983. The greater omentum: Anatomy, physiology, pathology, surgery with an historical survey. Berlin: Springer. p 111–116.
- Merz E, Miric-Tesanic D, Weber G, Bahlmann F, Weber G, Wellek S. 1996. Sonographic size of uterus and ovaries in pre- and postmenopausal women. *Ultrasound Obstet Gynecol* 7:38–42.
- Snedeker JG, Bajka M, Hug JM, Székely G, Niederer P. 2002. The creation of a high-fidelity finite element model of the kidney for use in trauma research. *J Visual Comput Animat* 13:53–64.
- Spitzer V, Ackerman MJ, Scherzinger AL, Whitlock D. 1996. The visible human male: a technical report. *J Am Med Inform Assoc* 3:118–130.
- Székely G. 2000. LASSO: laparoscopic surgery simulator. <http://www.vision.ee.ethz.ch/projects/Lasso/start.html>
- Székely G, Brechbühler Ch, Dual J, Enzler R, Hug J, Hutter R, Ironmonger N, Kauer M, Meier V, Niederer P, Rhomberg A, Schmid P, Schweitzer G, Thaler M, Vuskovic V, Tröster G, Haller U, Bajka M. 2000. Virtual reality based simulation of endoscopic surgery. *Presence* 9:310–333.