Reconstruction of Structures in the Human Body

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1. Introduction

Prior to the 19th century, the interior of the human body could not be observed without application of surgical stress. The discovery of X-rays by Roentgen in 1895 resolved this limitation. Until the development of X-ray CT (computed tomography) in 1972 by Hounsfield, the interior of the human body could only be obtained as a projection image (a type of shadow image) from a single angle. However, X-ray CT enabled observation of the state of each part of the human body as a three dimensional image. Thereafter, Magnetic Resonance Imaging (MRI) was established, which enabled visualization of internal organs in the human body with spatial resolution of the order of 1 mm. An example is shown in Figs. 1, 2, 4, 5, and 6. Today, images of X-ray CT or MRI can be applied to any topic in medical care, if necessary. This allows very accurate structural observations of each part of the human body as well as its components, the organs.

Nowadays, not only medical personnel but also ordinary individuals can access such images to gain a perception of human organs and their shapes. For example, image sources may come from anatomical charts in medical text books and illustrated reference books, explanatory drawings from various encyclopedias, display models from the event such as "exhibitions of human body", old religious illustrations from ancient eras and other sources.

Then, what kind of meaning does this new technology, that allows accurate human body images to be observed along with increased accessibility, impart to the science of shape and form? Out of this question arise the following expectations.

Even though the opportunity of encountering such organ images has grown fairly high as mentioned above, such images remain relatively rare in everyday life. Therefore, curiosity of the unknown and wonderment toward things that have never been witnessed before are examples of such expectations. If the readers observe very carefully, they will be impressed how precisely nature has created and refined the organ shapes and will become inspired. This inspiration may in turn act as a stimulus to arouse creativity in the design of new shapes. Through engagement of these perceptions with our mental faculties, strong motivations for creating new shapes can arise. The inspirational sensations that these images provide, therefore, brings about many challenges, such as the expression of shapes or the development of analytical methods, and as such, are worth pursuing.

For general introduction to the human anatomy the textbook by Rifkin *et al.* (2006) is recommended.

2. Classification of Organ Shapes from a Visual Perspective

Different organs possess a variety of different shapes and various organizational possibilities can be recognized. They are classified into the following typical forms.

- *Hollow organs*: Organs that possess an internal cavity (air inside), such as stomach, small intestine, large intestine and trachea (bronchia). Note that the heart, and the large artery, which contain blood, are not considered as hollow organs.
- *Parenchyma organs*: Solid organs that are composed of specialized tissues, such as liver, kidney and pancreas.
- *Tree*: Organs which possess a tree structure, such as trachea, bronchia, vessels and nerve system.
- *Network* (*network structure*): Such as vessels, nerve system.
- *Indeterminate form*: Such as micro CT images of inflated-fixed lung.

Compared to the parenchyma organs, the tree and the network organs can be seen more in different spatial areas. As a typical example, a network structure of small blood vessels at the micron level exists inside the liver. Tree organs possess a specific orientation that is intrinsic or built-in to their structure. Branches of tree lead away from the root via sub-divisions. In contrast, network organs do not possess this kind of orientation. Blood vessels possess a network structure since arteries and veins are combined. It should be noted that the organ classification described here is based simply according to observed shapes. Of course, explanations and classifications based on biological functions should be also possible.

The latest technologies and equipment have enabled visualization of the human body at various levels of resolution

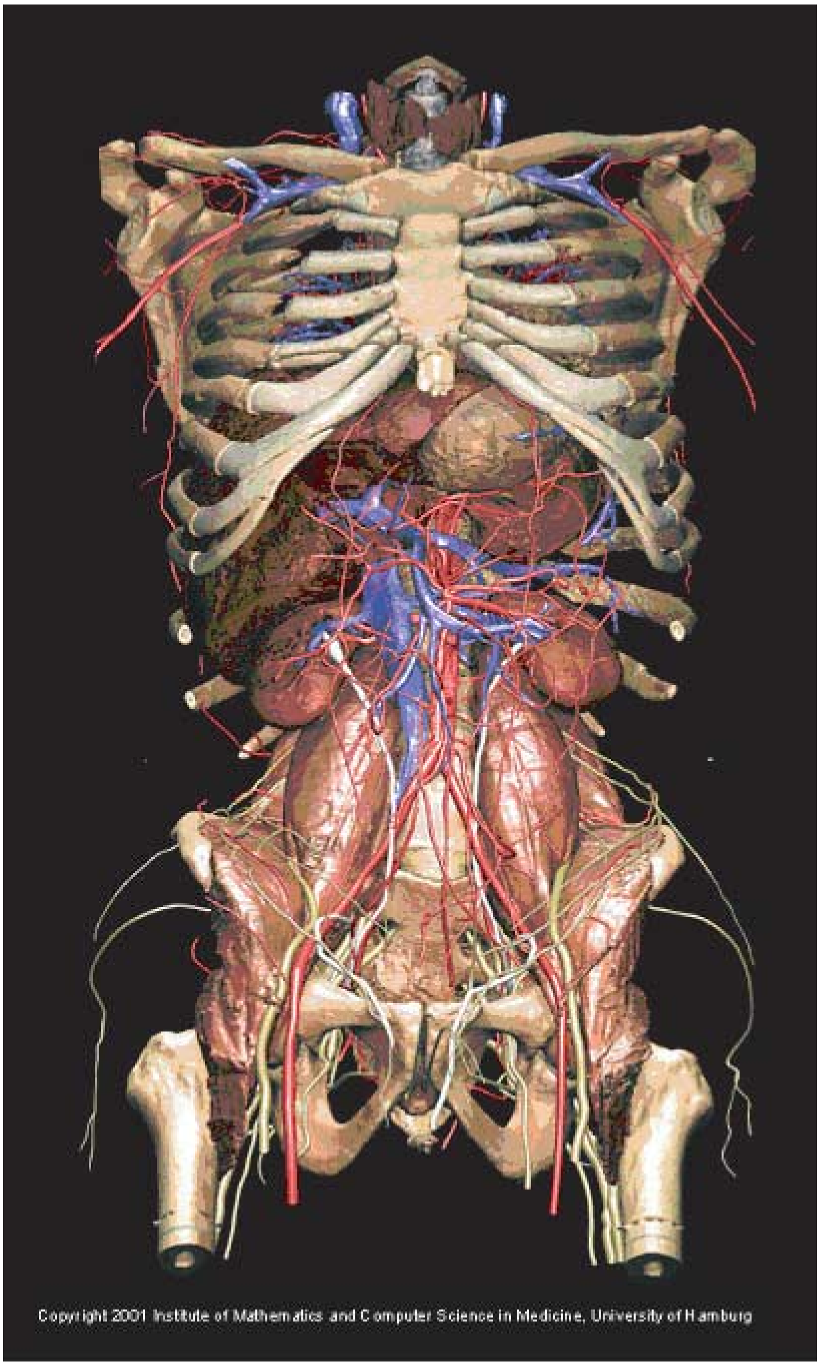

Fig. 1. An example of the internal structure of the human body visualized from recent three dimensional CT images. The figure was generated by K. H. Hoehne of Univ. of Hamburg by the use of the CT image of Visible Human Project of NIH, U.S.A. (Spitzer *et al.*, 1996). High level of rendering techniques such as gradient shading and volume rendering were used. Organs were segmented manually before rendering (reproduced with the permission of Prof. Hoehne).

as listed below.

- *Nano-micron order*: This level is much smaller than the organs themselves. It is on the scale of molecules in cells or the movement of atoms. An example is the molecular image.
- *Millimeter order*: Examples are the optical microscope images. Many of them are images of cells and their elegant arrangement.
- *Centimeter order*: Most of the images we come across belong to this level.

Observations of the shape of organs are conducted by removal of the organs or by depicting images of the organs. When the target containing the organs is a human body, direct access to the organs is not possible; therefore, photographs are usually taken. Currently, X-ray computed tomography (CT) and Magnetic Resonance Imaging (MRI) are the primarily methods used for this purpose. With these technologies, the human body, which is the target of the photograph, is transformed into a set of numbers called a three dimensional digital image.

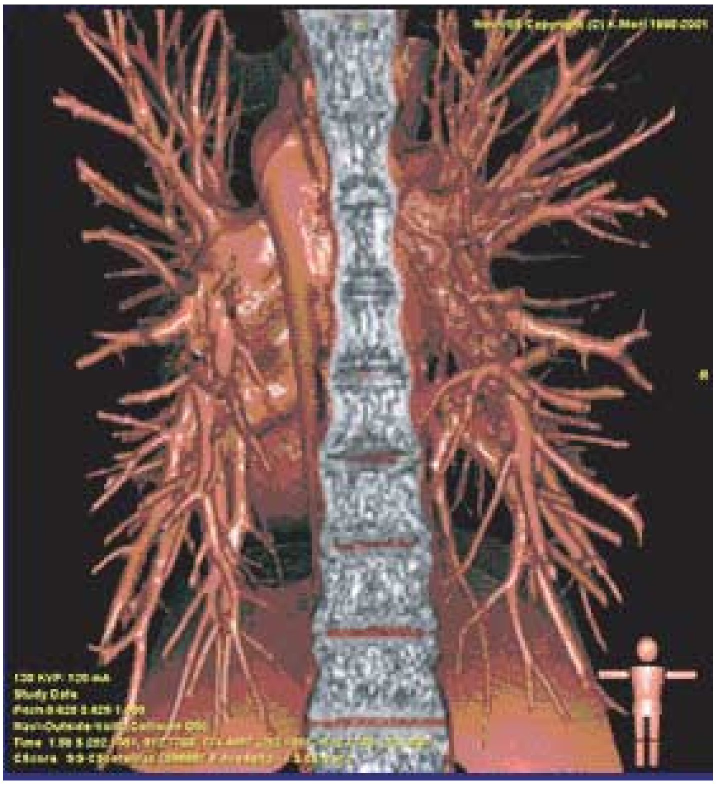

Fig. 2. An example of the tree structure—the bronchi extending to the inside of the left and the right lung from the trachea (drawn by the volume rendering).

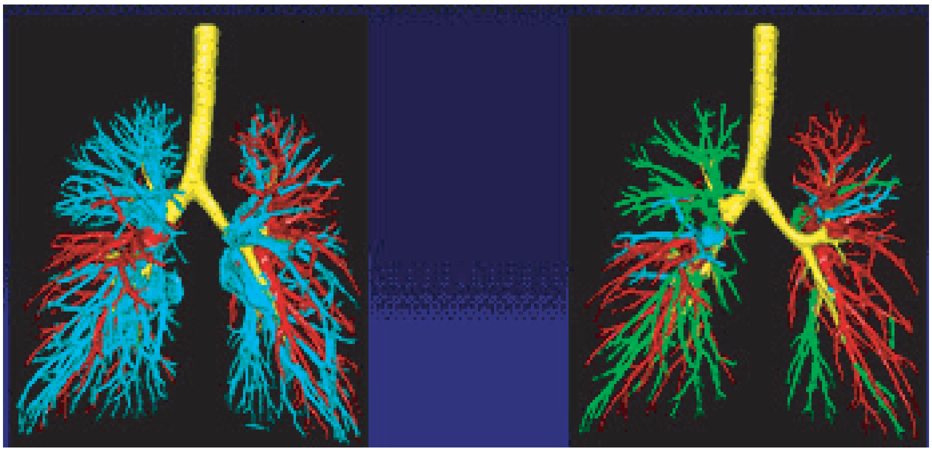

Fig. 3. An example of the image of tree-like structure vessels in the lung. Vessels were extracted by computer from a three-dimensional CT with a segmentation method by Mekada *et al.* (2005). Left: extracted arteries (red color) and veins (blue). Right: estimation of extraction, i.e. correctly extracted arteries (red), veins recognized as arteries (blue) and arteries not extracted (green).

However, we cannot observe this set of numbers directly. For three dimensional image processing, a method called segmentation is used and the image of the target organ is selected. There are basically two ways of carrying out this method. One is the contour extraction method in which the image is cut out by recognizing the contour of the organ. The other way is the region extract method in which each voxel is classified by the difference in contrast of the three dimensional image. For the details of each method, references on digital image processing are recommended (Toriwaki and Yoshida, 2009).

On the other hand, images that can be seen directly, such as optical microscope images, do not need image processing techniques for visualization.

The segmentation results become visible for the first time only after properly reprocessing the image. For this purpose, the shading method in computer graphics is used as a method of displaying three-dimensional objects. Of course, the illumination of the light source and the surface reflection model on which the shades are based are important as artificial devices for good visibility.

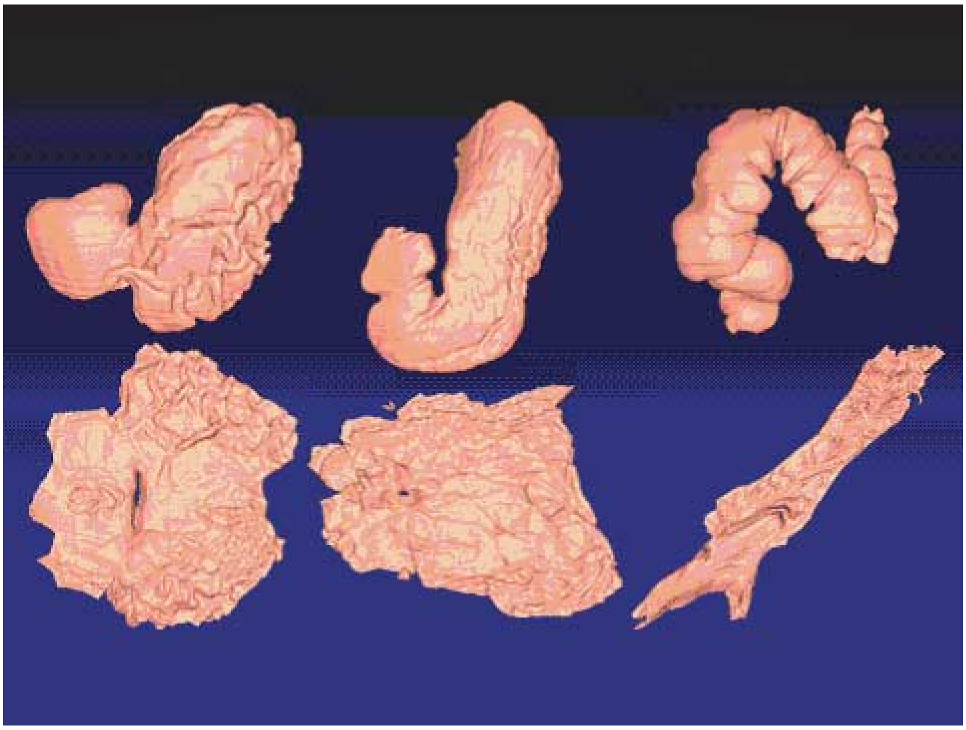

Fig. 4. Stomach—a hollow organ. The upper row shows two examples the three dimensional shapes of the inside of the stomach. The lower row shows their shapes expanded on a plane.

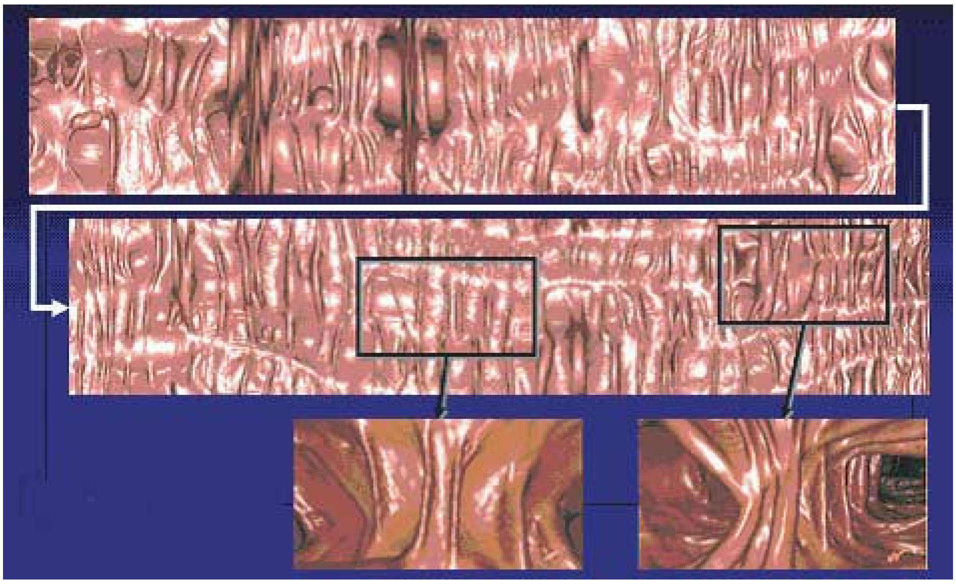

Fig. 5. The large intestine unfolded onto a two-dimensional plane.

3. Examples of the Images of Individual Organs

The bronchia and the blood vessels are shown in Figs. 2 and 3, respectively, as examples of tree structure organs. In both cases, automatic segmentation by the computer cannot be visualized very accurately and thus requires the interactive assistance from experts (medical doctors).

4. The Virtual Human Body and Its Use

The three-dimensional digital images of the human body taken by X-ray CT and MRI are considered as replications of the human body on the computer system. These replications of the human body on the computer system are called the virtualized human body (VHB). Since the VHB is a virtualized object, it can be manipulated freely without being tied to the various physical constraints which need to be considered when working with an actual human body.

Various novel virtual experiments are possible that can be conducted on the VHB. For example, surgical simulation and virtual unfolding of the organs can be conducted. In other words, the experiments allow heteromorphic engineering of the organ forms to be achieved freely. The followings are specific explanations of such experiments.

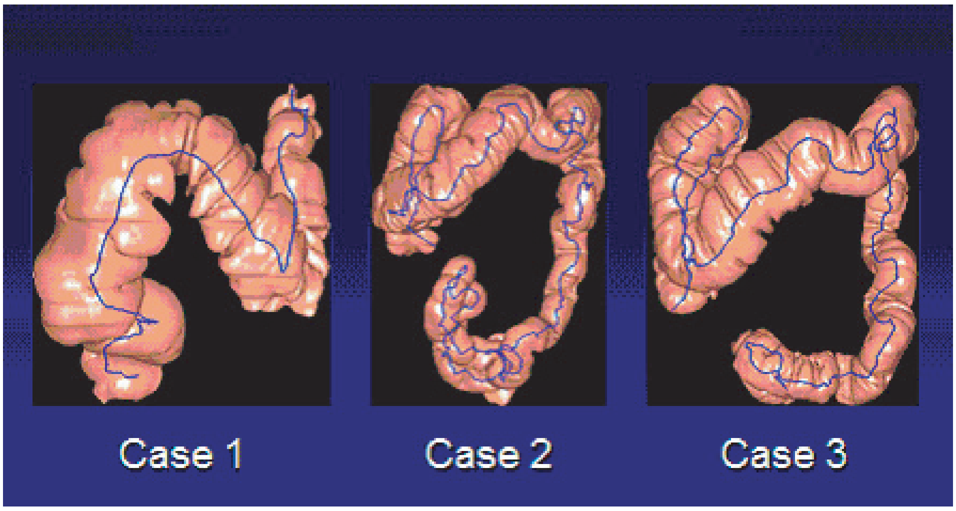

Fig. 6. Three examples of the outside view of the large intestine.

For example, let us think about the stomach. The three dimensional shape of the internal surface of the stomach is shown in Fig. 4. Usually, images of the stomach as viewed from the inside are displayed. It is quite similar to the image that doctors see from a gastro-scope inspection. However, the view of this kind of image is limited and it is difficult to see the complete view. Therefore we cut open the image of Fig. 4 and unfold them onto a flat plane. For the cutting lines, we follow the conventions established in the medical field. The image of the large intestine that is expanded in the same way is shown in Figs. 5 and 6. A virtually unfolded image is superior to an endoscopic image in its ability to provide an overview, and has been demonstrated experimentally to lead to fewer oversights of abnormal signs. However, the occurrence of some sort of distortion by expanding the three-dimensional image onto a flat plane is theoretically unavoidable. Additionally, rigorous theoretical analyses on the appropriateness of the expansion method have not been conducted yet.

5. Imaging the Inside of a Mummy

A mummy is the deceased body of an ancient Egyptian that has been preserved and placed in a unique-shaped coffin. Mummies are treasures of ancient cultural heritage. The coffins themselves, which are often covered in rich colorful symbols, are also considered as treasures and it is therefore very difficult to observe the actual body contained within them. In 1989, however, we were fortunate to have the opportunity, using X-ray CT, to photograph the internal structure of a mummy, which was then owned by the Archeology Department of the University of Tokyo, as part of a regular preservation treatment. To photograph the mummy, the entire coffin was scanned by X-ray CT and images of the mummy's cross section were taken.

The imaging conditions are indicated below. The resolution of the cross section was 320×320 pixels. The sampling interval was 1.3 mm and the slice interval was 2 mm (3 mm below the knee). The present helical method was not used. There were 750 image slices and the image data was saved on magnetic tape. The data was analyzed and displayed using the computer system of Nagoya University Computer Center (at that time). The CT equipment used in the study was most probably borrowed from a company.

Figure 7 shows an example of a cross section slice from the mummy. Inside the coffin, the body is wrapped in bandages according to the burial practices of the ancient Egyptians. At first, we separated the body and the coffin on the image slices using interactive processing. Thereafter, we proceeded with image processing, focusing only on the body, as follows.

(1) The bandages and the body (primarily composed of bones) were separated by thresholding.

(2) The full image of the bones was displayed by voxel representation.

(3) The full image of the body was displayed using volume rendering and gradient shading.

Owing to the processes (2) and (3), the internal condition of the mummy, that had remained hidden for 2800 years since its burial, was able to be observed. We also analyzed mainly the following characters of the bones.

(1) We corrected the position of the mandible because it shifted backward due to the bandages. As a result, mummy body recovered the natural state. By measuring features of the skull, it was found to have an average size of those of Egyptian people at that time.

(2) By observation of the nose, bony part of nasal septum was broken. The reason is the use of the typical mthod of removal of the brain.

(3) The row of teeth was observed and small irregularity was found. This shows the effects of eating habits of Egyptians in those days.

(4) The size of the pelvis was measured on the image, and the result showed this mummy was a man. This reversed the description in the historical document attached to the mummy.

To summarize, this study, as being the first to visualize an Egyptian mummy after 2500 years, was highly publicized. The research was conducted during 1988-1989, and since then, many independent research studies in mummy visualization using medical CT techniques emerged from all over

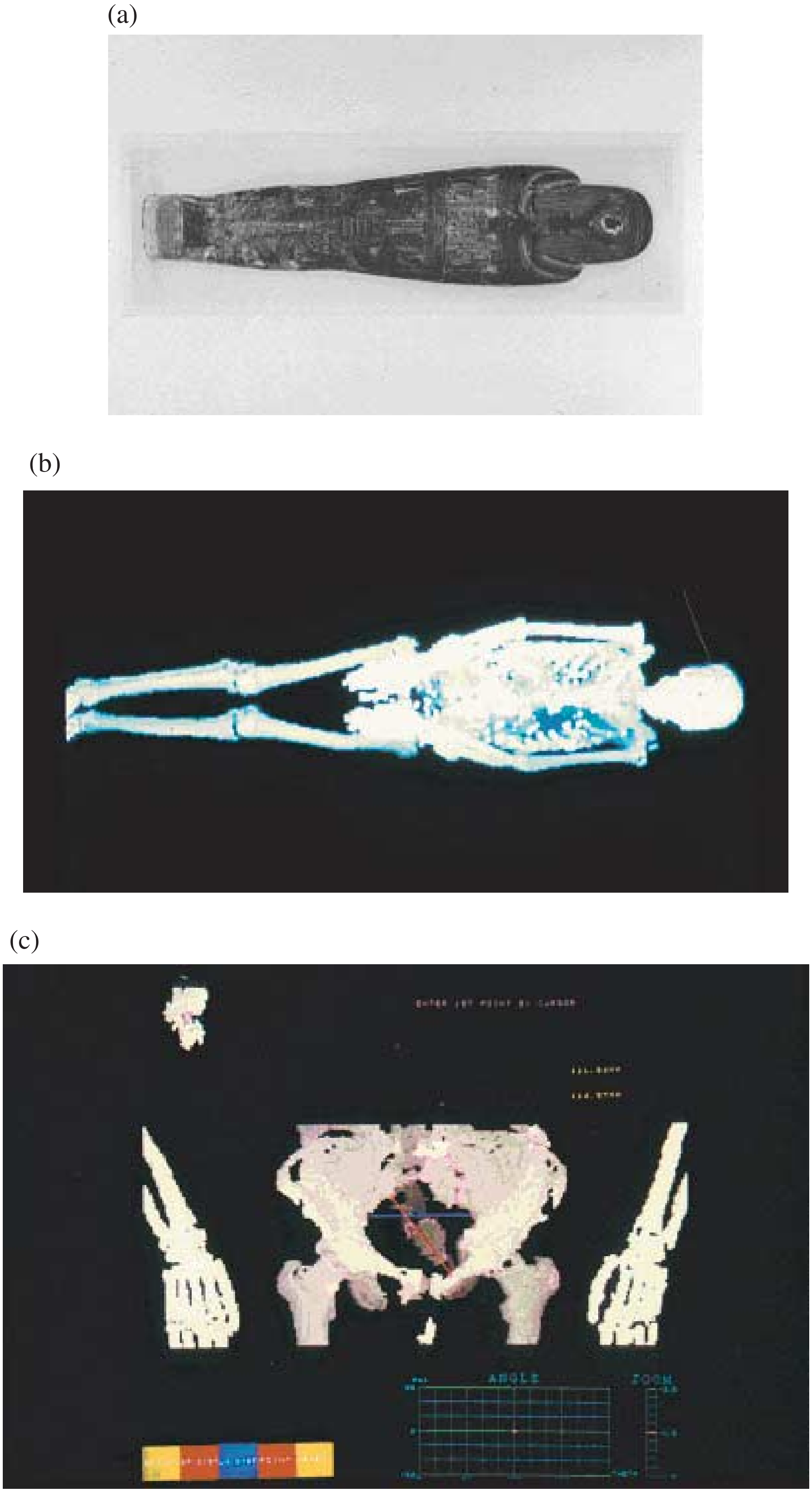

Fig. 7. Visualization of an Egyptian mummy by Yasuda *et al.* (1992). (a) Outside appearance, (b) the overview, (c) measurement of features of the hip joint.

the world. Examples include those by K. H. Hoehne (Hamburg University in Germany) and R. Robb (Mayo Clinic in The United States of America).

The mummy's contents were not only visualized but also treated with various imaging processes that yielded even more precise images. Attempts were also made to extract new information from these images. Examples of them are given as the reference below (Yasuda *et al.*, 1992).

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