Applications of the Visible Korean Human

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Abstract. Visible Korean Human (VKH) consisting of magnetic resonance, computer tomography, anatomic, and segmented images was created. In the VKH, several techniques were developed and numerous data were acquired. The VKH techniques majorly contributed to the generation of advanced segmented images, Visible Living Human, and Visible Mouse. Also, a software for sectional anatomy, three dimensional images for virtual dissection and virtual endoscopy, was developed based on the VKH data distributed worldwide. The VKH technique and data are expected to promote development of other serially sectioned images and software, which are helpful in medical education and clinical practice.

Keywords: Visible Korean Human, Magnetic resonance images, Anatomic images, Segmented images, Three dimensional images.

1 Introduction

Visible Human Project was the first trial ever made to obtain serially sectioned images of cadaver's whole body. The data derived from Visible Human Project have contributed largely in the medical image field [16]. Furthermore, technique used for the Visible Human Project has been modified in Korea for Visible Korean Human (VKH) [9, 10, 13] and in China for Chinese Visible Human [18]. By using the improved technique for VKH such as magnetic resonance (MR) scanning, computerized tomography (CT) scanning, serial sectioning, photographing, and segmenting, the VKH team acquired better data consisting of MR images, CT images, anatomic images, and segmented images. The improved VKH technique was introduced through article [9, 10, 13]; the VKH data were distributed worldwide. The objective of this report is to promote new trials by other researchers to create other serially sectioned images applying VKH technique and three dimensional (3D) images with VKH data, which will be greatly helpful in medical education and useful in clinical practice. To achieve this objective, this report describes the ideas and experiences in applying the VKH technique and data to generate new image data contributing in medical image field.

2 Materials, Methods, and Results

2.1 Application of VKH Technique for Detail Segmented Images of VKH

Three years ago, 13 structures (skin, bones, liver, lungs, kidneys, urinary bladder, heart, cerebrum, cerebellum, brainstem, colon, bronchi, and arteries) in the anatomic

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images were outlined to obtain basic segmented images [9]. However, these basic segmented images were insufficient to produce various 3D images; therefore, advanced segmented images of the many more structures were decided to be made, in order to complement and replace the basic segmented images.

By using segmentation technique on Adobe Photoshop™ (version 7.0) [9], important structures identifiable in anatomic images were segmented as follows: 104 structures of head and neck including brain components, 15 structures of heart, and 84 structures of left upper limb as well as 114 structures of left lower limb including each bone, muscle, nerve, and artery. Few segmented structures such as skin were used as they stand, and other segmented structures such as bone were classified into each bone; other unsegmented structures such as muscles were newly outlined. According to color difference of each structure in gross examination, segmentation was performed automatically, semiautomatically, or manually on Adobe Photoshop. Through stacking the segmented images, coronal and sagittal segmented images were made in order to verify segmentation. As a result, advanced segmented images of 317 structures were produced (Fig. 1).

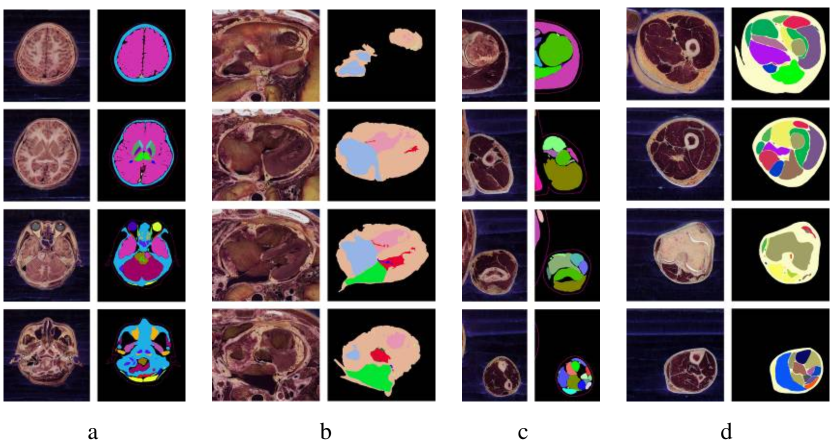
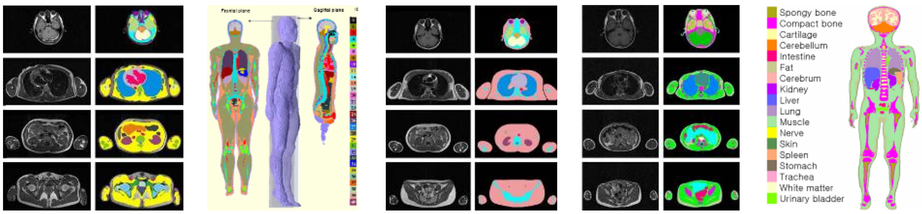


Fig. 1. Anatomic and segmented images of head (a), heart (b), left upper limb (c), and left lower limb (d)

2.2 Application of VKH Technique for Visible Living Human

Besides the VKH, Visible Living Human was newly planned to produce whole body MR images of living humans. While the Visible Living Human does not include anatomic images, it includes MR images of living human, whose body conditions are much better than those of cadaver. In order to carry out the Visible Living Human, MR images of a male adult, a female adult, and a male child were acquired and image processing was done as follows.

By utilizing MR scanning technique of the VKH, whole bodies of living humans were MR scanned. The whole body of an adult can not be MR scanned at once; through the experience from VKH, the first MR series from head to knees and the second MR series from knees to toes were scanned separately; subsequently, both MR series were combined and aligned. Living humans' organs move contrary to cadaver, thus new technique was utilized for the Visible Living Human: To minimize bowel movement, the volunteers had been starved for 12 hours prior to MR scanning; to compensate heart movement, electrocardiography sensor was attached; to compensate lung movement, lung movement sensor was worn by the volunteers. As a result, 613 MR images of male adult, 557 images of female adult, and 384 MR images of male child were acquired at 3 mm intervals (Fig. 2a,c,d) [8, 9].



a b c d e

Fig. 2. MR and segmented images of male adult (a) [8], female adult (c) [9], and male child (d). 3D images of male adult (b) [6] and male child (e) with the color bar which indicates the segmented structure.

Through the same segmentation technique, anatomic structures in MR images were segmented. The Adobe Photoshop was adequate for segmentation not only in anatomic images (24 bits color) but also in MR images (8 bits gray). Yet MR images did not show definite anatomic structures, so that more knowledge of anatomists and radiologists was necessary for segmentation process. In the Visible Living Human, segmentation of the anatomic structures was performed, whose absorptance of electromagnetic wave is quite different: 47 structures in male adult, 19 structures in female adult (segmentation in process), and 33 structures in male child (Fig. 2a,c,d) [6, 8, 9].

The segmented images of male adult were stacked and volume-reconstructed to produce 3D images of 47 structures. Electromagnetic wave was exposed on the 3D images in various ways to calculate influences of the electromagnetic wave on internal structures. In the same manner, the exposing simulation is being performed using the 3D images of the male child (Fig. 2b,e) [6]. In addition, the segmented images of male adult were stacked and surface-reconstructed to produce 3D images. A software on which the 3D images can be selected and rotated was produced for medical education [8].

2.3 Application of VKH Technique for Visible Mouse

Mouse anatomy is a fundamental knowledge for researchers who perform biomedical experiments with mice. So far the mouse anatomy has been educated through two dimensional images such as atlas, thus being difficult to be comprehended, especially the stereoscopic morphology of the mouse. In order to overcome this difficulty, it is necessary to produce 3D images made of Visible Mouse [12].

Through serial sectioning and photographing technique of the VKH, anatomic images of a mouse were obtained. The cryomacrotome with only 1 um error was designed for serial sectioning of any organism smaller than human. Using the cryomacrotome, a mouse was serially sectioned at 0.5 mm intervals to make sectioned surfaces. Every sectioned surface was photographed using a digital camera to produce 437 anatomic images. Distance between the sectioned surface and the digital camera could be adjusted closely to generate anatomic images with 0.1 mm pixel size. During photographing, the strobe light was flashed in the same condition to produce anatomic images with consistent brightness (Fig. 3) [10, 12].

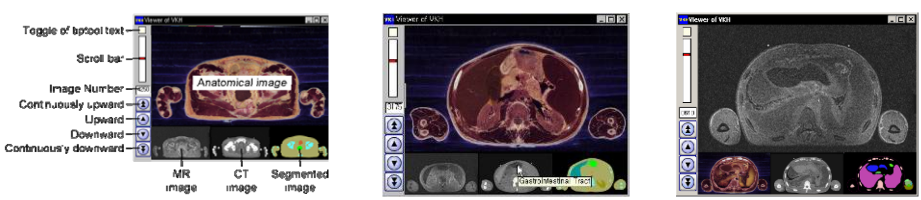
a b

Fig. 3. Anatomic images, segmented images (a) [12], and 3D images (b) of the mouse with skin and internal structures

By practising the same segmentation technique, 14 mouse structures in the anatomic images were segmented. The rodent structures were so small that exhaustive knowledge of mouse anatomy referred to mouse atlas was necessary for the segmentation process [5, 12]. From the segmented images, contours of the mouse structures were stacked on Alias™ Maya (version 7.0); stacked contours were volume-reconstructed on Autodesk™ AutoCAD (version 2007) (Fig. 3).

2.4 Application of VKH Data for Sectional Anatomy Education

Sectional anatomy is the course to learn anatomic structures on the sectional planes. The sectional anatomy has become much more important especially because medical students have to interpret MR and CT images. Because of the growing importance of sectional anatomy, browsing software of the VKH data was created. Raw data of the browsing software were 1,702 sets of MR, CT, anatomic, and segmented images



a b c

Fig. 4. Browsing software showing four images and graphic user interface (a), name of structure in CT image (b), and enlarged MR image (c) [11]

(1 mm intervals) of the whole body. On the browsing software, a set of four images corresponding to one another was displayed; different sets of images could be selected conveniently using graphic user interface; names of the segmented structures in all images were also displayed; among a set of four images, any image could be enlarged. The browsing software can be downloaded free of charge from our web site (anatomy.co.kr) (Fig. 4) [11].

2.5 Application of VKH Data for Virtual Dissection (Volume-Reconstruction)

As the traditional method in educating anatomy, cadaver dissection is exceptionally important; but the cadaver dissection with time and place restriction can not be performed commonly. The problem can be compensated by virtual dissection. For the virtual dissection, volume-reconstruction was carried out primarily to produce 3D images out of the VKH data because volume-reconstruction enables users to section 3D images of structures with the same color as real-life human structures [14].

Virtual dissection software of whole body was created at Inha University, Korea. For this research, basic segmented images of 13 structures and corresponding anatomic images were used as materials. As the preprocess, intervals and pixel size of the anatomic and segmented images were increased from 0.2 mm to 1.0 mm because original image files were too large to be processed on a personal computer. Anatomic and segmented images were stacked and volume-reconstructed on Microsoft™ Visual C++ (version 6.0) to produce 3D images. On programmed virtual dissection software, the 3D images with real color could be sectioned, selected, and rotated (Fig. 5a) [10].

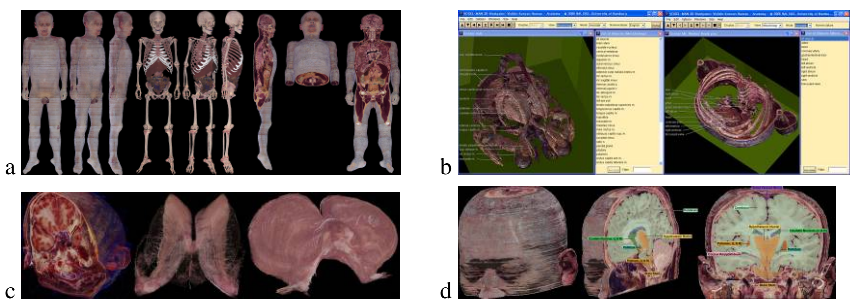


Fig. 5. 3D images by volume-reconstruction at Inha University, Korea (a) [10], University Medical Center Hamburg-Eppendorf, Germany (b), State University of New York at Stony Brook, US (c), and Texas Tech University, US (d)

Virtual dissection software of head and neck was produced at University Medical Center Hamburg-Eppendorf, Germany. For this research, advanced segmented images of 104 structures in head and neck were used as materials; Voxel-Man system was used for segmentation refinement and for volume-reconstruction [14]. On the virtual dissection software, the 3D images with real color could be stripped in sequence; the 3D images could be selected to display by names of structures; the 3D images could also be annotated. In the same manner, virtual dissection software of thorax including heart components was created (Fig. 5b). Additional virtual dissection software of head is being created at other institutes such as State University of New York at Stony

Brook (Fig. 5c), Texas Tech University (Fig. 5d), Stanford University Medical Media & Information Technologies, Pittsburgh Supercomputing Center, and Upperairway Company, US, as well as in MAÂT3D, France.

2.6 Application of VKH Data for Virtual Dissection (Surface-Reconstruction)

After the trial of volume-reconstruction, surface-reconstruction was tried with segmented images of the VKH to produce 3D images of structures with outstandingly small file size. The surface-reconstructed 3D images can be selected to display, rotate, and transform themselves in real time. In addition, the 3D images can be easily distributed through the Internet [17].

3D images of urogenital tract were made by surface-reconstruction at University Paris V René Descartes, France. Contours of 42 structures including urogenital tract, its neighboring bones, arteries, and skin were stacked and surface-reconstructed using SURFdriver software to produce 3D images. The 3D images could be manipulated individually or in-group with the 3D images' transparency adjusted (Fig. 6a) [17]. Additionally by surface-reconstruction, 3D images of skull and 3D images of lower limb bones were made at University Malaya, Malaysia (Fig. 6b) and at Konrad-Zuse-Zentrum für Information Stechnik, Germany (Fig. 6c), respectively.

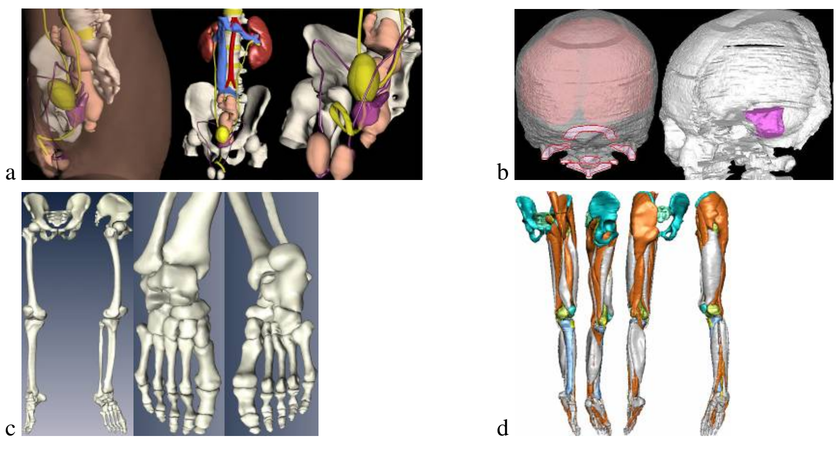


Fig. 6. 3D images by surface-reconstruction of University Paris V René Descartes, France (a) [17], University Malaya, Malaysia (b), Konrad-Zuse-Zentrum für Information Stechnik, Germany (c), and Ajou University, Korea (d) [15]

We tried to produce 3D images of left lower limb by surface-reconstruction on Maya and Rhino, which are both popular commercial software. Contours of 114 structures in left lower limb were stacked on Maya; gaps between contours were filled with non-uniform rational B-spline (NURBS) surfaces on Rhino; all NURBS surfaces were converted into polygon ones on Rhino; the surfaces were corrected to complete the 3D images on Maya. In this manner, surface-reconstruction can be done on the popular and commonly used software to produce 3D images in the Maya file format, thus be widely used by other researchers (Fig. 6d) [15].

2.7 Application of Vkh Data for Virtual Endoscopy

Virtual colonoscopy of a patient is becoming popular in diagnosing colon cancer. However, the virtual colonoscopy being based on the CT images, colon wall can not be displayed in real color. In the VKH, lumen of colon had been segmented. The anatomic and segmented images were stacked and volume-reconstructed to produce 3D image of colon wall's luminal surface, which held real color. Based on the 3D image, virtual colonoscopy was performed at Inha University, Korea. The virtual colonoscopy with real color was similar to real colonoscopy, so that educational effect could be enhanced. In the same manner virtual bronchoscopy and virtual arterioscopy were performed with the VKH data (Fig. 7) [13].

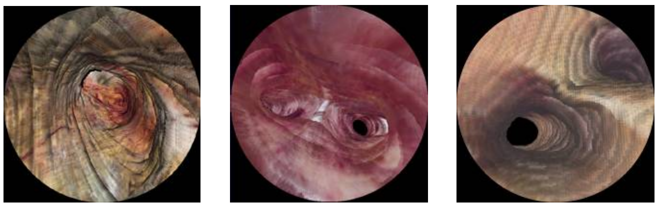


Fig. 7. Virtual colonoscopy (a), virtual bronchoscopy (b), and virtual arterioscopy (c) [13]

2.8 Application of Vkh Data for Radiation Simulation

Just as Visible Living Human data were used for exposing simulation of electromagnetic wave, VKH data were used for radiation simulation at Hanyang University, Korea. The raw data from VKH were the segmented images of 22 structures at 2 mm intervals. The segmented images were stacked and volume-reconstructed to produce 3D images. Then the 3D images were exposed by broad parallel photon beams in various ways to calculate effects of radiation on each structure. These results could be used to prevent workmen in radiation-polluted environment from receiving radiation damage [4].

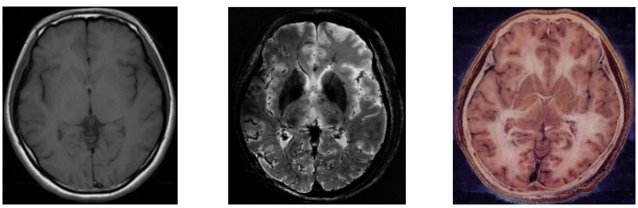
3 Discussion

Various applications performed with the VKH technique and data have been described. In discussion, further potential applications to be performed in the future are presented.

Segmented images of the VKH will be acquired to completion. For the VKH, it required a day and three months only to obtain MR images and anatomic images, respectively. Then it required three years to obtain segmented images of 317 structures (Fig. 1); nevertheless, segmentation has not been finished yet [9, 10, 13]. It will take three more years to finish segmentation in whole body. Three years later, the segmented images accompanied by corresponding anatomic images will be distributed worldwide free of charge. It is anticipated that other researchers reform some incorrect segmented images and make more detailed segmented images for their own purposes. In any case, the segmented images, which will be finished by authors, are expected to save precious time and effort of other researchers.

Female data of the VKH will be acquired. The female data, which are later than male data, need to be upgraded as follows. The female cadaver for the VKH needs to be of young age, good body contour, and with few pathologic findings. Anatomic images of whole body need to have 0.1 mm intervals, 0.1 mm pixel size, and 48 bits color depth. It seems that 0.1 mm voxel size of anatomic images is the last trial in this research, which belongs to gross anatomy. Additionally, the female data are desirable to be followed by the child data, fetus data, and embryo data. The systematic data according to sex and developmental age will be the main contents in the medical image library [10, 13].

Visible Head data including 7.0 Tesla MR images will be made. State-of-the-art 7.0 Tesla MR machine has been developed by Professor Zang-Hee Cho in Neuroscience Research Institute of Gachon University, Korea [3]. By using the 7.0 Tesla MR machine, a cadaver's head were MR scanned recently. Surprisingly, several structures of brain (for example, cerebral arteries) appeared better in the MR images than in the anatomic images of VKH while the other structures appeared better in the anatomic images (Fig. 8). The cadaver's head will be serially sectioned to obtain anatomic images in correspondence to the MR images. These Visible Head data are expected to be milestone images in neuroscience field.



a b c

Fig. 8. 1.5 Tesla MR image with T1 (a), 7.0 Tesla MR image with T2 (b), and anatomic image (c)

Visible Patient data will be acquired by registration of the VKH data to a patient's data. For example, MR images of a patient are produced. Anatomic images of the VKH are transformed, thus be corresponding to the MR images of the patient. For the transformation, high level of registration technique and segmented images of VKH will be utilized. The anatomic images registered to the patient have color information and high resolution. Therefore, anatomic images can be used in production of realistic 3D images, which will be the basis for preoperative virtual surgery of the patient [7].

Pregnant female data of the Visible Living Human will be made. MR images of male adult, female adult, and male child have been scanned (Fig. 2) [8, 9]. Likewise, MR images of pregnant female will be scanned, including fetus images. The pregnant female data will be used for the exposing simulation of electromagnetic wave too [6].

Visible Rat data and Visible Dog data will be made. Like the Visible Mouse (Fig. 3) [12], Visible Rat and Visible Dog can be performed for biomedical experiment and veterinarian education by using the same cryomacrotome of VKH. In order to make better images than other Visible Rat [1] and other Visible Dog [2], micro MR machine and micro CT machine will be used for the rat; high level of serial sectioning and detail segmentation will be tried for both the rat and the dog.

In this report, our ideas from experiences to apply the VKH technique and data have been introduced. By applying the VKH technique, other images such as Visible Living Human (Fig. 2) [6, 8]. Visible Mouse (Fig. 3) [12] can be created; by applying the VKH data, sectional anatomy (Fig. 4) [11], virtual dissection (Figs. 5, 6) [9, 10, 17], virtual endoscopy (Fig. 7) [13], radiation simulation [4], and Visible Patient can be performed. Based on this report and the distributed VKH data, other researchers are expected to make better images and more progressive applications for use at medical education and clinical practice.

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