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ORIGINAL ARTICLE

The Visible Human Projects in Korea and China with improved images and diverse applications

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Abstract
Purpose The Visible Human Projects, which were launched in the United States, have also been developed in Korea and China during the past decade. This article includes the new trials to promote a variety of their applications.
Methods In a Korean laboratory, whole bodies of two cadavers were serially sectioned (Visible Korean), while two Chinese institutes have sectioned nine cadavers (Chinese Visible Human and Virtual Chinese Human). For acquiring sectioned images and stereoscopic models of better quality, appropriate cadavers were chosen; equipments and techniques for embedding, sectioning, photography, and computer processing were continuously improved in the two countries. To facilitate the research, Korean and Chinese scientists have visited each other.
Results The sectioned images with thinner intervals (0.2 mm or less) and higher resolution were obtained. From the advanced data, the segmented images of comprehensive structures were prepared to construct three-dimensional models. Then, cross-sectional images and models were offered for medical education and clinical practice such as electronic anatomy atlas and virtual lumbar puncture.
Conclusion Every project has its strengths and weaknesses with regard to the image data; users in the world can choose the project that best suits their needs.

Keywords Visible Human Projects · Cadaver · Frozen sections · Three-dimensional imaging · Anatomy

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Introduction

The American Visible Human Project, Korean Visible Human Project, and Chinese Visible Human Project are the entry terms for the Visible Human Projects, a medical subject heading, used by the National Library of Medicine. The Visible Human Project (VHP) in America was the first trial performed to obtain serially sectioned images of whole cadavers in 1994 and 1995; the attempt was a milestone in the medical imaging field and anatomy education sphere [22, 30, 31]. However, acquisition of the sectioned images from other cadavers was discontinued in the VHP. Instead, the trial was repeated in Korea (Visible Korean, VK) to produce data on the first Korean in 2002 [16, 18]. Succeedingly, the sectioned images of Chinese cadavers were constructed in Chongqing, China (Chinese Visible Human, CVH) [43, 44] and also in Guangzhou, China (Virtual Chinese Human, VCH) [34, 40, 46] (Table 1). Since 2001, the Korean and Chinese scientists have met one another to share their experiences. The collaboration enhanced not only the instruments and techniques for improved images but also various applications of the data. The purpose of this report is to review the advantages and availability of the Visible Human Projects in Korea and China so that investigators can choose and utilize the set of data according to their aims. The applications of the raw and processed images to various medical

Table 1 Features of the sectioned images from individual cadavers in the American, Korean and Chinese projects

	Year[a]	Sex	Age (years old)	Intervals (mm)	Pixel size (mm)
Visible Human Project	1994	Male	38	1	0.33
	1995	Female	59	0.33	0.33
Visible Korean	2002	Male	33	0.2	0.2
	2010	Female	26	0.2–1	0.1
Chinese Visible Human		Male	35	0.1–1	0.25–0.5
		Female	22	0.25–0.5	0.17
		Male	21	0.1	
		Female	25	0.25–1	
		Female	25	0.2	
Virtual Chinese Human	2003	Female	19	0.2	0.2
	2003	Male	24	0.2	0.2
	2004	Female	10 months old	0.1	0.1
	2005	Male	28	0.2	0.1

[a] Year refers to when the serial sectioning of the cadaver was finished

simulations can be accomplished by many technical and clinical groups around the world.

Materials and methods, results and discussion

Selection of cadavers

The increase in the data sets of the sectioned images from additional cadavers provides greater selection for potential users. In the VK, whole bodies of two cadavers (1 male, 1 female) were serially sectioned; they were the same subject numbers as the VHP. For the extra work, the head extracted from a male cadaver and the pelvis from a female cadaver were sectioned as well. In the CVH and VCH, five cadavers (2 males, 3 females) and four cadavers (2 males, 2 females) were available for the study (Table 1).

Every researcher has tried to adopt the cadavers, representing the normal population; the standard anatomical models are of great use as reference images. Basic factors include age, body measurements, and pathological findings.

The subjects were younger in the VK, VCH, and CVH than in the VHP. For example, female subjects (59 years old) in the VHP comprised regressed genital organs, while Korean and Chinese female subjects, prior to menopause, demonstrated the dynamic ovaries involving the various stages of the ovarian follicles [7]. One VCH subject was 10 months old, whose data set could be used for the construction of pediatric simulation [34] (Table 1).

The Korean and Chinese subjects were not as heavy as the American cadavers were. The three-dimensional (3D) models made of the VK, CVH, and VCH data show more appropriate body contours for their ethnic groups (Fig. 1).

While no cadaver is totally free of pathology, an attempt to search and use healthy individuals is valuable. In the VHP, the male subject had a past history of appendectomy and unilateral orchiectomy [30]. In the Korean subjects, male died of leukemia, which caused pneumonia and splenomegaly [16]; and female died of stomach cancer with lymph node metastasis and pneumonia. However, the drawback of the VK involved just limited sections of the whole body. In China, strictly chosen subjects were almost ideal with little pathology. In the case of the VCH, a male subject was executed by lethal injection, like the male for the VHP. Two other female subjects died of food poisoning, and a child died of fetal distress [34].

All cadavers including a child were selected from those donated for medical research and education with the consent of their relatives. In case of the court-ordered lethal injection, the subject gave a willing consent for the research in advance.

MRI and CT scanning

In all of the Visible Human Projects, sectioned images with high resolution and real body colors are the main data sets; while the magnetic resonance images (MRIs) and computed tomographs (CTs) of the same cadaver are supplementary. The MRI and CT scans are valuable because medical students/doctors easily recognize anatomical structures found on the MRIs and CTs by referring to the corresponding sectioned images.

With respect to the MRIs, only the cadaver head was scanned in the United States [30], while whole bodies were scanned in Korea and China. The VCH first did 3 Tesla MRI scanning in 2003 rather than 1.5 Tesla imaging [41, 46]. In 2007, the VK acquired 7 Tesla MRIs of a cadaver head. However, the cadaver MRI was not similar to the MRI of the living body in quality [19].

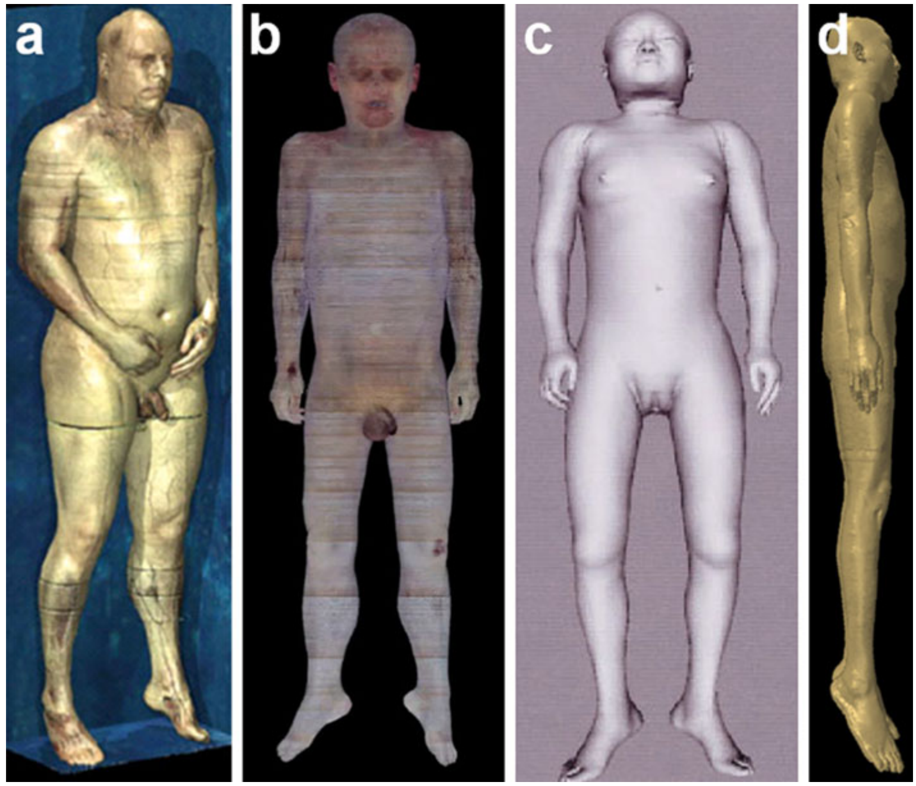

Fig. 1 Volume models reconstructed from Visible Human Projects. **a** Visible Human Project. **b** Visible Korean [16]. **c** Chinese Visible Human. **d** Virtual Chinese Human [34]

Cadaver preparation

In Korea, neither fixative nor dye was perfused into the fresh cadavers. Therefore, the cross-sectional images were preserved in the genuine colors of a living human [16]. However, in the United States and China, fixative was injected into the cadavers' arteries to promote more definite tissue characteristics in the sectioned images [30]. In China, the fixative injection was followed by subsequent perfusion of red dye, which was very helpful in the identification of the arterial branches of the serially sectioned images [34, 40, 43, 44, 46]. These unequal cadaver preparations resulted in diverse qualities of the sectioned images, which provided some variability in the data sets for users to choose from.

The male cadaver of the VHP had a posture of the palms placed in front of the trunk, so that the hand structures (e.g., intrinsic hand muscles) were hard to identify in the horizontal planes (Fig. 1a). Therefore, in Korea and China, the palms were located on the sides of the trunk bilaterally, relatively close to the anatomical position, which is familiar to medical doctors (Fig. 1b, c, d).

The cadaver tended to have a flat back and buttocks because of the supine position around the time of death. After freezing the cadaver, the flattened back was irreversible in the two-dimensional images and 3D models. Even though the flattening artifact is not a significant issue, as long as the anatomical relationships are accurate, the natural contours of both the skin and underlying muscles make the simulation more realistic. The VCH was the only project to resolve this artifact by a massage step and an embedding procedure with the cadaver in the upright posture (Fig. 1d) [34].

Embedding, serial sectioning, and photography

In the first study, namely the VHP, the researchers had no choice but sawing the cadaver into four parts due to the size limitations of the embedding box and cryomacrotome. As a result, there was unavoidable tissue loss between the four pieces, which meant missing data in the sectioned images [30]. In Korea and China, this imperfection was eliminated by manufacturing of instruments large enough to contain a complete human body (Fig. 1).

As a rule, the equipments were built and used for a cadaver in the supine position (Fig. 2a) [16]. However, in the VCH, the whole body of the cadaver was upright in the embedding box and high cryomacrotome. The standing posture seemed desirable for constant conditions at all areas of the sectioned surfaces (Fig. 2b) [34].

In the VK, a huge laboratory (15 m × 8 m × 4 m) was needed for the equipments including: installation of the cryomacrotome (5 m × 4 m × 3 m), photography instrument, illumination facility, and computer. The large area was beneficial for all procedures of sectioning and photography to generate high-quality images. The laboratory must be

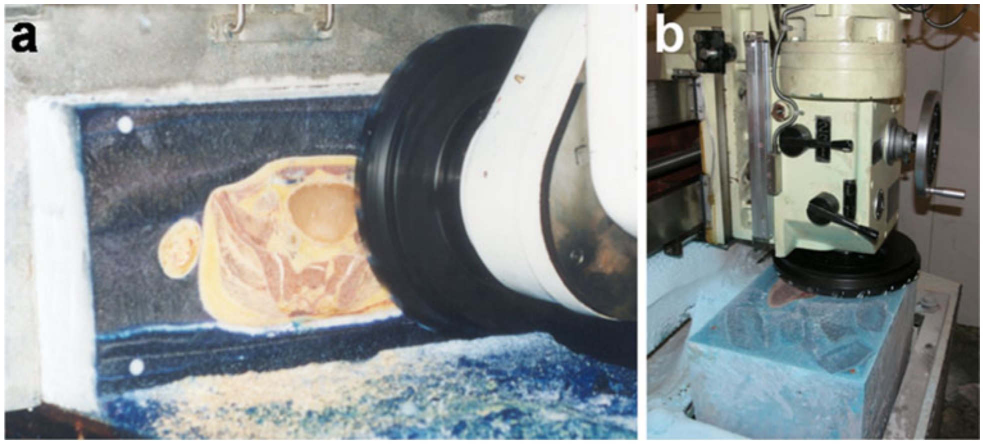

Fig. 2 Cryomacrotomes, sectioning cadavers in the frozen embedding boxes. **a** During sectioning as well as embedding, the cadaver is placed in the supine position in the Visible Korean [16]. **b** The cadaver is upright in the Virtual Chinese Human [34]

sufficiently cold (around 0°C) to prevent the embedding box from melting during sectioning (Fig. 2a). In fact, this big space was hard to be adequately cooled, so that the cadaver was sectioned only during the winter season with the laboratory windows opened. At most, one-hundred times of serial sectioning could be carried out a day [16, 18].

However, for the CVH, a freezer (7 m × 3 m × 2 m, below 30°C) was manufactured as the laboratory having a small cryomacrotome and photography equipment excluding a computer. Therefore, sectioning was possible regardless of the season [43, 44]. Meanwhile the VCH laboratory was designed and constructed in the basement and ground level floors of a building, where a tall cryomacrotome was installed. In order to keep the cold cadaver block, the basement itself was a freezer. To facilitate manual cleaning of the sectioned surfaces, the ground floor was a refrigerator (Fig. 2b) [34]. Two Chinese cities (Chongqing for CVH and Guangzhou for VCH) maintain a warm climate even in winter, so that sufficiently chilled laboratories were required. The cold rooms enabled more cadavers to be serially sectioned in China (Table 1).

In the VHP, the intervals of serial sectioning for the male and female cadavers were 1 and 0.33 mm, respectively. The 0.33 mm was determined by the pixel size (0.33 mm) of the sectioned images that was influenced by the size of sectioned surface and digital camera resolution at that time. The same size (0.33 mm) of intervals and pixels permitted a sophisticated volume reconstruction because the users could construct 0.33 mm-sized voxels, the unit of volume models [30]. In both Korea and China, approximately 0.2 mm-sized intervals and pixels were achieved by more labor and better digital cameras. Subsequently, 0.1 mm-sized voxels were obtained from the head and pelvis of the cadavers and the entire body of an infant (Table 1) [7, 19, 34]. The final attempt, in the future, might be 0.1 mm-sized voxels of the entire adult body.

Despite careful trials of sectioning and photography, incorrect alignment and inconstant brightness between neighboring sectioned images occurred. The misalignment and irregular brightness were found by use of fiducial rods and gray scales, respectively. In all laboratories of three countries, the rods and scales were photographed together with the sectioned surfaces of the cadavers [30]. In a different way, the sectioned images were sequentially stacked to produce the coronal and sagittal planes, by which the errors in alignment and illumination were readily discovered. The VK team preferred the vertical planes for identifying and fixing the problems of the sectioned images [18].

Atlas for sectional anatomy

Compilations of atlases, showing the entire body's sectioned images with significant structures annotated, have been published. This information contributes to the understanding of sectional anatomy and the interpretation of MRIs and CTs.

The first sectional atlas was issued based on the male data from the VHP [32]. The second atlas included both the male and female sectioned images from the CVH [42]. Researchers from the VCH followed their initial publications by third and fourth atlases featuring the female images [35] and the male images [36]. The fifth atlas from the VK dealt with the horizontal, coronal and sagittal sectioned images of only the cadaver head, where thousands of complicated brain structures were labeled [3].

Segmentation and 3D reconstruction

The sectioned images themselves do not fulfill all of the demands of users. In order to construct 3D models of the body structures for medical simulation, the outlines of the structures in the sectioned images must be drawn in

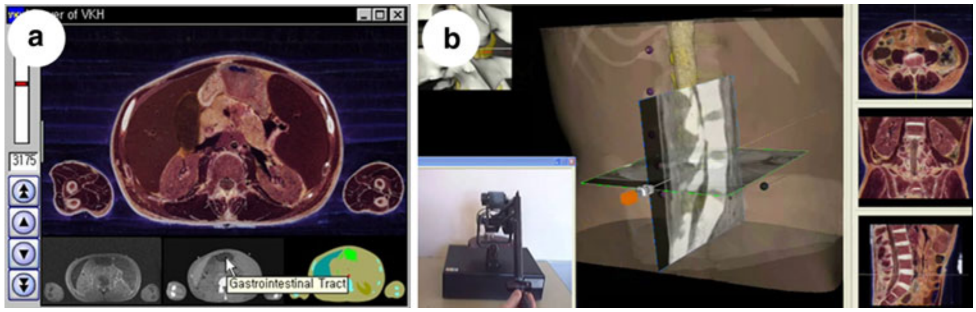

Fig. 3 Applications of the Visible Korean data. **a** Browsing software of the four kinds of images, all corresponding to one another [24]. **b** Virtual lumbar puncture system, equipped with a haptic device [25]

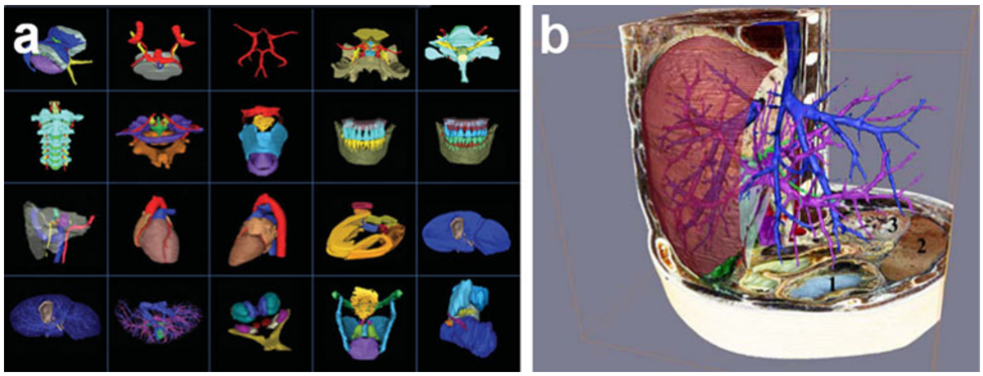

Fig. 4 Applications of the Chinese Visible Human. **a** Three-dimensional surface models of various organs [43]. **b** Surface models of the liver constituents in combination with volume models of the liver and surrounding structures [2]

advance; this segmentation work is almost manual and is very time-consuming [17, 28]. In the Korea and China projects, the segmented images and the resultant 3D models, software packages have been elaborated for several years.

In the case of the VK, just after segmentation, the researchers composed browsing software of the MRIs, CTs, sectioned images, and segmented images. In the software, the four corresponding images can be expediently browsed, then the normal structures in the MRIs, CTs, and sectioned images are easily identified with the help of the segmented images (Fig. 3a). The electronic atlas can be downloaded from the VK homepage (anatomy.co.kr) [24].

In the VK, detailed 3D surface models of for example the cerebrum, ear, liver, gastrointestinal tract, urogenital organs, and lower limbs were built from the serial outlines of segmented images. During the work, optimized surface reconstruction technique has been devised in the popular software packages, eliminating the need for computer language programming skills [8, 15, 21, 23, 26, 27, 29, 38]. Surface and volume-rendered models of the lumbar region were reconstructed and utilized for establishing a virtual lumbar puncture system (Fig. 3b) [4, 25]. Moreover, virtual colonoscopy, based on the volume models, was achieved to show the real color of the inside of the colon wall [18].

In the CVH, the investigators have actively carried out surface and volume reconstruction on the basis of the outlined images of the cerebrum, nasal and temporal bones, parapharyngeal space, superior mediastinum, heart, liver, prostate and associated neighboring structures for diverse applications. Especially, the surface and volume models were combined for illustration of diverse anatomical information of the structures (Fig. 4) [2, 6, 11–13, 39, 43].

The CVH staff executed preliminary experiment to register the cadaver's sectioned images to a patient's MRIs with the help of the segmented images. If the registration were successful, the patient's 3D volume models of high resolution in real color could be attained. The 3D models permit a realistic virtual operation prior to actual practice with the patient [10]. The same type of registration was studied by the VK team [20].

In general, the segmentation process was performed at 1 mm intervals, not at the initial intervals (usually 0.2 mm) (Table 1), to reduce the amount of manual work [28]. However, in the VCH, 0.6 mm-sized intervals of delineation in the entire body were planned and accomplished [34].

The VCH project had wide applications based on the surface models of various anatomic structures of an individual cadaver. The applications included the virtual dissection, virtual endoscopy, motion simulation (Fig. 5a), as well as game and examination modules. In addition, image-guided neurosurgery was studied based on the same data [41]. In another research project on computational physiology, multiparticle radiological dosimetry data were derived

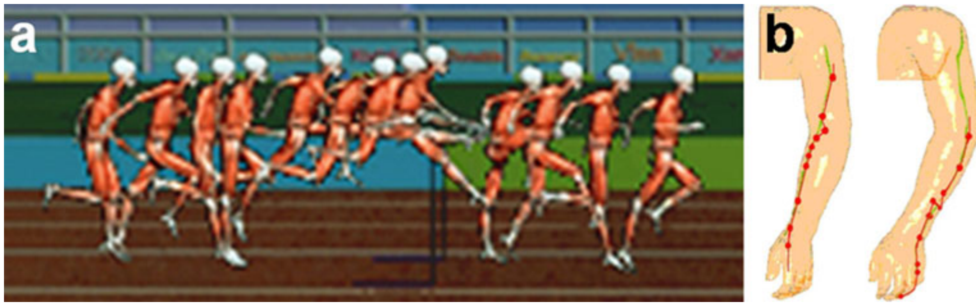

Fig. 5 Applications of the Virtual Chinese Human. **a** Motion simulation of three-dimensional models of the skeletal and muscular systems [41]. **b** *Red* acupuncture lines, related to *green* fascial lines [1] (color figure online)

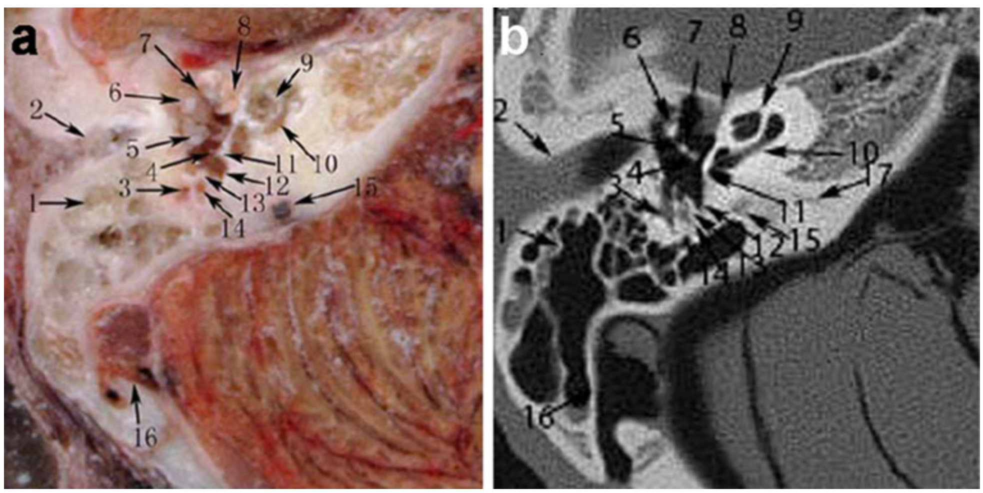

Fig. 6 Fine structures of the temporal bone in the equivalent images from Jinan. **a** Sectioned image. **b** Computed tomograph [45]

from the VCH data [5], which was supplemented by a similar trial of the VK data [9].

VCH researchers have been concerned with the anatomical interpretation of the Chinese acupuncture. In the sectioned images of upper limb, areas rich in connective tissue were marked along the border of the subcutaneous tissue and intermuscular septum. On the reconstructed 3D models, the line connecting the marked areas corresponded with the well-known acupoints. The result showed that the fascial framework constituted by the connective tissues could be the morphologic basis for appropriate acupuncture therapy (Fig. 5b) [1].

Providing detailed segmented images would make the data of the Visible Human Projects more widely available. Even though many structures have been segmented in Korea and China, much remains to be done for satisfying the various demands of medical simulation. Users, for whom the segmented images are provided, can outline additional structures as needed. Although the outlines were drawn by medical experts in each project, and inaccurate outlines were revised after verification, there inevitably were some errors. Users would benefit from correction of the mistakes by themselves after considering the sectioned images, source data. It is hoped that interested investigators share the added and amended outlines to upgrade the segmented images data over time [28].

Other projects in China

Another Chinese laboratory was established in Jinan to join the VHP. The basic form of the cryomacrotome and related equipment was similar to that for the CVH. Its intended purpose was to contribute to sectional anatomy inquiries. Sectioning of regions such as the pineal region, sellar region, temporal bone, and liver was performed to provide specific images. Precise structures in the sectioned images were compared to CTs or MRIs (Fig. 6). Some structures in the sectioned images were outlined and reconstructed to build 3D models, similar to other projects [14, 33, 37, 45].

The VCH project team recently initiated one more laboratory in Shenzhen close to the VCH's headquarter in Guangzhou. The lab is equipped with the small-scale cryomacrotome for serial sectioning of the small parts such as pterygopalatine fossa as well as the experimental animals (e.g., mouse). The facility is expected to contribute to the morphological discovery of field between gross anatomy and histology.

Communication between projects

Conferences on the VHP were held in the United States to present the applications of the VHP on four occasions (1996, 1998, 2000, 2002). Similar conferences were then held in Chongqing (2003) and Qingdao (2007), China, where all scientists in charge of American, Korean, Chinese Visible Human Projects attended to inform their novel techniques and utilizations. In addition, the Korean and Chinese investigators visited each other several times for further collaboration.

The Visible Human Projects from dissimilar sites have been reported continuously in the academic press and mass media. In 2006, a special issue of Clinical Anatomy covered the details of the three projects (VHP, VK, CVH) and played a role in the popularization of Visible Human Projects around the world [18, 31, 43].

Conclusion

The Visible Human Projects in Korea and China have progressed by using suitable cadavers as well as advanced equipments and techniques for embedding, serial sectioning, photographing, segmentation, and 3D reconstruction. Every project has merits and demerits about the images constructed; users can choose the data set that suits their needs. One goal is to set up a virtual image library with the final data from the different projects. The image library will hopefully facilitate worldwide access to this information for those who can develop useful 3D models and software that can be employed for example in medical education, clinical training, and ergonomics.

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