



Four learning tools of the Visible Korean contributing to virtual anatomy

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Abstract

Purpose The sectioned images of a male's whole body were used for making the four learning tools: the first tool to show the sectioned and color-filled images; the second tool to show surface models of individual structures; the third tool to show a volume model that was continuously peeled; the fourth tool to show a volume model that was freely sectioned. This study was intended to propose the possible learning effects of the four tools.

Methods The fourth tool that was recently developed to facilitate oblique sectioning and rotation of the volume model in real time.

Results The four learning tools had their own characteristics, so that they could be separately used for specific achievements. Further, the combination of the tools based on the same raw data may result in a synergic effect. All the tools can be downloaded from the Visible Korean homepage (anatomy.co.kr) gratis.

Conclusions With the four learning tools, students may experience virtual dissection simulation regardless of the place, time, or economic status. Such free learning tools and commercial learning tools need to be improved to compensate and compete with each other.

Keywords Visible Human Projects · Cross-sectional anatomy · Three-dimensional imaging · Computer simulation

Introduction

As the initial data set of the Visible Korean project, the sectioned images of a male's whole body were elaborated [18]. Hundreds of structures in the sectioned images were segmented to create color-filled images [24]. The two-dimensional (2D) sectioned images and color-filled images are the source of the three-dimensional (3D) models of human body. The 2D images were shared with other researchers to promote virtual dissection and simulated surgery [6, 9, 30–32].

Independent of other researchers, the Visible Korean research team has manufactured and presented the learning tools: the first tool to browse the sectioned images and color-filled images [13]; the second tool to select and rotate the 3D surface models [22]; the third tool to browse the peeled 3D volume model [14]. Visible Korean team recently

developed the fourth tool to section the volume model in arbitrary angles. The new tool is expected to compensate the previous ones and compose a package with them.

Purpose of the present study was to suggest the usefulness of the four learning tools of Visible Korean (male whole body) that are presented for free. Thus, the fourth tool to handle the volume model freely was introduced in detail and compared not only to the former three tools but also to other commercial tools.

Methods

The whole process for this study was approved by the institutional review board (AJIRB-MED-MDB-18-315).

8505 horizontally sectioned images (intervals 0.2 mm; pixel size 0.2 mm; resolution 2468 × 1407; color depth 24 bit) of whole body of a Korean male cadaver (age 33 years; stature 1.64 m; weight 55 kg) were prepared [18]. It was decided to use the sectioned images for the fourth learning tool. The pixel size and intervals were increased by five times to prepare the 1701 sectioned images (intervals 1 mm;

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pixel size 1 mm; resolution 493×281). The lowered resolution facilitated real-time operation of the final volume model (voxel numbers $1701 \times 493 \times 281$) on the currently used personal computer (CPU 3.4 GHz, main memory 16 GBytes; video memory 8 GBytes).

The sectioned images in tagged image file format (TIFF) were converted to digital imaging and communications in medicine (DICOM). After stacking the aligned DICOM files, the volume model was reconstructed and saved as a neuroimaging informatics technology initiative (NIfTI-1 = NII) file [16].

The color-filled images derived from segmentation [24] were also processed to prepare another volume model in the same scale.

Results

The previous three tools to elucidate human anatomy with diverse images had been developed as follows: the first tool with the 2D sectioned images and segmentation data, the second tool with the surface models, and the third tool with the peeled volume models. In this study, the fourth learning tool contained two volume models: the volume model of sectioned images (file size 170 MBytes) and that of the color-filled images (file size 7 MBytes) (Table 1). They could be downloaded free of charge or registration just by clicking the menu “Volume model (Male-sectioned images)” and “Volume model (Male-segmented images)” on the Visible Korean homepage (anatomy.co.kr) [5]. The downloaded volume models, which are compressed in ZIP format, should be extracted for use.

To operate the volume models, it was also needed to download the free software MRICroGL (file size 75 MBytes) from Professor Chris Rorden’s homepage (mccausland-center.sc.edu/mricrogl/home) after license agreement.

On the MRICroGL, the volume model could be sectioned either orthogonally or obliquely (Fig. 1). The oblique sectioning was performed by inputting numbers in three variables: azimuth (angle on the horizontal plane), elevation (angle on the vertical plane), and depth (depth from the surface) (Fig. 2).

Moreover, it was possible to show the horizontal, coronal, and sagittal planes simultaneously as if a block part of the volume model were removed (Fig. 3a). This sectioning was carried out by inputting numbers in other variables. Even after removing a block part, the remaining volume model could be obliquely sectioned (Fig. 3b). The resultant volume model was freely rotated using computer mouse (Fig. 3c).

In total, the four learning tools of Visible Korean had their own features so that they could be used for different achievements. The first tool was useful for learning the basic sectional anatomy and the axial computed tomographs (CTs) and magnetic resonance images (MRIs) (Fig. 4a); the second tool was for the stereoscopic anatomy (Fig. 4b); the third tool was for the surface anatomy (Fig. 4c); the fourth tool was for the advanced sectional anatomy and the ultrasonograms (Figs. 1, 3) (Table 1). The four learning tools could be utilized in any combinations as users liked it. It might cause the synergic effect especially because all tools were made from the identical data set of a cadaver.

Compared to the previous three tools, the new fourth tool had the following strong points. The fourth tool involved the volume model with the real color of human body, whereas the second tool involved the surface models with the artificial color (Fig. 4b) (Table 1). The volume model demonstrated much morphological information (Figs. 1, 3) unlike the surface models [20].

The fourth tool dealt with the genuine volume model that could be sectioned and rotated at arbitrary angles, whereas the third tool dealt with the captured images of the peeled volume model (Fig. 4c) (Table 1). This result was caused by

Table 1 Comparison of the four learning tools of the Visible Korean

	Data	Color	Dimension	Function of software	Sectioning	Structure identification	Software provider ^a	Data size	Operating speed
First tool	Sectioned images	Real	2D	Browsing	Horizontal	+	Visible Korean team	355 MBytes ^b	++
Second tool	Surface models	Artificial	3D	Selecting, rotating		+	Adobe Inc.	73 MBytes	+
Third tool	Peeled volume model (captured)	Real	2D (looking like 3D)	Browsing	Curved	+	Visible Korean team	391 MBytes ^b	++
Fourth tool	Volume model	Real	3D	Sectioning, rotating	Free	–	MRICroGL team	177 MBytes	+

^aAll data are provided by Visible Korean team

^bSoftware size is included

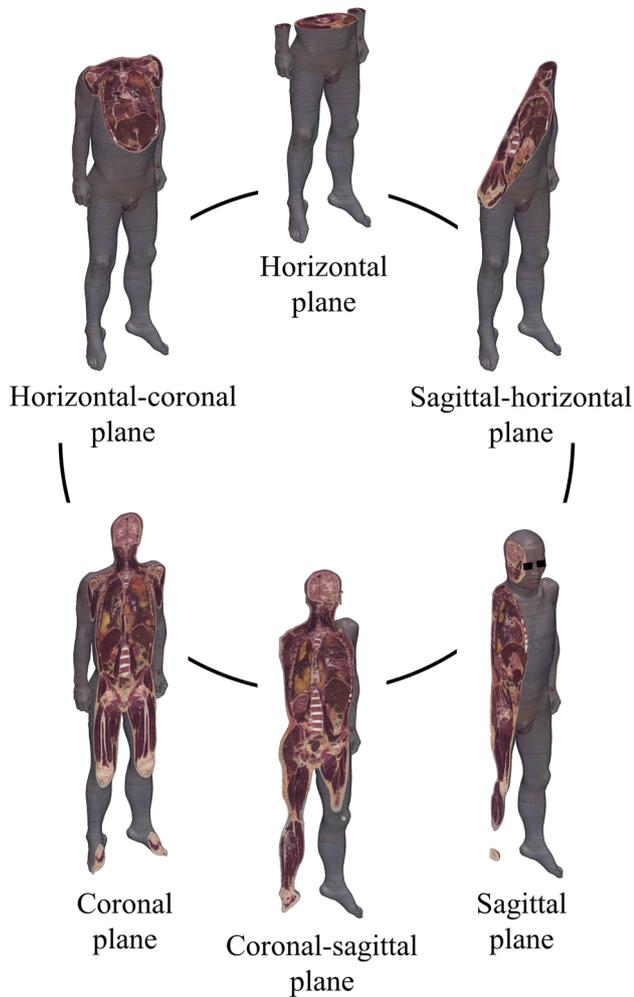


Fig. 1 Three oblique planes of the volume model between its horizontal, coronal, and sagittal planes

the technical difference: for the fourth tool, the technique to section and rotate in real time was developed, whereas for the third tool, the technique to peel and rotate in real time was not [23].

The fourth tool simultaneously displayed the various oblique planes (Figs. 1, 3), whereas the first tool displayed only the horizontal planes (Fig. 4a) (Table 1). By observing the diverse planes together, sectional anatomy may be understood at higher level. It is meaningful because the clinicians should be familiar not only with the orthogonal planes but also with the oblique planes such as ultrasonography.

Discussion

The four tools for virtual anatomy presented in this research are applicable, expansible, and complimentary.

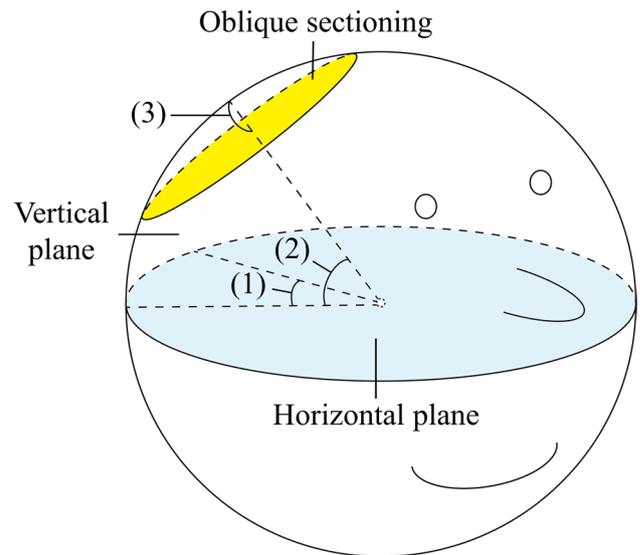


Fig. 2 Conceptual diagram of the azimuth (1), elevation (2), and depth (3)

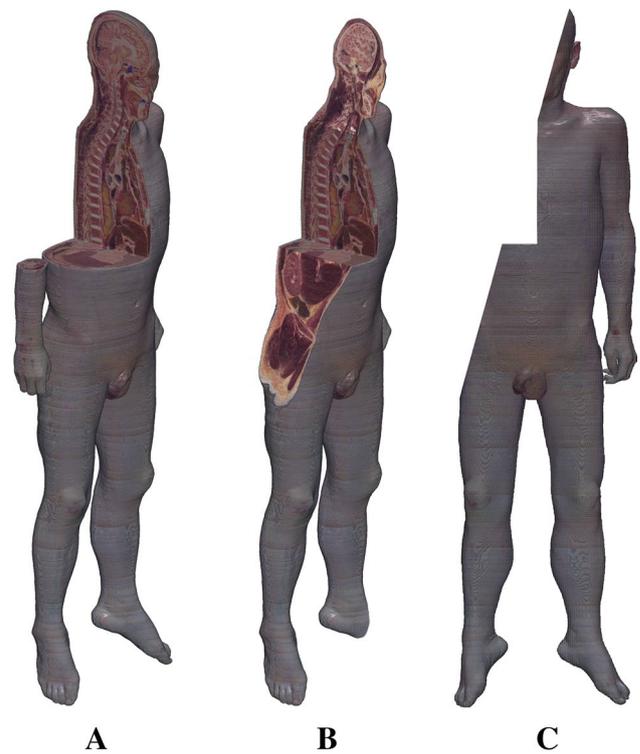


Fig. 3 Volume model with a block part removed (a), which is obliquely sectioned (b), and then rotated (c)

The four tools are collectively available for learning the clinical images such as CTs and MRIs. The software of early three tools, which are the lab-made browsing software and the Adobe Reader version 9 (Adobe Systems, Inc., San Jose, CA, USA), may contain CTs, MRIs, and their 3D models.

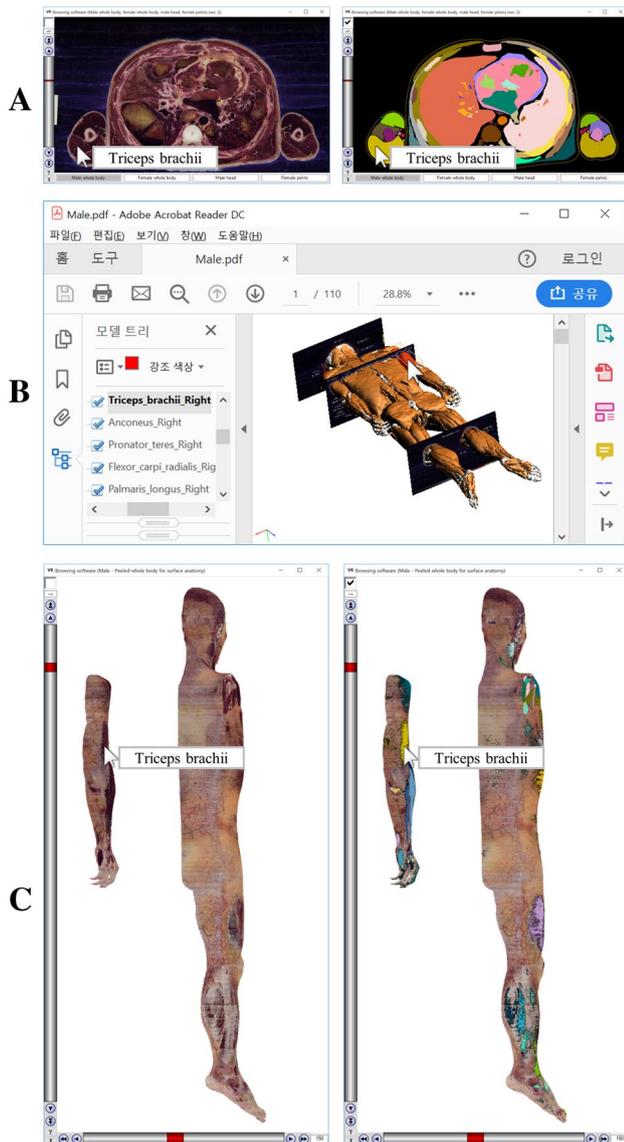


Fig. 4 Former three learning tools displaying the triceps brachii. The first tool shows the sectioned and color-filled images (a); the second tool shows the surface models overlapped by sectioned images (b); the third tool shows the peeled volume models made from the sectioned and color-filled images (c). The clicked structure's name (triceps brachii) is displayed on the pop-up menu (a, c) or on the left window (b)

The software of the fourth tool that enables free sectioning of the volume model is the MRICroGL which has been originally developed to deal with CTs and MRIs (Table 1).

Nevertheless, in this study, the sectioned images have been chosen rather than the CTs and MRIs. It is because the more the detailed structures are discernible and segmented, the higher learning effect is.

In another trial, Visible Human Project data have been employed for handling the volume model on the MRICroGL [16]. Concerning the resultant images, the Visible Korean

data yield the improved quality in spite of the resolution reduced from the original images (Fig. 5).

It is also expected that volume model made of the Visible Korean data is more realistic than that made of other data set. Unlike the sectioned images from Visible Human Project [25] and Chinese Visible Human [36], no dye was injected into the blood vessels when making the sectioned images of this study. Therefore, the blood vessels have been segmented not automatically, but manually on the images of this study using Adobe Photoshop. However, absence of the dye enables the observation of actual color and appearance of the blood vessel without artifacts. Moreover, by not embalming the cadaver, the images of this study have more natural color of body tissues including muscles [18].

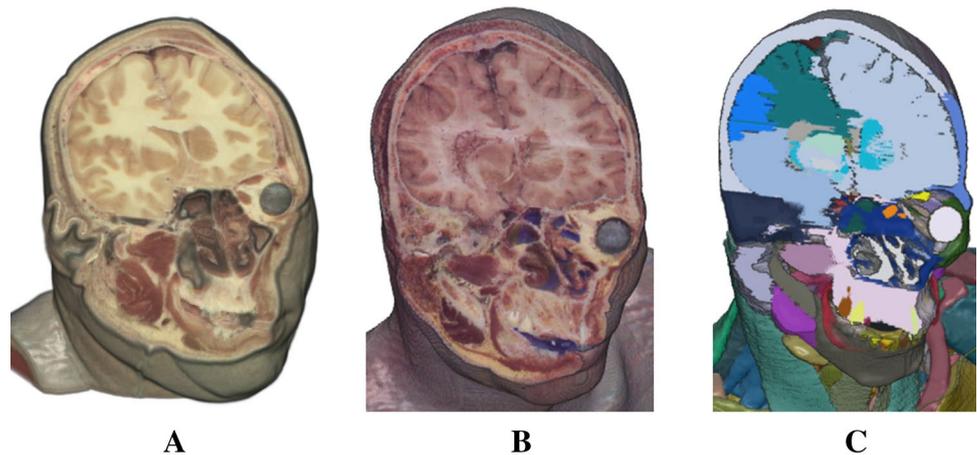
In successive studies, other data sets of the Visible Korean such as that from a female whole body [17] will be the source of the learning tools. On the other hand, alternative segmentation methods can be chosen. For instance, the cardiovascular structures on the female data set of the Visible Korean have been successfully segmented using WinSurf (SURFdriver Software Company, Honolulu, HI, USA). Unlike the Adobe Photoshop, the WinSurf can instantly generate preliminary 3D models for the verification of stereoscopic structures during segmentation [30, 31]. Various materials of the Visible Korean along with various processing methods will produce learning tools that expand the users' options.

By combining the characteristic of four learning tools (Table 1), new learning tools with supplementary effects can be developed. A trial is automatic annotation of the segmented structures. In the first and third tools, the browsing software has a powerful function to show names of the segmented structures based on the color-filled images (Fig. 4a, c) [13]. For the fourth tool, another volume model has been reconstructed with the color-filled images. Oblique planes of the original volume model and those of the color-filled volume model can be simultaneously captured (Fig. 5b, c) and put on the browsing software. As a result, the segmented structures will be conveniently identified to overcome the current weakness of the fourth tool.

Another trial is overlapping the oblique planes and surface models. In the second tool, the sectioned images are selected and inserted into the surface models. It is known that overlapping the 2D images and the corresponding 3D models is the best way to understand the 2D images (Fig. 4b) [7, 21, 22]. The oblique planes of the volume model in the fourth tool (Figs. 1, 5) can be inserted into the surface models. With a number of surface models, structures on the oblique planes will be intuitively identified.

These two trials will be greatly helpful in understanding the oblique planes of body regions. These trials can be applied for learning ultrasonograms of heart and liver [2, 35], the oblique CTs in neuro-ocular plane [3], or the probe's

Fig. 5 Volume models made from the sectioned images of Visible Human Project (a), the sectioned images of Visible Korean (b), and the color-filled images of Visible Korean (c)



eye and trajectory view of MRIs in deep brain stimulation surgery [11, 26]. For such applications, the customized segmentation should be carried out; the resultant surface models and the oblique planes should be cautiously chosen referring to the learning goals.

The free learning tools of Visible Korean differ from the commercial learning tools. In general, the commercial tools comprise the tempting usage environment and function. An instance is Anatomage virtual dissection table using the same Visible Korean data. The table is equipped with the large monitor for life-size and touch screen. Unavoidable limitation is that people can experience the table only in a school or an institute having it. The free tools by the authors permit the participants to preview and review what they learn on the table, namely the free tools have potential for enhancing the learning effect of the commercial tools [6].

Visible Korean team has presented the free learning tools available on the personal computer off-line. Reason is to make students use the tools independent of economy, place, time, or internet access. It does not matter whether students study in group or alone. Moreover, anatomy teachers are allowed to use the presented tools for any lectures and publications without restriction.

Anatomy learning tools on mobile devices have another merit: the portability enables the tools to be utilized even during anatomy lesson or cadaver dissection [29, 34]. Therefore, Visible Korean team has developed the smart phone version of the browsing software [15]. Likewise, the smart phone version or tablet computer version of the other three learning tools could be manufactured by the authors or other investigators.

Virtual reality, which is getting the limelight for its educational benefits, can be applied to the 3D models of this study [8, 19]. Diverse hardware including haptic devices and Hologens will enhance the value of the models [10, 12].

It is also possible that the surface models of the second learning tool are 3D printed with suitable materials [1, 33].

Then the 3D-printed matters can be utilized with the four tools, which will accelerate the learning effect. Furthermore, all of them could be the constituents for virtual reality or augmented reality [4, 27, 28].

In future study, detailed learning effect of the four tools needs to be assessed. So as to obtain it, the appropriate experimental design including questionnaire survey is required.

Conclusion

The four learning tools comprising the outstanding image data and cutting-edge computer technique are expected to contribute to the virtual dissection simulation and to enhance the anatomy knowledge of numerous students.

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Author contributions BSC data management, data analysis, and manuscript writing; MSC project development, data collection, and manuscript writing.

Compliance with ethical standards

Conflict of interest All the authors declare that they have no conflict of interest.

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