

## Automatic 3D Modeling of Liver Segments Including Segmental Branches of Portal Triad and Hepatic Vein Based on the Sectioned-Images

Modelado 3D Automático de Segmentos Hepáticos, con las Ramas Segmentarias de la Tríada Portal y la Vena Hepática Basadas en las Imágenes Seccionadas

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**SUMMARY:** The liver dimensional (3D) models, consists of eight segments including portal triad (portal vein, hepatic artery, and bile duct), are necessary because it is difficult to dissect a liver and its inner structures. But it is difficult to produce 3D models from high resolution and color sectioned-images. This study presents automatic and accurate methods for producing liver 3D models from the sectioned-images. Based on the sectioned-images and color-filled-images of the liver, a 3D model including both the portal triad and hepatic vein was made. Referring to the 3D model, 3D models of liver's eight segments including the segmental branches of the portal triad and hepatic vein were completed and saved as STL format. All STL files were combined and saved as Liver-3D in PDF format for the common user. By functional subdivision of liver, the Liver-3D was divided into left (segments II, III, and, IV) and right (segments V, VI, VII, and VIII) liver in bookmark window of the PDF file. In addition, in Liver-3D, the primary to tertiary segmental branches of the portal triad could be shown in different colors. Owing to the difficulty of 3D modeling of liver including eight segments and segmental branches of the portal triad and hepatic, we started this research to find automatic methods for producing 3D models. The methods for producing liver 3D models will assist in 2D selection and 3D modeling of other complicated structures.

**KEY WORD:** Liver; Hepatic veins; Cross-sectional anatomy; Three-dimensional imaging; Visible Human Projects.

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### INTRODUCTION

The liver segments including the portal triad (portal vein, hepatic artery, and bile duct) and hepatic vein are very important clinically. Therefore, anatomical dissection of liver is being performed for medical education of not only medical students but also clinician. However, it is not easy to dissect a liver because its segments, portal triad, and hepatic vein are complicated. To overcome the difficulty of a liver dissection and improve the accuracy of a surgical operation, three dimensional (3D) models of a liver from computed tomography (CT) or magnetic resonance imaging (MRI) are used in anatomy and surgery education (Shin *et al.*, 2009; Goryawala *et al.*, 2014; Le *et al.*, 2015; Li *et al.*, 2015). On the other hand, it is difficult to produce 3D models of the segments with segmental branches of its artery, duct, and vein from CT, MRI, and sectioned-images. In case of CT and MRI, 3D models can be made automatically, but the 3D models are not sophisticated (Liu *et al.*, 2013; Goryawala *et al.*; Dong *et al.*, 2015; Le *et al.*; Li *et al.*; Gotra *et al.*, 2017).

Unlike CT and MRI, in sectioned-images of high resolution (0.1 mm X 0.1 mm X 0.1 mm sized-voxel) and real color (48 bit color), the terminal branches of the portal triad and hepatic vein can be seen (Park *et al.*, 2005, 2015). Despite this, 3D models of the segments and segmental branches of the liver cannot be made automatically (Shin *et al.*, 2009) for the following reasons. First, there are no boundaries of the liver segments at not only outer surface, but also at the inner parenchyma. Second, the portal triad and hepatic vein cannot be distinguished in the two dimensional (2D) images. Third, each branch of the portal triad and hepatic vein in liver is quite complicates. Therefore, we tried to outline the sectioned-images manually in previous work (Shin *et al.*, 2009), but it was quite tedious and time consuming.

The aim of this study was to develop automatic and accurate methods for producing liver 3D models from high resolution sectioned images. Another purpose was to present

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3D models of the liver segments and terminal branches of the portal triad and hepatic vein in a PDF file that can assist in learning and training with anatomy and clinical surgery. To achieve of this 3D models of liver segments with segmental branches of the portal triad and hepatic vein were produced from the sectioned-images.

## MATERIAL AND METHOD

In a previous study, 4,935 sectioned-images of a whole female body and 1,642 color-filled-images of 27 structures including the liver surface were made (Park *et al.*, 2015). For this study, the 651 sectioned-images of the abdominal region (intervals, 0.2 mm; pixel size, 0.1 X 0.1 mm $\Sigma$ ; bit depth, 48 bit color) and the color-filled-images, including the liver and inferior vena cava, were used.

**1. First step: Producing a Ref-3D of the portal triad and hepatic vein together.** Using the ‘Magic wand’ tool on Photoshop CC 2015 (Adobe Systems, Inc., San Jose, CA, USA), by clicking the inferior vena cava in the sectioned-images, similar-colored structures both on the inside and outside of the liver were selected simultaneously. The most selected-structures were the portal triad and hepatic vein in inside the liver and some selected-structures were several structures in outside the liver. Using the sections of liver surface in the previous study (Park *et al.*, 2015), the outside selected-structures were deleted automatically by ‘Select-Inverse’ and ‘Action-Batch’ tools. Consequently the portal triad and hepatic vein in the liver selected. The selected structures were filled automatically with a color and saved as A-color-filled-images in BMP format (Fig. 1A; Table I).

The A-color-filled-images were imported in Mimics version 10.01 (Materialize, Leuven, Belgium). On Mimics,

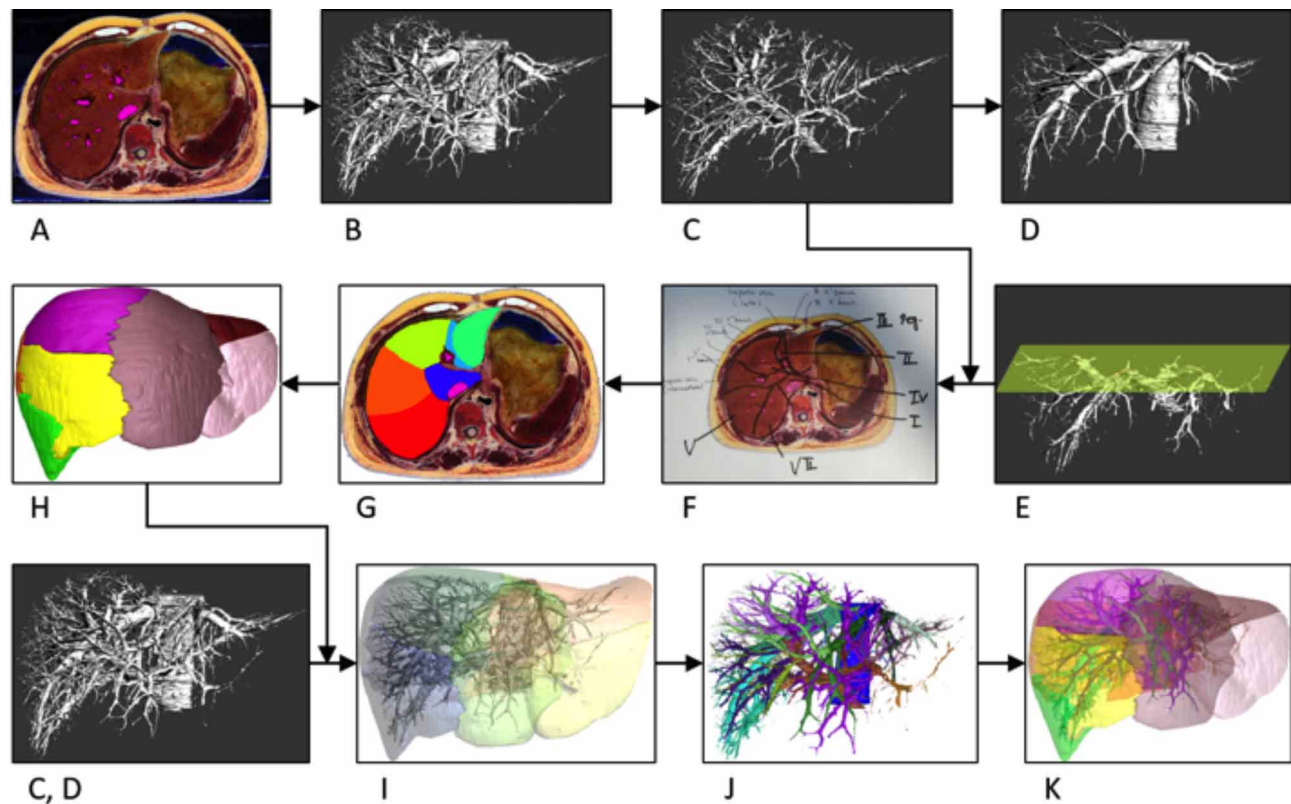


Fig. 1. Procedures for making automatically Liver-3D.pdf. In the first step, A-color-filled-images of whole branches of both the portal triad and hepatic vein are automatically made of the sectioned images (A). Ref-3D is automatically made of a pink color in A-color-filled-images (B). From Ref-3D, Portal-triad-3D (C) and Hepatic-vein-3D (D) are separated manually and automatically respectively. In the second step, the segmental branches of the portal triad are identified using the cross-sectioning view the Portal-triad-3D (E). The identified branches are drawn and their names are written on printed papers (F). Referring to the identified branches in the papers, 8 segments of the liver are outlined on the papers (F). Referring to the papers (F), Color-filled-images of the liver's 8 segments are manually made of A-color-filled-images (G). Segment-3D was made automatically from the Color-filled-images by surface modeling (H). From Portal-triad-3D (C) and Hepatic-vein-3D (D) using Segment-3D (H), each segmental branch of are separated automatically (I) to make a Portal-triad-branch-3D and Hepatic-vein-branch-3D (J). All 3D results are combined into the Liver-3D (K).

Table I. Sequential procedures for segmentation and 3D modeling of liver.

Step	Procedures (software)	Raw data	Resultants		Fig.
			File name (file format)	Structures	
First	Automatic selecting (Photoshop)	Sectioned-images	A-color-filled-Ref-3D (stl)	Whole branches of both PT and HV	A
	Automatic 3D modeling (Mimics)	A-color-filled-Ref-3D	Portal-triad-3D (stl)	Portal triad	B
	Manual separating (Maya)		Hepatic-vein-3D (stl)	Hepatic vein	C
	Automatic separating (Maya)				D
Second	Manual segmenting (Photoshop)	A-color-filled-images	Color-filled-images (bmp)	Eight segments of liver	G
	Automatic 3D modeling (Mimics)	Color-filled-images	Segment-3D		H
Third	Semi-automatic dividing (Maya)	Portal-triad-3D	Portal-triad-branch-3D (stl)	Segmental branches of portal triad	J
		Hepatic-vein-3D	Hepatic-vein-branch-3D (stl)	Segmental branch of hepatic vein	J
Final	Automatic combining all 3D	All 3D files of STL	Liver-3D (pdf)	8 segments of liver including	K

PT, portal triad; HV, hepatic vein.

the A-color-filled-images were reconstructed using the 'Calculate 3D' tool to produce a referential 3D model (Ref-3D) of STL format (Fig. 1B; Table I).

In the Ref-3D including both the portal triad and hepatic vein, the hepatic vein was removed manually to produce a Portal-triad-3D using Maya version 2016 (Autodesk, Inc., San Rafael, CA, USA) because the hepatic vein was not as complicated as the portal triad in either Ref-3D or the real liver. In the Ref-3D, the Portal-triad-3D was subtracted automatically using the 'Boolean' tool to leave the Hepatic-vein-3D (Fig. 1C, 1D; Table I).

**2. Second step: Making eight segments of the liver.** After each segmental branch of the portal triad was identified in Ref-3D using the cross-sectioning view of the 'Toggle Cross Section' tool on Adobe Reader version 9 (Adobe Systems, Inc., San Jose, CA, USA) (Fig. 1E), the identified branches were marked on the printed paper of the sectioned images (Fig. 1F). In the identified branches, the tertiary branches were set as the criterion of the liver segments according to the anatomy textbook (Moore *et al.*, 2014). According to the criterion, the boundaries of eight segments of the liver are marked on the papers (Fig. 1F). Referring to the papers, eight segments were outlined on A-color-filled-images using the 'Lasso' tool and filled automatically with a specific color to make the Color-filled-images on Photoshop (Fig. 1G). The Color-filled-images were reconstructed by surface modeling and saved as Segment 3D-I to Segment-3D-VIII in STL format on Mimics (Fig. 1H).

**3. Third step: Producing 3D models of the segmental branches of the portal triad and hepatic vein.** Portal-triad-3D in the first step and segment-3D-I in the second step were

loaded in Maya together. The intersection of the portal triad and segment I were extracted automatically using the 'Boolean' tool and saved as Portal-triad-branch-3D-I. In the same way, segmental branches of the portal triad in segments II to VIII were divided and saved as Portal-triad-branch-3D-II to -VIII in STL format. Also, in the same manner, branches of the hepatic vein were divided by segment-3D-I to -VIII and saved as Hepatic-vein-branch-3D-I to -VIII of STL format (Fig. 1I, 1J; Table I).

**4. Final step: Combining all 3D models.** All STL files of eight segments and segmental branches of the portal triad and hepatic vein were loaded on the Deep Exploration Standard (Right Hemisphere, San Ramon, CA, USA), which was used to produce a list tree of the 3D structures. The combined STL files were saved as Liver-3D of PDF format (Fig. 1K; Table I).

## RESULT AND DISCUSSION

The 3D models of the liver including the eight segments and segmental branches of the portal triad and hepatic vein were produced and stored as STL file, which has high applicability (Fig. 2; Table I). For the common user, the STL files were put into a PDF file and the PDF file can be downloaded freely at neuroanatomy.kr.

A human liver is classified into two viewpoints: Anatomical lobes and functional subdivision. By functional subdivision, segments II, III, and IV of the left liver and segments V, VI, VII, and VIII of the right liver in the Liver-3D could be shown in bookmark window of Acrobat Reader. In addition, in Liver-3D, the primary to tertiary segmental

branches of the portal triad could be shown in different colors. Although the tertiary or more branches of the portal triad and hepatic vein could be shown in Liver-3D, the color of the branches was identical (Fig. 2). In the case of the hepatic vein, each segmental branches of the vein was shown instead of the right, intermediate, and left hepatic vein in the textbook (Moore *et al.* ).

The volume of the each structure could be measured by the STL file size. In contrast, the right liver was larger than the left, the largest segment was segment IV in the left lobe (55.8 MB). Segment II in the left lobe was the smallest (27.6 MB) to almost half that of segment IV. Segmental branch IV of the portal triad was the largest like segment IV. Segmental branch VI was the smallest. In the segmental branches of the hepatic vein, the largest was VII, which was similar to that segment VII (Table II).

In the sectioned-images, the main to terminal branches of the portal triad and hepatic vein could be identified by the naked eye due to the high resolution and real color (Park *et al.*, 2009, 2010; Shin *et al.*, 2012) unlike MRI and CT. In the sectioned-images, however, it was difficult to separate automatically or manually the whole branches in the liver for 3D modeling because of the considerable color information by the high resolution and real color. In particular, the high resolution and true color of the images are both a strength and

weakness. Therefore, easier and more accurate separation methods of the liver structures are needed for 3D modeling.

In liver 3D modeling, there are two difficulties. First was selection of the segmental branches of the portal triad and hepatic vein in sectioned-images. Second was that the selected branches were divided into segmental branches. To solve the difficulties, 2D (sectioned-images) selection and 3D division were used as follows.

The criterion of auto-selection for the portal triad and hepatic vein from main to terminal segmental branches was the similar color in the sectioned-images. We choose the inferior vena cava with a similar color to the portal triad and hepatic vein. The inferior vena cava existed in every sectioned-image, was large enough, and did not change its position significantly. Therefore, anyone would find it easy to locate and select it automatically. In this study, by clicking the inferior vena cava in the sectioned-images using the 'Magic wand' tool in Photoshop, most of the portal triad and hepatic vein were selected automatically.

The criteria of auto-division for the segmental branches of a portal triad and hepatic vein were the intersection regions in the 3D models. There is 'Boolean' tool in Maya in that the intersection region at two objects can be chosen. After making Segment-3D of liver, the

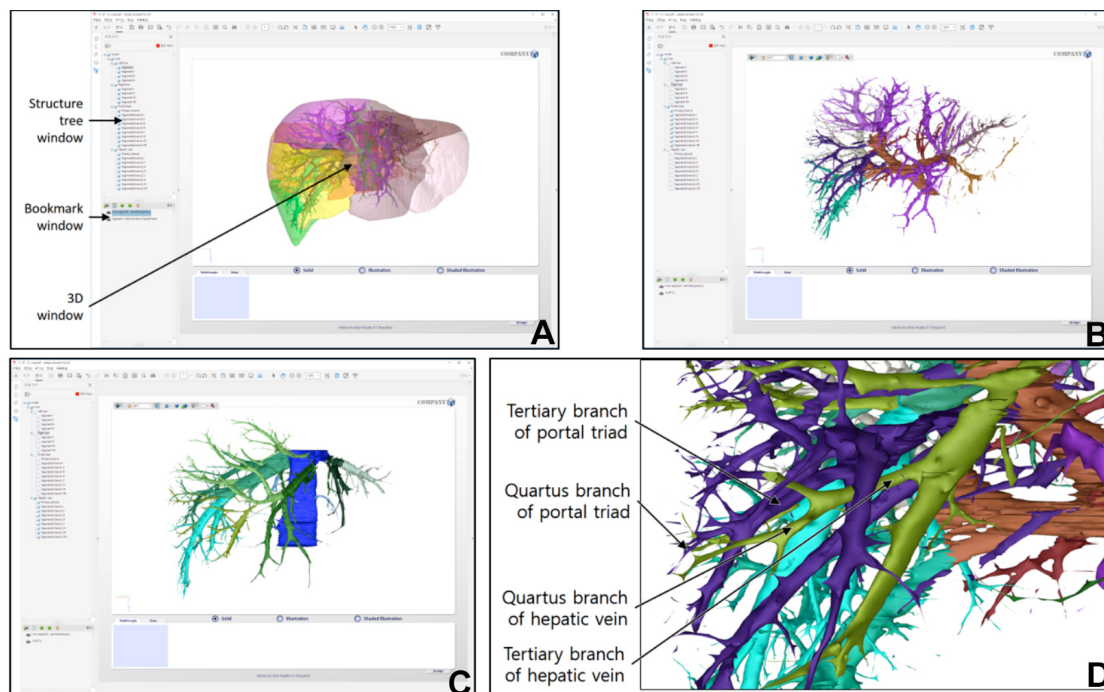


Fig. 2. Liver-3D in Adobe Reader. In the Liver-3D of the 3D window, whole branches of portal triad and hepatic vein can be selected and manipulated freely by mouse dragging and wheel rotating (A). By selecting a view in the bookmark window, each segmental branches of the portal triad (B) or hepatic vein (C) can be shown either individually or together. The portal triad and hepatic vein in liver-3D can be magnified to the tertiary or more branches.



Table II. STL file sizes of eight segments and segmental branches of the portal triad and hepatic vein.

	Part	Segment (MB)	Segmental branch	
			Portal triad (KB)	hepatic vein (KB)
Left	I	33.9	1,046	459**
	II	27.6**	1,227	1,561
	III	32.6	1,302	829
	IV	55.9*	6,493*	3,232
Right	V	33.7	2,885	1,557
	VI	29.2	572**	2,408
	VII	47.7	729	9,029*
	VIII	43.0	816	2,878

\*Biggest structure in the column; \*\*Smallest structure in the column; The primary segmental branch of the portal triad were 11.1 MB.

intersection regions of each segment in the Segment-3D and each segmental branch in Portal-triad-3D or Hepatic-vein-3D occurred. The intersection segmental branches could be divided automatically using 'Boolean' tool in Maya. Automatic process would be easier and time saving.

The liver 3D models of this study will assist in the anatomical and clinical education of medical students and medical doctors. In addition, the methods for making liver 3D models will assist in 2D selection and 3D modeling of other structures. We distributed the Liver-3D of PDF file free of charge at neuroanatomy.kr.

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**RESUMEN:** Los modelos hepáticos dimensionales (3D) consisten en ocho segmentos que incluyen la tríada portal (vena porta, arteria hepática y conducto biliar), y son necesarios ya que es difícil disecar un hígado y sus estructuras internas. Sin embargo, es difícil producir modelos 3D a partir de imágenes en alta resolución e imágenes seccionadas en color. Este estudio presenta métodos automáticos y precisos para producir modelos 3D de hígado a partir de las imágenes seccionadas. Sobre la base de las imágenes seccionadas y las imágenes del hígado llenas de color, se realizó un modelo 3D que incluía tanto la tríada portal como la vena hepática. En referencia al modelo 3D, se completaron modelos 3D de los ocho segmentos del hígado que incluían las ramas segmentarias de la tríada portal y la vena hepática y se guardaron como formato STL. Todos los archivos STL fueron combinados y guardados como Liver-3D en formato PDF para el usuario común. Por subdivisión funcional del hígado, el hígado-3D se dividió en hígado izquierdo (segmentos II, III y IV) y derecho (segmentos V, VI, VII y VIII) en la ventana de marcador del archivo PDF. Además, en Liver-3D, las ramas segmentarias primarias a terciarias de la tríada

portal podrían mostrarse en diferentes colores. Debido a la dificultad del modelado 3D del hígado, incluidos ocho segmentos y ramas segmentarias de la tríada portal y hepática, comenzamos esta investigación para encontrar métodos automáticos para producir modelos 3D. Los métodos para producir modelos 3D de hígado ayudarán en la selección 2D y el modelado 3D de otras estructuras complicadas.

**PALABRAS CLAVE:** Hígado; Venas hepáticas; Anatomía transversal; Imagenología tridimensional; Proyectos humanos.

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