Creating computer aided 3D model of spleen and kidney based on Visible Human Project

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ABSTRACT

Objective: To investigate the efficacy of computer aided 3-dimensional (3D) reconstruction technique on visualization and modeling of gross anatomical structures with an affordable methodology applied on the spleen and kidney.

Methods: From The Visible Human Project Dataset cryosection images, developed by the National Library of Medicine, the spleen and kidney sections were preferred to be used due to their highly distinct contours. The software used for the reconstruction were SurfDriver 3.5.3 for Mac and Cinema 4D XL version 7.1 for Mac OS X. This study was carried out in May 2004 at the Department of Anatomy, Hacettepe University, Ankara, Turkey.

Results: As a result of this study, it is determined that these 2 programs could be effectively used both for 3D modeling of the mentioned organs and volumetric analyses on these models. It is also seen that it is possible to hold the physical models of these gross anatomical digital ones with stereolithography technique by means of the data exchange file format provided by the program and present such images as anaglyph.

Conclusion: SurfDriver 3.5.3 for Mac OS and Cinema 4 DXL version 7.1 for Mac OS X can be used effectively for reconstruction of gross anatomical structures from serial parallel sections with distinct contours such as spleen and kidney and the animation of models. These software constitute a highly effective way of getting volumetric calculations, spatial relations and morphometrical measurements of reconstructed structures.

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The first 3-dimensional (3D) reconstructions from serial sections were carried out by Born[1] in 1883 and His[2] in 1885. Since then a variety of reconstruction techniques has been developed, and the building of physical models has become a valuable tool in morphological sciences. These techniques were primarily used for analyzing complex structural relationships and morphogenetic processes.[3]

In the 1880's, Born[1] and His[2] made their reconstructions by putting one cut-out wax plates above the other, a technique which were tiring and time consuming. But nowadays, it is easier to get 3D reconstructions, parallel to the improvements of computer technology. It is clear that computer assisted physical or digital models have a lot of advantages to the classical anatomical drawings. Among these is the better visualization of an object. It is possible to perceive the spatial position and relations of objects with adjacent organs, with sensitivity close to the information held from direct contact with the anatomical structures. In this context, it is arguing that this type of models would settle to a closer range to the cadavers in modern anatomy education.[4] Additionally, 3D reconstructions of the anatomical structures have a noteworthy importance on preparing educational simulations, surgical planning, virtual endoscopic and surgical practices. The Visible Human Project

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dataset by the National Library of Medicine,[5] the most complete computerized cross-sectional image database of the human body ever assembled, enables the creation of 3D models of the human body. The high resolution data of the Visible Human Male is an ideal basis for a computerized 3D modeling.

The practice of computer assisted 3D reconstruction technique on Visible Human Project Male Dataset's of left kidney and spleen is a method currently used today, with the purpose of developing an affordable and coherent methodology that could be easily used by numerous researchers.

Methods. ***Cadaver***. In our methodological study, a 38-year-old male cadaver from Visible Human Project Male dataset was used. This cadaver is 71 inches in height and weighting 199 lbs. There were no reported pathologies except for an appendectomy at the age of 21, left orchiectomy at 15 and extracted number 14 tooth at 38. The cadaver was fixed by injecting 19 liters of 1% formalin and anticoagulant from the right femoral artery. Sixteen liters of the formalin was injected in the cranial and 3 liters in the caudal direction. The cadaver was frozen with 150 lbs of dry ice and followed with another 175 lbs of the same. Parallel serial sections obtained with cryomacrotoming technique was photographed on high resolution.[5]

Data acquisition. To obtain the computer assisted 3D reconstruction of the spleen and left kidney that is in close relation with the spleen, we used the Visible Human Project Male Dataset's cross-sectional cryosections, which has 1 mm intervals (**Figure 1**).

When purchasing a licensed SurfDriver 3.5.3, one can get and use these sections that include in the software. These sections have 1 mm intervals and are 1878 in number (it can be easily calculated that the total specimen length is 187.8 cm). The most cranial (first) section has the number 1001 and the most caudal (last) one has 2878. One hundred and eighty-one sections (equals the number of the last section used less the number of the first section used plus one) were used for the reconstruction. They were between number 1487 where the spleen appears, and number 1667 where the last contours of the left kidney were seen. The sections where the spleen and left kidney are in relation are between the number 1562 where the left kidney appears and number 1607 where the spleen was seen lastly. These 181 sections have contours of the spleen or the left kidney. Each has 72 pixels per inch of resolution, 1748 x 966 pixels of dimension. File sizes were approximately 290 KBytes and all the sections were transferred to SurfDriver 3.5.3 for Mac OS as a block.

Software used. In our study, SurfDriver 3.5.3 for Mac OS software was used in order to trace and reconstruct the serial parallel cryosections that was digitalized. This program was highly effective, especially on reconstruction, volumetric analyses, viewing spatial relations and morphometrical measurement steps of the digital images. Cinema 4D XL version 7.1 for Mac OS X was used for advanced retouching of the post-reconstructive images. This second software also enabled us to animate the transferred reconstruction in a chosen scenario, to save the animation as a movie file in any preferred format and to obtain the stereopairs of the reconstructed models. Additional information on the software used in this study is available from http://www.surfdriver.com and http://www.maxon.net URL addresses.

Hardware used. In this study, Apple PowerMac G4 1.25 MHz Dual Processor computer was used. The technical properties of the computer can be listed as 512 MB RAM, 80 GB hard drive and Apple 23 inch Cinema Display. The system software operating on this hardware is Mac OS X 10.2.8 (Jaguar). As SurfDriver 3.5.3 does not support Mac OS X, the system software of the computer was switched to Mac OS Classic 9.2 when needed. Wacom Graphire 2 graphic tablet was used for tracing the contours as freehand. In some sections where the contours were presenting high contrast and evident distinction with the neighboring structures, the automatic contour selection tool of the software was also used.

Tracing of anatomical structures. The main principle of computer assisted 3D reconstruction is to introduce the structure or area (region of interest (ROI)) on the serial parallel cross-sections into the computer, manually or automatic. This process was expressed as term "segmentation" in image analysis. Segmentation is a term that are mainly used in the reconstructions of radiological images, in the event of reconstruction of gross or microscopic anatomical sections, although the process is entirely the same, the term "contour tracing" was used. In our study, we made the tracing or ROI from the Visible Human Project Male Dataset's serial cryosections with semi-automatic contour-tracing tool provided by SurfDriver 3.5.3 (**Figure 2**). A specific anatomical knowledge is needed for tracing (segmentation) of the cross-sectional images. Thus, insufficiencies of the boundary detection that the software automatically provides were corrected manually. By this manner, all contours concerning the spleen and left kidney within the sections transferred to the program were traced.

Three-dimensional reconstruction. After segmentation (or tracing) of the boundaries of the anatomic structures (spleen and left kidney) by

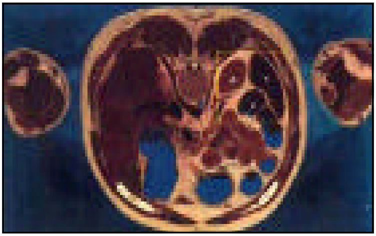


Figure 1 - An example of the cryosections within the Visible Human Project dataset. The rectangle in yellow represents the area of the reconstruction as a whole. This area is expressed as ROI (region of interest) in image analysis. LK - left kidney, S - spleen, LI - large intestine near the left colic (splenic) flexure.

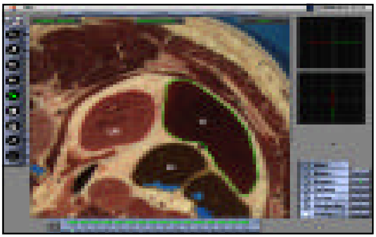
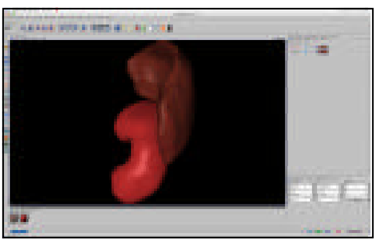


Figure 2 - A view of the user interface of the software where reconstructions have been made (SurfDriver 3.5.3). The cryosection numbered 1570 in Visible Human Project dataset was processed for the reconstruction. With the tools seen on the left side of the monitor, the contours of the spleen are marked as green and the left kidney with red. The right arrow enables the user to go to the next section and the left arrow to the previous. When the process finished, one should click the "done" button to have the reconstruction. LK - left kidney, S - spleen, LI - large intestine near the left colic (splenic) flexure.



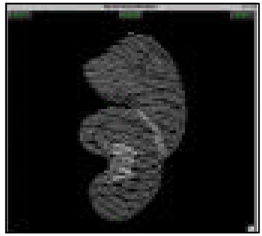


Figure 3 - After having finished marking the contours of all the sections within ROI, it is passed to a wire-frame reconstruction step. Then the model is rendered with the triangulation of the neighboring contours. ROI - region of interest.

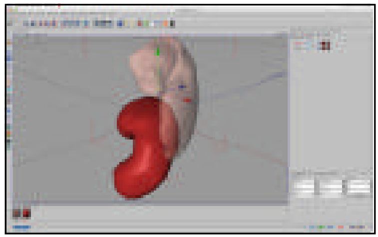


Figure 4 - The reconstructed models from the SurfDriver are transferred to Cinema 4D XL version 7.1 in DXF format. This software provides cover to the model surfaces with a preferred material or adjust the transparency if needed. It is possible to rotate the objects in X, Y or Z-axis or move in a chosen scenario with this program. The software enables photorealistic rendering of the 3D models with its advanced user interface. DXF - Data exchange file, 3D - 3 dimensional

Figure 5 - A view of photorealistically reconstructed Visible Human Project Male left kidney and spleen in Cinema 4D XL version 7.1 window. It was given 70% opacity (30% transparency) to the spleen surface in order to demonstrate its close relation with the left kidney on its visceral surface.

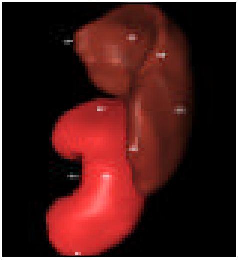


Figure 6 - The photorealistic view of the left kidney and the spleen of the Visible Human Project Male Dataset. All the anatomical details belonging to the 2 organs can be seen with a high sensitivity. PP - posterior pole, GI - gastric impression, AB - anterior (crenate) margin, AP - anterior pole, DS - diaphragmatic surface, SP - superior pole, AS - anterior surface, IP - inferior pole.

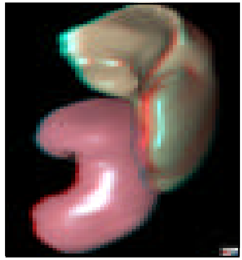


Figure 7 - An anaglyphic image of reconstructed objects. Anaglyphic views are images where deepness could be perceived using special glasses. It should have red glass at right and blue glass at left eye in order to perceive the deepness of this anaglyphic image, which was obtained from the processing of the reconstructed objects with Adobe Photoshop 7 software. Three-dimensional view could not be sensed by 3% of the viewerpopulation who have color blindness (Daltonism) even if they use anaglyphic glasses.

cross sections, 3D reconstruction was performed to create computerized anatomic models of these structures with a slice interval of 3 in Surfdriver 3.5.3 for Mac OS. Initially the wire-frame (**Figure 3**) and the surface-rendered reconstructions were obtained by the software. The dimensions of the reconstructed objects were measured and recorded with the ruler tool that is located on the user interface of the program. The anatomic structure was measured in millimeters (mm) considering the slice thickness, which was introduced as 1 mm. In addition to the dimensional measurements, the volumetric measurements of the objects were performed by SurfDriver and recorded by the default format of the software. Following the measurements, the reconstructed models were re-saved in DXF (Data Exchange File) format. This format enables the reconstructed models to be processed in more professional programs such as Cinema 4D XL version 7.1 (**Figure 4**), which enables the digital models to transform into solid form with CAD/CAM applications (such as stereolithography) or to make advanced manipulations of models and increase the transparency of the surfaces in order to demonstrate the spatial relationships.

Retouching, rendering, generating stereopairs and movies. The models of the spleen and left kidney were recorded in DXF format and imported to Cinema 4D XL version 7.1 software. With this program, the manipulation of the polygons that form the model surfaces was performed; also the colors and transparency degrees of the surfaces were assigned. The models which were together at X, Y and Z axis, center coordinated (0,0,0) (**Figure 4**) were rendered again as high resolution images in a smooth form (**Figures 5 & 6**). In addition, stereopairs were obtained resulting from 5 degrees rotation of the models in Y axis. These stereopairs were processed with Adobe Photoshop 7.0 software and anaglyphic images of the objects were held (**Figure 7**). Anaglyphic images are specific images that can be seen with specialized anaglyph glasses that allow only one part of the stereopair to be visualized by each eye and so deepness is perceived with a cerebral organization. To see the anaglyphic views of our models, anaglyphic glasses with red glass in the right and blue glass in the left half should be used.

Results. Using the methods described above, we built a digital model of the left kidney and spleen of the Visible Human Man. The results we obtained from this digital model could be arranged in 2 groups: morphometrical results and methodological results.

Morphometrical results. With the morphometrical evaluation of the spleen reconstruction, its dimensions were found 135.418 x 67.195 x 58.274 mm. The first one was the length of the spleen along its long axis. This axis extends from the superior to inferior and from the posterior to anterior. The second diameter, which measured 67.195 mm, was the length of the spleen between the most projecting points of the superior and inferior margins; this vertical diameter could be named as the height of spleen. The latter 58.274 mm was the length between the visceral and diaphragmatic surfaces and can be assumed as the thickness of the spleen. The total volume of the spleen was 252579.3 mm^3, using SurfDriver 3.5.3 the morphometrical measurements have been made (this calculation was established on an algorithm in which the area of the traced structures, the thickness, number and interval of the sections were taken into consideration). This value is equal to 252.579 cm^3.

With the morphometrical evaluation of the left kidney, its dimensions were found 117.145 x 48.014 x 45.426 mm. The first one was along the long axis of the left kidney and named as its height. The second was the width of the kidney, which is between the hilum and the most convex point of the lateral border. The latter 45.426 mm is the distance between the most projecting points of the anterior and posterior surfaces of the kidney and can be expressed as its thickness. The volume calculated for the left kidney was 199721.5 mm^3 or 199.722 cm^3.

Methodological results. The most important methodological result is the demonstration of SurfDriver and Cinema 4D XL pair, which can be reliably used for the computer-aided reconstructions of the serial parallel sections of gross anatomical structures.

The first program of the pair, SurfDriver 3.5.3 for Mac OS, has some limitations from the aspect of the user interface of the program. But the software has many advantages such as automatic contour detection, enabling the realignment of the sections that have alignment or rotation problems, allowing to introduce and customize the thickness, interval and dimensions of the sections. On the other hand, the volumetric and dimensional measurement tools within the software gives a large amount of information on the numerical values, in addition to viewing the object that the researcher is interested in. In our aspect, the most important feature of the software is the possibility of transfer of the reconstruction into more professional programs in DXF format. It is observed that this program is a unique alternative for similar applications, with its price approximately US$ 400, including the Visible Human Project Male Dataset. The point in consideration, is surely the optimal performance and price relation. Indeed, the methodological results are highly satisfactory as understood from the numerous figures given within the article.

The second software, which should be handled on methodological results is Cinema 4D XL. The user interface of this software was designed professionally. It is possible to take the data from SurfDrive without any problem. The surface features and details of the reconstructed objects can be easily performed with the Body Paint tool, which is included in the program. The software enables easy manipulation of the spatial features of the reconstructed object. With this property, it is possible to get stereopairs of the model and establish anaglyphic images that deepness is perceived visually. **Figure 7** shows the anaglyphic example of the models we obtained. The deepness of this image can be easily perceived using anaglyphic glasses with red glass at the right, blue glass at the left eye side. The anaglyphic glasses can be obtained from URL: http://www.3dstereo.com. The software provides communications and supports with CAD/CAM applications by means of Virtual Reality Modeling Language (VRML) formats. It is also possible to have solid models of the reconstructions with a cost of 2.5 Euros per 1 cm^3 (http://www.cadem.com.tr). In addition, the program can animate the models as QuickTime files, which are mostly widespread movie-sharing format. It is possible to reach an animation of the viscus models that we have reconstructed in this study(http://www.aldur.net/3d.mov).

Discussion. Computer-aided 3D reconstruction was first introduced by Glaser and Van Der Loos[6] in 1965. A review of 54 different software packages, using an assessment system that included 173 items for computer aided 3D reconstruction, was prepared by Huijsmans et al[7] in 1986. With the improvements in both computer hardware and software engineering tools, computerized modeling of anatomical and histological morphologies has become very useful for visualizing complex 3D forms. Computer models not only provide a means to visualize complex morphology derived from 2-dimensional tissue or organ outlines, they also permit mathematical modeling of growth or function attributes not otherwise observable.[8] A lot of software have been developed, numerous computer aided reconstruction techniques, which uses these software and many studies using these techniques on gross or microscopic anatomy have been introduced parallel to the technological developments.[9-13] The important point was to determine an affordable and current technique especially for the use of researchers or laboratories, which have a middle level financial support. This study describes an easy and reliable methods for computed 3D reconstruction of gross anatomic serial sections based on Visible Human Project dataset.

Computer print outs or photographs of a 3D image rarely provide an impression of the 3D structure. The computer aided 3D reconstruction of the gross anatomic structures is useful for demonstrating the shape and size of structures, for showing relationships between the organs, for demonstrating connection between structures and for performing volumetric measurements on tissues that would not normally be suitable for examination due to their small size. There are several reasons for choosing computer reconstruction: volumetric calculation, measurement of structures and assessing precise relationships of these structures. Additionally, viewing of a rotating image on computer screen gives a clear understanding of 3D relationships of the reconstructed structures.

The coherence between volumes and dimensions of the spleen and kidney; reconstructed with the dimension and volume measurement studies for the spleen[14] and the kidney[15] in literature, exactly brings out the efficacy and the compatibility of the technique on volumetric and morphometrical calculations. Also, the technique can be used for the reconstruction of either gross or microscopic anatomical structures.

Stereolithographic biomodeling is a new technology that allows 3D imaging data to be used in the manufacturing of accurate solid plastic replicas of anatomical structures. The biomodels can be used for diagnosis, operative planning, surgical simulation, instruction for less experienced neurosurgeons, and patient education. The major advantage of this technology is that surgeon can closely study complex anatomical structures from any perspective using a haptic, "real reality" biomodel, which can be held, allowing simulation of intraoperative situations and anticipation of surgical challenges.[16] Stereolithography is a computer-mediated method that can be used to quickly create anatomically and correct 3D epoxy and acrylic resin models from various types of medical data. Multiple imaging modalities can be exploited, including computed tomography, magnetic resonance imaging, and gross anatomical serial sections. The technology was first developed and used in 1986 to overcome limitations in previous computer-aided manufacturing/milling techniques. Stereolithography is presently used to accurately reproduce both the external and internal anatomy of body structures. Current medical uses of stereolithography include preoperative planning of orthopedic and maxillofacial surgeries, the fabrication of custom prosthetic devices; and the assessment of the degree of bony and soft-tissue injury caused by trauma.[17-19]

In conclusion, the SurfDriver 3.5.3 for Mac OS and Cinema 4D XL 7 for Mac OS X gives an example of a computer visualization system that is capable of excellent 3D reconstruction from a serially sectioned material for scientific interpretation and measurement or demonstration purposes. Additionally, by using the stereolithography technique, it is possible to have solid replicas of models obtained with this pair.

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