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Three-dimensional geometrical models of the liver

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SUMMARY

In this work we used a virtual approach to study the human liver by three-dimensional geometrical models. We built the models through computer aided geometric modelling techniques starting from pictures taken during both real dissections and diagnostic medical imaging. The results show in a complete modular synthesis and with a schematic iconology the structural organization of this organ in a logic sequence of layers and topographic and spatial relationship among its components. This approach represents an amazing support to clinical anatomy for teaching and research.

INTRODUCTION

The use of computers in both classrooms and laboratories of human anatomy (Aziz et al., 2002; Nieder et al., 2004) determined an advancement in information technology (Bodemer et al., 2004; Khalil et al., 2005) and a more extensive use of three dimensional computer obtained images for both didactic and scientific purposes (Cooper et al., 2001; Kim et al., 2003).

In the past, we used a three-dimensional geometrical approach to study the carpal tunnel (Peri et al., 2001), the carotid region (Peri et al., 2002) and the inguinal region (Peri et al., 2003). Our results were considered of some utility for both teaching and research purposes in human anatomy and embryology.

In the present work, we studied for the first time a parenchimatous organ, the liver, using the same approach. The liver presents two faces, a diaphragmatic one and a visceral one, and it is divided in four lobes and eight portobiliar segments (PBS). Lobes are anatomically distinct areas that may be described looking the surfaces of liver; by contrast, segments are undistinguishable zones of parenchyma provided by a vascular and functional autonomy that surgeons study in case of partial liver dissection. Nevertheless, the distribution of PBS in hepatic parenchyma could be hard for first timing students of human anatomy. A computer-aided stereology model may help the teacher in his work; moreover, may become also a useful tool for morphological researches.

The aim of this work was to realize stereological models by computer aided geometric modelling and synthetic image rendering techniques. This approach could also be useful for surgeons in their practice for reduction techniques to obtain fast recovery of the patient, good reconstruction of anatomical structure and low incidence of relapses.

MATERIALS AND METHODS

The study was carried on digital images from Visible Human Dataset and CT scan images and formalin fixed anatomic specimen that showed: a) the external morphological features of the liver and the traditional subdivision in lobes; b) the functional subdivision of the liver in lobes and segments; c) the blood afflux and defluxion system.

We processed the digital images using a software system (Peri et al., 2001; Peri et al., 2002; Peri et al., 2003) obtaining a geometric model of the liver and of its vascular tree. The software system exploits a knowledge driven paradigm aimed at either semi-automatic or fully automatic image processing and three-dimensional reconstruction of parts of the body from section images. The processing paradigm is based on rules describing the targeted objects in terms of their shape and other not geometric features as long as their reciprocate spatial relationships in a symbolic formalism entangling first-order and fuzzy logics.

The chosen formalism allows for a great degree of freedom in the description of the objects targeted for reconstruction. The range of possibilities includes descriptions based on interpolating points of contour, sequences of image processing operations or even complex abstract rules describing how objects' sections should appear into medical imaging modalities series. Depending on the specific application different set of rules can be loaded into the system knowledge base and used to obtain geometric models of the targeted objects.

In this study we employed at first contour shape descriptions to build the external shape of the liver, then we used rules based on digital images features to extract the vascular tree of the liver from the set of CT scan images.

In the former case, the models were built by manual sampling of points on anatomic sections images. A set of ten section images of a liver was used. For each image of set a manual sampling of points along the contour of the liver was performed. The closed polygons obtained so far were then extruded by the software system along the normal to the section plane to generate reconstructed slices with the same thickness of the sections the CT images. This yielded a sliced geometric model of the liver we used to obtain synthetic views with several rendering approaches.

Semi-automatic processing was instead adopted to build the vascular tree of the liver. A series of digital CT scan images was introduced in the knowledge base of the software system as well as a set of rules describing the operations to perform. Each image is at first thresholded to select just the area having pixels in a specific range of values. This step detects the areas of the images which densities were in the same range of the vascular components as each pixel in a CT scan image refers actually to an elementary volume (voxel), having specified geometric dimensions and density proportional to the gray level value of the pixel. Image segmentation is then applied on each image obtained with the thresholding processing to obtain. Segmentation extracts from each image, by a region growing algorithm, the sections of the vascular components in the image. The areas selected by the thresholding processing adding them to the knowledge base of the software system. Each area is represented in the knowledge base as a set of voxel belonging to the section they were taken from. To avoid that the system could extract areas of the images having pixels in the range of intensities specified for the vascular components but actually not belonging to any of them, a manual pre-processing was performed on each image. This pre-processing was used to select the areas of the images to perform the segmentation process on. The last processing merges all the set of voxel representing sections of vascular components obtained so far obtaining a 3-D object made of the voxel extracted from the CT-scan images.

Eventually, we used the "ray-tracing" rendering method in order to obtain synthetic images of the reconstructed organ. This method renders photorealistic images from a virtual scene whose components are geometric models, light sources and a virtual camera. Positions of camera and models as well as light and camera parameters can be finely adjusted. The synthetic image is obtained simulating the behaviour, according to a given optical model, of a great number of light rays emitted by the light sources in the virtual scene. Rendering of models is thus dependent on the interaction of the surfaces of the objects in the scene with the simulated light rays. Several parameters can be specified for the optical behaviour of the surfaces that permit to obtain natural looking objects.

RESULTS

Results are represented by geometric models of the liver and of its vascular tree. Geometric models of the liver show the external morphology relatively to the diaphragmatic face and the visceral face (fig. 1). The subdivision in lobes and segments was indicated with lines over the images rendered from the geometric models (fig. 2). The geometric model of the vascular tree shows: 1) the structure formed by lobes

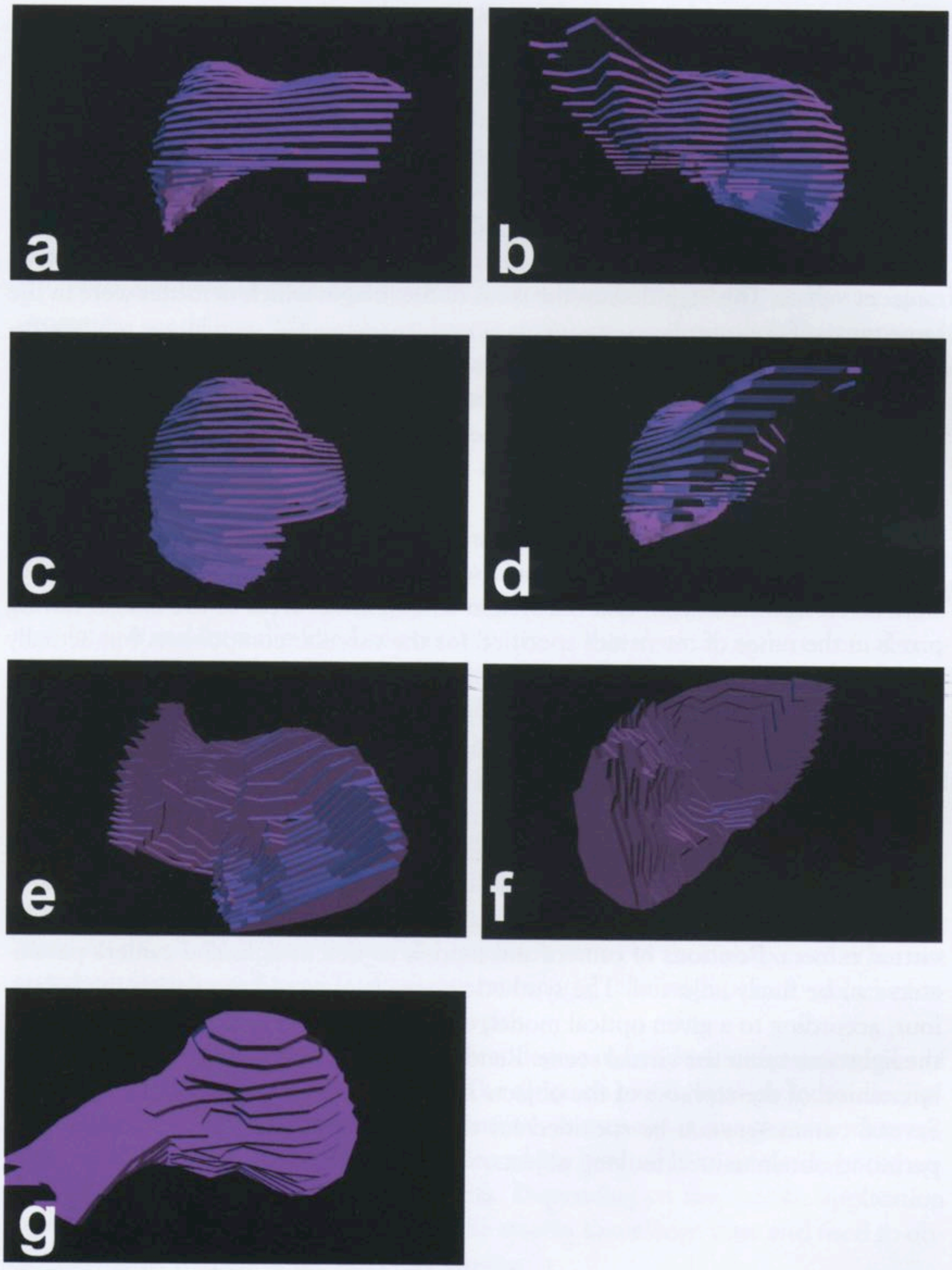

Fig. 1 — This panel shows geometric models of the diaphragmatic face (a) and the visceral face (b), also in lateral right (c) and left (d) view and during rotation of the model (e: visceral face is rotated upper and laterally; f: visceral face is rotated down and laterally; g: view of "nude area" and vena cava sulcus from above).

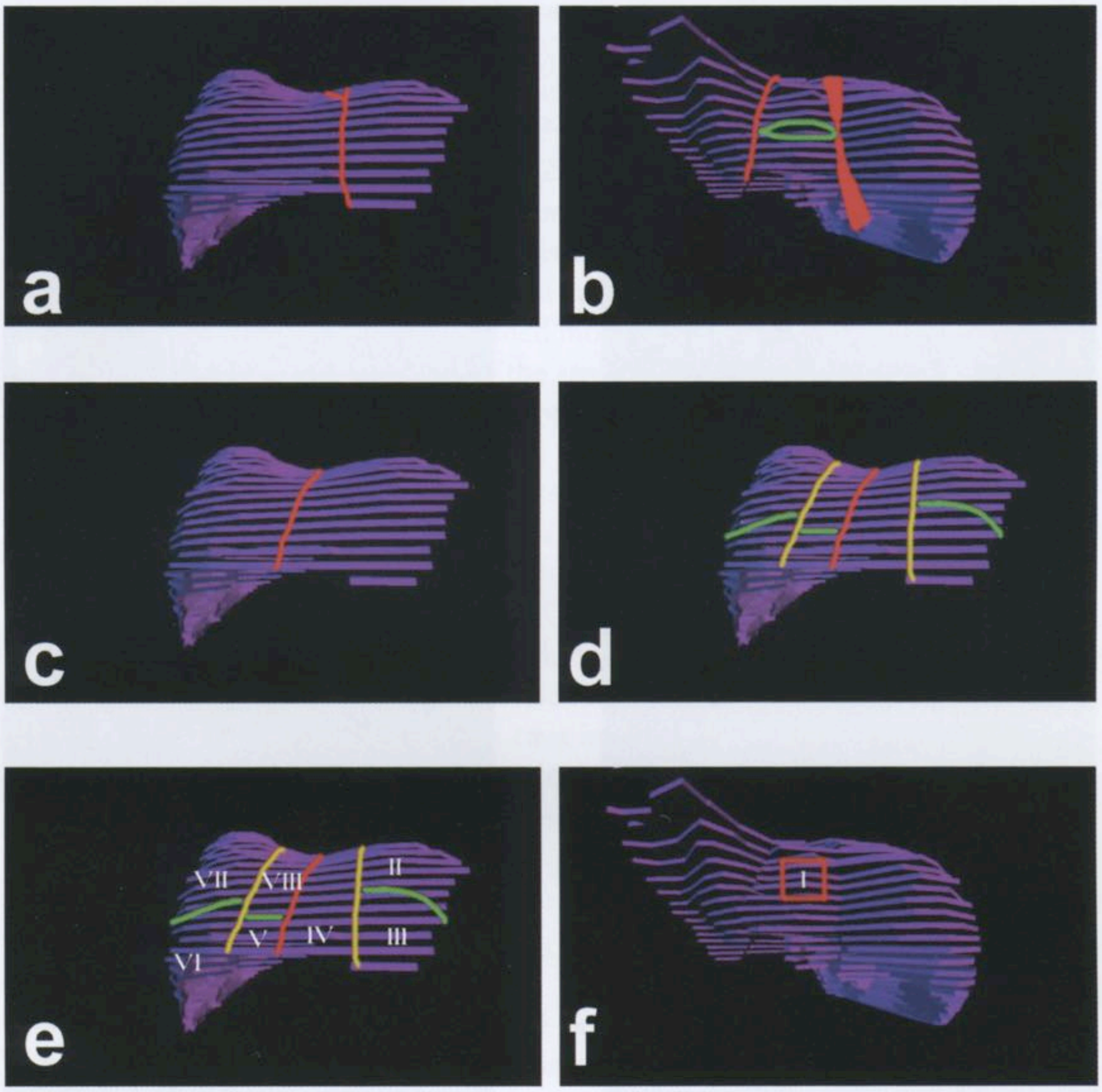

Fig. 2 — This panel shows the subdivision in lobes (a: anterior view; b: posterior view) and segments (c-e: anterior view; f: posterior view), indicated by lines over the images.

and segments; 2) the organisation of the afflux vascular tree constituted by the portal vein, the hepatic artery and their division branches; and 3) the defluxion one made up of hepatic veins and inferior vena cava (fig. 3).

DISCUSSION

The purpose of interactive and dynamic anatomical visualization systems is to create a more advanced type of computer-based and learner-controlled approach that may be personalized in relationship with the different groups of students of morphological disciplines (Catrambone, 1998). In the future, these techniques should obtain the goal to enhance the learning strategies and to decrease the intrin-

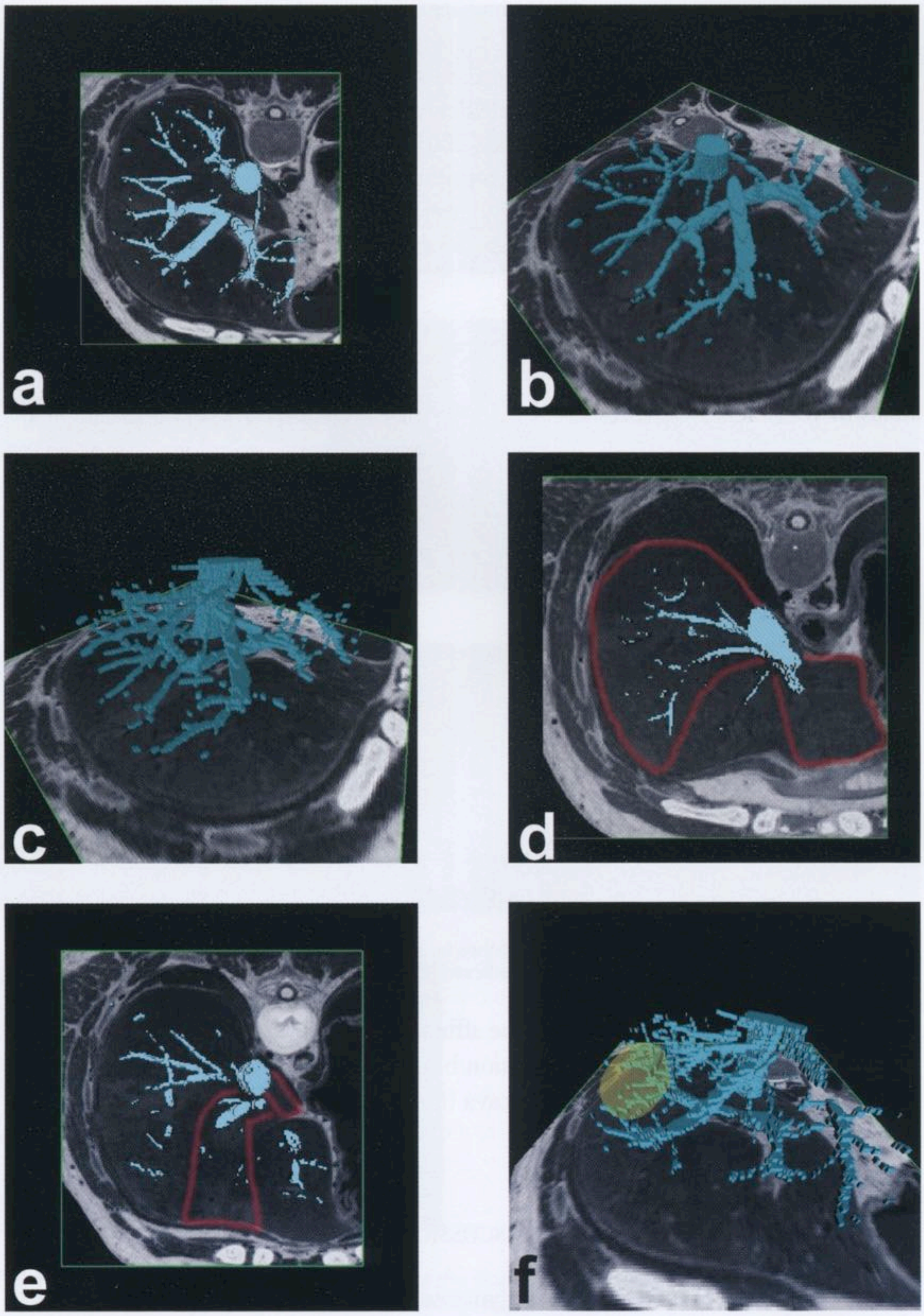

Fig. 3 — This panel shows the organisation of the afflux vascular tree constituted by the portal vein, the hepatic artery and their division branches (a, b, c) and the defluxion one made up of hepatic veins and inferior vena cava (d: left and right venous segments; e: central venous segment); picture f shows in yellow a common territor between afflux and deflux vascular trees.

sic and extraneous cognitive loads that are irrelevant for teaching (Miller et al., 2002).

In the past, we demonstrated the didactic utility of three-dimensional reconstruction for the study of carpal tunnel (Peri et al., 2001), of carotid region (Peri et al., 2002) and inguinal region (Peri et al., 2003). Our results were in agreement with other studies made with analogous computer aided approaches (Aziz et al., 2002; Miller et al., 2002; Kim et al., 2003; Nieder et al., 2004).

The results obtained in the present work represent three-dimensional geometrical models of the liver. The obtained models show in a complete modular synthesis and with a schematic iconology the structural organization of the anatomical districts in a logic sequence of layer and topographic and spatial relationship among its components. The models represent an amazing support to anatomy and clinical anatomy for teaching and research purposes organogenesis, surgery and diagnosis. In particular, geometric models of the liver show external morphology of the hepatic organ to the diaphragmatic and visceral surface.

The software system, digital images, CT scanner images that process geometric models of the liver explain external morphological features, the functional partition in lobes and segment, and the afflux and defluxion system (vascular tree: portal vein, hepatic artery, hepatic veins and vena cava inferior). The ultimate outcome of our research will be in the future the improvement of the dynamic visualization to better support learning of the anatomical sciences.

CONCLUSIONS

Our results show the importance of geometric models in understanding and learning the study of the liver. Such models can be used to obtain views of this organ under any angle, with different scaling factor, emphasising or hiding any component or changing its optical properties. The comparison between real images of specimens and three-dimensional reconstructions improved the perception of the peculiar features of anatomic structures and their spatial relationship. The information about geometric relations among structures, making possible to build knowledge bases to be used automatic feature extraction systems from CT and MR images, shows even further the importance of employing such systems in research and open new scenario on image based diagnosis of hepatic pathologies.

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