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The use of a projection method to simplify portal and hepatic vein segmentation in liver anatomy

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ABSTRACT

In living donor liver transplantation, the volume of the potential graft must be measured to ensure sufficient liver function after surgery. Couinaud divided the liver into 8 functionally independent segments. However, this method is not simple to perform in 3D space directly. Thus, we propose a rapid method to segment the liver based on the hepatic vessel tree. The most important step of this method is vascular projection. By carefully selecting a projection plane, a 3D point can be fixed in the projection plane. This greatly helps in rapid classification. This method was validated by applying it to a 3D liver depicted on CT images, and the result was in good agreement with Couinaud's classification.

1. Introduction

Living donor liver transplantation is being increasingly performed as an alternative to cadaveric transplantation [1]. The volume of the potential graft must be measured to ensure sufficient liver function after surgery. The ratio between the graft size and the recipients' body weight must ideally be higher than 0.8–1% [2] or the ratio between the graft size and the standard liver volume (which is calculated based on the surface area) [3] must be higher than 50% [4]. In the donor, a remnant liver volume of 30% of the standard liver volume is usually considered to be the lower limit [5]. Lower values are associated with higher morbidity and mortality in both the recipient and the donor owing to the small-for-size syndrome.

Preoperative liver segmentation has proved useful for measuring the graft volume before living donor liver transplantations in previous studies [6–8]. Couinaud's classification system is often used for the calculation of resection proposals [9], as shown in Fig. 1. According to the Couinaud model, the liver can be divided in 8 areas (or segments) that are related to the portal network ramifications. Each segment has its own vascular inflow, outflow, and biliary drainage. Tumor localization in one or more hepatic segments allows the ablation of only the involved segment(s), without injuring the other adjacent segments.

In the aforementioned studies [6–8], the liver segments were manually delineated on each image section. The area of each delineated segment was multiplied by the section thickness to obtain the volume, and the volumes of all sections were added to obtain the total volume of all the liver segments. This process is tedious and time consuming. To overcome this problem, we developed a rapid method to segment a liver according to Couinaud's classification. The purpose of our study was to combine the accuracy and repeatability of an automatic segmentation algorithm with those of manual segmentation for determining the liver volume in living liver transplant donors at CT imaging. Our method is based on the hepatic vessel tree

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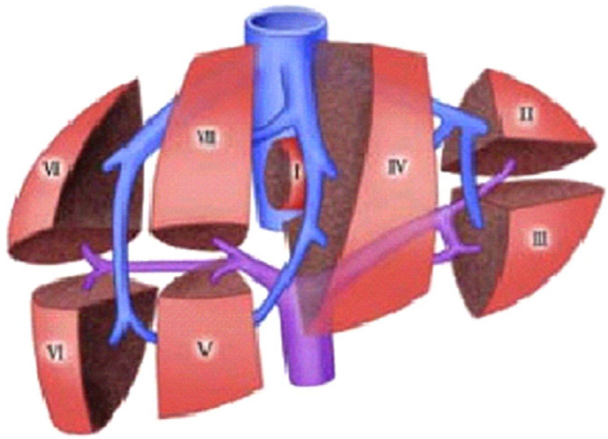

Fig. 1 – **Segmental anatomy of the liver according to Couinaud.**

data extracted from the liver CT images. This method includes the following 4 steps.

(1) Vasculature segmentation: Intrahepatic vessels are segmented with the help of a refined region-growing algorithm to meet the demands of runtime, robustness, and level of automation for acceptance in clinical routine.
(2) 3D thinning: Algorithms based on graph-theoretical methods are used to analyze the geometry and the ramification structure of the segmented vessels. For this purpose, the skeletons of the vessels are determined.
(3) Vascular tree pruning and classification: Algorithms are used for modeling the vessels as a tree. In this procedure, multiresolution vessel trees would be generated to satisfy different purposes.
(4) Vascular projection: To avoid classifying the liver in 3D space directly, this step is used to simplify the procedure of classification.

2. Liver segmentation

2.1. *Vasculature segmentation*

In CT images, the Hounsfield unit (HU) value of vessels is continuous and greater than that of the liver matter. Taking this into consideration, we can use threshold-based 3D-region-growing algorithms to segment the vessels. In this algorithm, the first step is the careful selection of the seed point to ensure that it lies in the portal vein. The second step is the region-growing procedure; here, we grow this point under 2 rules: (1) the HU value of the grown point must be greater than a given threshold and (2) the grown point must be within a given distance of the seed point. Rule 2 ensures that our region-growing procedure may continue in spite of small holes.

Automatic determination of an appropriate threshold is possible. Our algorithm can be described as follows: when we increase the threshold from 0 to 255, the number of voxels in the grown region may decrease accordingly. At the end of this procedure, a threshold–voxel number curve can be obtained, as shown in Fig. 2.

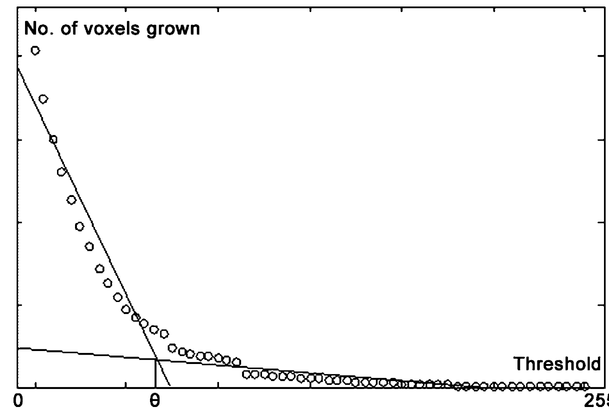

Fig. 2 – **Automatic algorithm detects an appropriate threshold. Here, the X-axis represents the threshold, and the Y-axis represents the number of voxels in the grown region.**

In Fig. 2, at threshold θ, the slope changes considerably because many voxels belonging to the liver vessel are collected at thresholds below θ. Thus, the optimal θ can be determined by calculating an optimal fit of 2 straight lines for the threshold. For this purpose, 2 characteristic parts of the curve are approximated by 2 regression lines. The points, respectively, are employed to calculate the correlation coefficients for both the lines. The threshold θ must be selected such that the sum of the 2 correlation coefficients is maximal. In practice, we found that the X-coordinate of the intersection point of these 2 lines yields a good selection of θ in most cases. Fig. 3 shows the result of vessel segmentation.

2.2. *3D thinning*

Because the grown region usually contains many redundant points, thinning the final region is a necessary preprocess to analyze the vessel tree. This type of thinning algorithm can be divided into 2 classes [10]: One class is based on distance transform; it selects the local extreme points as key points and then connects these points as the skeleton. The other class is based on morphology; it repeatedly erodes the edge until an

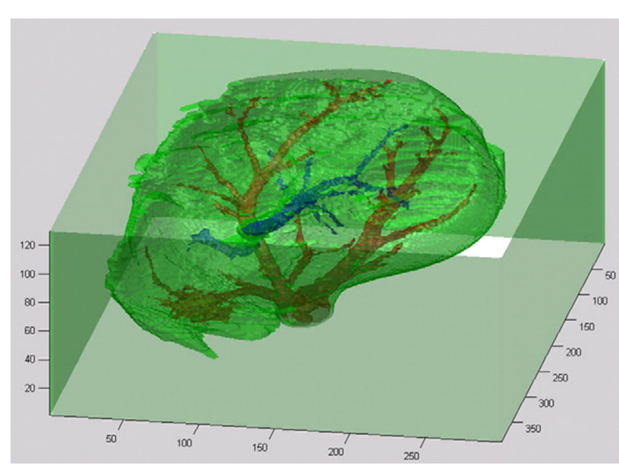

Fig. 3 – **Result of the 3D-region-growing algorithm.**