

ORIGINAL ARTICLE

Three-dimensional volumetry in 107 normal livers reveals clinically relevant inter-segment variation in size

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Abstract

Background: The anatomic resection of Couinaud's segments is one of the key techniques in liver surgery. However, the territories and volumes of the eight segments are not adequately assessed based on portal branching.

Methods: Three-dimensional (3D) perfusion-based volumetry was performed in 107 normal livers. Based on Couinaud classification, the portal branches were identified and the volumes of each segment were calculated. The relationships between branching patterns of the portal veins and segmental volumes were assessed.

Results: In descending order of volume, median volumes of segments VIII, VII, IV, V, III, VI, II and I were recorded. Segment VIII was the largest, accounting for a median of 26.1% (range: 11.1–38.0%) of total liver volume (TLV), whereas segments II and III each represented <10% of TLV. In 69.2% of subjects, the portal branches of segment V diverged from the trunk of the branches of segment VIII. No relationship was found between branching type and segment volume.

Conclusions: The territories and volumes of Couinaud's segments vary among segments, as well as among individuals. Detailed 3D volumetry is useful for preoperative evaluations of the dissection line and of future liver remnant volume in anatomic segmentectomy.

Received 8 April 2013; accepted 31 May 2013

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Introduction

The aim of this study is to elucidate volumetric differences among Couinaud's eight liver segments in 107 healthy living donor liver transplant (LDLT) candidates using three-dimensional (3D) image-processing software. Volumetric analysis plays a crucial role in liver surgery in: (i) the selection of the optimal parenchymal transection plane, and (ii) estimation of the future liver remnant (FLR) volume. Evaluation of the FLR is vital for preventing post-operative liver failure in patients with either borderline liver function or a small-for-size FLR.^{1–6} Conventional two-dimensional (2D) volumetry can accurately predict the volumes of the four sections of the liver [right paramedian sector (RPMS), right lateral sector (RLS), segment IV, and segments II and III]. However, the exact volumes and borders of Couinaud's segments cannot be determined with conventional 2D volumetry.^{1,2}

The anatomic resection of Couinaud's segments is one of the key techniques in liver surgery. A precise parenchymal transection along the watershed of each segment minimizes blood loss, preserving the maximal functional liver remnant.^{7–15} Essential steps in anatomic segmentectomy include: (i) clarifying the anatomy of the corresponding branches of the portal veins, and (ii) identifying segmental borders on the liver surface.^{15,16} However, these steps are technically demanding, firstly because the complicated and anomalous branching of the portal veins can make exact understanding of the anatomy difficult, and secondly because the actual borders cannot be estimated *preoperatively* using conventional 2D volumetry and the surgeon must determine the borders *intraoperatively* after staining or after compressing the portal branches supplying the respective segments.^{11,15,16}

Recent advances in image-processing software allow for the calculation of the vascular territories of the corresponding vessels

and provide surgeons with 3D visualization of the liver.^{17–22} With this technique, the borders and volumes of Couinaud's segments can be calculated based on the portal branches of each segment *preoperatively* without necessitating an invasive procedure.

It is known from 2D volumetric analysis of the liver that liver sections have significant inter-patient volumetric variations.¹ However, no studies to date have assessed the volumes of Couinaud's segments based on portal branching, which, as noted, would be crucial for determining exact segmental postoperative FLR volumes and the exact parenchymal transection plane. In the present study, the volumes of Couinaud's eight segments in 107 normal livers of donor candidates for LDLT were analysed using 3D image-processing software. With the aid of perfusion-based visualization of each segment, the branching types of the portal veins based on Couinaud's classification were evaluated and the volumes of the eight segments were calculated. In addition, the relationship between the branching pattern of the portal veins and the segmental volumes of the right liver were investigated. Finally, perfusion-based volumetry of Couinaud's segments was put into clinical practice.

Materials and methods

Three-dimensional reconstruction and volumetric analysis of the liver were performed in 107 consecutive donor candidates for LDLT between January 2004 and April 2009 at the University of Tokyo Hospital. The subjects included 57 men and 50 women; their median age was 37 years (range: 20–63 years). Median weight, height and body surface area in this cohort were 57 kg (range: 43–104 kg), 164 cm (range: 146–185 cm) and 1.57 m² (range: 1.34–2.28 m²), respectively. The subjects had no history of liver disease and had normal liver function; all the subjects had undergone a screening computed tomography (CT) scan with an i.v. contrast agent prior to this analysis to confirm the absence of hepatic lesions. Dynamic CT for image processing was performed as described previously.²⁰

3D image-processing software

Region-growing method software (Organ Volume Analysis; Hitachi Medico Inc., Chiba, Japan), designed for the analysis of liver imaging, was used in this study.^{18–21} First, the software reconstructs the liver structures (liver parenchyma, portal vein, hepatic veins) as 3D structures, extracting neighbouring voxels of similar CT density. The three parts are combined and volumetric measurements are obtained based on an algorithm in which the liver parenchyma is divided in proportion to the diameters of and the distance between the vessels. By selecting a branch of interest, the corresponding territory and volume are calculated. The estimated territories were confirmed using not only 3D imaging, but also 2D image software based on the segments.

Definitions of Couinaud's eight segments

Couinaud's classification was used to define the corresponding branches; the term 'segment' always refers to one of Couinaud's

segments (third-order division) in this study.²³ First, total liver volume (TLV) and the volumes of the following parts were measured: right liver; left liver (segments II, III and IV); caudate lobe; RPMS (segments V and VIII), and RLS (segments VI and VII). A detailed volumetry of each segment was performed based on the definitions described below. 'Pn' represents the branch of the portal vein supplying segment n. Volumetric data are expressed as the median (range). How the branches were selected for subsequent calculations will be described.

Segments II and III

The portal branches of the two segments are small in number and have little anomaly.²³ Each branch was selected according to the following definitions: P2 derives from the cross of the left portal vein and Rex's recessus, and P3 derives from the left angle of the cul-de-sac. A few livers had known anomalies, such as a branch arising from the trunk of the umbilical portion of the portal vein or a common trunk formation between the two branches. In these subjects, the tributaries were classified by referring to the left hepatic vein (e.g. P2 and P3 perfuse the ventral and dorsal parts, respectively, of the left hepatic vein).

Segment IV

The innumerable branching patterns of P4 precluded the selection of every P4,²³ and the volume of segment IV was calculated by subtracting the volumes of segments II and III from that of the left liver. The falciform ligament and umbilical portion of the left portal branch were used as landmarks on the 2D and 3D images to distinguish P4 from P3.

Segments V and VIII

P5 was selected based on the description of the axial plane of the hepatic hilum as a partition between segments V and VIII.²³ The branches diverging caudally or laterally from P8 were classified as P5 when they mainly supplied the caudal side of the hepatic hilum in the RPMS (Fig. 1a). Every territory of the selected P5 was confirmed with 2D and 3D images. The volume of segment VIII was calculated by subtracting the volume of segment V from that of the RPMS.

Segments VI and VII

The major branching patterns of P6 and P7 are of the bifurcation type;²⁴ however, the selection of P6 is ambiguous when it ramifies radially from P7, described by Hjortsjo as 'branch-rays',²⁵ because no apparent definition delimiting segments VI and VII has been made. In this study, the axial hepatic hilum was used as the partition between the two segments in this sector also. The portal branches supplying mainly the caudal side of the hepatic hilum in the RLS were selected as P6 with visual confirmation of the terri-

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