Journal of Surgical Research **166,** 146–155 (2011)
doi:10.1016/j.jss.2009.07.042

"Anatomical" *versus* "Territorial" Belonging of the Middle Hepatic Vein: Virtual Imaging and Clinical Repercussions

Arnold Radtke, M.D.,*,‡,[1] Georgios C. Sotiropoulos, M.D.,*,‡ George Sgourakis, M.D.,*,‡ Ernesto P. Molmenti, M.D.,* Tobias Schroeder, M.D.,† Fuat H. Saner, M.D.,* Susanne Beckebaum, M.D.,* Andrea Schenk, Ph.D.,§ Hauke Lang, M.D., F.A.C.S.,*,‡ Christoph E. Broelsch, M.D., F.A.C.S.,* and Massimo Malagó, M.D.*

**Department of General, Visceral, and Transplantation Surgery, University Hospital Essen, Essen, Germany; †Department of Diagnostic and Interventional Radiology, University Hospital Essen, Essen, Germany; ‡Department of General and Abdominal Surgery, Johannes Gutenberg University Hospital, Mainz, Germany; and §MeVis Center for Medical Diagnostic Systems and Visualization, University of Bremen, Germany*

Submitted for publication February 23, 2009

Background. **Venous drainage patterns are of vital importance in live donor liver transplantation. The purpose of this study was to delineate "anatomical-topographical" and "territorial-physiologic" patterns of the middle hepatic vein (MHV) in a 3-D liver model as determined by the Pringle line and its drainage volume of the right and left hemilivers.**

Methods. **One hundred thirty-seven consecutive live donor candidates were evaluated by 3-D CT reconstructions and virtual hepatectomies. Based on right (R) and left (L), anatomical (A) and territorial (T) belonging patterns of the MHV, each individual was assigned to one of four possible types: type I:A^R–T^R; type II:A^L–T^L; type III:A^R–T^L; type IV:A^L–T^R. Couinaud's anatomical MHV variants A–C were subsequently included in our combined anatomical/territorial MHV belonging classification.**

Results. **The MHV showed a significant predominance of right "anatomical" (59.1%) and left "territorial" belonging patterns (65.7%). The paradoxical combinations A^R–T^L (type III) and A^L–T^R (type IV) were encountered in 36.5% and 11.7% of cases, respectively. The constellations Couinaud's A-belonging type IV and Couinaud's C-belonging type IV were predictive of right hemiliver venous congestion.**

Conclusions. **(1) Almost half of all livers in our series had paradoxical "anatomical"/"territorial" MHV belonging patterns that placed them at risk for right and left hepatectomies. (2) The proposed combined "anatomical"/"territorial" MHV belonging types (I–IV) provide useful preoperative information. (3) Combined types III and IV as well as Couinaud's A–IV, and Couinaud's C–IV should be considered particularly risky for venous congestion in right hemiliver grafts and in extended left hepatectomies.** Crown Copyright © 2011 Published by Elsevier Inc. All rights reserved.

Key Words: **liver surgery; living donor liver transplantation; liver anatomy; 3-D reconstruction; 3-D CT; liver imaging; liver venous drainage; hepatic vein anatomy; hepatic vein dominance; hepatic vein classification.**

INTRODUCTION

An inevitable step when performing right graft hepatectomies for living donor liver transplantation (LDLT) is the transection of the drainage territory of the middle hepatic vein (MHV). Such transection has the associated potential of severe postoperative congestion of "marginal zones" in both hemilivers [1]. Determining the proper management of the MHV remains a matter of discussion, since it can be preserved only with one of the two hemilivers [2]. Couinaud identified three MHV anatomical variants: type A (characterized by equally-sized branches to segments 5 and 4B), type B (with strong tributaries from segments 8 and 4A joining the MHV trunk, but only a rudimental branch from segments 5 and 4B), and type C (containing a strong branch from segment 5/6 and a small one from segment 4B, and being particularly relevant in the venous drainage of the medial sector of the right hemiliver) [3]. Neumann

[1] To whom correspondence and reprint requests should be addressed at Department of General and Abdominal Surgery, Johannes Gutenberg University Hospital, Mainz, Langenbeckstrasse 1, 55131 Mainz, Germany. E-mail: radtke@ach.klinik.uni-mainz.de.

0022-4804/$36.00
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et al. confirmed this observation with 3-D volumetry studies, showing that MHV type C had the largest drainage volume in the medial segments (V, VIII) of right liver grafts [4]. Our group first described the phenomenon of "territorial" belonging of the MHV and proposed a classification based on volumes at risk of venous congestion in the right and left hemilivers [5]. However, in our experience, the "anatomical" belonging of the MHV, as defined by the topographic relationship between the MHV trunk and the Pringle demarcation line on the duplex scan, does not overlap the "territorial" belonging as determined by the MHV drainage volumes in either hemiliver.

The purpose of this study was to:

(1) Distinguish between "anatomical" and "territorial" belonging of the MHV.
(2) Compare venous congestion volumes (CV) among "anatomical" and "territorial" MHV belonging patterns.
(3) Identify "high risk" MHV belonging categories for the right and left hemiliver as determined by the Pringle demarcation line.

In this article, we demonstrate our experience with venous mapping based on 3-dimensional-CT-imaging reconstructions and virtual hepatecomies by simulating the Pringle maneuver.

MATERIAL AND METHODS

Study Population

From January 2003 to August 2007, 137 consecutive donor candidates were evaluated for adult living donor liver transplantation. There were 72 females and 65 males, with a mean age of 37±10 y. According to our routine evaluation protocol, each donor candidate underwent 3D-CT imaging analysis of the liver anatomy [6].

Computed Tomography (CT) Protocol

CT imaging was performed using a 16-row-Multidetector-CT-Scanner (Sensation16; Siemens, Erlangen, Germany) using the following parameters: kVp 120, mAs 140–170, slice collimation 0.75 mm, feed/rotation 12 mm, and rotation time 0.5 s as originally published by Schroeder *et al.* [7]. The first image set, outlining the biliary system, was acquired 30 (±5) min following intravenous short-infusion of 100 mL of a biliary contrast agent (Biliscopin; Schering, Berlin, Germany). To delineate the hepatic vasculature, patients received 140 mL of an iodinated contrast agent (Xenetix300; Guerbet GmbH, Sulzbach, Germany). This was administered intravenously by an automated injector system (CT 9000; Liebel-Flarsheim, Cincinnati, OH) at a rate of 4 mL/s. Automated bolus tracking with bolus detection at the level of the ascending aorta assured accurate timing of the arterial phase. For the display of the portal and hepatic venous anatomy, third and fourth CT image sets were acquired effectively at 10 and 40 s following the arterial imaging. Reconstruction increments were 1 mm for the arterial and venous scans.

Image Analysis and Virtual Liver Resection

CT images were analyzed with the software assistant HepaVision, originally developed at the research center MeVis (Bremen, Germany) for preoperative planning in liver surgery [8]. Intrahepatic systems (bile ducts, hepatic arteries, portal veins, and hepatic veins) were extracted from the 2-D CT image data, and subsequently segmented, registered in a hierarchical structure representing degrees of branching and direction of flow, and finally reconstructed three-dimensionally. Portal, arterial, biliary, and hepatic venous displays with their corresponding territorial volume assessments were fashioned. Virtual resections were performed in 3-D liver models by applying the Pringle maneuver arising from simulated right- or left-sided porto-arterial occlusions. The virtual 3-D CT imaging reconstructions allowed for evaluations of the overlap of the individual hepatic venous territories within the right and left hemilivers as determined by the Pringle demarcation lines.

Data obtained from the 3-D liver simulations allowed us to:

- Display the Pringle demarcation line on the liver surface by simulating a one-sided porto-arterial occlusion
- Determine the "anatomical" belonging of the MHV to the right or left hemilivers based on the topographic relationship between the MHV trunk and the Pringle demarcation line on the "virtual" duplex scan
- Define hepatic vein drainage "territories"
- Determine the "territorial" MHV belonging pattern to the right or left hemilivers based on our physiologic definition
- Estimate "congestion volumes" by simulating outflow impairment, defining them as relative percentages of the right and left hemilivers volumes
- Identify "high risk" categories with particularly unfavorable constellations of "anatomical/territorial" MHV belonging patterns.

Definitions

Middle Hepatic Vein (MHV) Anatomy

Middle hepatic vein (MHV) anatomy was based on the Couinaud [3], Masselot [9]. and Gupta [10] classification. In variant A, the MHV trunk was formed by equally-sized branches from segments 5 and 4B. In variant B, strong tributaries from segments 8 and 4A joined the MHV trunk, with only a rudimental branch from segments 5 and 4B. Variant C was similar to variant A, except for an unequally sized bifurcation that included a strong branch from segment 5/6 and a small one from segment 4B (Fig. 1A–C)

Anatomical (topographic) Belonging of the Middle Hepatic Vein (MHV)

Anatomical (topographic) belonging of the middle hepatic vein (MHV): MHV belonging was assigned to the side that contained >50% of the length of MHV trunk as determined by the Pringle demarcation line (Fig. 2A–B).

Middle Hepatic Vein (MHV) Trunk

Middle hepatic vein (MHV) trunk: extending between the confluence of the inferior vena cava (ICV) and the crotch (bifurcation) point without inclusion of the main MHV branches.

Venous Drainage Territory and Volume

Venous drainage territory and volume: determined by the volume of each hepatic vein territory according to our 3-D liver model. We considered the RHV and the inferior (accessory) hepatic veins (IHV) (when present) as a combined territory.

Right/left Hemilivers

Right/left hemilivers: determined by the simulated right/left hepatectomy following the virtual Pringle demarcation line in 3-D liver model.

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