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Anatomical and Physiological Classification of Hepatic Vein Dominance Applied to Liver Transplantation*

A. Radtke[1], T. Schroeder[2], G. C. Sotiropoulos[1], E. Molmenti[1], A. Schenk[3], A. Paul[1], S. Nadalin[1], H. Lang[1], F. Saner[1], H. O. Peitgen[3], C. E. Broelsch[1], M. Malagò[1]

[1]Department of General Surgery and Transplantation,
[2]Department of Diagnostic and Interventional Radiology, University Hospital Essen, Essen, Germany,
[3]MeVis-Center for Medical Diagnostic Systems and Visualization, University of Bremen, Germany

Abstract

Background: Proper outflow reconstruction is essential in LDLT. Preoperative planning requires meticulous attention to hepatic vein dominance patterns. The purpose of our study was to provide a combined anatomical-physiological classification of hepatic vein dominance useful for surgical decision-making in both donors and recipients.

Methodology: We analyzed 3-dimensional CT-imaging reconstructions of 55 potential live liver donors evaluated at our Institution between January 2003 and May 2004.

Results: Our data revealed that: 1) The middle hepatic vein (MHV) and left hepatic vein (LHV) show a relative lack of anatomical diversity, whereas the right hepatic vein (RHV) exhibits multiple variants, 2) 45% donors had inferior hepatic veins (IHV) with anatomically and physiologically relevant venous drainage territories, 3) The RHV is usually dominant when present as a single vein without anatomical IHV (**type 1A**), or when considered as a complex with IHV (**type 1Bx**) (80% vs. 88%), 4) Only 55% of dominant **type 1Bx** RHV/IHV-complex automatically included a dominant **type 1By** RHV by itself, 5) A single RHV out of anatomical complex with IHV (**type 1By**) was dominant in only 48% of our donor candidates, 6) The MHV **types 2A and 2By** are strongly dominant accounting for up to 57% of total liver volume (TLV).

Conclusions: We propose a new classification based on both anatomical and physiological hepatic venous configurations. Our model also provides a new nomenclature that can be universally applied to preoperative planning in LDLT.

Key words: Liver surgery, live donor liver transplantation, hepatic vein dominance, hepatic vein classification, venous drainage, 3-dimensional reconstruction

Abbreviations: CHV: caudate veins; CT: computed tomography; D LHV: dominant LHV ; D MHV: dominant MHV ; D RHV: dominant RHV ; IHV: inferior hepatic vein; IVC: inferior vena cava; LDLT: live donor liver transplantation; LHV: left hepatic vein; MHV: middle hepatic vein; ND MHV: non-dominant MHV; RHV: right hepatic vein; TLV: total liver volume:

Introduction

The emergence of segmental liver transplantation brought together with it a rebirth and reconsideration of the classic concepts of vascular anatomy of the liver [2, 4, 8-9, 12, 17]. Vascular outflow, with its high degree of variability, was found to be equally or even more important than vascular inflow. The consideration of anatomical-physiological venous patterns that had previously received limited attention created a need for additional classifications to complement the old ones [3, 15-16]. Pivotal to the concept of venous outflow is the finding of segmental congestion [3, 5-6, 11, 14, 18-20, 22]. In this paper we outline our experience with venous mapping using the software HepaVision (MeVis, Germany), and propose a classification scheme based on that experience.

The purpose of this study was to provide a combined anatomical and physiological classification of the various types of hepatic venous drainage patterns. Venous dominance was given especial consideration. Although developed for live donor liver transplantation, the concepts proposed herein were also successfully applied to non-transplant hepatic surgery.

Methodology

Study population: We evaluated 55 potential donors who presented at our Institution between January 2003 and May 2004. There were 34 females and 21 males. Mean age was 38.8 years (range 18-59 yrs, SD10). When performing our routine evaluation [14,23], both graft and remnant liver volumes were calculated. Venous drainage territories were calculated and defined with the aid of virtual 3-D MeVis technology.

Image analysis and virtual resection: Computer Tomography images were analyzed with the prototypical software assistant HepaVision, originally developed at the research center MeVis (Bremen, Germany) (19) for preoperative planning in liver surgery. HepaVision allowed for the automatic calculation of total liver vol-

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ume, venous territories, and liver split proposals. Vascular structures (portal and hepatic venous systems, hepatic artery) were first extracted from the image data. Intrahepatic vessels were transformed into a hierarchical graph representing degrees of branching and direction of blood flow. Subtrees were electively assigned different colors in the 3D venous graph. Liver parenchyma information was obtained from the data in a semi-automatic way, allowing for the calculation of total liver volume. The use of mathematical models enabled the fusion of vascular analysis and liver segmentation results and the calculation of individual vascular territories for both venous systems. Previous trials had shown significant concordance between virtual and liver cast vascular territories [21].

Virtual resections were performed on 3D liver models that could also display venous trees. The overlap of hepatic venous territories with those arising from the manually or automatically (Pringle line) defined grafts and remnants were automatically calculated, providing further estimation of venous sub-territories as they were considered in the paper.

Statistical Analysis

Results were expressed as mean ± SD together with maximum/minimum values.

Results

We initially evaluated hepatic vein dominance based on the volume of liver parenchyma drained by each hepatic vein. According to this definition, the dominant hepatic vein territory was the one with the largest percentage of total liver volume (TLV).

In our series, 30/55 (55%) cases had no detectable inferior hepatic veins (IHV). In the remaining 25 cases, there were IHV of 2 mm or more in diameter observed, being considered of potential relevance as determined by their territory of venous drainage. There were no cases in which the IHV has not been detected in both imaging and operative modes. In 36 (65%) of the cases evaluated, it was possible to visualize independent venous drainage from the caudate lobe (CHV) into the IVC. .

Type A: *Single RHV with no anatomical IHV* (n = 30). In our series, 30/55 (55%) cases had no detectable IHV. In these cases, the mean volume territory for RHV, MHV, LHV and HV Caudate was 657, 451, 303 and 18ml respectively (or 46%, 32%, 21% and 1% of the TLV, respectively).

Type B: *RHV as a complex with IHV* (n = 25). In the remaining 25/55 (45%) cases there were IHV considered of potential relevance, with a mean drainage volume of 177 ml, or 11% of the TLV. In these cases, the mean volume territory for RHV/IHV-complex, isolated RHV, MHV, LHV and HV caudate was 719, 542, 519, 297 and 23ml respectively (or 46%, 35%, 33%, 19% and 2% of the TLV, respectively).

Type Bx: *Types A and B together*, or all cases consisting of RHV with no IHV and RHV in complex with IHV (n = 55). In these instances, the mean volume territory for RHV, MHV, LHV and HV caudate was 685, 482, 300 and 21ml, respectively (or 46%, 32%, 20% and 2% of the TLV, respectively).

Type By: *Type A (single RHV with no anatomical IHV)* plus those RHV out of complex with IHV, or otherwise stated all patients with RHV excluding IHV when present (n = 55). In these cases, the mean volume territory for RHV, MHV, LHV, IHV and HV caudate was 605, 482, 300, 80 and 21ml, respectively (or 41%, 32%, 20%, 5% and 2% of the TLV, respectively).

Type C: *IHV in the absence of RHV*. We did not encounter any of these cases in our series.

Dominance relationships among hepatic veins were then stratified according to 4 different groups. In all instances, there was a clear RHV dominance. Table 1 shows the incidence of hepatic vein types according to their dominance relationship in the whole liver.

Group 1°: In this group, 24 out of 30 individuals (80%) had dominant type **1A RHV** (*single RHV with no anatomical IHV*) (Fig. 1). In 6 cases (20%), the type **2A MHV** was dominant (Fig. 4).
Group 2°: Had 22/25 (88%) individuals with dominant type **1Bx RHV** (*RHV in complex with IHV*) (Fig. 2). In 12% of the cases, the **type 2By MHV** was dominant (Fig. 6).
Group 3°: Had 12/25 (48%) with dominant type 1By RHV (*single RHV out of complex with IHV*) (Fig. 3). In 9 cases (36%), the type **2Bx MHV** was dominant (Fig. 5), while in (4%) the dominant type was **3Bx LHV** (Fig. 7). The remaining 12% (3/25) represented the dominant type 2By MHV. Only 55% (12/22) of dominant type 1Bx RHV / IHV-complex automatically included a dominant type 1By RHV by itself.
Group 4°: Had 36/55 individuals (66%) in whom types **1A + 1By RHV** (*single RHV with no anatomical IHV plus RHV out of complex with IHV*) were dominant. In this group, there were also 15/55 (27%) dominant types **2A + 2Bx MHV** and 2% dominant type 3Bx LHV. In the cases of dominant types 2A + 2Bx MHV (15/55), the mean volume was 567 ml, or 38% of the total liver volume. This contrasts with the non-dominant MHV (accompanying dominant types 1A + 1By RHV), where the mean volume was 421 ml, or 29% of the total liver volume (Table 2).
Group 5°: In this group, 46/55 (84%) had a totally dominant type **1A + 1Bx RHV** (*RHV with and without IHV*). Nine of 55 had dominant types **2A + 2By MHV**. In the latter cases (dominant types 2A + 2By MHV), the mean volume was 682 ml, or 45% of TLV. This compares with non-dominant MHV (n = 46) accompanying dominant types 1A + 1Bx RHV, where the mean volume was 442 ml, accounting for 30% of the total liver volume (Table 2).

Table 3 outlines the overall incidence of hepatic veins types in our study cohort (n = 55) according to our proposed classification. **Hepatic vein classification:** Having considered anatomical and physiological variations, we developed the following classification scheme.

Structural classification of the right hepatic vein system:

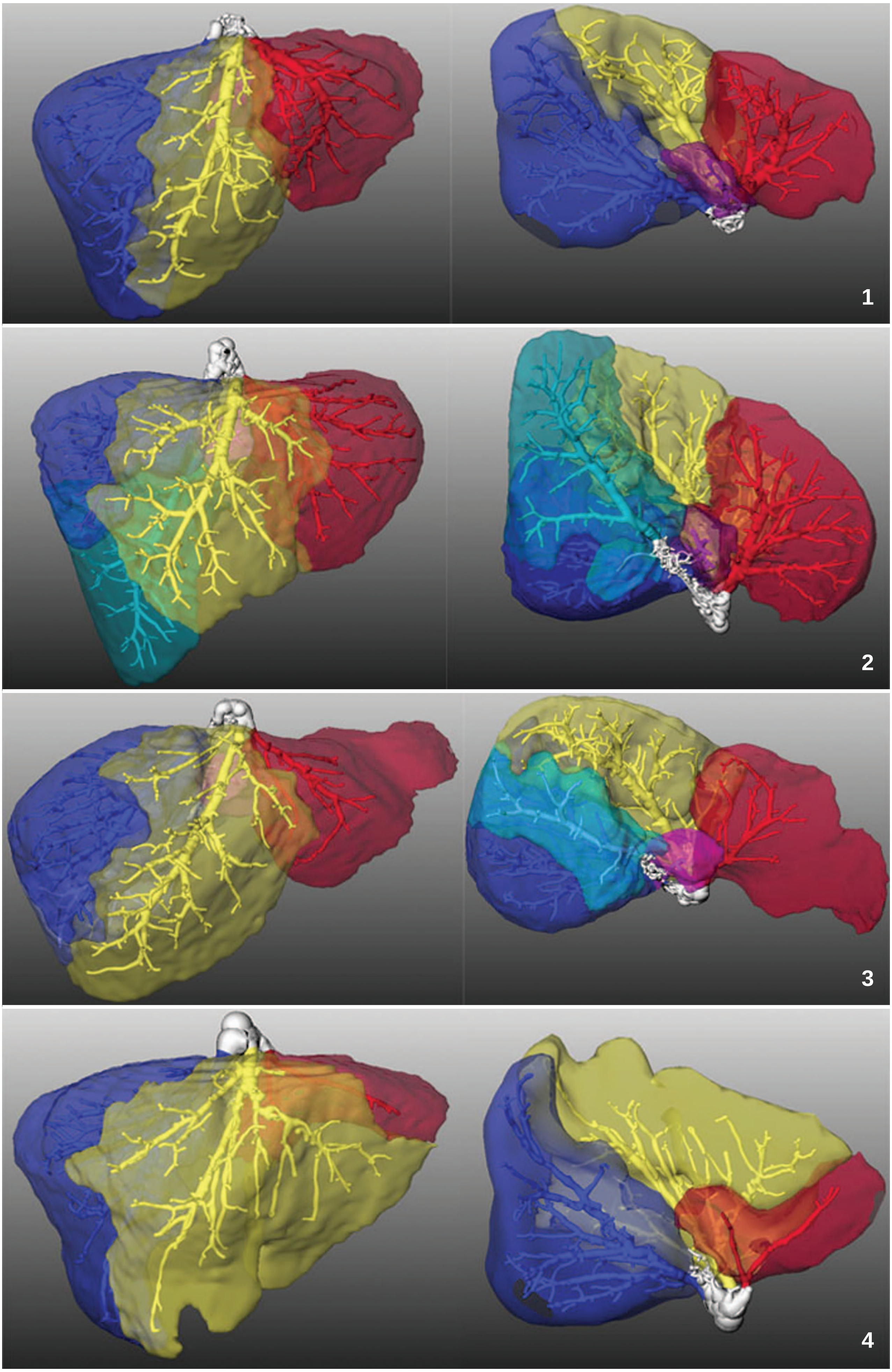
A:	RHV anatomically without IHV
B:	RHV anatomically with IHV
Bx:	RHV considered together with IHV
By:	RHV considered independently from IHV
C:	IHV without RHV

Dominance classification of the hepatic venous system:

1 A		RHV dominant without anatomical IHV
1 B		RHV anatomically with IHV
	1 Bx	RHV dominant together in complex with but not without IHV
	1 By	RHV dominant both with and without IHV
2 A		MHV dominant without anatomical IHV present
2 B		MHV dominant when anatomical IHV present
	2 Bx	MHV dominant when RHV considered without IHV
	2By	MHV dominant when RHV considered either with or without IHV
3 A		LHV dominant (when no anatomical IHV present)
3 B		LHV dominant (when anatomical IHV present)
	3 Bx	LHV dominant when RHV considered without IHV
	3 By	LHV dominant when RHV considered either with or without IHV
4 A		IHV dominant (when no anatomical RHV present)
4 B		IHV dominant (when anatomical RHV present)
5		other types

Table 1. Hepatic vein dominance relationships according to the new classification model. d –dominant; nd- non-dominant; IHV – inferior hepatic vein.

Type of dominancy	**Characteristics**	**Patients n (%)**	**Complementary type of dominance**	**Patients n (%)**
Group A	No IHV	N = 30		
Type 1A (1°d RHV)	no IHV	N = 24/30 (80%)	Type 2A (1°d MHV)	N = 6/30 (20%)
Group B	including IHV	N = 25		
Type 1Bx (2°d RHV)	including IHV	N = 22/25 (88%)	Type 2By (2°d MHV)	N = 3/25 (12%)
Type 1By (3°d RHV)	no IHV out of : 2°d RHV (1Bx)	N = 12/25 (48%)	Type 2Bx (3°d MHV) Type 3Bx (3°d LHV)	N = 9/25 (36%) N = 1/25 (4%)
Group Bx	A + B including IHV	N = 55		
Types: 1A + 1Bx (5°d RHV)	including IHV 1°d RHV + 2°d RHV	N = 46/55 (84%)	Types: 2A +2By (5°d MHV)	N = 9/55 (16%)
Group By	A + B without IHV	N = 55		
Types: 1A + 1By (4°d RHV)	no IHV 1°d RHV + 3°d RHV	N = 36/55 (66%)	Types: 2A + 2Bx Type 3Bx	N = 15/55 (27%) N = 1/55 (2%)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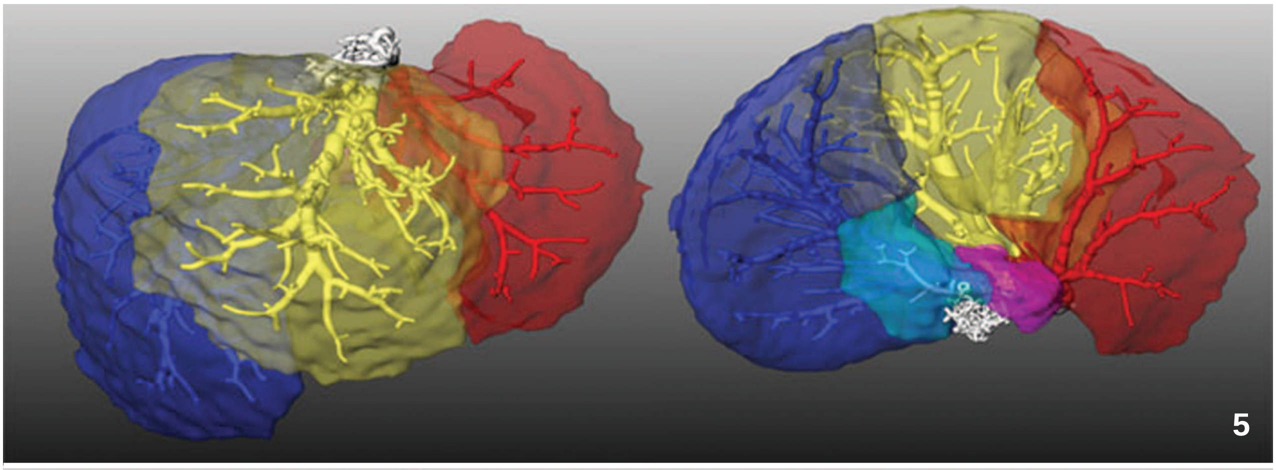

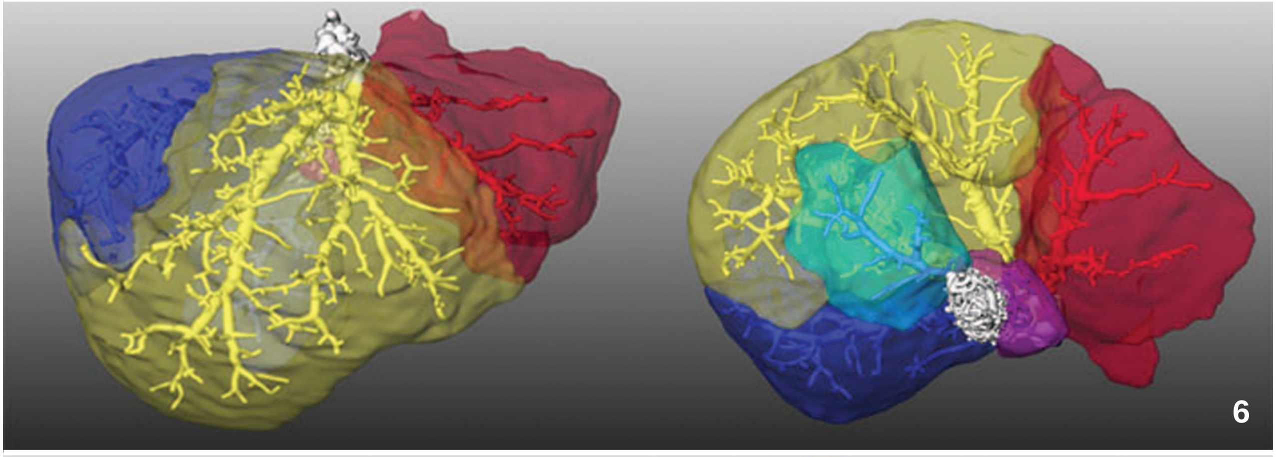

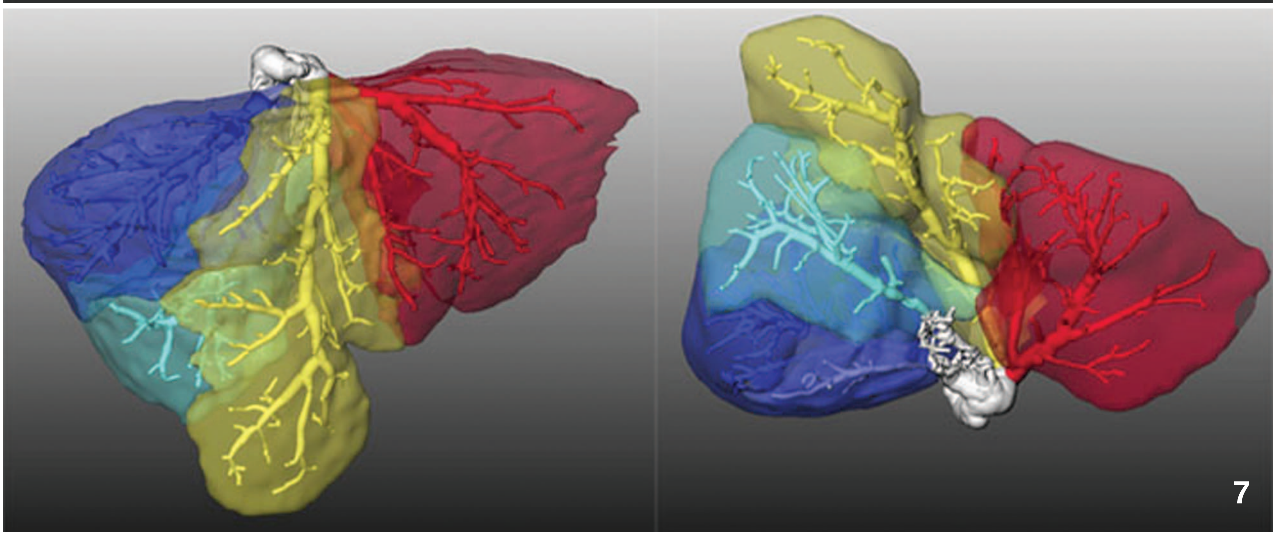

Fig. 1. 3-D reconstruction of the hepatic venous drainage as a percentage of TLV in a case of **type 1A RHV**. RHV (blue), MHV (yellow), LHV (red), CHV (purple) are outlined.

Fig. 2. 3-D reconstruction of the hepatic venous drainage as a percentage of TLV in a case of **type 1Bx RHV**. RHV (blue), MHV (yellow), LHV (red), IHV (cyan), CHV (purple) are outlined.

Fig. 3. 3-D reconstruction of the hepatic venous drainage as a percentage of TLV in a case of **type 1By RHV**. RHV (blue), MHV (yellow), LHV (red), IHV (cyan), CHV (purple) are outlined.

Fig. 4. 3-D reconstruction of the hepatic venous drainage as a percentage of TLV in acase of **type 2A MHV**. RHV (blue), MHV (yellow), LHV (red) are outlined.

Fig. 5. 3-D reconstruction of the hepatic venous drainage as a percentage of TLV in a case of **type 2Bx MHV**. RHV (blue), MHV (yellow), LHV (red), CHV (purple) are outlined.

Fig. 6. 3-D reconstruction of the hepatic venous drainage as a percentage of TLV in a case of **type 2By MHV**. RHV (blue), MHV (yellow), LHV (red), CHV (purple) are outlined.

Fig. 7. 3-Dreconstruction of the hepatic venous drainage as a percentage of TLV in a case of **type 3Bx LHV**. RHV (blue), MHV (yellow), LHV (red), IHV (cyan) are outlined.

Table 2. MHV drainage volume based on total liver volume (TLV) (TLV). d-dominant; nd-non-dominant; TLD-total liver dominancy-definition.

Donor N = 55	Whole liver MHV drainage volume based on TLV dominance							
Group	4°d MHV n = 15 (2A + 2Bx)		4°nd MHV n = 36 (d RHV: 1A+1By)		5°d MHV n = 9 (2A + 2By)		5°nd MHV n = 46 (d RHV: 1A + 1Bx)	
	Vol. ml	%TLV	Vol. ml	%TLV	Vol. ml	%TLV	Vol. ml	%TLV
Mean	567	38%	422	29%	682	45%	442	30%
Min	426	30%	268	20%	497	38%	268	20%
Max	814	48%	659	42%	996	57%	662	42%
SD	94	5	101	5	149	5	106	6

Table 3. Incidence of hepatic vein types in our study cohort according to the proposed classification nomenclature; the overall incidence in the study cohort. "IHV excluded from calculation" – IHV out of RHV/IHV-complex.

	Donor n = 55	
HV Dominance Type	HV Characteristics	n
1A	RHV without IHV	24
1Bx	RHV with IHV	22
1By	RHV with or without IHV	12
2A	no anatomical IHV	6
2Bx	IHV excluded from calculation	9
2By	RHV with or without IHV	3
3Bx	IHV excluded from calculation	1

Discussion

Living donor transplantation has rapidly expanded from the pediatric to the adult recipient populations. This expansion has been associated with a need to obtain imaging studies that provide both anatomical and physiological information. The advent of 3-dimensional reconstruction techniques such as the one depicted in this paper has provided some of this vital information. Although both donor safety as well as recipient outcomes have benefited [7], it was our belief that further work in the field was required.

Our own experience as well as that of others has shown that hepatic venous outflow is equally, or sometimes even more relevant than portal inflow in assuring optimal graft outcome [13-14, 19]. Furthermore, outflow complications are augmented in cases of small grafts in recipients with prominent portal hypertension, where an otherwise controllable small for size syndrome can easily turn into graft failure [5-6, 10, 13-14, 19, 20, 22].

The purpose of developing a new nomenclature to include both anatomical and physiological attributes was to simplify the evaluation process of live donor candidates. When evaluating 3-D reconstructions, we were especially interested in hepatic venous anatomy and physiology.

In this study cohort we encountered 30 (55%) livers with anatomical type A RHV (single RHV without IHV). Type B RHV (RHV in complex with IHV) were present in 45% (n = 25) of cases. In these cases the IHV were 2mm or more in diameter, which made them detectable by 3-D imaging. In his series, Nakamura proposed a fundamentally structural classification of hepatic veins, and described 39% (n = 32) of livers with type I RHV (single RHV with no IHV) and 61% (n = 51) with types II+III RHV (including IHV) on liver casts [16].

Although venous anatomy by itself is of great importance, a physiological component is an essential complement. Together, they constitute what we defined as venous dominance. Our initial observations defined a marked variety of venous patterns associated with an even greater variety of liver volumes. This became especially prominent at the time when patterns of venous dominance were considered. Our daily experience until then had proven that it was often difficult for the operator to provide complete information without stating, for example, whether the inferior hepatic veins (if present) were considered independently or as part of the RHV territory, or how the caudate lobe was considered. We formulated our classification in an attempt to provide a universally applicable standard. We believe it allows for the delineation of venous dominance and of RHV variability, and ultimately serves as a guide in the decision of whether or not to include the MHV with right hemiliver grafts.

Our data revealed that the MHV and LHV showed a relative lack of anatomical diversity. The RHV however, exhibited multiple functional variants of surgical relevance and a strong dominance in the whole as well as in the right hemiliver. The RHV was usually dominant when present as a single vein without anatomical

IHV (type 1A), or when considered in complex together with IHV (type 1Bx). Its incidence of dominance was 80% in group 1° vs. 88% in group 2°. When both types were considered together (group 5°), dominance was present in 84% of cases. Only 55% of dominant type 1Bx (RHV / IHV- complex) automatically included a dominant type 1By RHV by itself (group 3°). A single RHV out of anatomical complex with IHV (type 1By) was dominant in only 48% of our donor candidates. This observation emphasizes the importance of IHV reconstruction (even when small in size) in right grafts, or alternatively the inclusion of the MHV with right liver grafts given its more dominant role in these circumstances. Only 1 of 55 (1,8%) donors had a dominant **type 3Bx LHV** (group 3°).

Kubota et al. reported on three cases with a severe venous congestion in the right medial liver sector following a living-donor-right graft-donation despite performing the IHV reconstruction, and sufficiently restoring their drainage territory in the posterior sector of the grafts. In all these cases the MHV was neither included into graft nor its right sided venous drainage was reconstructed (23).

The management of tributary veins draining the right medial liver sector is usually much more challenging than the reconstruction of the inferior hepatic veins. This leads to the practical suggestion that the reconstruction of IHV of small diameter should be seriously considered, and questions the current view that veins less than 5 mm in diameter need no reconstruction.

The MHV and LHV were found to be much more constant than the RHV. The MHV **types 2A and 2By** were strongly dominant and accounted for up to 57% of total liver volume (TLV) (Table 2). Their overall incidence in our series was 16% (group 5°).

Our models generated several conclusions. 1) A dominant single RHV-**type 1A** clearly dominated the right hemiliver, and assigned MHV belonging to the LHH, 2) A dominant RHV/IHV complex-**type 1Bx** showed a strong dominance in the right hemiliver, including a dominant RHV by itself (**type 1By**) in 55% of cases. According to this observation, the MHV belonged to the right liver graft, and its presence there avoided venous congestion of the marginal zone (Couinaud`s segments V and VIII) in cases where the IHV was not reconstructed, 3) Both dominant MHV **types 2A and 2By** most often belonged to the RHH, and should be included with right liver grafts to assure satisfactory venous outflows, 4) A dominant MHV **type 2Bx** should probably be included with the right graft, given its greater dominance in the RHH when either its right sided tributaries are not suitable for reconstruction or the IHV can not be reconstructed.

The proposed classification provides useful assistance in surgical decision-making for both donors and recipients. It also addresses one of the most difficult and problematic issues in right graft LDLT: the management of the MHV. We believe that the classification we propose will aid in the better organization and categorization of the variants encountered within the hepatic venous system. It is our hope that it will be as useful to the readers as it has been to us.

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Address for correspondence:
Massimo Malagó M.D.
The Ilse Bagel Professor of Surgery and Transplantation
Department of General Surgery and Transplantation
University Hospital Essen
Hufelandstr. 55
D-45122 Essen, Germany
Tel.: +49-201/723-1105
Fax: +49-201/723-1113
E-mail: Massimo.malago@uni-essen.de