The "Territorial Belonging" of the Middle Hepatic Vein: A Troublesome Dilemma in Adult Live Donor Liver Transplantation – Anatomical Evidence Based on Virtual 3-Dimensional-computed Tomography-imaging Reconstructions*

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Abstract

Background: The venous drainage of the liver plays an essential role in securing viability of both graft and remnant in live donor liver transplantation (LDLT). There is still controversy on whether the middle hepatic vein (MHV) should be routinely included as part of the graft or retained with the remnant liver. The purpose of this study was to analyze hepatic venous drainage patterns based on information obtained by 3-dimensional CT-imaging reconstructions.

Methodology: Fifty five potential live liver donors were evaluated between January 2003 and May 2004 at our Institution. We analyzed two anatomical definitions of liver dominance: total liver dominance (TLD) and hemiliver dominance (HLD). The following concepts were addressed: 1) Hepatic vein territories, 2) Hepatic vein dominance relationship, 3) Territorial belonging-patterns of the MHV to the right and left hemilivers, additionally an analysis of venous outflow in the central liver sectors was performed.

Results: Our results showed that: 1) The definitions of dominance: TLD vs. HLD overlap, displaying the MHV belonging, by taking into account the individual right hepatic vein (RHV) variability; 2) A dominant RHV for the whole liver indicates that the RHV is also dominant in the right hemiliver; 3) The MHV belongs predominantly to the left hemiliver (LHL); 4) The left hepatic vein (LHV) is dominant in the LHL.

Conclusion: Both dominance definitions provide independent mappings of the liver and offer helpful insight into venous dominance relationship.

Key words: living donor liver transplantation; liver surgery; liver venous drainage; small-for-size syndrome; 3-dimensional reconstruction

Abbreviations: HL = hemiliver; HLV = hemiliver volume; HLD = hemiliver dominance; IHV = inferior hepatic vein; IVC = inferior vena cava; LHL = left hemiliver; LHV = left hepatic vein; MHV = mid hepatic vein; RHL = right hemiliver; RHV = right hepatic vein; TLD = total liver dominance; TLV = total liver volume; D = dominant; ND = non dominant

INTRODUCTION

Living donor liver transplantation is a standardized and widely established procedure for pediatric recipients; however its applicability to the adult recipients is still limited by the risk of postoperative liver failure for both donor and recipient. Initially efforts to prevent a postoperative small-for-size situation were aimed at optimizing arterial and venous inflow to the graft [2, 23, 34, 46]. Our experience, as well as that of others, showed that equally or even more important was the concept of venous outflow [8, 21]. Of special consideration is the adequate venous drainage in the "marginal zones" of both hemilivers, which reveals the dilemma of the middle hepatic vein (MHV), which drains both the right and left hemilivers but can be preserved only on one side. The issue of how to cope with the middle hepatic vein is still controversial, particularly in right graft living donor liver transplantation [6-7].

Given the limited functional volumes of graft and remnant livers, vascular mapping and preservation of vascular structures have acquired paramount importance in adult LDLT [18, 24]. In this paper we outline our experience with venous mapping using the software HepaVision (MeVis, Germany).

PURPOSE

The purpose of this study was to define the venous drainage pattern of the liver based on anatomical properties. Especially the issue on the "territorial belonging" of the MHV to the right or left liver parts

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was addressed to. In order to do this, we analysed the information obtained from live liver donor candidates by means of a virtual 3-dimensional non-invasive imaging reconstruction.

METHODOLOGY

STUDY POPULATION

55 potential donors (34 females and 21 males) were evaluated between January 2003 and May 2004 in accordance with our routine protocol [26, 37]. Twenty-seven (49%) potential donors ultimately underwent hepatic resection for transplantation.

The liver partition was performed according to the preoperative virtual simulation. Venous drainage volumes were calculated and defined prior to surgery by means of virtual 3-D MeVis technology.

CT PROTOCOL

CT imaging was performed with a 16-row-Multidetector-CT- (MDCT-) Scanner (Sensation 16®, Siemens, Germany). The CT protocol consisted of four serial image sets of the liver. The first image set, outlining the biliary system, was acquired 30 ($\pm$ 5) minutes following intravenous short-infusion of 100 ml of a biliary contrast agent (Biliscopin,, Schering, Berlin, Germany). CT angiography was then performed to display the liver arteries and the portal as well as the hepatic venous systems. 140 ml of an iodinated contrast agent (Xenetix300®, Guerbet GmbH, Sulzbach, Germany) were administered intravenously using an automated injector (CT 9000, Liebel-Flarsheim, Cincinnati, OH, USA) at a rate of 4 ml/s. All data sets were collected in succession using identical parameters: kVp 120, mAs 140-170, slice collimation 0.75 mm, feed/rotation 12 mm, and rotation time 0.5 sec. The reconstruction increment was 1 mm.

IMAGE ANALYSIS AND VIRTUAL RESECTION

For the analysis of CT images the prototype software assistant HepaVision developed at the research center MeVis (Bremen, Germany) was used. HepaVision is an application destined for preoperative planning in liver surgery and provides automatic calculations of total liver volume, venous territories, and intended liver splits.

Portal and hepatic venous systems were first extracted from the image data. Intrahepatic vessels were transformed into a hierarchical graph representing branching dependencies and direction of blood flow. Subtrees were labelled with different colors according to the 3D venous graph.

Liver parenchyma data were obtained in a semi-automatic way, allowing for the calculation of total liver volume. The use of mathematical models enabled fusion of the results of vascular analysis and liver segmentation in order to calculate individual vascular territories for the portal and hepatic venous systems.

Virtual resections were performed in a 3-D liver model capable of displaying venous trees and venous territories. The overlap between virtual hepatic venous territories and both manually (surgeon line) or automatically defined (Pringle line) graft and remnant livers was calculated automatically, and allowed further estimation of venous sub-territories considered in this paper. The resection model was developed by the senior author of this paper and is routinely employed at our institution for LDLT [22]. When performing this liver partition, the liver transection took place along the course of the mid hepatic vein (MHV). The vein itself was "carved" out of the surrounding liver parenchyma. The line of division lied exactly over the MHV, exposing its left or right sided border on the transection surface.

The data thus obtained allowed us to define:
- Hepatic vein territories
- Hepatic vein dominance relationships
- Territorial belonging- patterns of the MHV to the right and left hemilivers
- Venous drainage contribution of the MHV to the right and left hemilivers - expressed as a relative volume % of the RHL and LHL

Definition 1: Total liver dominance (TLD)
Hepatic vein dominance was determined according to the liver volume drained by the RHV, MHV, and LHV. On the base of this definition, the dominant hepatic vein territory was the one with the largest percentage of total liver volume (TLV).

Definition 2: Hemiliver dominance (HLD)
Based on this definition, the dominant hepatic vein territory in the hemiliver (HL) was the one with the largest percentage of right or left hemiliver volumes.

Definition 3: MHV "territorial" belonging
This definition assigned the MHV belonging pattern in accordance to the ratio RHV/MHV in the right hemiliver when compared to the ratio LHV/MHV in the left hemiliver. MHV belonging based on it`s proportional volume contribution in the RHL and the LHL was assigned to the liver site with the smallest ratio.

When analyzing our data, we considered the RHV and the inferior hepatic veins (IHV) (if present) as a single territory.

Results were expressed as mean $\pm$ standard deviation (SD) values.

RESULTS

In our series of 55 donors candidates the mean total liver volume (TLV) was 1508 $\pm$ 217 ml. The right hemiliver volume (RHL) was on mean 982 ml (SD 162), and accounting for mean 65 $\pm$ 4% of TLV. The left hemiliver volume (LHL) was on mean of 526 $\pm$ 95 ml, yielding mean 35 $\pm$ 4% of TLV.

Definition 1: Total liver dominance (TLD)
In 84% of cases (n = 46), the RHV was dominant (Fig. 1a, b). Its mean volume was 715 $\pm$ 143 ml, and accounted for mean 48 $\pm$ 5% of the TLV. In the remaining 16% of the cases (n = 9), the MHV was dominant (Fig.1c, d), and had a mean volume of 682 $\pm$ 149 ml accounting for mean 45 $\pm$ 5% of TLV. The LHV was never dominant.

Definition 2: Hemiliver dominance (HLD)
The RHV had an overall incidence of dominance in the RHL of 95% (n = 52), with the MHV being dominant in the remaining 5% (n = 3). 98% of dominant RHV according to definition TLD (n = 45) were automatically dominant in the RHL (Fig. 2). In cases of dominant MHV according to definition TLD (n = 9), only 78% of RHV were dominant in the RHL (Fig. 3).

The LHV had an overall incidence of dominance in the LHL of 84% (n = 46) (Fig. 4), with the MHV being dominant in the remaining 16% (n = 9) (Fig. 5). In the subgroup of dominant RHV according to definition TLD (n = 46) the LHV had a dominance in the LHL of 87%. In cases of dominant MHV according to definition TLD (n = 9), 67% donors had dominant LHV in the LHL.

Figure 6 outlines the dominance relationship among RHV, MHV and LHV for either hemiliver and shows in detail the overlap between two definitions: TLD.

Definition 3: MHV territorial belonging
In the total group of donors candidates (n = 55), the MHV was found to "belong" to the LHL in 84% of cases (n = 46), while in the remaining 16% (n = 9) of cases it "belonged" to the RHL. When taking into consideration the definition 1 (TLD), in the subgroup of dominant RHV (n = 46), the MHV belonged to the LHL in 91 % (n = 42) of donors, while it belonged to the RHL in the remaining 9% (n = 4). In subgroup of dominant MHV according to TLD (n = 9), the MHV belonged to the LHL in 44% of donors and to the RHL in 56% of cases.

Figure 6 shows in detail the MHV-belonging types by taking into consideration both definitions of hepatic vein dominance: TLD vs. HLD.

DRAINAGE VOLUME CONTRIBUTION OF MHV TO RIGHT VS LEFT HEMILIVERS (HL)

1 subgroup: all donor candidates (n = 55)
The MHV drainage volume contribution to the RHL was on mean 29 ± 9%, (range 14-62%) and to the LHL on mean 38 ± 11% (range 18-76%) respectively.

2. subgroup: dominant RHV according to TLD (n = 46)
The MHV drainage volume contribution to the RHL was on mean 26 ± 6% (range 14-39%), while to the LHL on mean 37 ± 10% (18-68%) respectively.

3. subgroup: dominant MHV according to TLD (n = 9)
The MHV drainage volume contribution to the RHL was on mean 44 ± 9% (range 30-62%), and to the LHL on mean 47 ± 15% (range 26-76%) respectively.

4. subgroup: right-sided MHV belonging type (n = 9)
In these cases, the MHV drainage volume contribution to the RHL was on mean 43 ± 9% (range 29-62%), and to the LHL on mean 32 ± 7% (range 18-43%) respectively.

5. subgroup: left-sided MHV belonging type (n = 46)
In these cases, the MHV drainage volume contribution to the RHL was on mean 27 ± 6% (range 14-45%), and to the LHL on mean 40 ± 12% (range 19-76%) respectively.

Figure 7 delineates in detail the drainage volume contribution to the RHL and LHL in case of right- and left-sided MHV-belonging types.

OPERATIVE DATA

Twenty one of the 27 grafts obtained were right lobes that included the MHV, 2 were right lobes with no MHV, 2 were left grafts with MHV, and 2 were left lateral segment grafts.

1. subgroup: left grafts with MHV (n = 2)
In both donors the preoperative computer analysis revealed a dominant RHV in the right hemiliver, associated with a left-sided MHV belonging type. The drainage volume contribution of MHV to the LHL was: 55.4% and 56.5% respectively. The drainage volume contribution of RHV to the RHL was: 78.5% and 82.4% respectively. There were no postoperative complications due to venous congestion in the right medial sector in both remnant livers.

2. subgroup: right grafts without MHV (n = 2)
In these two donors a left-sided MHV belonging type with a drainage volume contribution to the LHL of 54.5% and 57.3% was encountered. In one case a dominant single RHV in the right hemiliver, with a drainage volume contribution to the RHL of 80.1% was present. The calculated GVBWR of the right hemiliver graft in this case was 1.01. In another patient there was a dominant RHV/IHV complex with a drainage volume contribution to the RHL of 75.4% present. The additional reconstruction of the IHV was necessary because of its volume drainage contribution to RHL of 17.6%. The calculated GVBWR of the right hemiliver graft in this case was 0.93. In both recipients there was neither a venous congestion in the marginal zone of the graft, seen intraoperatively, nor postoperative vacular or biliary complications occured.

3. subgroup: right grafts with MHV (n = 21)
Seven donors showed a dominant single RHV (according to TLD and HLD). Its volume drainage contribution to the RHL was on mean of 69 ± 5%. In all these cases a left-sided MHV belonging type with a volume drainage contribution to the LHL on mean of 32 ± 9% was identified. In case of retaining the MHV in the remnant, the calculated graft-GVBWR was on mean of 0.67 ± 0.09, thus the decision to include the MHV with the graft was made.

In 6 further donors a dominant RHV/IHV complex (according to TLD and HLD) was seen. In all these cases there was a latently dominant MHV, having a volume drainage contribution to the RHL on mean of 47 ± 10% and to the LHL on mean of 29 ± 12% respectively. In three cases an additionall IHV reconstruction was performed, in order to secure the venous drainage in the right posterior sector.

In the additional 8 donors a right-sided MHV belonging type having a volume drainage contribution to the RHL on mean of 40 ± 4% and to the LHL on mean of 28 ± 5% respectively, was encountered. In all these cases a dominant LHV in the remnant liver was present.

None of all donors and recipients in this subgroup developed a small-for size syndrome postoperatively. There were no biliary or vascular complications seen in the remnant livers.

DISCUSSION

Living donor liver transplantation is characterized by tightly calculated anatomical and physiological reserve volumes for both graft and remnant livers. In this regard hepatic venous outflow plays a major role [4, 9, 11, 22, 28, 30-31]. In fact, many cases of graft loss can be attributed to unrecognized venous outflow dysfunction [9, 11-12, 25, 32]. In these cases, segmental or sub-segmental venous territories develop venous congestion and become functionally affected [1, 14-15, 19-20]. Such changes can lead to small for size syndrome, physiological impairment, compromised regenerative capacity, and even vascular complications [9-10, 17, 28-29]. The areas most prone to congestion are the right and left medial sectors (Couinaud's segments V-VIII, and IV respectively) [1, 3-5, 9-16, 19-20, 25, 27, 29, 31-33].

There are no defined standards for reconstruction of tributaries of the MHV on either graft or remnant, nor are there standards for inclusion of the MHV in any of the two hemilivers. Reports describe reconstruction of the main hepatic veins as well as some of their tributaries in order to preserve adequate liver function [1, 7, 9, 13, 16, 27, 29, 33-34]. It is unclear if and when patients develop sufficient collateral venous drainage via shunts ("rescue circulation") between RHV, MHV, and LHV [9-10, 15, 18, 31-33]. It has been suggested by Kubota et al. that venous reconstruction should be pursued when the volume of congested tissue is larger than 50% of the surface of the medial sector in the right liver graft [16]. Tanaka et al. developed a selection algorithm for the inclusion of the MHV into the right liver graft based on the drainage pattern of the hepatic veins. They distinguish a RHV dominant from a MHV dominant graft in which more than 40% of the graft volume drains into either the right or the middle hepatic vein [34].

New computer technology (i.e. HepaVision) makes it possible to construct virtual 3-D models in order to assess partial or total liver volumes and analyse intrahepatic vascular territories. In this paper we outline our experience with venous mapping using the software HepaVision (MeVis, Germany).

We considered two definitions, aimed at hepatic vein dominance relationhip and territorial belonging of the middle hepatic vein. Both dominance definitions (TLD and HLD) provide independent mappings of the liver and give helpful insight into venous dominance relationship. We thus suggest a needed anatomical-territorial re-evaluation of the venous drainage of the liver. We believe this study provides information on how to optimize outcomes for the recipient while maintaining the highest degree of safety for the donor.

The data analyzed allowed us to reach several conclusions:

1. The anatomical definitions of dominance (TLD vs. HLD) overlap, displaying the MHV belonging, by taking into account the individual RHV variability.
2. The information gained from the volume analysis allows us to state that:
   a) A dominant RHV for the whole liver indicates that the RHV is also dominant in the right hemiliver (RHL).
   b) The MHV belongs predominantly to the left hemiliver (LHL).
   c) In cases of right-sided MHV belonging, the MHV drainage volume contribution to the RHL is high, making up to 62% of the RHL volume. This occurs especially when single RHV are considered out of complex with IHV. Such finding highlights the necessity of MHV inclusion into the right graft unless the IHV is/are reconstructed in order to avoid congestive derangements in the marginal zone.
   d) The LHV is predominantly dominant in the LHL.
   e) The MHV drainage volume contribution to the LHL is nearly equal (mean range of 8%) regardless of its belonging pattern. Under these circumstances, the trend to include the MHV into the left liver grafts or alternatively to reconstruct its left sided tributaries (currently favored by a majority of experts) may be considered less dogmatic.

The recognition of the individually variable venous dominance-relationship and MHV belonging-patterns is one of the major challenges in planning adult LDLT and plays a key role for the successful venous outflow management in both donor and recipient. The proposed computed analysis usefully assists in the surgical decision making in both donor and recipient by addressing the aspect of the individually adjusted MHV management according to the appropriate donor / recipient-match. This constitutes one of the most difficult and problematic issues in adult LDLT, especially when right grafts are used.

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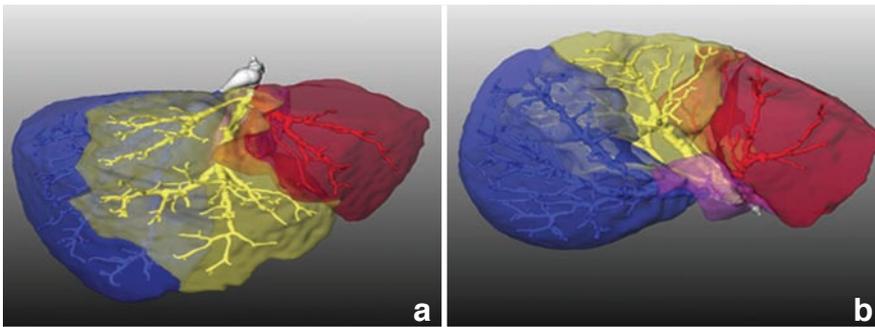
Fig. 1. 3-D reconstruction of the individual venous drainage as a percentage of total liver volume in a case of dRHV (1a, b) and of dMHV (1c, d). RHV (blue), MHV (yellow), LHV (red), IHV (cyan), separate HV caudate drainage through direct tributaries into IVC (purple), are outlined
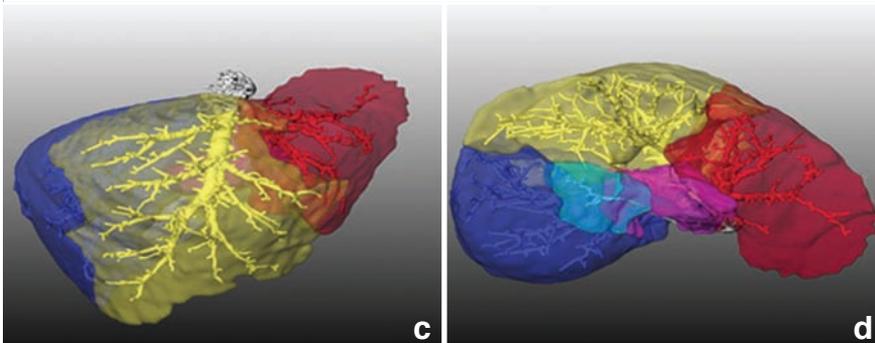
Fig. 2. 3-D reconstruction of the RHV / MHV drainage contribution in RHL according to hemiliver dominance definition in a case of dRHV. RHV (blue), IHV (cyan), MHV (yellow), LHV (red). The RHV drainage volume (blue), the MHV drainage volume (yellow), the LHL territory (white) are outlined.
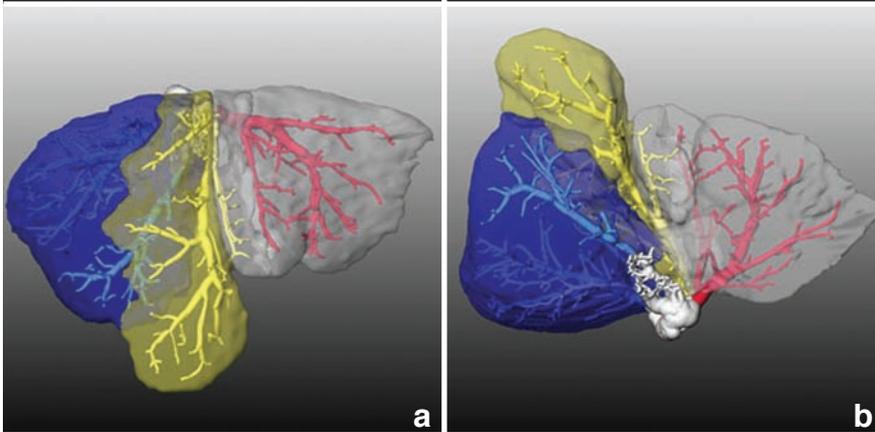
Fig. 3. 3-D reconstruction of the RHV / MHV drainage contribution in RHL according to hemiliver dominance definition in a case of dMHV. RHV (blue), MHV (yellow), LHV (red), separate HV caudate drainage through direct tributaries into IVC (purple). The RHV drainage volume (blue), MHV drainage volume (yellow), LHL territory (white) are outlined.
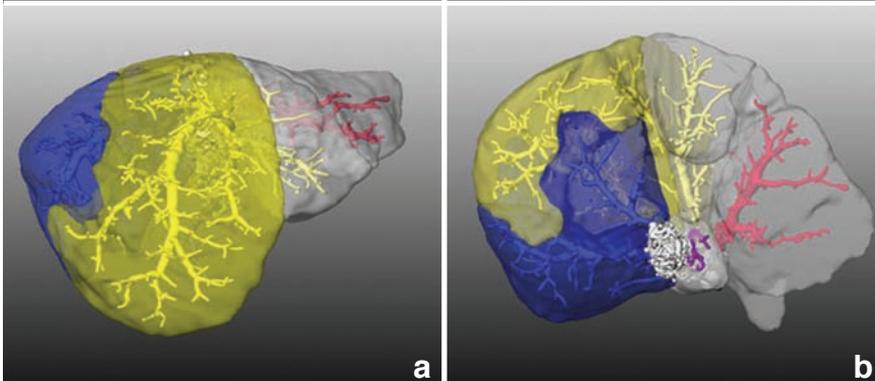
Fig. 4. 3-D reconstruction of the LHV / MHV drainage contribution in LHL under a concept of hemiliver dominance in a case of dLHV. RHV (blue), MHV (yellow), LHV (red), separate HV caudate drainage through direct tributaries into IVC (purple). The LHV drainage volume (red), MHV drainage volume (yellow), RHL territory (white), are outlined.
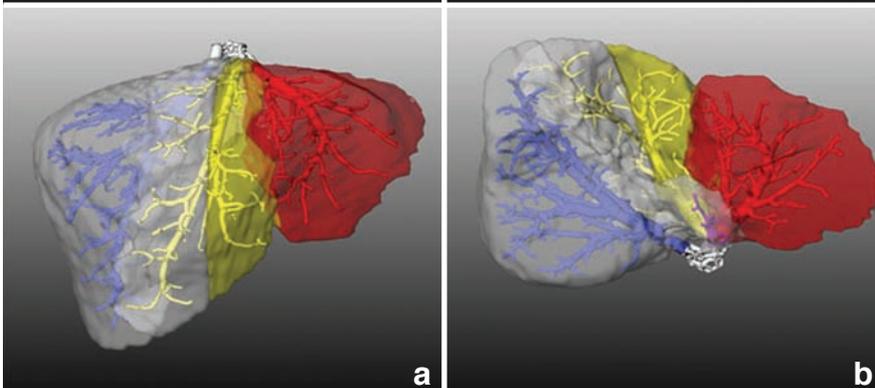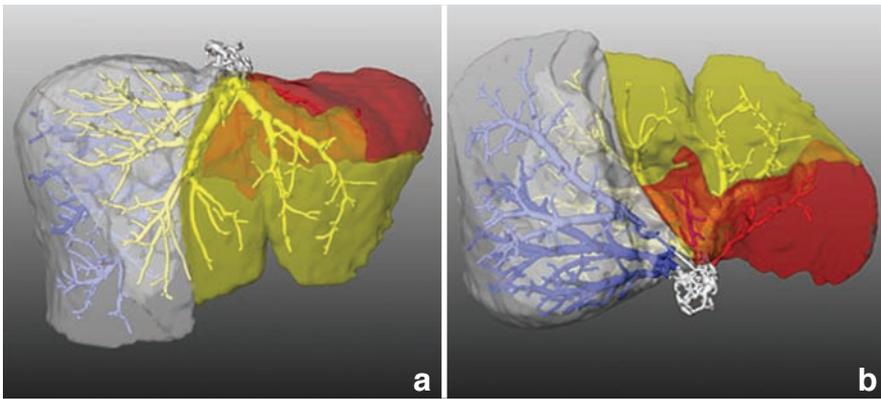
Fig. 5. 3-D reconstruction of the LHV / MHV drainage contribution in LHL under a concept of hemiliver dominance in a case of dMHV. RHV (blue), MHV (yellow), LHV (red). The LHV drainage volume (red), MHV drainage volume (yellow), the RHL territory (white) are outlined
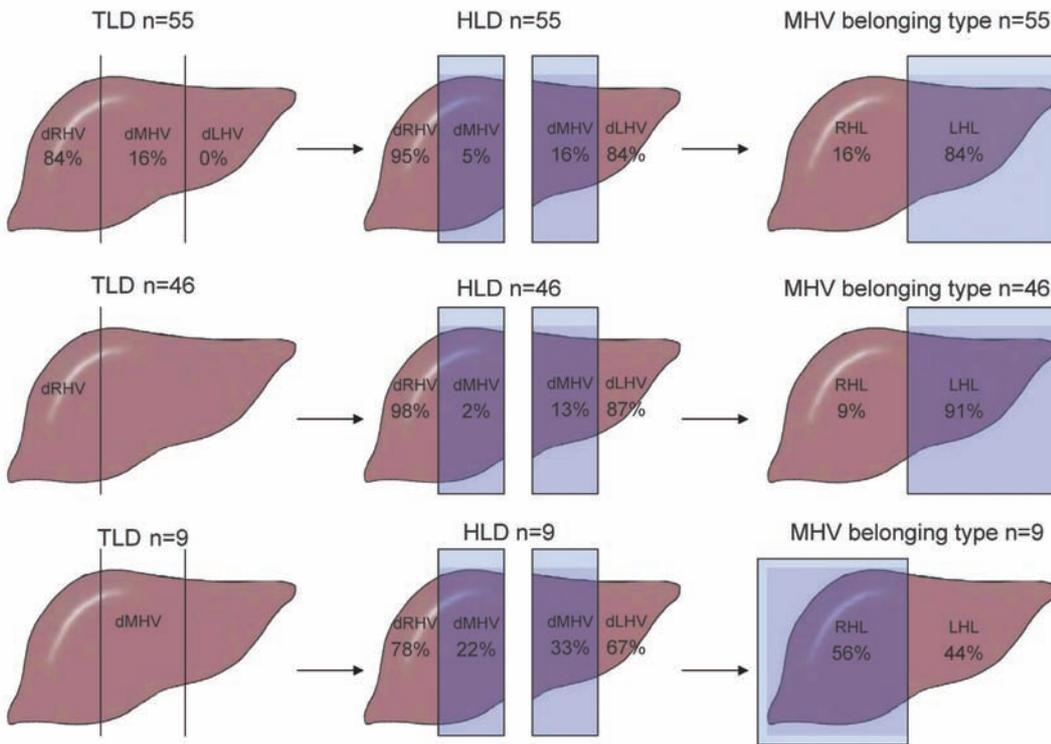
Fig. 6. Incidence of MHV belonging patterns according to HV dominance definitions: TLD versus HLD. R HL - right hemiliver; L HL - left hemiliver; TLD – total liver dominance; HLD – hemiliver dominance; d – dominant; RHV- right hepatic vein; MHV- middle hepatic vein; LHV – left hepatic vein.
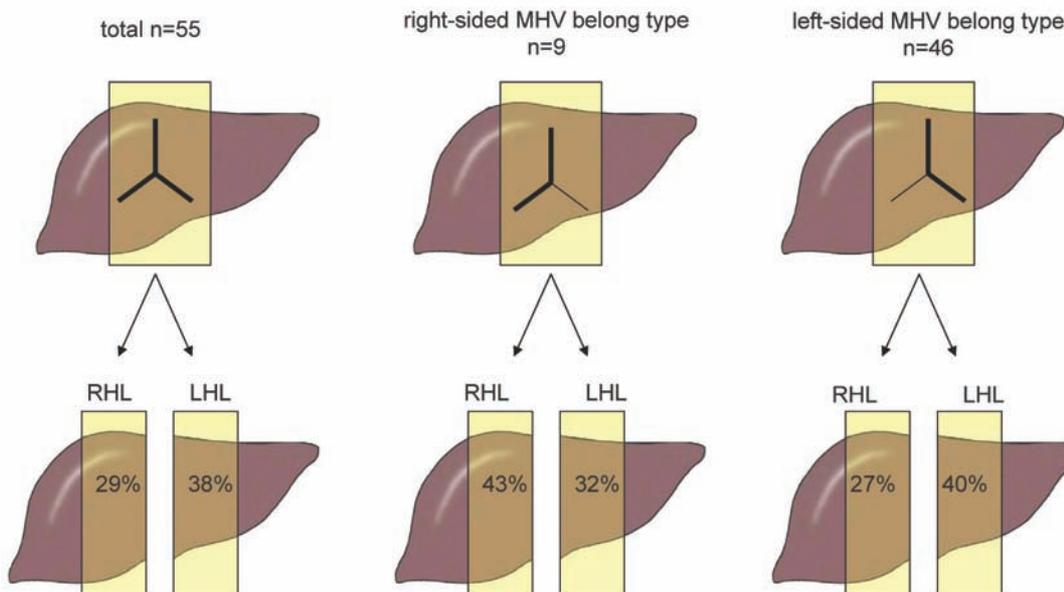
Fig. 7. MHV belonging types – drainage volume in RHL versus LHL. MHV – middle hepatic vein; R HL - right hemiliver; L HL - left hemiliver.

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