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Living Donor Liver Transplant:

Comprehensive Radiological Evaluation Prior to Surgery.

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Objective

Objective of this poster presentation is to

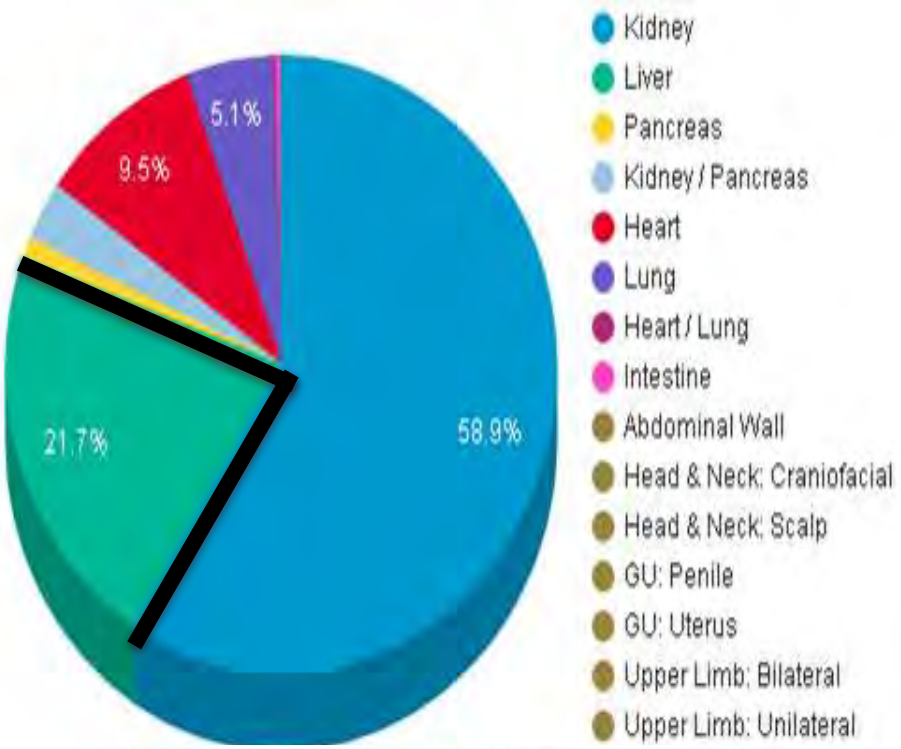
1. Review relevant and aberrant anatomy to aid in pre surgical planning of split Living Donor Liver Transplant;
2. Review imaging techniques and reconstruction methods available for identifying the same.

Content

1. Review of variation in living donor surgical approach for both left and right lobe donation.
2. Imaging sequences and reconstruction techniques available.
3. Review of
   - Normal arterial, venous and biliary anatomy and the surgical importance of each for liver transplantation.
   - Accessory, and aberrant arterial, venous and biliary anatomy.
4. Additional quantitative imaging biomarkers for assessment of underlying liver disease in potential live donors.

Introduction

- Liver is the second most transplanted organ. (Figure 1 demonstrates UNOS data from 1988-2018.)
- However, several people die while waiting on the transplant list, due to inadequate availability of organs.
- Partial grafts from living and deceased donor pools are increasingly being performed to overcome the lack of organs, although the number still remains at ~4% every year.



Year	Deceased Donor Transplants	Living Donor Transplants
2017	7,715	367
2018	7,170	356
Total	**14,885**	**723**

Transplants By Donor Type - Liver
January 1, 2014 - December 31, 2018
Based on OPTN data as of January 3, 2019

https://optn.transplant.hrsa.gov/data/citing-data/

Hallmarks and Requirements of a Living Donor Liver Transplant.

Both donor and recipient require adequate liver volume.

Key Determinants:

- The residual donor liver must be greater than 30% of the total donor hepatic volume to ensure adequate postoperative liver function,
- The graft-to-recipient body weight ratio must be > 0.8 to minimize the risk of small for-size syndrome in the recipient.[2]

Hence:

- Adult to Adult Graft usually involves the complete right lobe and less commonly the complete left lobe.
- Adult to Pediatric Graft can often suffice with a left lobe graft or left lateral lobe segmentectomy.

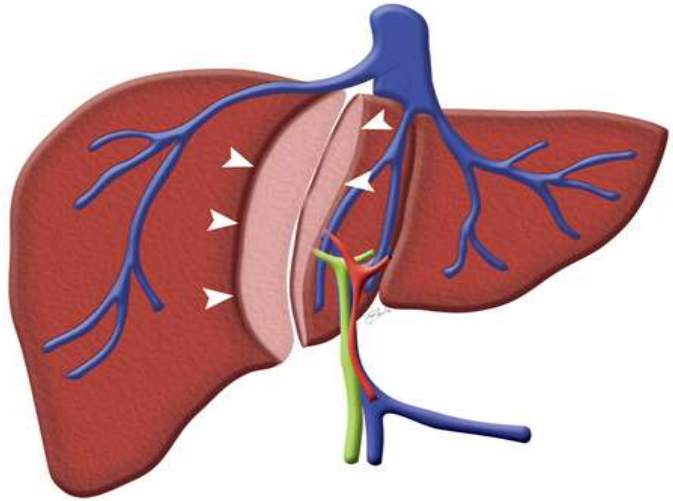


Figure demonstrating Right lobe resection plane. (Obtained from Catalano et al.)[1]

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1. *Catalno et al., Vascular and Biliary Variants in the Liver: Implications for Liver Surgery. Radiographics March, 2008.*
2. *Marcos A, Fisher RA, Ham JM, et al. Selection and outcome of living donors for adult to adult right lobe transplantation. Transplantation. 2000; 69:2410–2415.*

Typical Complete Right Donor Liver Excision

- Complications can occur when there is:
  - Recipient: Inadequate graft function
  - Donor: Inadequate donor remnant liver function
- Therefore, both graft and remnant need detailed evaluation of anatomical blood supply, as well as venous and biliary drainage.
- Aberrant arterial/portal supply to the right lobe not adequately recognized will lead to inadequate function of that lobe/segment.
- Aberrant biliary drainage or venous drainage will lead to eventual loss of graft/remnant liver function and put the patient at risk for small for size syndrome.

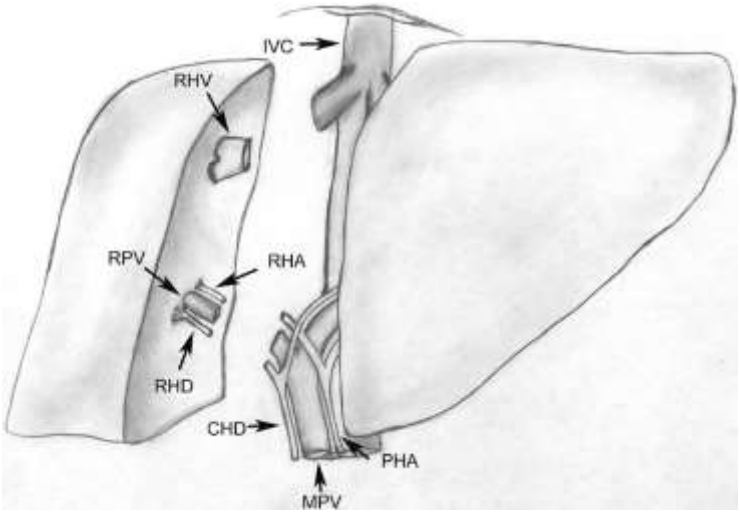


Diagram obtained from Limanond et al. demonstrating the plane of dissection for a right lobe transplant.

Limanond et al., Preoperative Imaging in Adult-to-Adult Living Related Liver Transplant Donors What Surgeons Want to Know. (J Comput Assist Tomogr 2004;28:149–157)

Sequences and Reconstructions Obtained for Pre-op Planning (Slide 1)

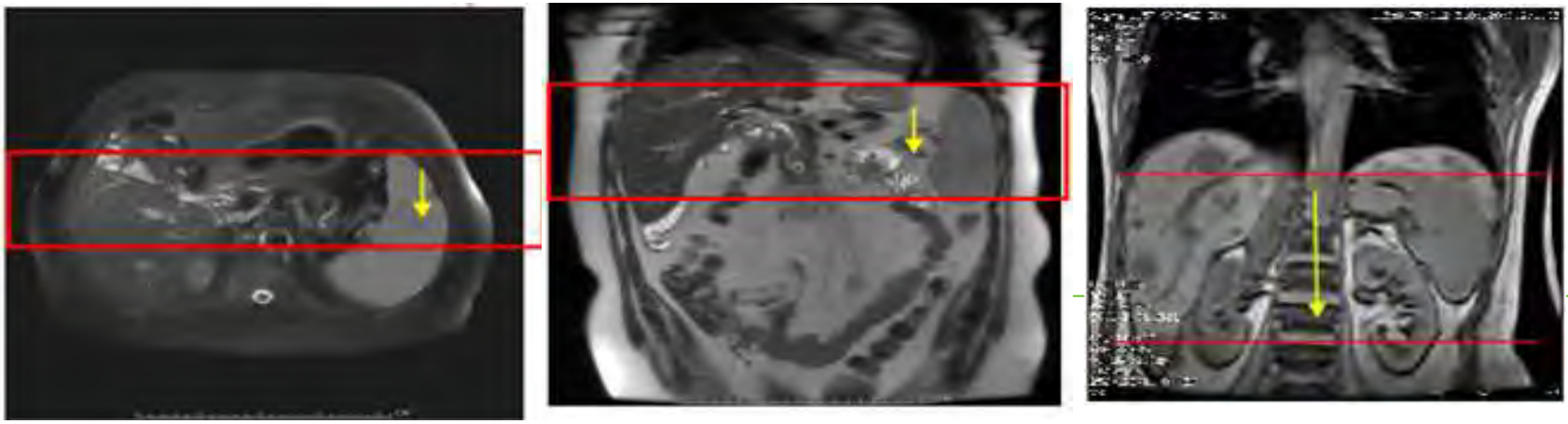
<u>Adequate Pre-op Donor Anatomy Evaluation - Sequences</u>

CTA Abdomen and Pelvis

- Scan pre contrast abdomen 5x5
- Dual energy
- Arterial: 7 second delay once triggered, scan upper abdomen
- Venous: 30 second delay after arterial, scan upper abdomen
- Late Venous: 10 second after venous, scan abdomen and pelvis
- Sagittal and Coronal reformats off all I+ series (2x2).

MRI

- MRCP for Biliary Anatomy Evaluation
- In and Out Phase for evaluation of diffuse liver disease.



Slab Selection for MRCP at our institution

Sequences and Reconstructions Obtained for Pre-op Planning (Slide 2)

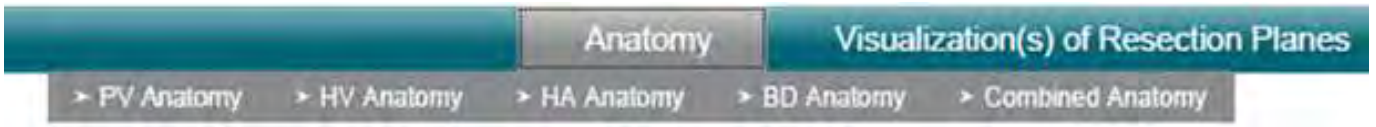
- Reconstructions are helpful to provide the surgeons with a suggested surgical excision plane and also to determine adequate volume of residual liver and donor liver.
- Each institution has variable methods of obtaining 3D reconstructions. Some have in house capabilities while others use 3rd party vendors.
- At our institution we use a 3rd party vendor for 3D reconstructions.

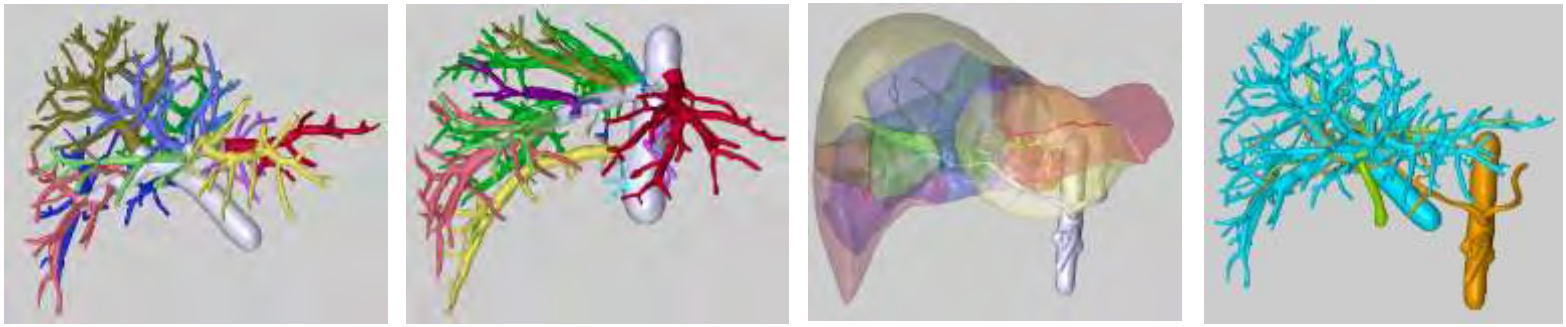
Reconstructions:

Our Institutional Experience with MeVis which has the following advantages:

- 3D volume Rendering,
- Aids in vascular and biliary anatomy assessment and identification of subtle accessory and variant anatomy.
- Visualization of various resection planes depending on surgical approach.

3D Recons: Anatomical Mapping and Surgical Planning

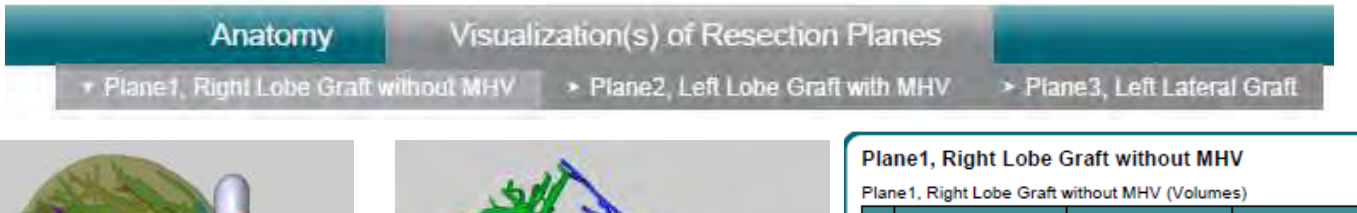


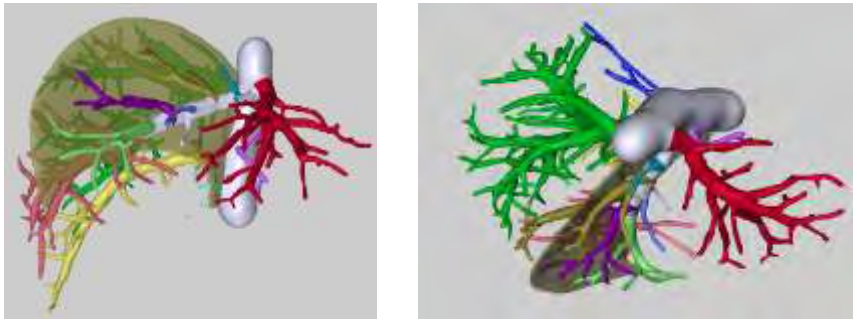


1A 1B 1C 1D

3D Anatomical Rendering of Portal Vein (1A), HV (1B), HA with territory (1C) & Combined vascular and Biliary (1D).

Surgical Planning with 3D planar visualization and Objective Volumetric Data





Right Lobe Graft without MHV, Graft and Remnant Visualization in interactive 3D planes (2 planes selected).

Plane1, Right Lobe Graft without MHV

Plane1, Right Lobe Graft without MHV (Volumes)

	Territory	Volume	Relative (%)
	Plane	21 ml	1.2
	Graft	1186 ml	67.8
	Remnant	541 ml	30.9
	Total	1748 ml	100.0

Minimal deviations can be caused by rounding errors.

The estimated graft weight is about 1079 g.

Key figures

Ratio	Based On	Value
Graft Recipient Body Weight Ratio	Estimated Graft Weight	15.42
Graft Recipient Body Weight Ratio	Graft Volume	16.94

Complications associated with Living Donor Liver Transplant

Marsh et al. reviewed complications in 121 living donors.

As per their results documented in the adjacent table:

Biliary leaks are the most common complications associated with living donors, followed by vascular complications.

These findings highlight the need for significant preoperative planning from a radiological standpoint.

Type of complication	Clavien Grade			Total	
	III	IV	V	n	(%)
Biliary					
Leak	23	5		28	(23)
Stricture	14			14	(12)
Leak and Stricture	3	1		4	(3)
Ampullary dysfunction	5			5	(4)
Biliary Total	**45**	**6**		**51**	**(42)**
Vascular					
Hepatic Artery Thrombosis	2	4	2	8	(7)
SFSS		2	3	5	(4)
Hepatic Artery Stenosis/Stricture	1	1		2	(2)
Portal Vein Stricture/Thrombus			2	2	(2)
Hepatic Artery Rupture			1	1	(<1)
Vascular Total	**3**	**7**	**8**	**18**	**(15)**
Other	6	3	2	11	(9)
Grand Total	**54**	**16**	**10**	**80**	**(66)**

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Marsh et. al., Complications of right lobe living donor liver transplantation. Journal of Hepatology. October 2009.

Review of Normal Anatomy and Aberrant Anatomy Pertinent to Living Donor Transplantation.

Portal Venous Anatomy

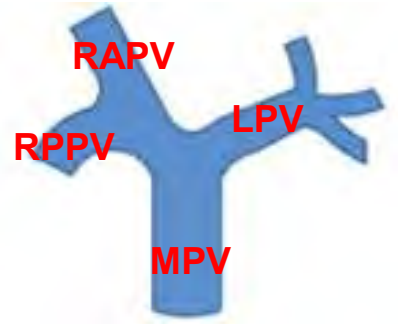
Hepatic Artery Anatomy

Hepatic Venous Anatomy

Biliary Anatomy

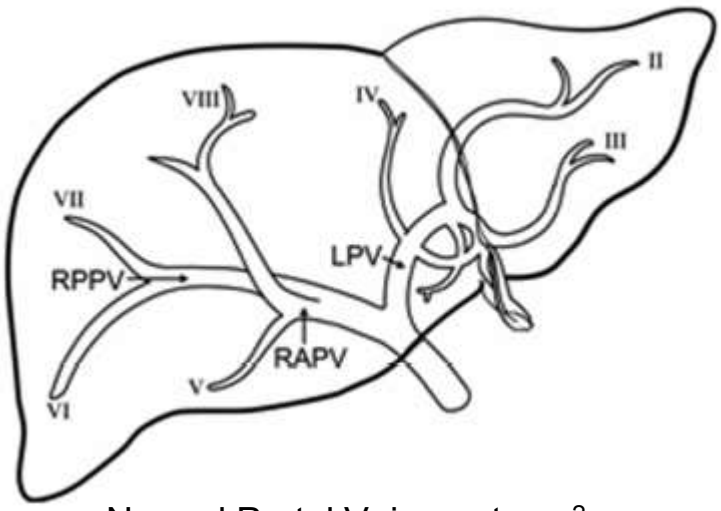
Normal Portal Vein Anatomy & Common Variants

The Portal Vein Anatomy is vital as 75% of the blood supplied to the liver comes from the portal vein, and it supplies 50% of the oxygen supply to the liver.[1]



Normal

MPV: Main Portal Vein
LPV: Left Portal Vein
RAPV: Right anterior portal Vein
RPPV: Right posterior portal Vein



Normal Portal Vein anatomy[2]

Aberrant Anatomy occurs in 25% of cases .[4]

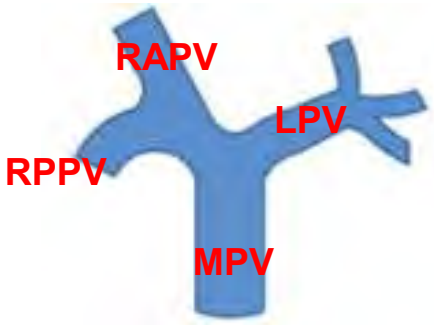
Type 2 aberrant Anatomy is the most common - Trifurcation of the portal vein.

Type 1 (Normal) **Type 2 (Trifurcation)** **Type 3** **Type 4**

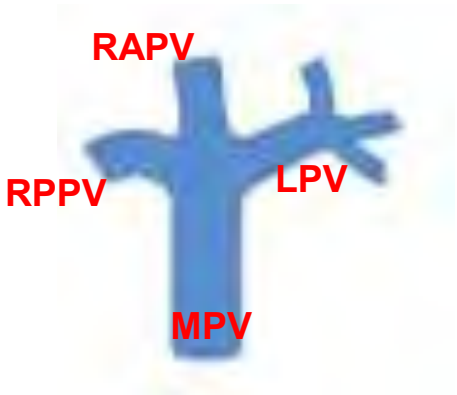
Portal Venous Anatomy

1. https://radiopaedia.org/articles/portal-vein?lang=us
2. *Covey et al. Incidence, Patterns, and Clinical Relevance of Variant Portal Vein Anatomy. AJR. October 2004.*
3. *Germain et al., Liver Segmentation: Practical Tips. Diagnostic and Interventional Imaging. 2014*
4. Sureka B, Patidar Y, Bansal K et-al. Portal vein variations in 1000 patients: surgical and radiological importance. Br J Radiol. 2015;88 (1055): 20150326.

Aberrant Portal Vein Anatomy (Type 2)

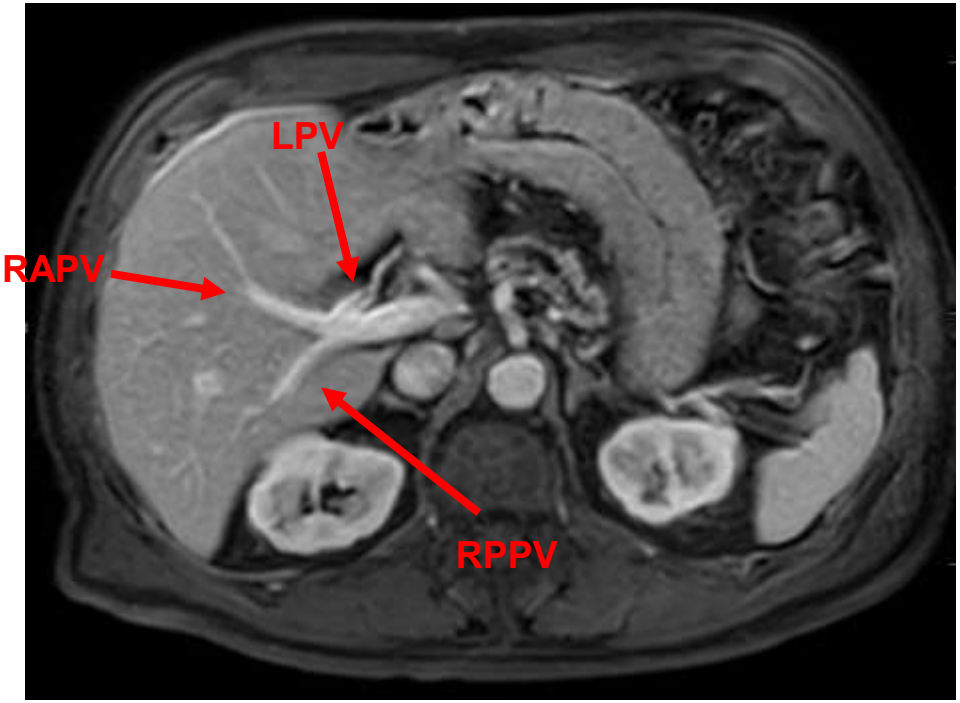


Normal



Type 2: Trifurcation

MPV: Main Portal Vein
LPV: Left Portal Vein
RAPV: Right anterior portal Vein
RPPV: Right posterior portal Vein



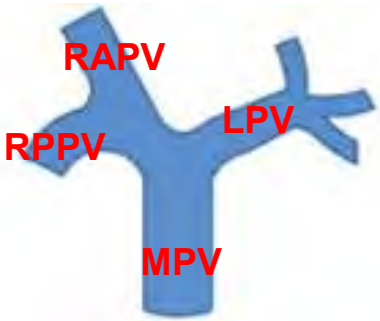
MRI of the most common portal venous anomaly showing a portal vein trifurcation.

Portal Venous Anatomy

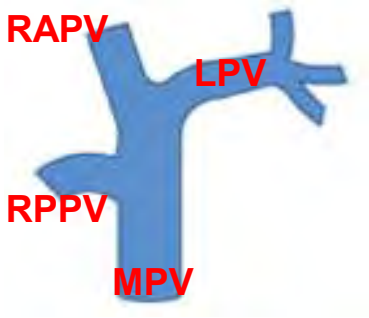
Germain et al., Liver Segmentation: Practical Tips. Diagnostic and Interventional Imaging. 2014

Aberrant Portal Vein Anatomy (Type 3)

Portal Venous Anatomy

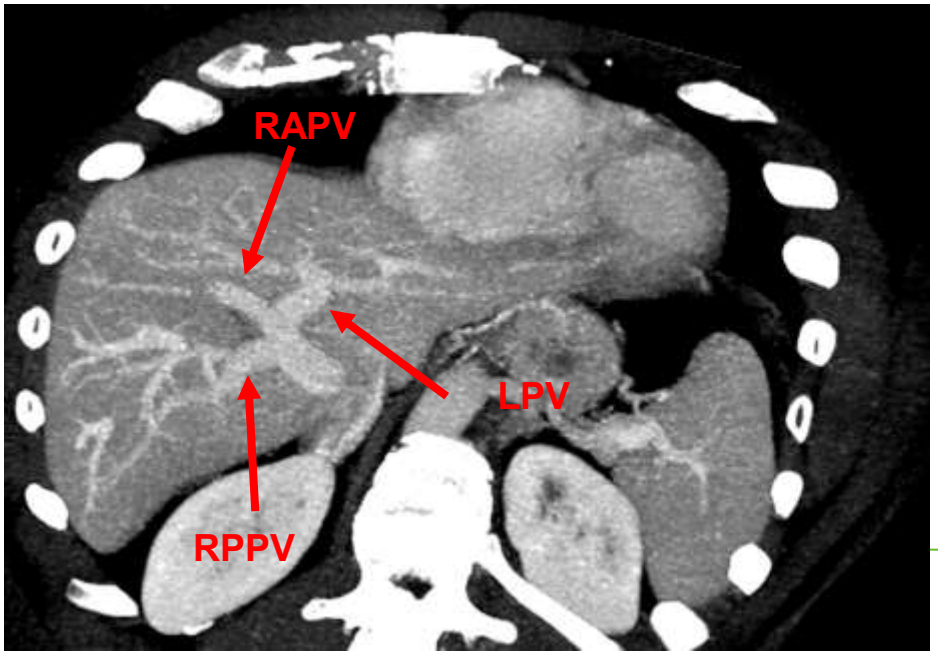


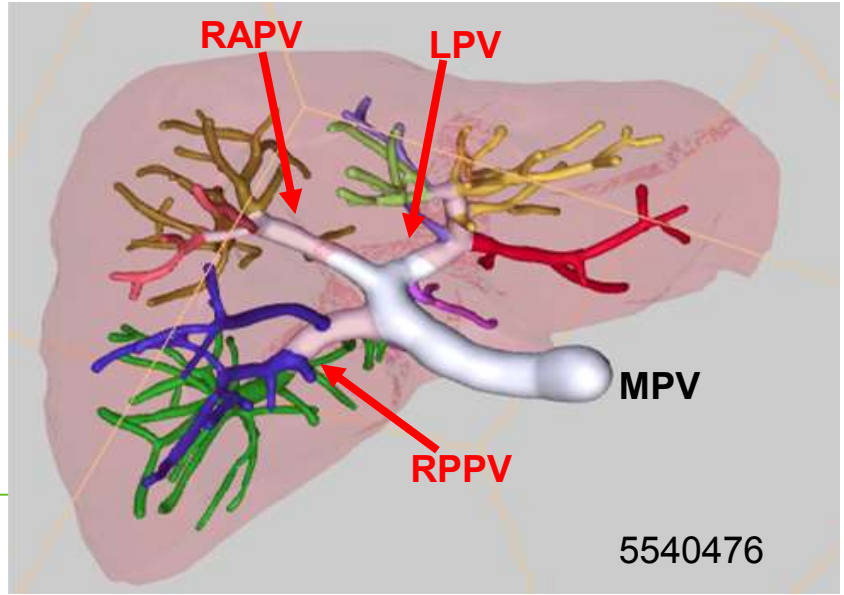
Normal



Type 3

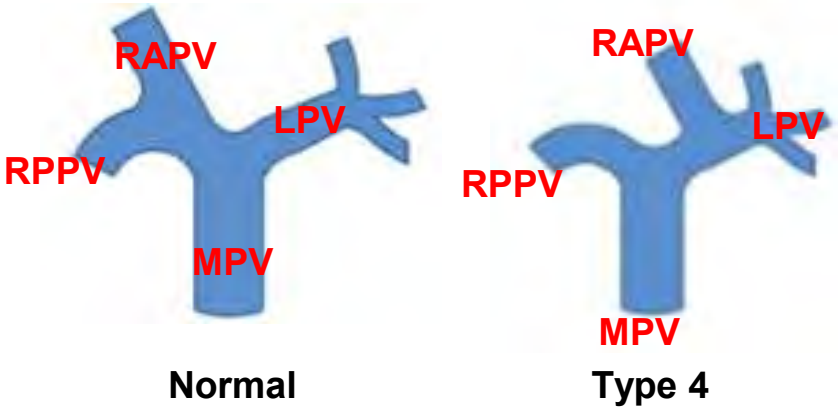
Type 3 portal vein variant anatomy is extremely important to recognize as a short segment anomaly of the RPPV can be easily confused with normal anatomy and lead to surgical complications.

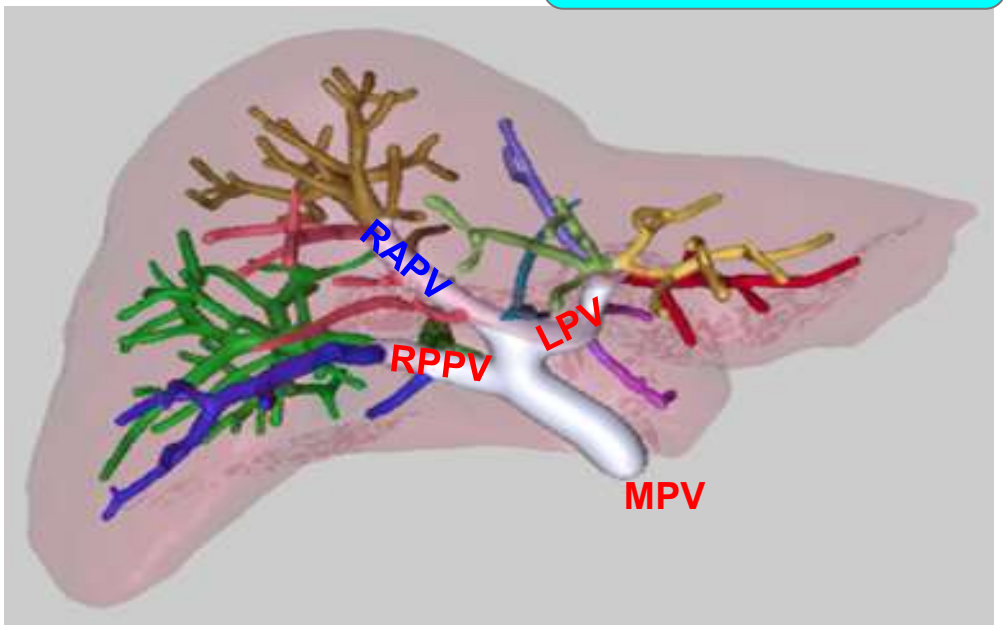




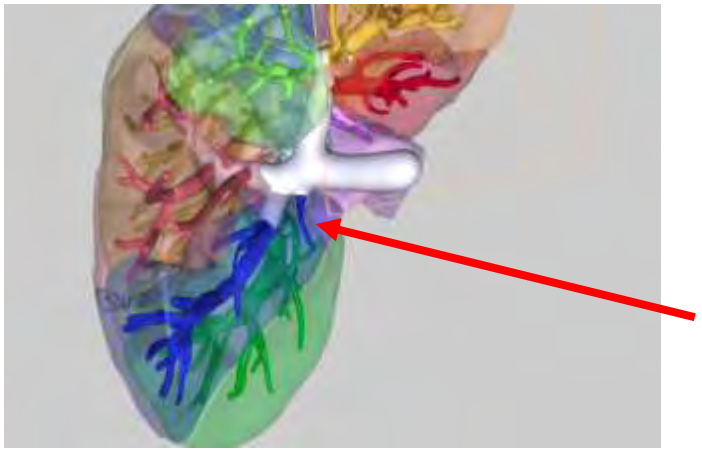
Germain et al., Liver Segmentation: Practical Tips. Diagnostic and Interventional Imaging. 2014

Aberrant Portal Vein Anatomy (Type 4)





Example of an accessory segment 6 branch arising from main portal vein (below)

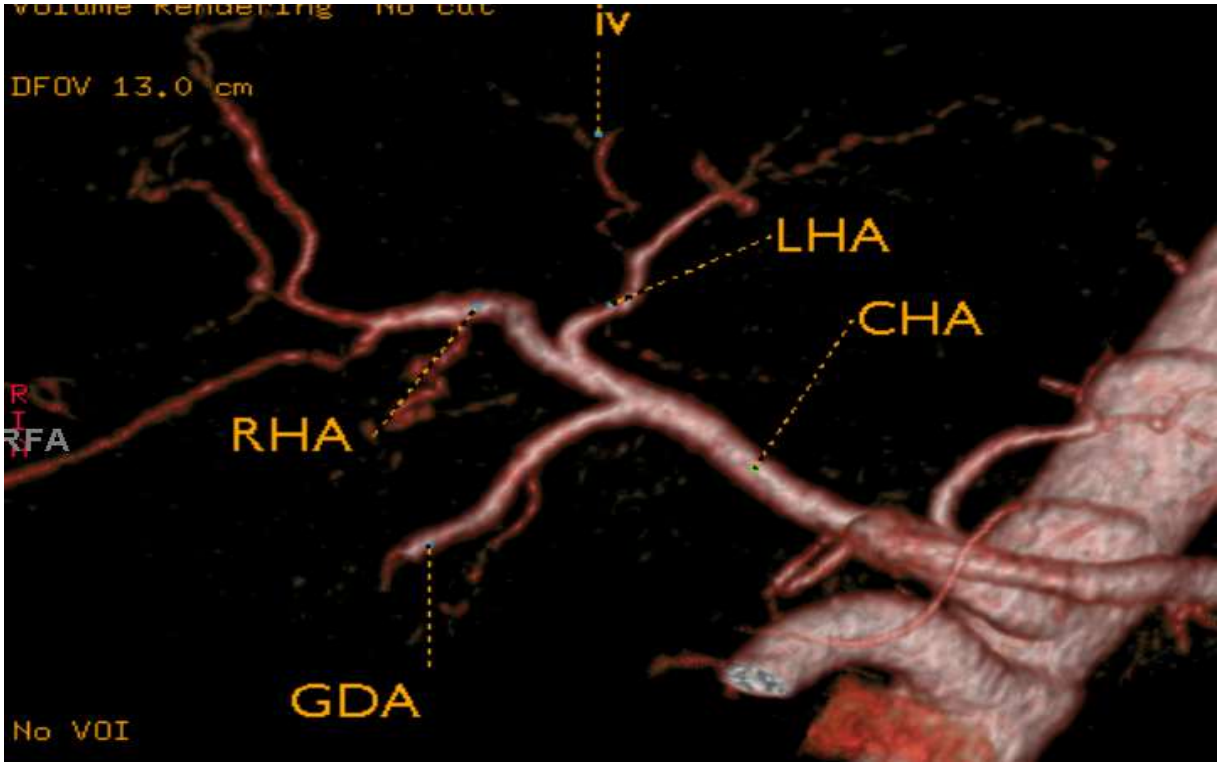


Germain et al., Liver Segmentation: Practical Tips. Diagnostic and Interventional Imaging. 2014

Hepatic Artery Anatomy

Normal Hepatic Artery Anatomy

Standard anatomy ~60% (range 55-61%)



CHA: Common hepatic artery
GDA: Gastroduodenal artery
RHA: Right hepatic artery
LHA: Left hepatic artery
IV: Segment 4 artery arising from LHA

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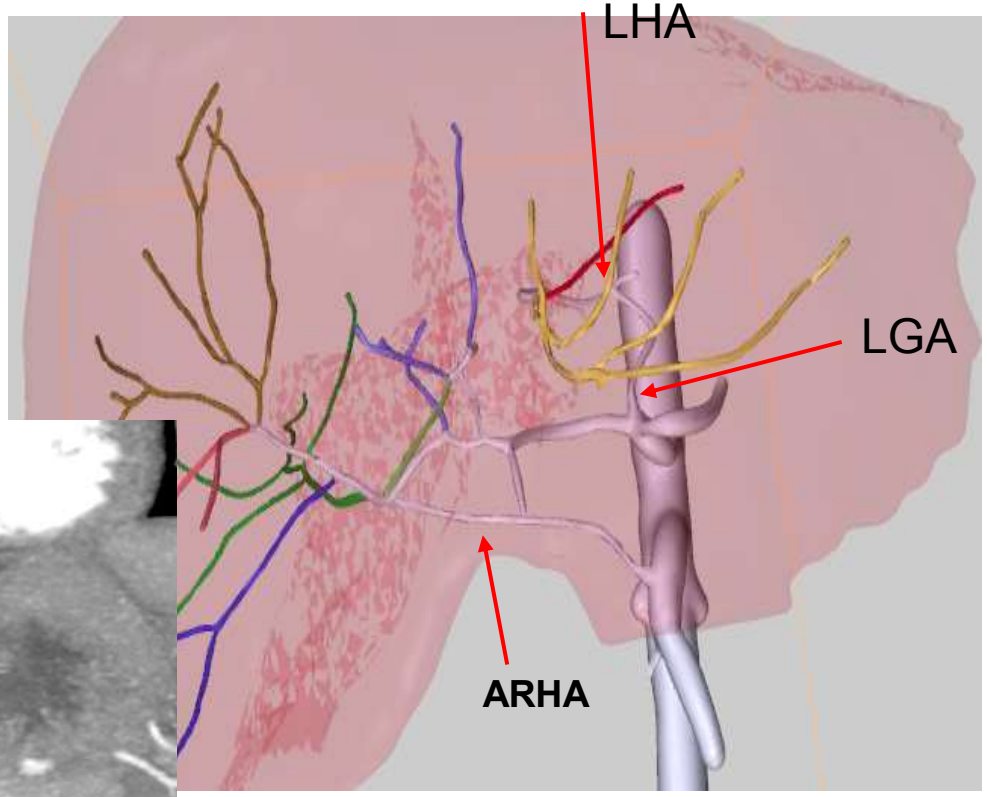
Covey AM, Brody LA, Maluccio MA et-al. Variant hepatic arterial anatomy revisited: digital subtraction angiography performed in 600 patients. Radiology. 2002;224 (2): 542-7.

Replaced left hepatic artery from left gastric (incidence ~7.5%)

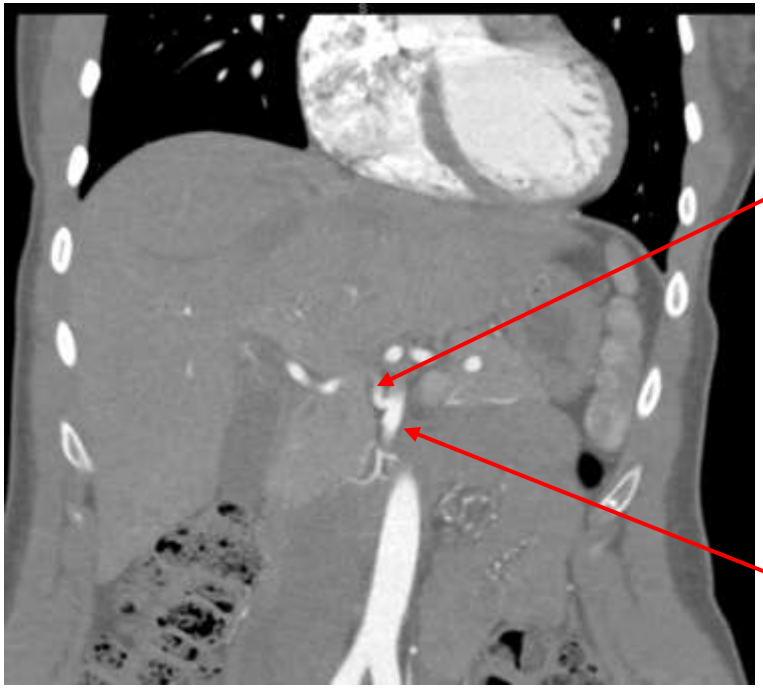
Arrow demonstrates left hepatic artery(LHA) arising from left (LGA) gastric artery. Incidental note is also made of an accessory right hepatic artery (ARHA).



Hepatic Artery Anatomy

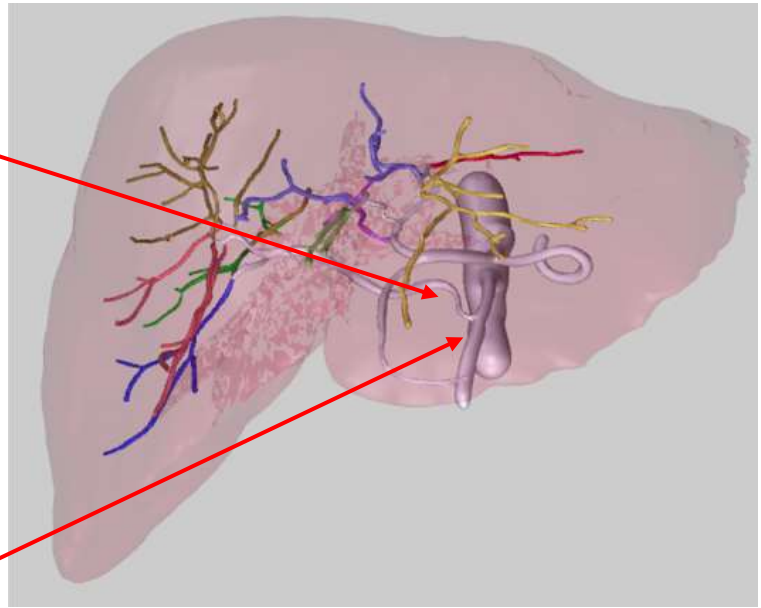
Replaced right hepatic artery from SMA (incidence ~10%)

- Right hepatic artery arising from SMA occurs in ~10% cases and adds complexity to the surgical procedure.
- Preoperative evaluation with 3D reconstruction allows the surgeon to be prepared and plan accordingly.



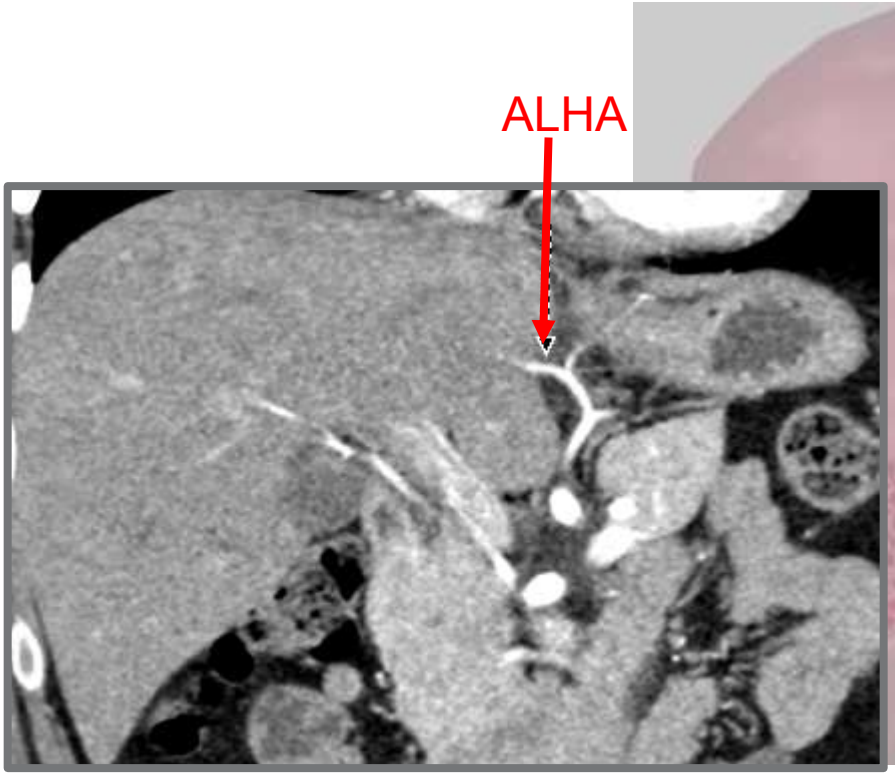
Replaced Right Hepatic

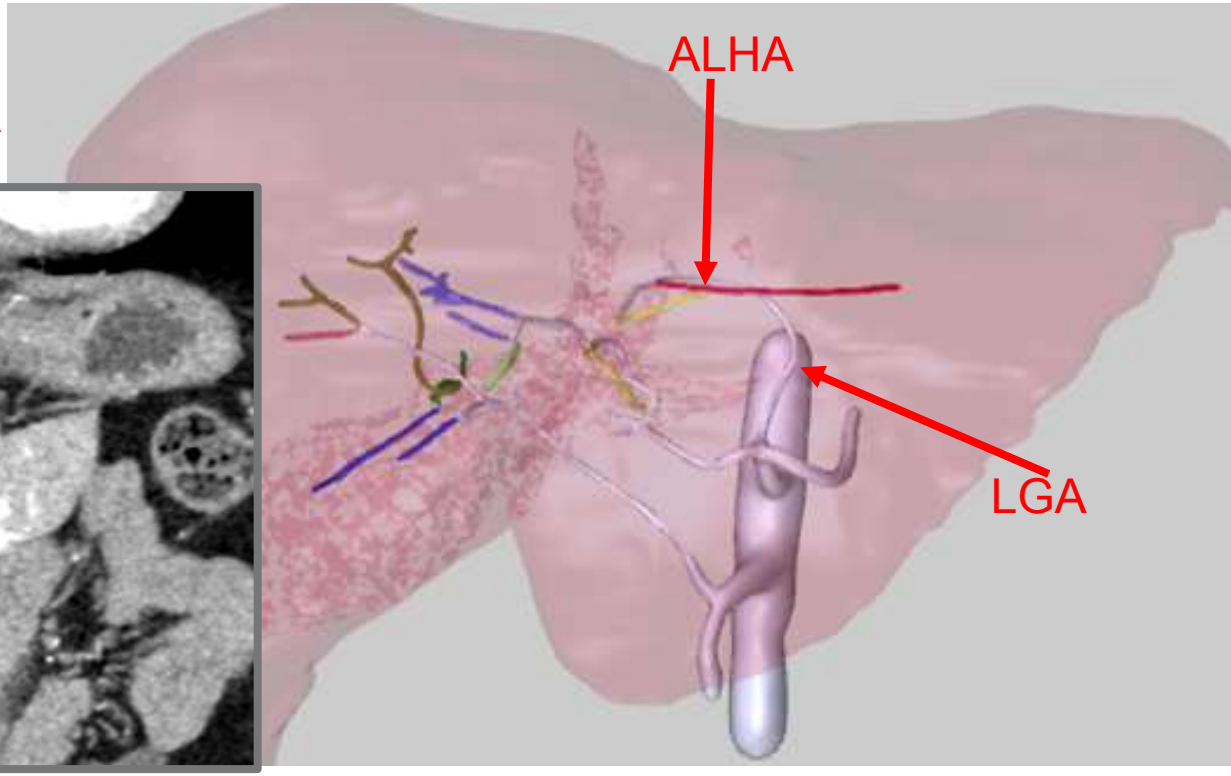
SMA



Accessory left hepatic artery from left gastric artery (incidence ~10%)

Patient has an accessory left hepatic artery (ALHA) arising from the left gastric artery (LGA) in addition to the normal anatomy where the left hepatic arises from the proper hepatic. Incidental replaced right hepatic artery.



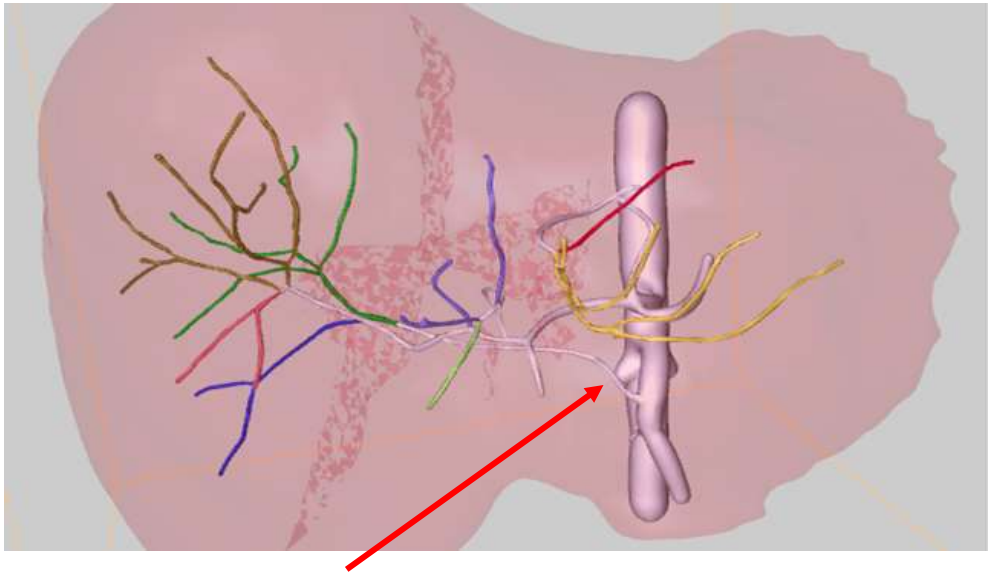


Hepatic Artery Anatomy

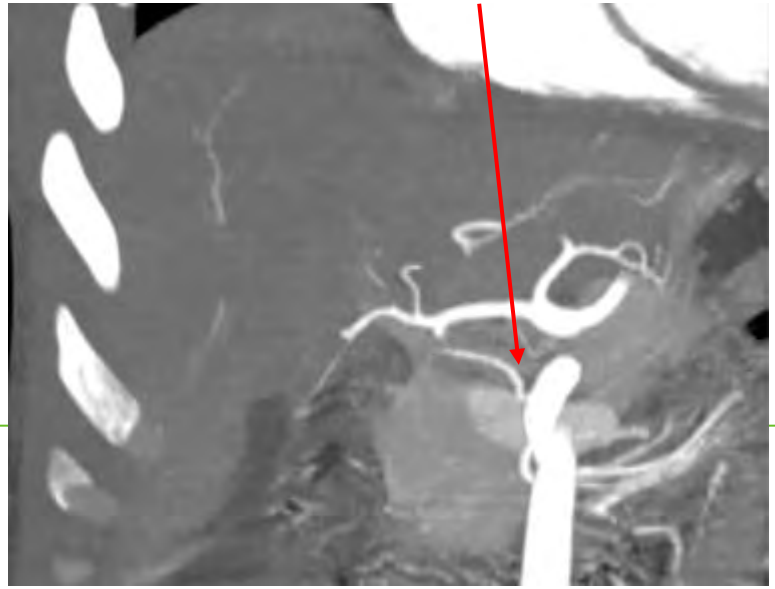
Covey AM, Brody LA, Maluccio MA et-al. Variant hepatic arterial anatomy revisited: digital subtraction angiography performed in 600 patients. Radiology. 2002;224 (2): 542-7.

Accessory right hepatic artery from SMA (~5% Cases)

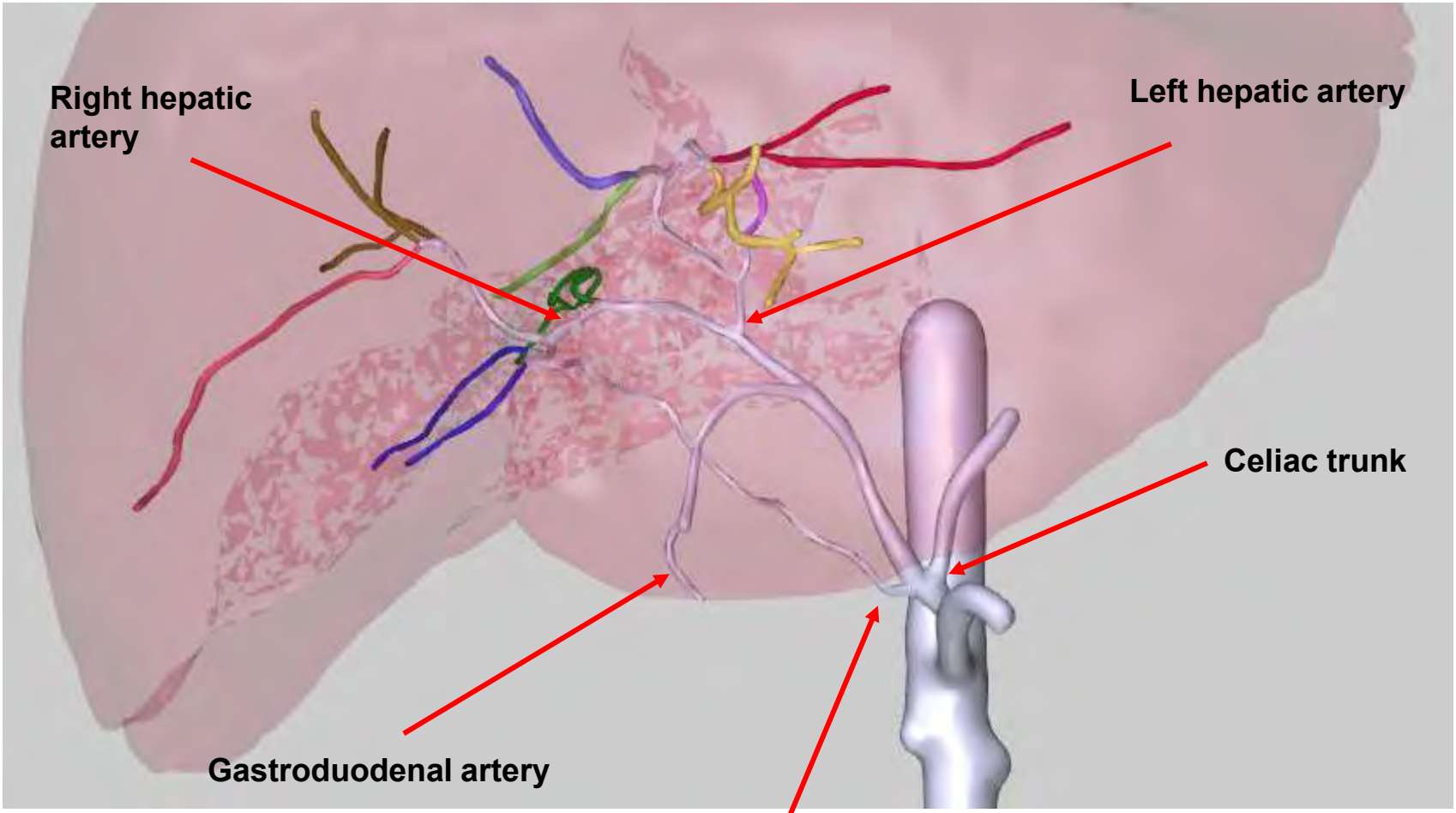
Accessory Right Hepatic Artery in a 32 year old male who was a potential liver donor.



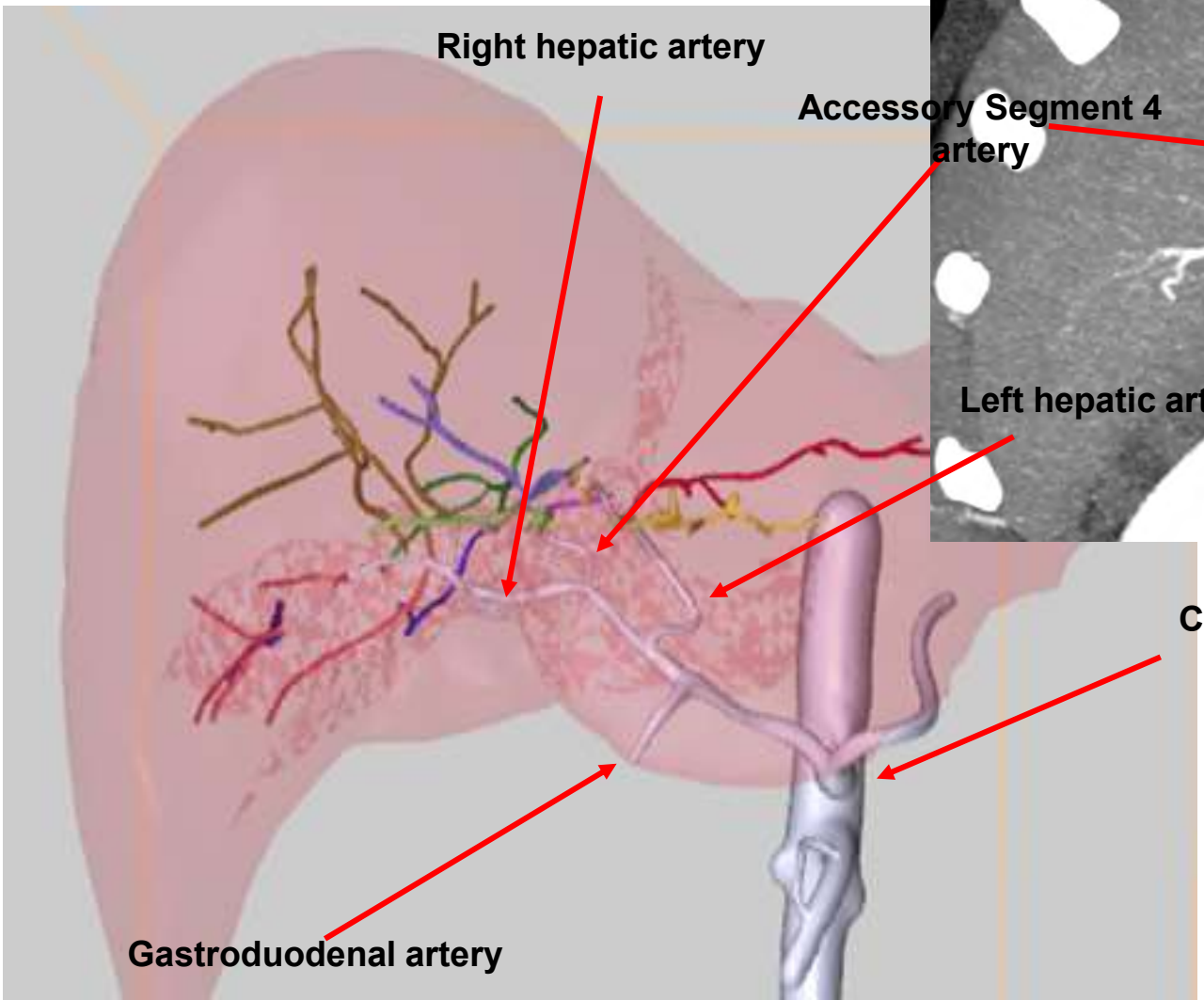
Accessory Right Hepatic Artery from SMA

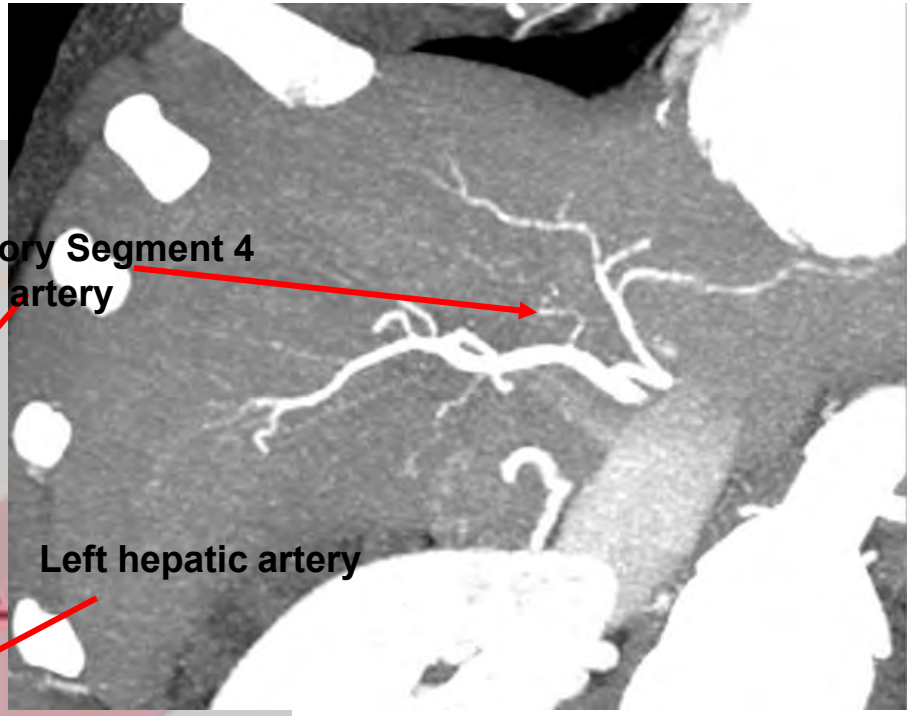


Accessory right hepatic from proximal celiac trunk



Accessory segment 4 artery arising from right hepatic artery





Celiac trunk

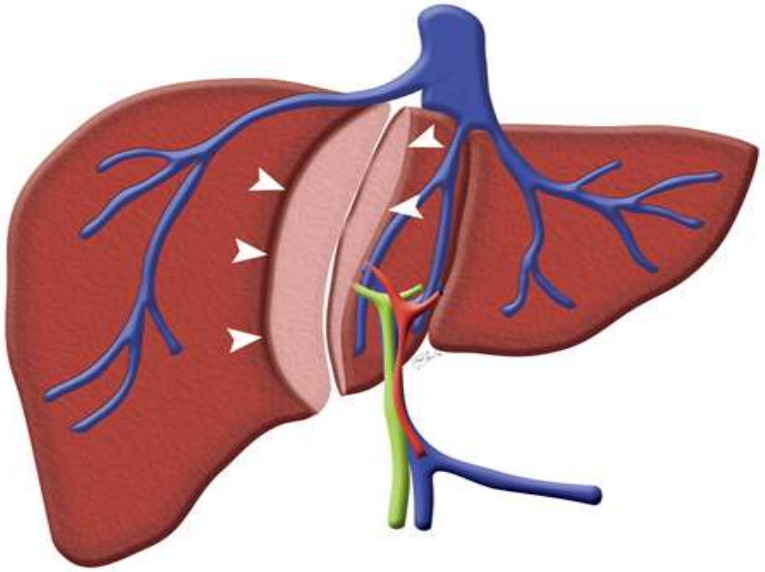
Hepatic Artery Anatomy

Hepatic Venous Anatomy

Hepatic Vein Anatomy & Common Variants

- Failure to fully understand the functional and aberrant anatomy of the hepatic veins may lead to graft dysfunction and small-for-size syndrome (SFSS), even in a liver graft of adequate size.[1]

- More importantly, it may also jeopardize donor safety because of a possible postoperative venous congestion of anterior sector (AS) of the liver remnant.



Catalno et al., Vascular and Biliary Variants in the Liver: Implications for Liver Surgery. Radiographics March, 2008.

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1. *Lee S, Park K, Hwang S, et al. Congestion of right liver graft in living donor liver transplantation. Transplantation 2001;71:812-4.*
2. *Dayangac et al. The evolution of anterior sector venous drainage in right lobe living donor liver transplantation: does one technique fit all? HepatoBiliary Surg Nutr 2016;5(2):151-158.*

Middle hepatic vein drains segments 5 and 8 (part of right lobe) (Slide 1/2)

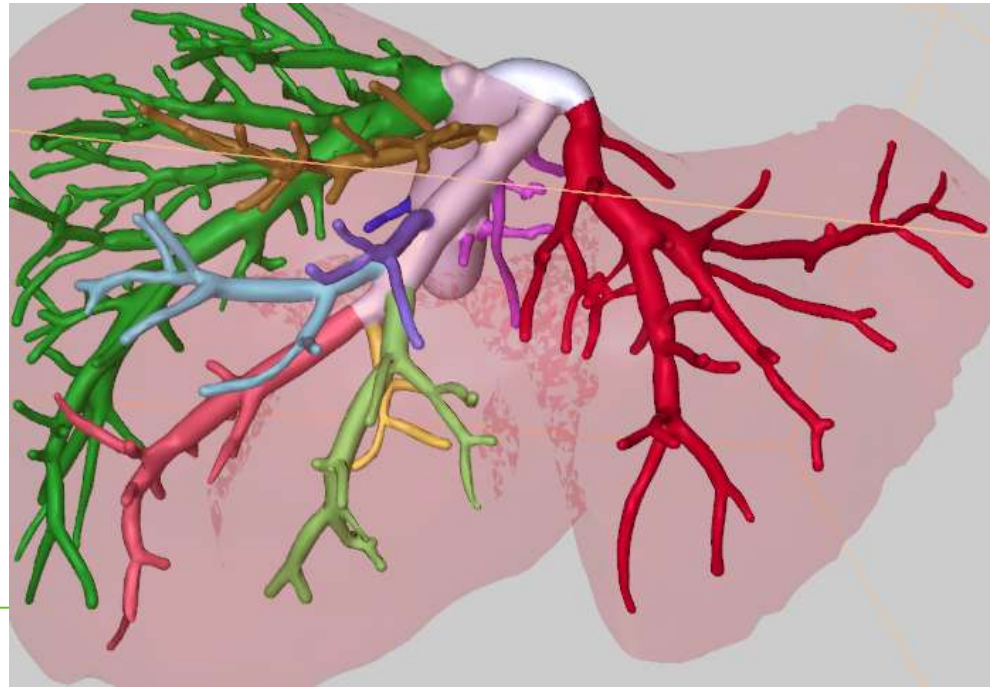
- Segment 5 and 8 being drained into the middle hepatic vein in ~9% cases.[1]
- Figure below left demonstrates color key with subsequent columns demonstrating volume and relative percentage of liver being drained by each vein. In this case, ~20% of the liver volume is being drained by the accessory veins.
- MeVis reconstruction (middle figure) showing the diagrammatic reconstruction below.

HV Anatomy

HV Territories (Volumes)

	Territory	Volume	Relative (%)
	HV1	44 ml	3.1
	inf.HV	15 ml	1.1
	LHV	285 ml	20.2
	MV4a	31 ml	2.2
	MV4ba	87 ml	6.2
	MV4bp	19 ml	1.3
	MV5	119 ml	8.4
	MV8i	77 ml	5.5
	MV8s	84 ml	6.0
	RHV	650 ml	46.1
	Total	1411 ml	100.0

Minimal deviations can be caused by rounding errors.



Erbay et al. Living donor liver transplantation in adults: vascular variants important in surgical planning for donors and recipients. AJR Am J Roentgenol 2003;181(1):109 –

Reconstruction for Segment 5 & 8 drainage. (Slide 2/2)

- Segment 5 & 8 venous drainage in to the Middle Hepatic Vein while adding surgical complexity does not necessary preclude possible surgery.
- In order to avoid graft congestion (Figure 1), venous reconstruction (Figure 2) can be performed.
- This is feasible as long as detailed preoperative evaluation is performed and relayed to surgeon for adequate preoperative planning.

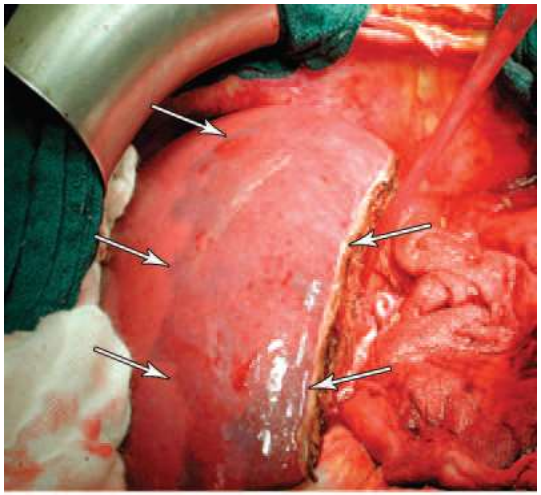
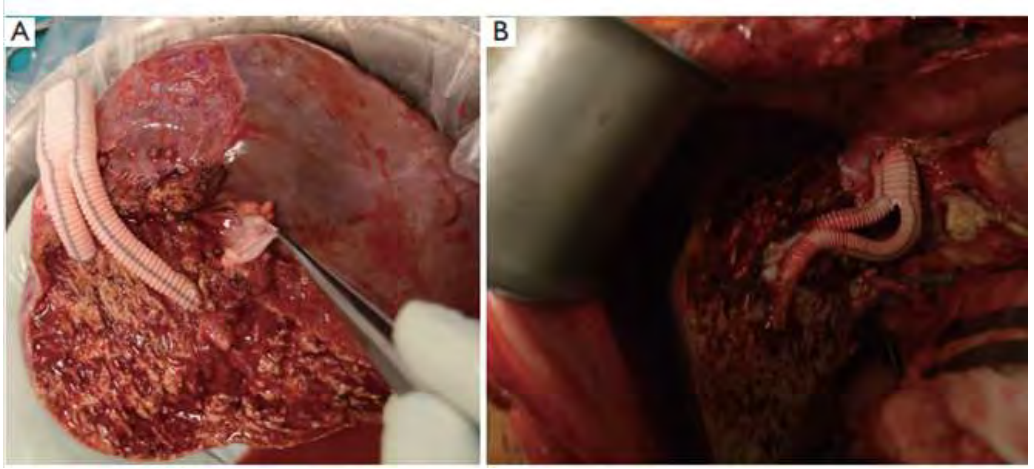


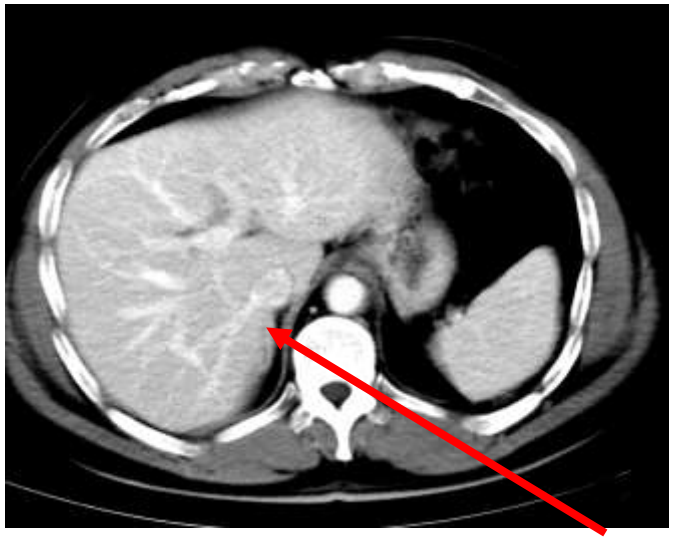
Figure obtained from Catalo et al., demonstrates venous congestion in segments 5 and 8.

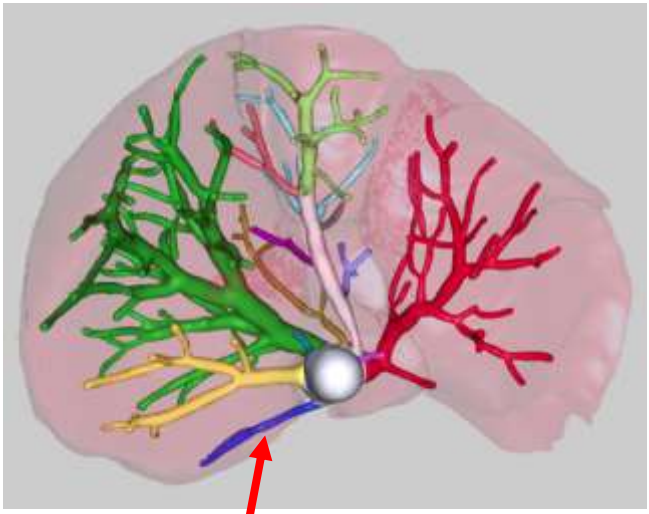


Venous reconstruction of Seg 5 & 8 veins to recipients MHV-LHV junction via interposition of Dacron graft.
(Figure obtained from Dayangae et al.)

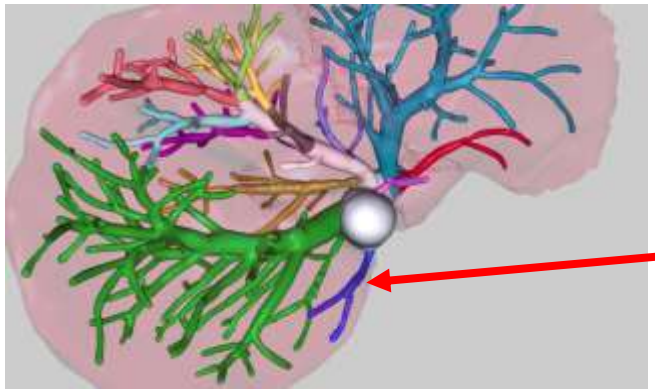
1. *Catalno et al., Vascular and Biliary Variants in the Liver: Implications for Liver Surgery. Radiographics March, 2008.*
2. *Dayangac et al. The evolution of anterior sector venous drainage in right lobe living donor liver transplantation: does one technique fit all? HepatoBiliary Surg Nutr 2016;5(2):151-158.*

Accessory hepatic veins





Accessory Segment 7 vein draining into IVC.



Small accessory right hepatic vein draining segment 6/7 joining the IVC at the level the cephalad caudate.

Normal Biliary anatomy & Common variants

Right posterior duct (RPD - draining segments VI and VII) joins Right anterior duct (RAD - draining segments V and VIII), to form Right hepatic duct (RHD).

Segmental bile ducts from segments II to IV unite to form the Left hepatic duct (LHD).

The left and right hepatic ducts unite to form the **Common hepatic duct (CHD)**. Bile duct(s) from segment I drain into the angle of their union.

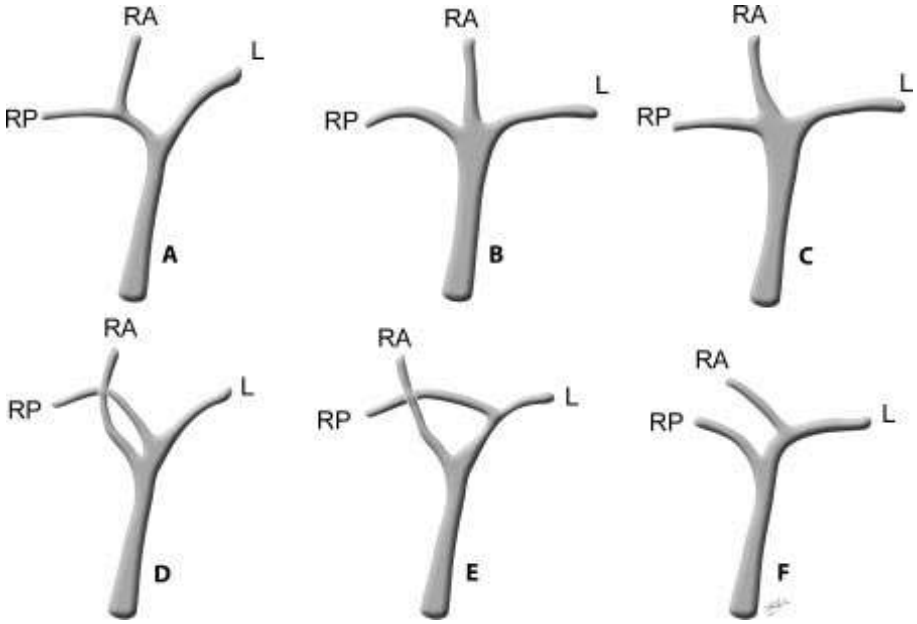


Figure demonstrating Normal Anatomy (A) and variants (B-F).
L: Left Biliary Duct. RA: Right Anterior. RP: Right Posterior.
Figure obtained from Castaing et al.

Biliary complications occur in 7%–10% of donors.

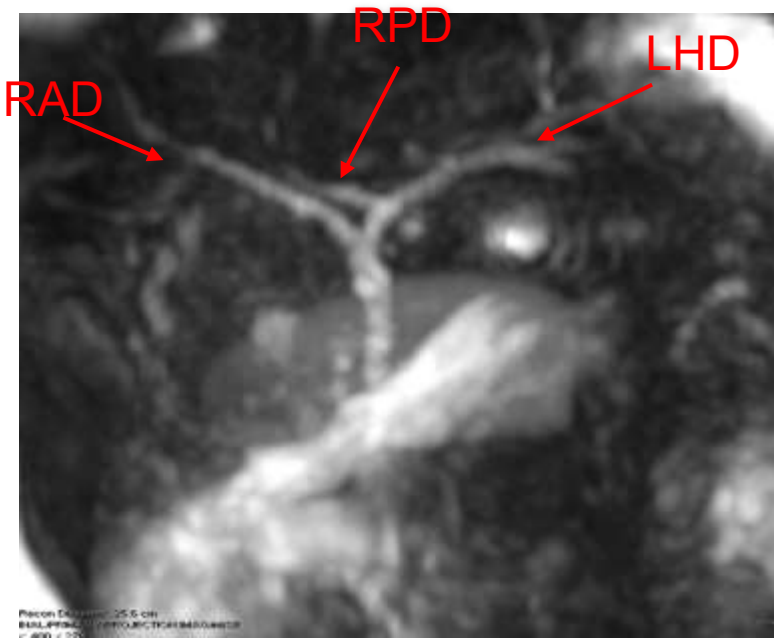
Biliary Anatomy

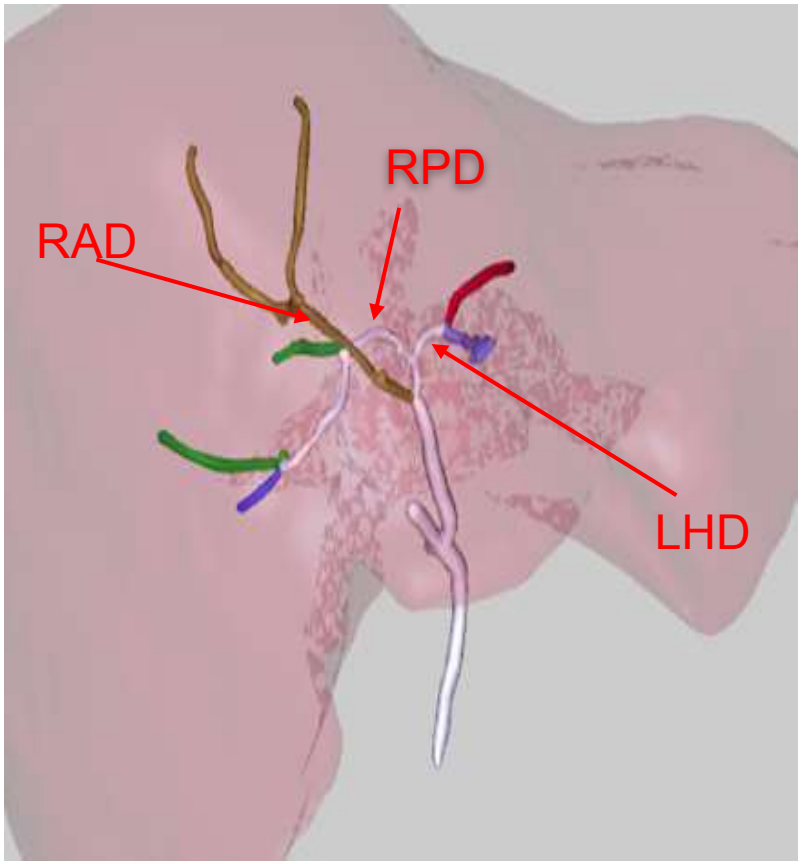
Castaing D. Surgical anatomy of the biliary tract. (2008) HPB : the official journal of the International Hepato Pancreato Biliary Association. 10 (2): 72-6.

Biliary Anatomy Variants

- RPD draining into LHD ~15% (range 13-19%)

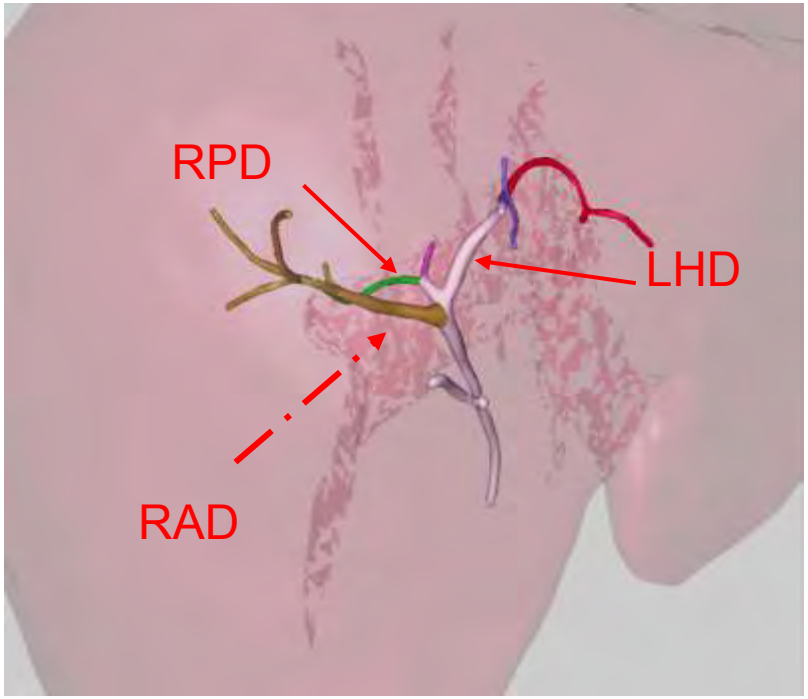
Aberrant biliary anatomy with the right posterior segmental biliary duct arising from left hepatic duct, 4 mm proximal to the hepatic duct confluence.

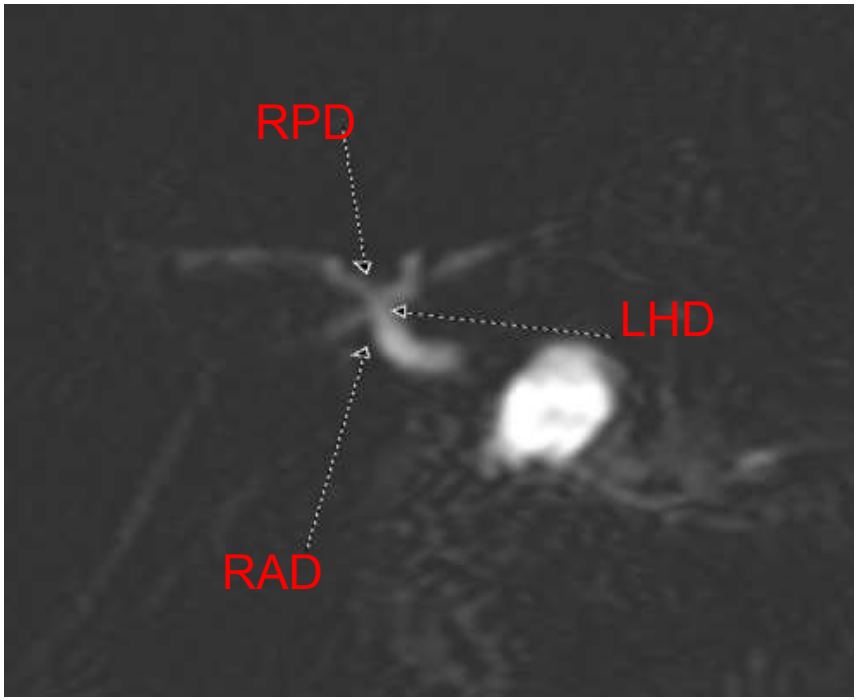




RAD: Anterior right hepatic duct
LHD: Left hepatic duct
RPD: Posterior right hepatic duct

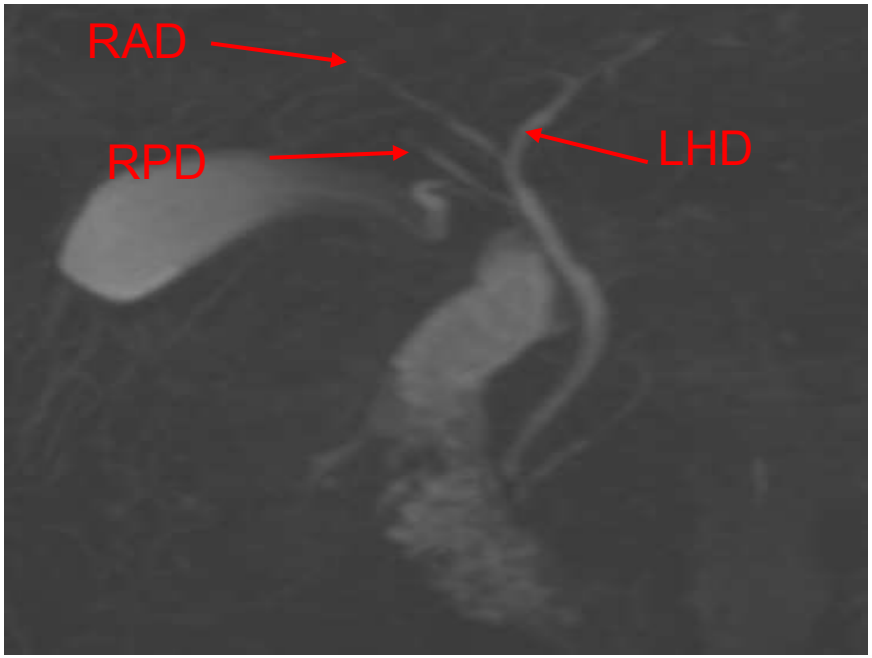
"Triple Confluence": union of RPD, RAD and LHD to form CHD (~11%)

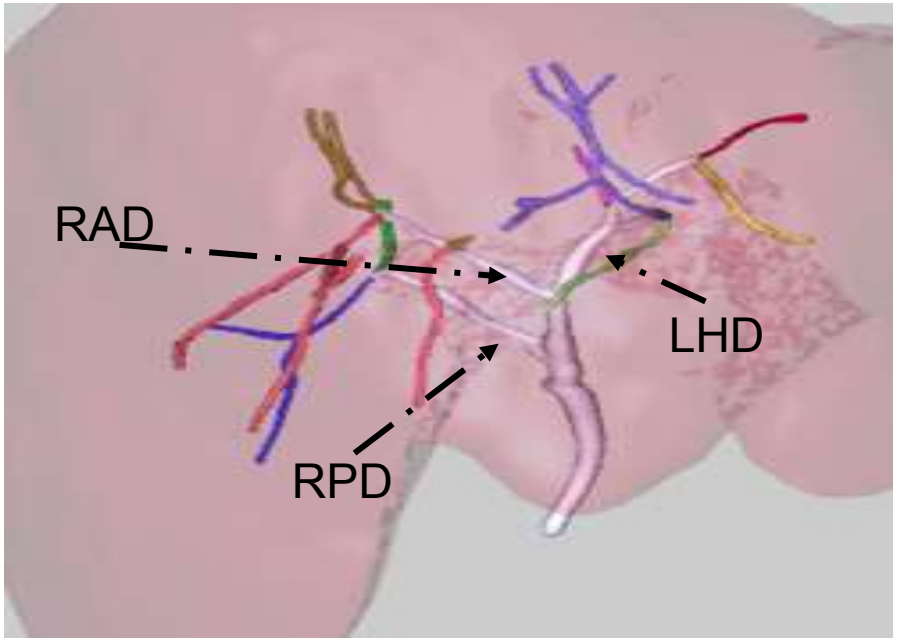




3D Reconstruction and MRCP images confirm Triple Confluence of Biliary Tree

Aberrant Biliary Anatomy; RAD draining into LHD (~6%)





Aberrant biliary anatomy is noted, with the anterior right hepatic duct arising from the left hepatic duct. Of note, the right posterior hepatic duct has a low insertion on the common hepatic duct.

RAD: Anterior right hepatic duct
LHD: Left hepatic duct
RPD: Posterior right hepatic duct

Biliary Anatomy

Mortelé KJ, Rocha TC, Streeter JL et-al. Multimodality imaging of pancreatic and biliary congenital anomalies. Radiographics. 2006;26 (3): 715-31

Underlying Diffuse Liver Disease

- Diffuse Liver disease can be diagnosed using several methods.
- At our institution we perform MRI including in and out of phase imaging in addition to the CT images and clinical data to provide a comprehensive assessment of liver disease.
- Newer applications that can potentially add value for a more comprehensive evaluation include: **MRI Elastography, MRI Iron Quantification techniques and MRI Proton density fat fraction** for detailed assessment of steatosis that has shown to be at par with histological examination.
- While macrovesicular steatosis has been shown to affect graft function in the postoperative period[1] further studies of functional imaging could potentially further impact preoperative planning in the live donor.

1. *Limanond et al., Preoperative Imaging in Adult-to-Adult Living Related Liver Transplant Donors What Surgeons Want to Know. (J Comput Assist Tomogr 2004;28:149–157)*

Conclusion

- Live donor liver transplantation is increasingly being performed.
- Knowledge of state of the art available imaging and reconstruction techniques is vital for the radiologist.
  - Allows the radiologist to provide more detailed and accurate information.
  - Aids in pre-surgical planning to mitigate potential complications and post-op morbidity in both donors and recipients.

Thank You..!!

Lahey Health