SBRT in Hepatocellular carcinoma: Contouring & Planning

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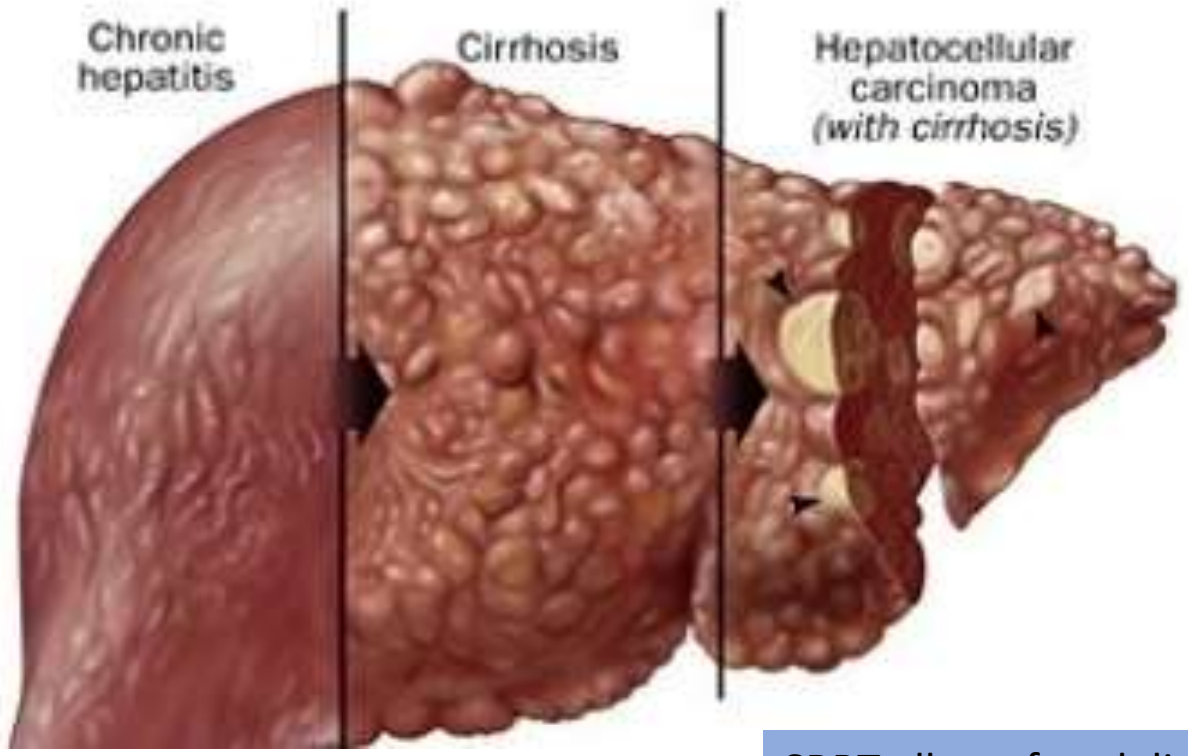
Introduction



- Hepatocellular carcinoma (HCC) is the sixth leading cause of cancer globally (fifth in men and eighth in women) with 750,000 new cases per year.
- Poor prognosis with 5-year survival 7%
- **Challenges in treatment(radiation)-**

❖ Two diseases in one: a chronic viral liver disease and a malignancy affecting treatment & survival.

❖ Proximity to diaphragm- movement

❖ OARS in proximity

SBRT allows for delivery of potentially ablative doses of radiation with rapid dose fall off at periphery of target.

ROAD MAP

- Choosing the right case
- Prerequisites
- Simulation and motion management
- **Target volume delineation OAR contouring**
- **Dose prescription & Dose constraints**
- **Plan evaluation**

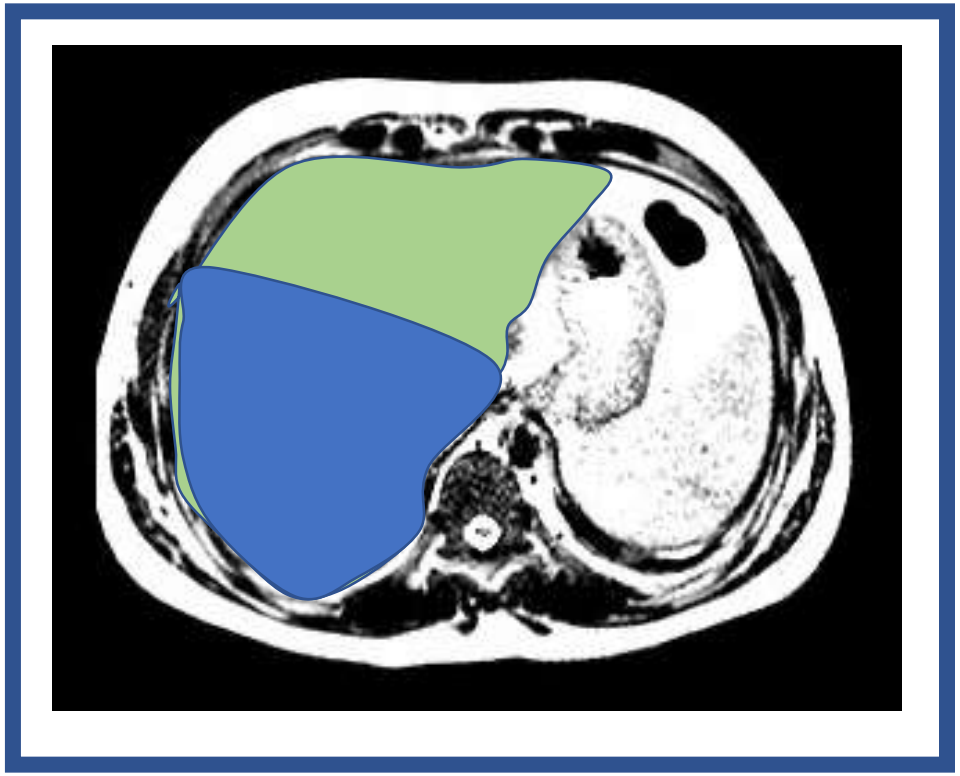
Patient selection

- MDT discussion to determine - optimal treatment
- **Ideal SBRT candidates are good PS patients with adequate organ function- with small, peripheral tumors located away from the bowel, chest wall, or central liver**

Selection Factor	Ideal Parameters for Liver SBRT	Exclusion Criteria Parameters
Patient immobilization	Able to tolerate immobilization	Unable to tolerate immobilization
Imaging	Tumor clearly defined on triphasic enhanced CT or MRI (HCC)	
Eligibility for other therapies	Ineligible for resection or other local therapies because of technical considerations or concerns of efficacy and/or toxicity	
Liver function	Child–Pugh class A or B7/8	Child–Pugh class C
Healthy liver volume	Ability to meet dose constraints	<700 cm^3 remaining healthy liver volume
Tumor location	>1 cm from critical OARs, such as bowel, diaphragm, chest wall, or central liver	<5 mm from critical OARs
Great vessel involvement	May be involved	
Burden of extrahepatic disease	None	Uncontrolled or significant extrahepatic burden

Preplanning Exercise

- Contouring on the diagnostic scan
- Volumetric assessment in the diagnostic scan
- Feasibility
- Technical Challenges
- Requirement of additional imaging



Diagnostic MRI

Multimodal Radiologic assessment … backbone of SBRT

- **CECT** underestimates tumour volume→ Multiphase CT better
- **MRI** - Higher contrast ratios

  Superior lesion detection and characterization

  Differentiates dysplastic nodules from HCC
- **PET** is useful in target delineation in previously treated liver tumors (distinguish active tumour from fibrosis)

HCC planning workflow

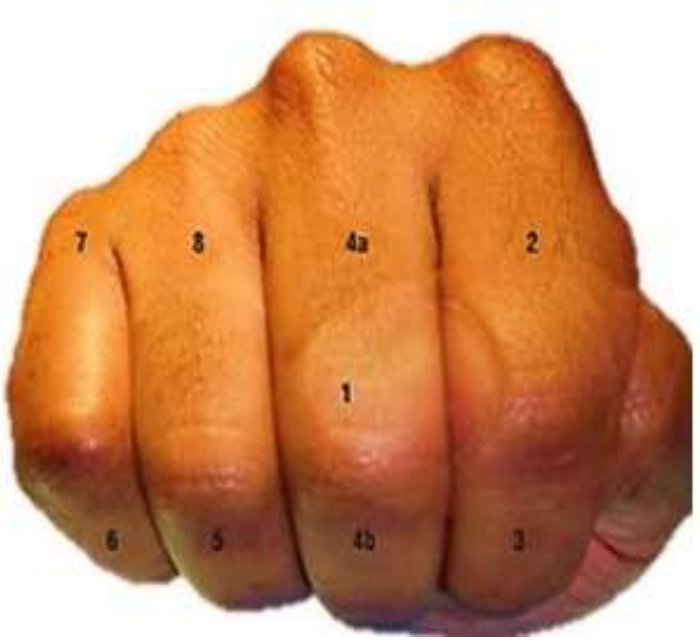
Obtain multi phasic CT /MRI in treatment position either in breath hold or in addition to 4DCT scan

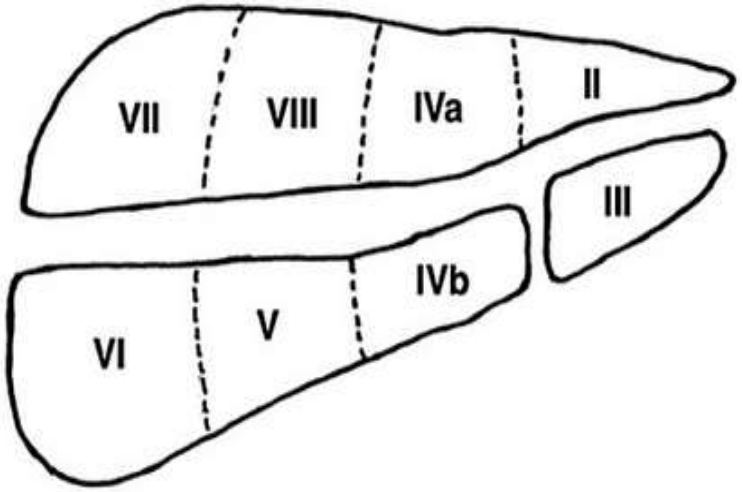
Identify all series in which tumour is well visualised

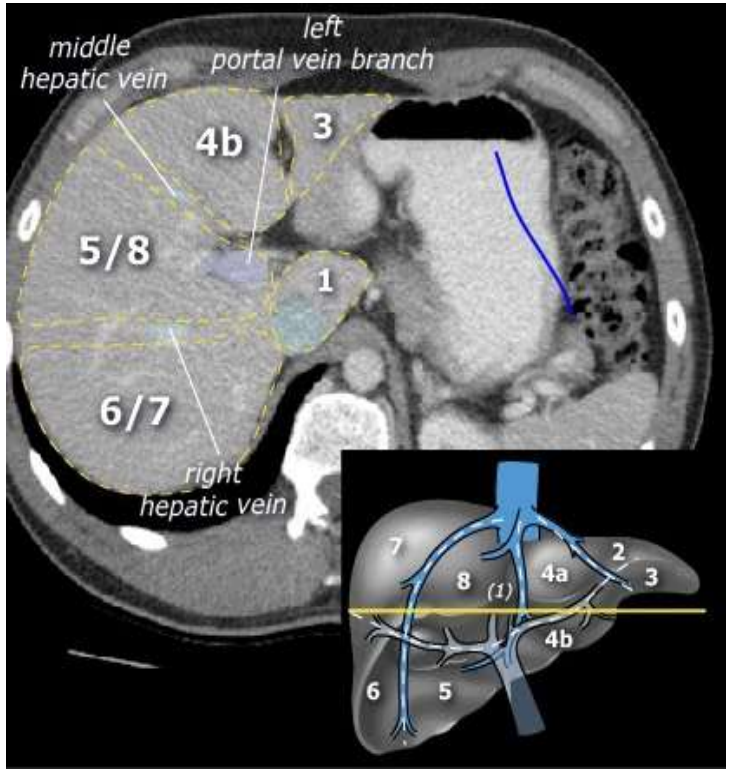
Determine which primary data set will be used for contouring

Register all planning data sets & any useful diagnostic data sets where HCC sets to primary planning data set

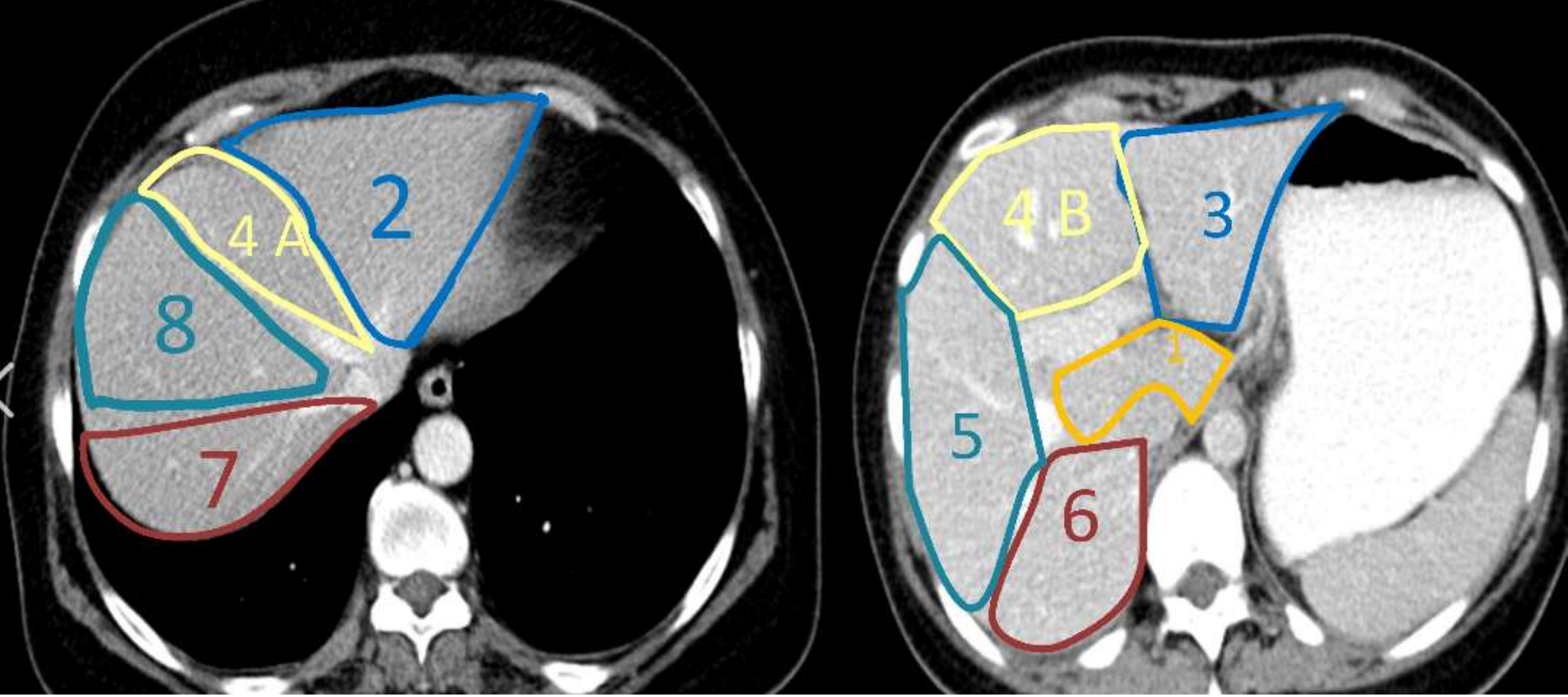
Radiation Therapy Oncology Group (RTOG)



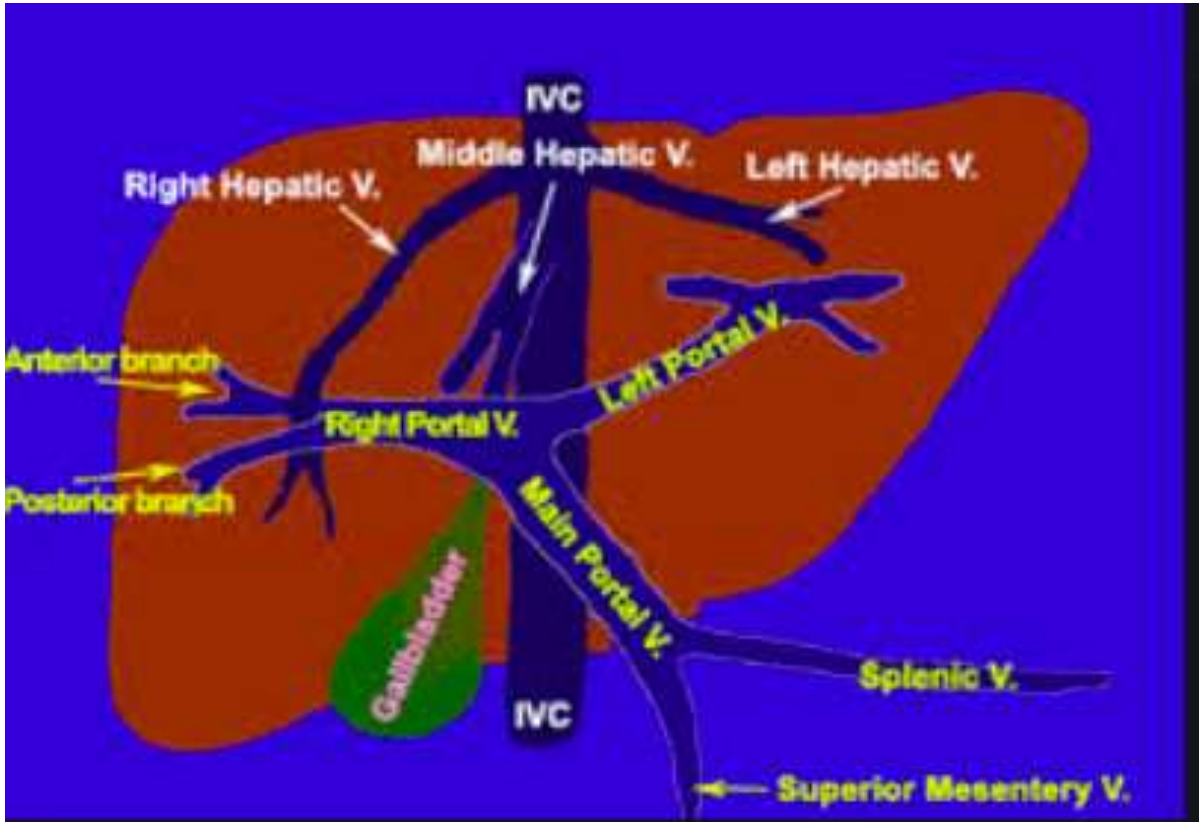




Understand the segmental anatomy of liver and vascular anatomy



Segments of liver

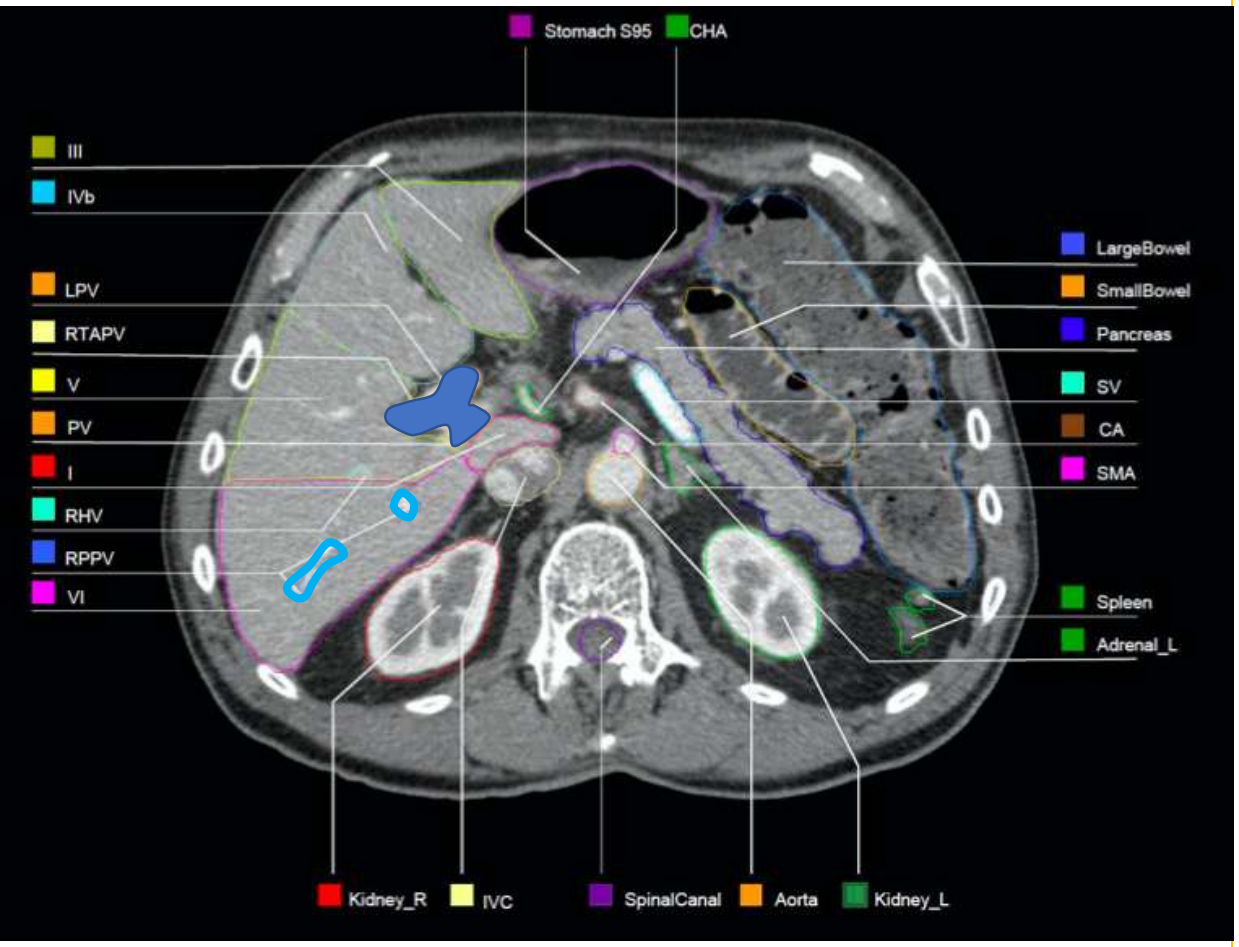


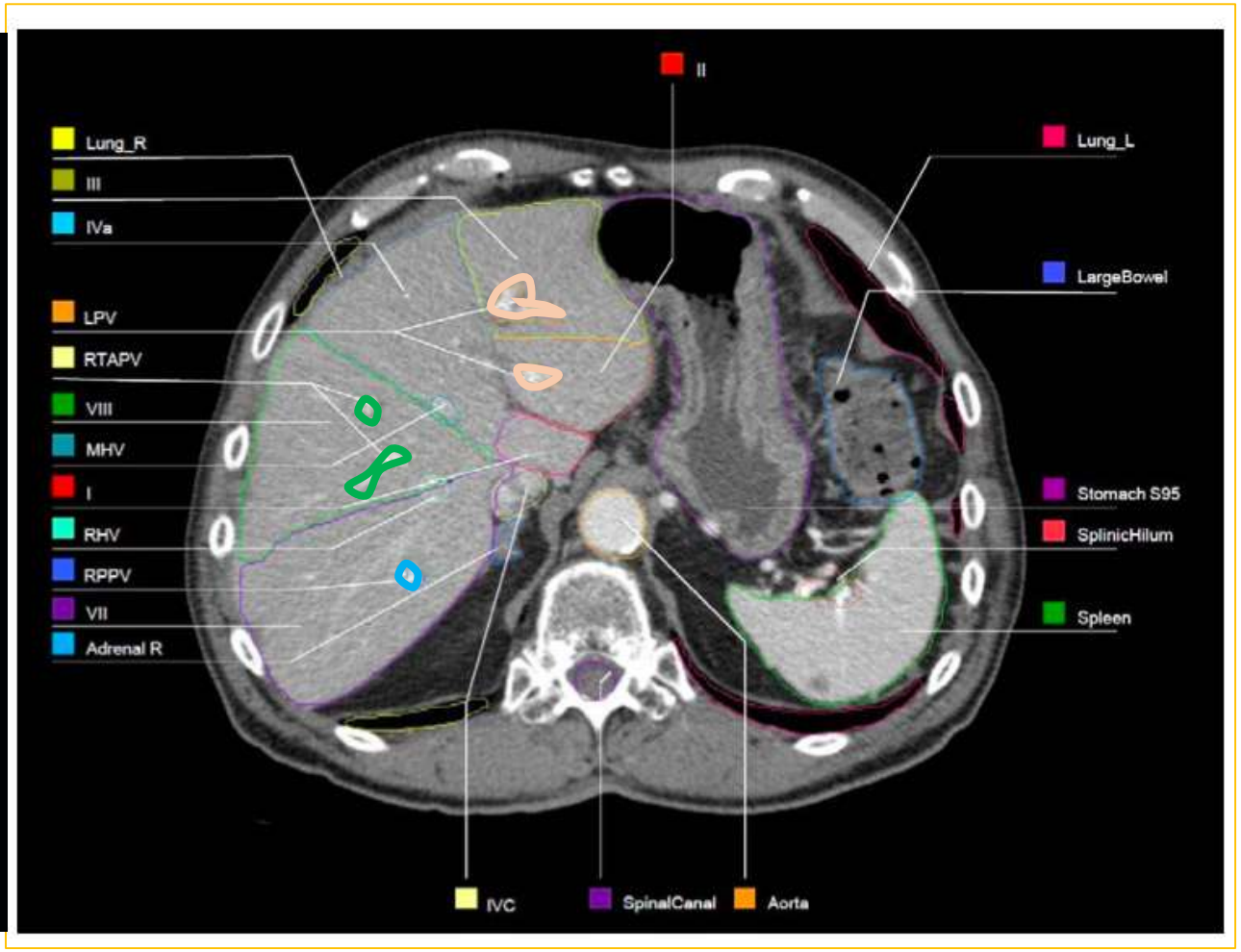
Triple phase CT better understood
https://www.youtube.com/watch?v=z_M3oQytmGY

https://liveratlas.org/diagnosis/14/

Vascular anatomy liver

Vascular anatomy



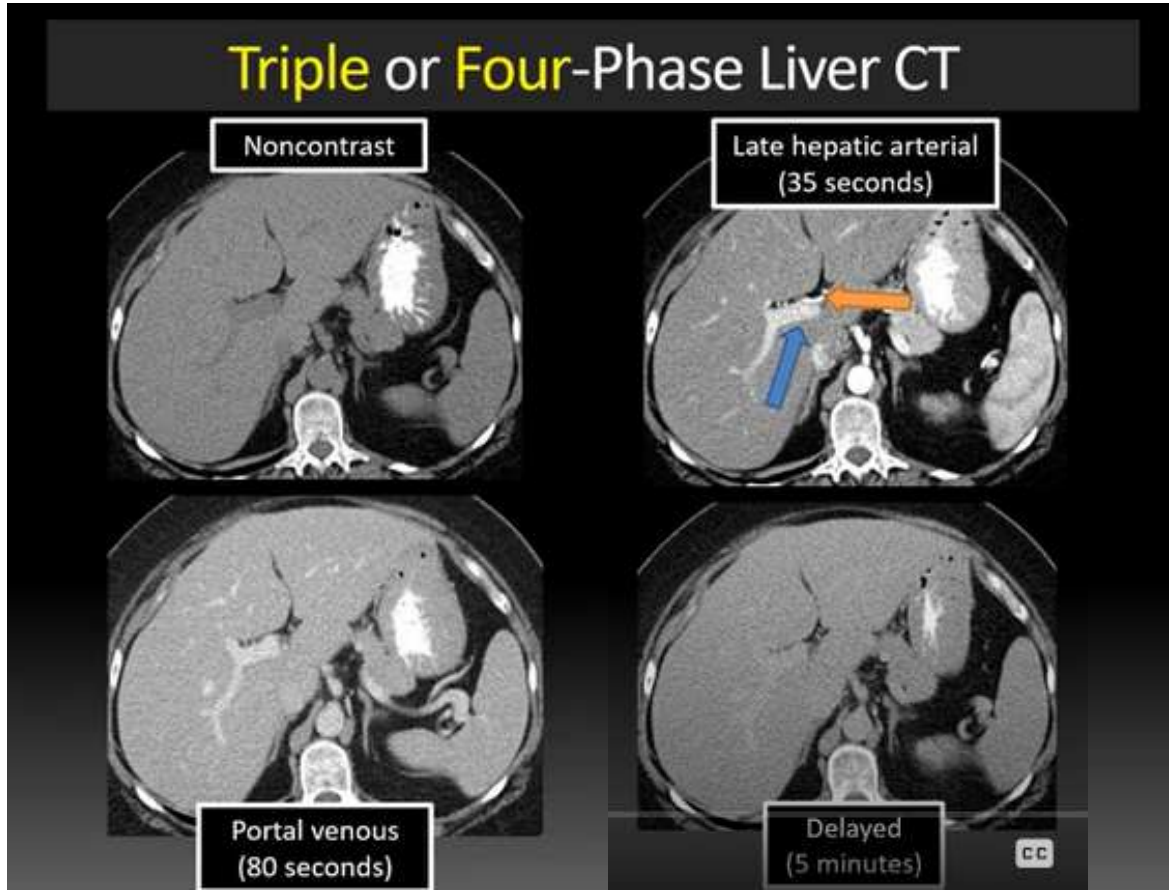


Portal Vein is formed behind pancreatic neck by intersection of the SMV and SV

- PV is located posterior to CBD & hepatic artery
- PV bifurcates into RPPV, RTAPV and LPV
- Left gastric vein enters the PV near its SV/PV confluence

Multi phase CT interpretation

Multi CECT scans are conducted with 1.25-mm slice thickness



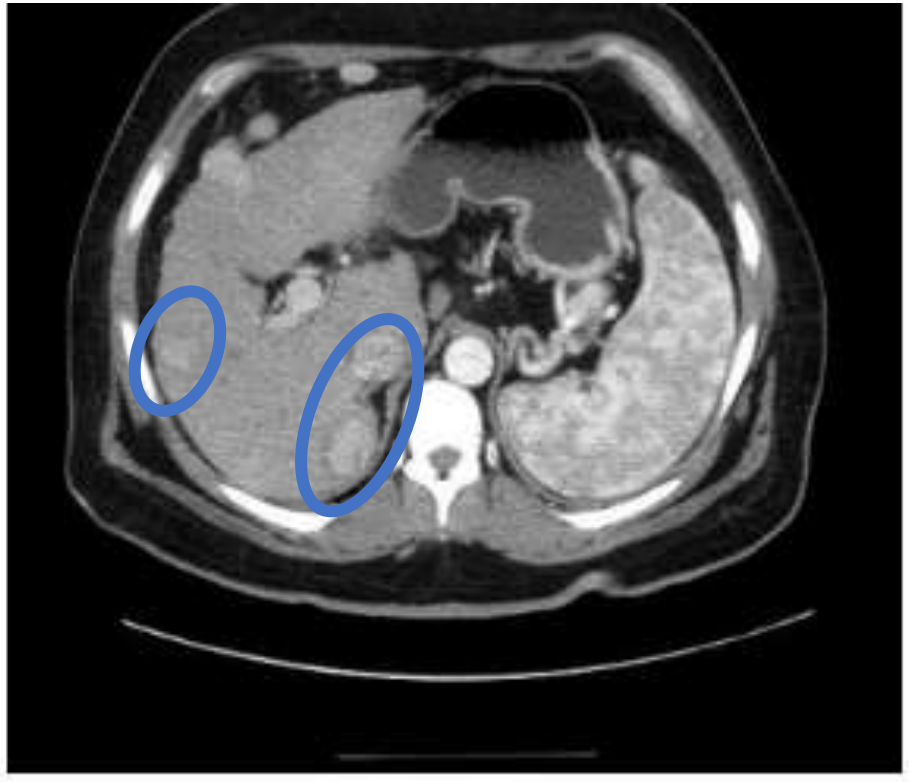
Four phase HCC protocol includes

- Non-contrast CT
- Arterial phase**(A)** imaging-demonstrates hypervascularity of HCC.
- Portal venous phase **(V)** imaging for visualization of vascular thrombi
- Delayed phase **(D)** imaging-demonstrates washout of HCC.

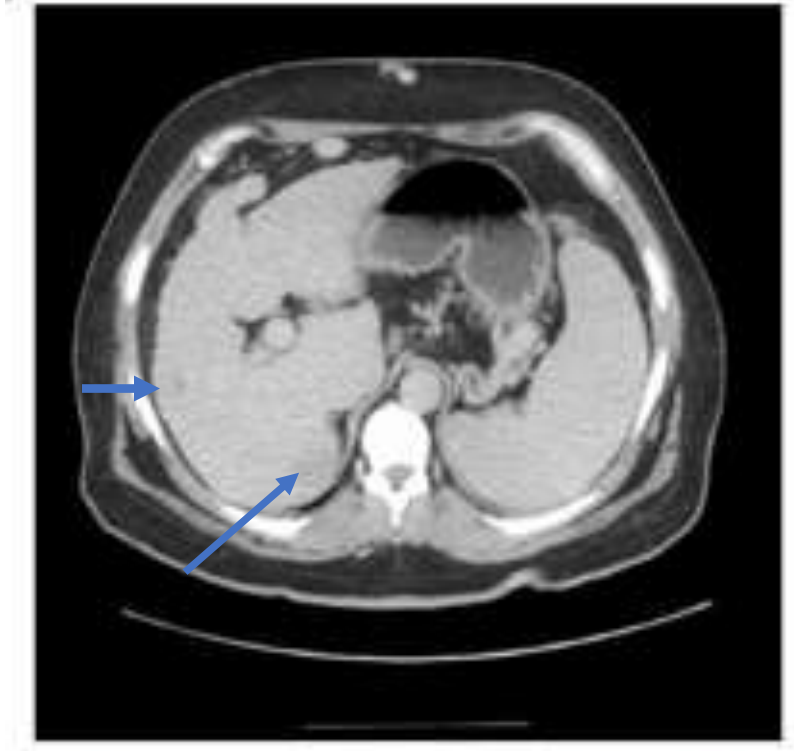
Arterial Phase
Hepatic artery and portal vein enhance but not hepatic veins
If no portal veins= too early
If no hepatic veins = too late

Classical picture

Arterial enhancement with delayed washout is the hallmark radiographic appearance



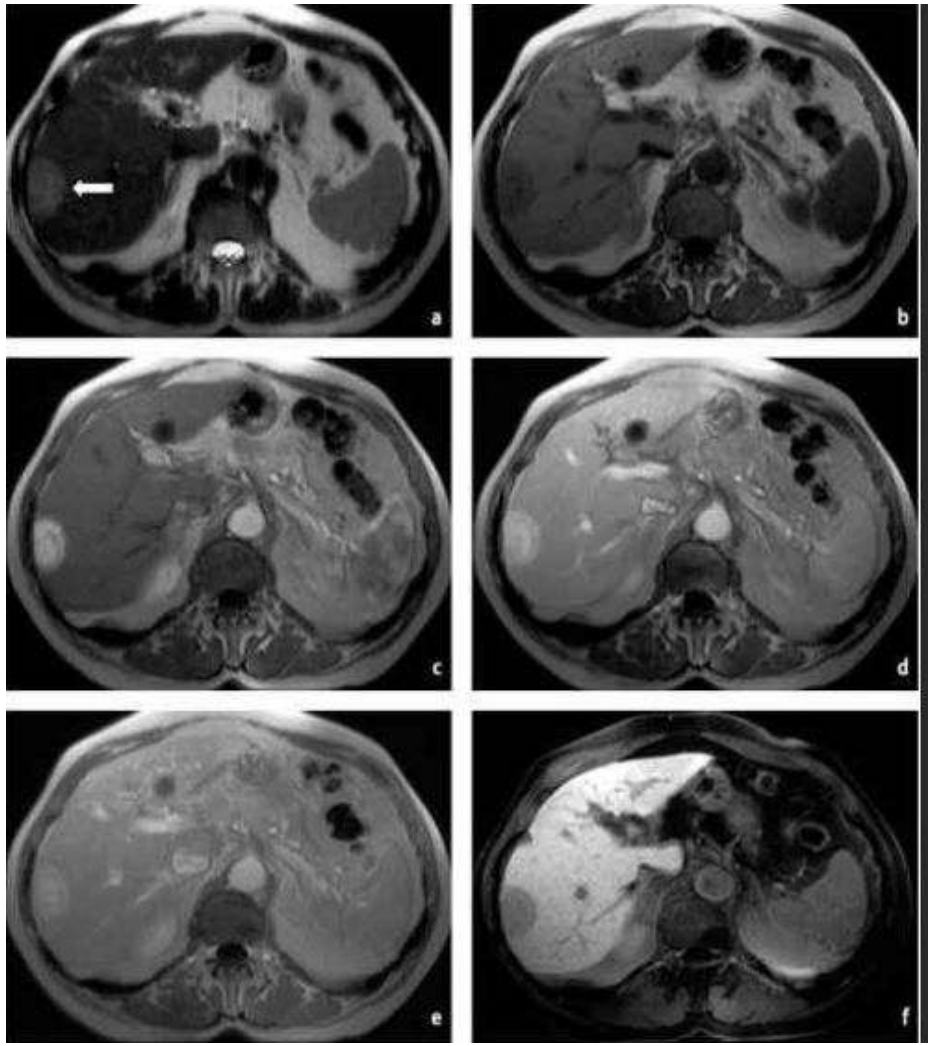
Arterial phase CT scan demonstrating enhancement of hepatocellular carcinoma.



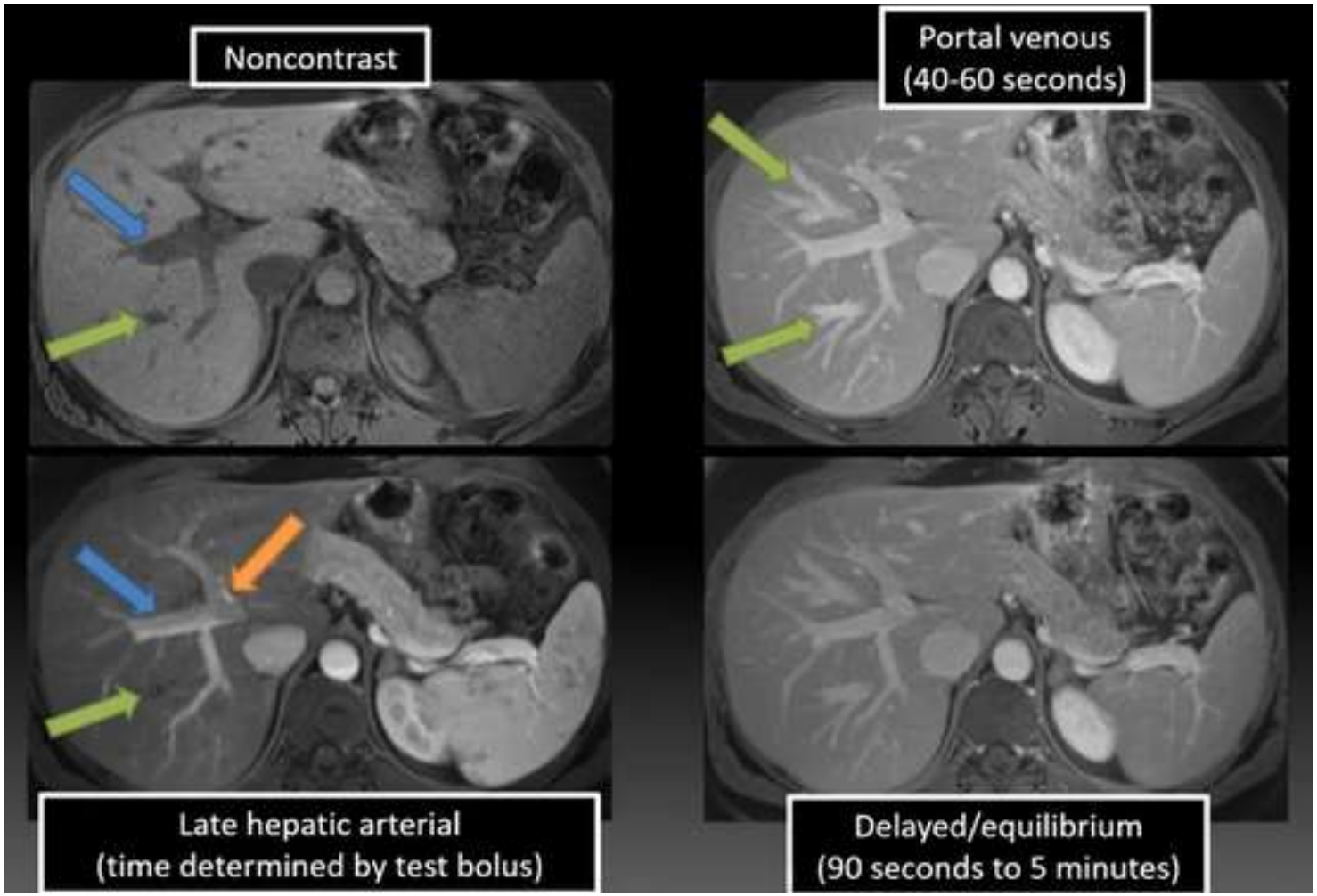
Portal venous phase CT scan demonstrating washout of hepatocellular carcinoma

MRI for HCC

- On T2-weighted images-high signal intensity.
- Gad-enhanced MRI -densely enhance, usually in arterial phase
- Can detect smaller tumours
- **Superparamagnetic iron oxide-**demonstrate HCC.
- **Mangafodipir trisodium** can evaluate questionable lesions-Differentiate HCC, from secondary hepatic masses.



Interpreting multiphase MRI

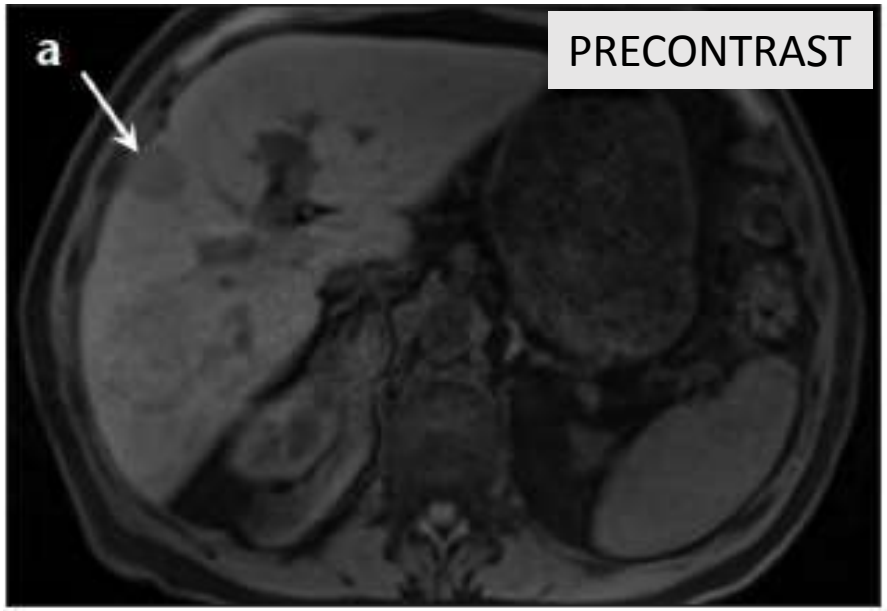


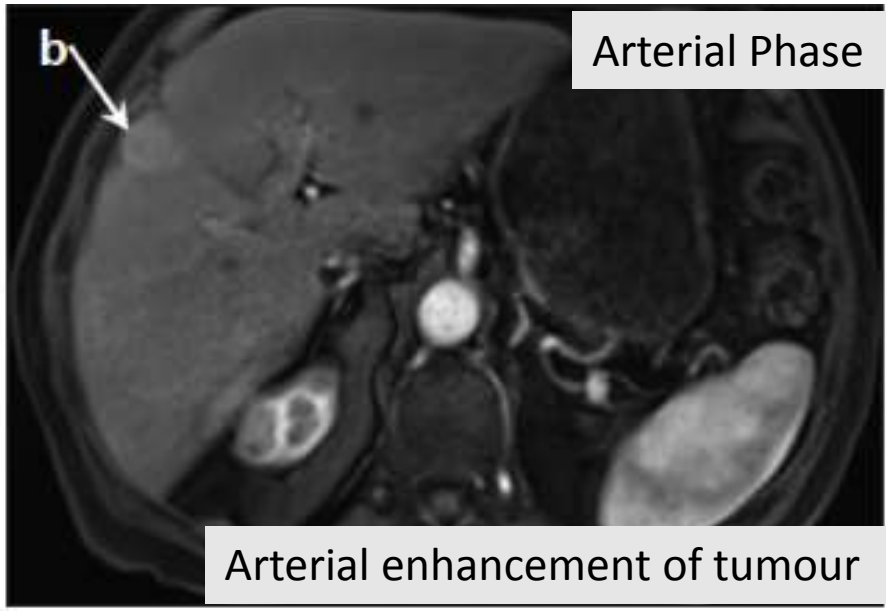
Non Contrast Images

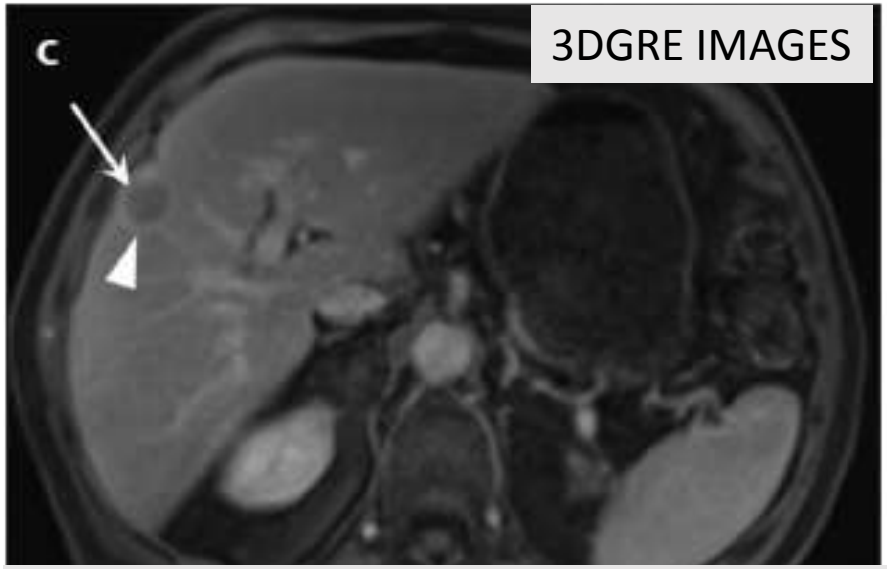
- T1 in phase -identify intra cellular fat
- T 2 compare liver lesion intensity relative to spleen
- DWI/ADC Detects restricted diffusion often seen with abscess and malignancy

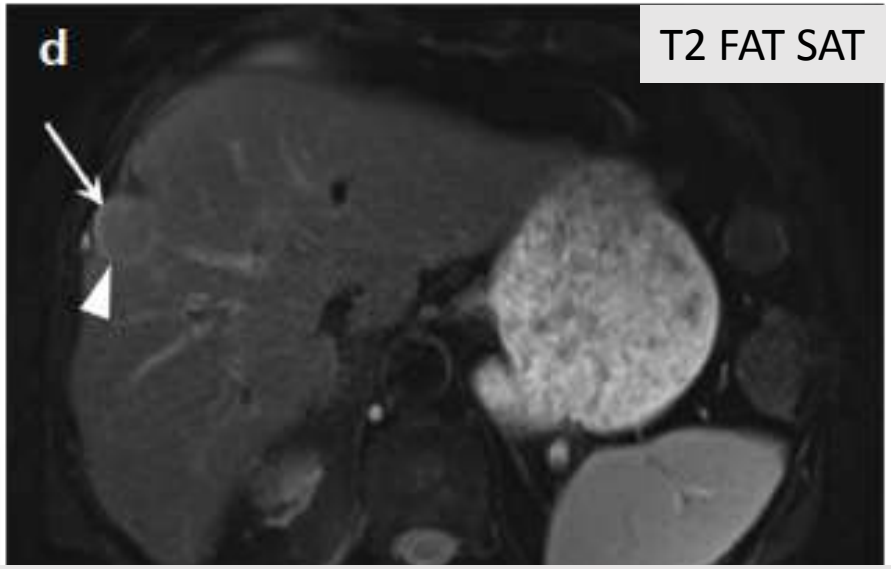
Post contrast images

Can obtain at more time points compared to CT (Immediate post contrast one minute three minute 4 minute 5 minute) subtraction imaging





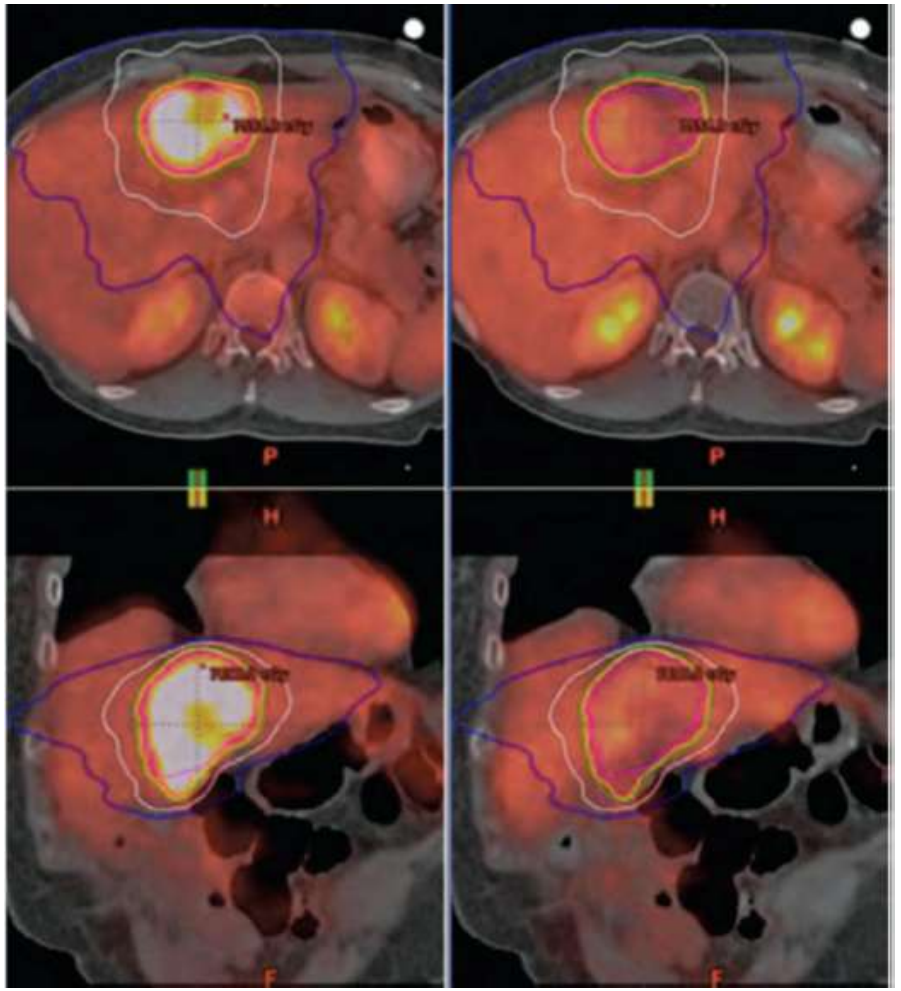




Washout & capsule enhancement Elevated T2 signal intensity within tumor & tumor capsule

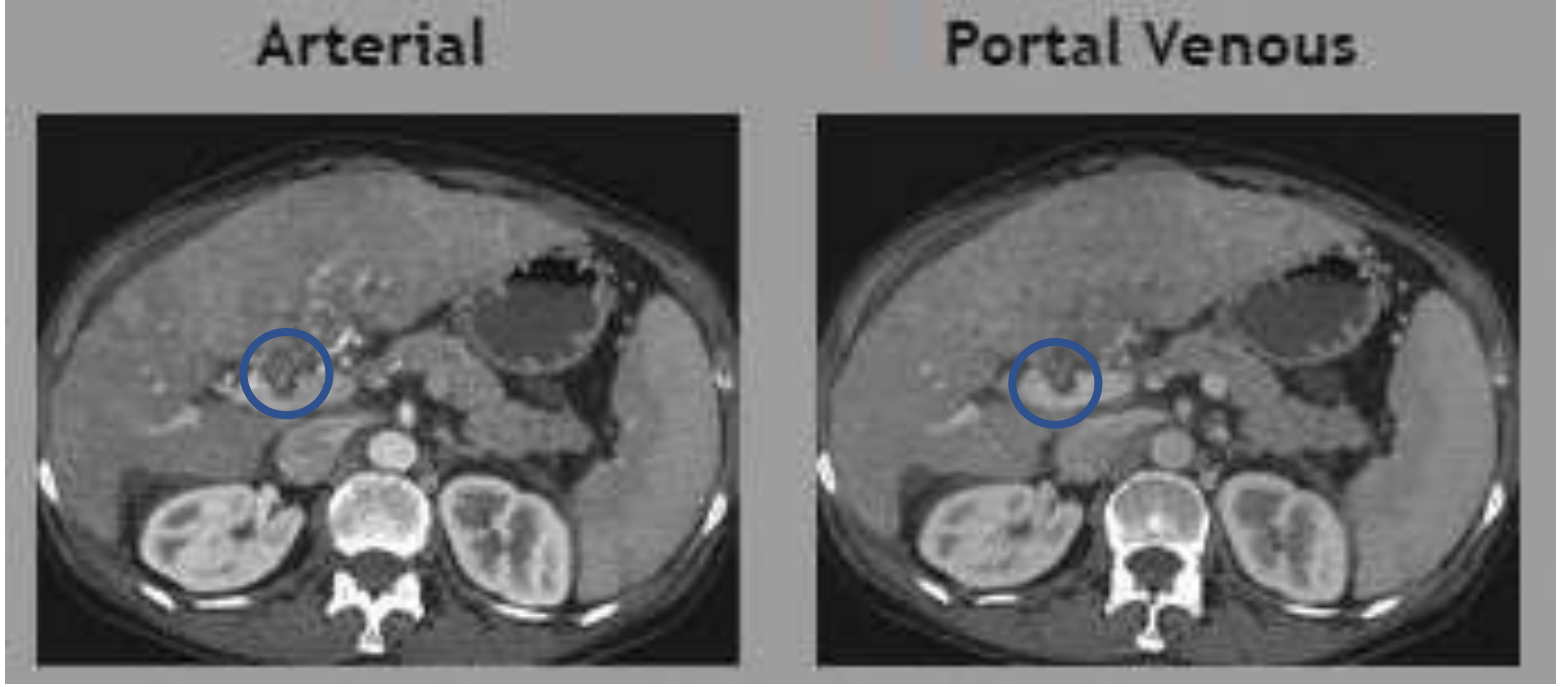
PETCT in HCC

- 18F-FDG PET may provide additional information in localizing the existing metabolically active tumor
- Can help in detecting occult or new tumors

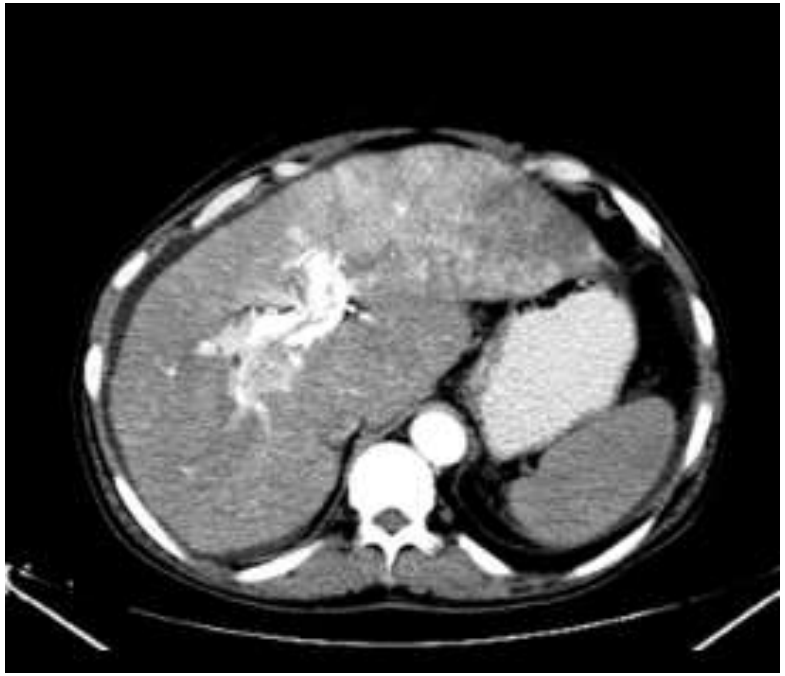


HCC Radiologic variations

Characterized by neo-angiogenesis -Variable enhancement pattern and general appearance as a function of both vascularity & endothelial cell leakiness

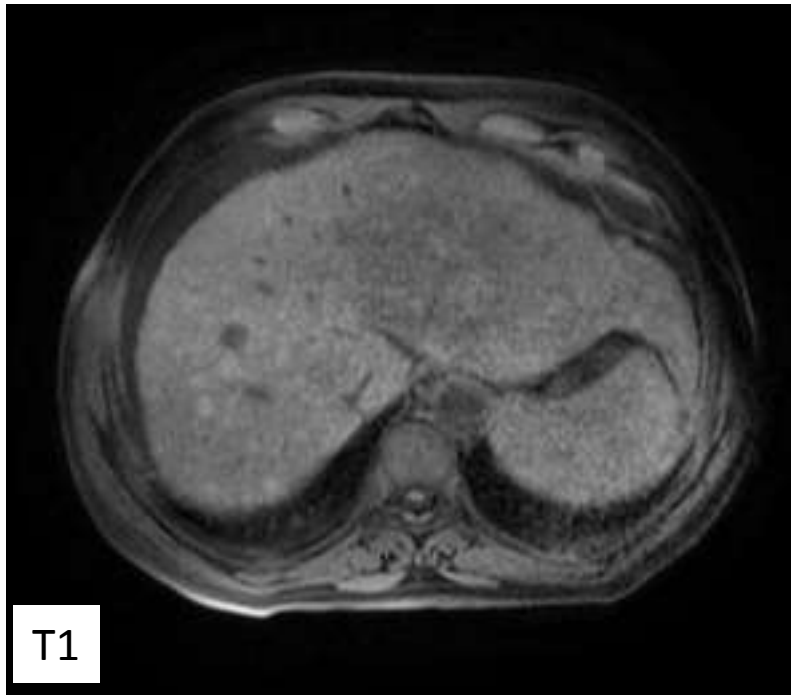


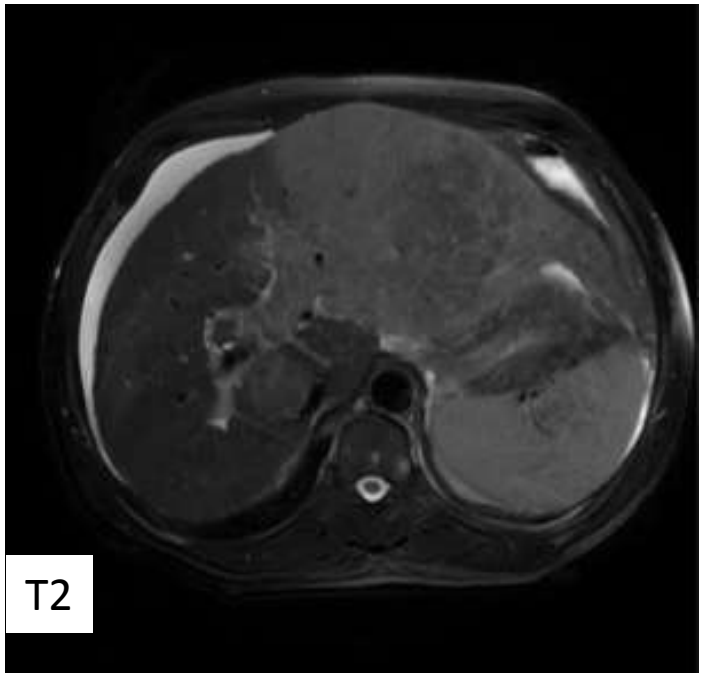
Infilterative HCC in cirrhosis with left portal venous thrombus



- Difficult to evaluate -**infiltrative growth pattern, patchy appearance & heterogeneous enhancement**
- Difficult to distinguish from cirrhotic liver .
- In delayed portal venous phase - they will still display delayed washout as surrounding liver continues to retain contrast.

Diffuse HCC MRI findings





Slightly hyperintense in comparison to normal surrounding liver

- Shows minimal arterial enhancement, hypoenhancement or isoenhancement
- Miliary pattern of enhancement

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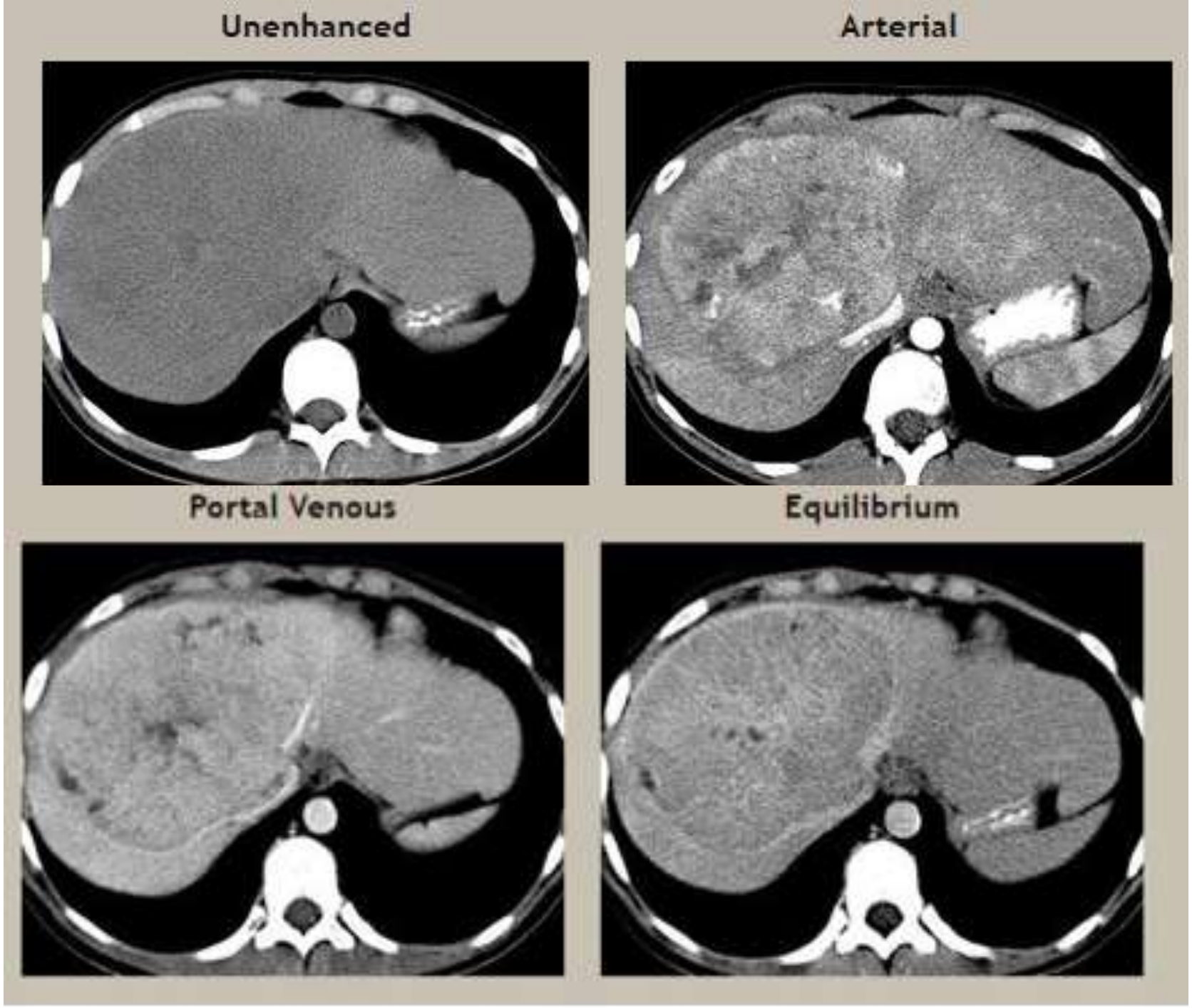
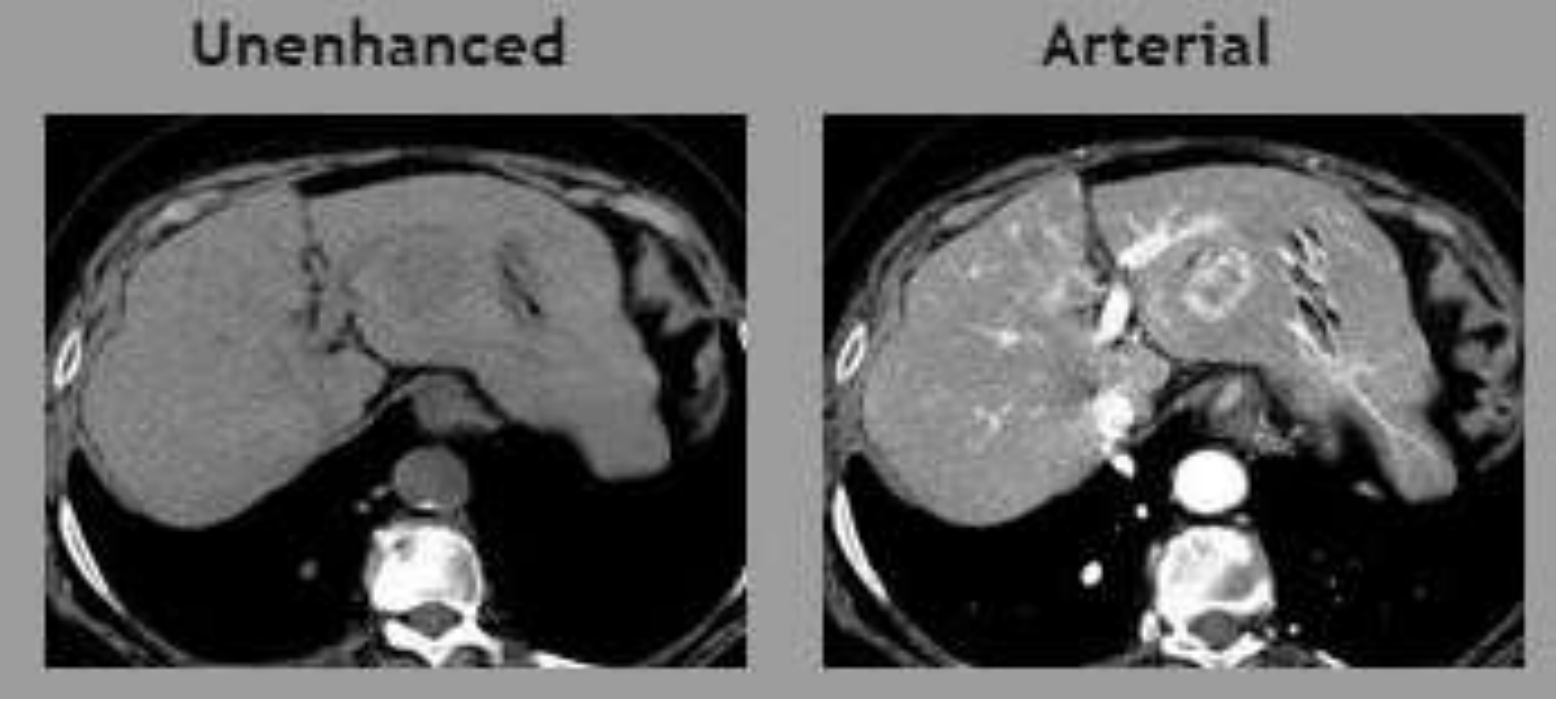
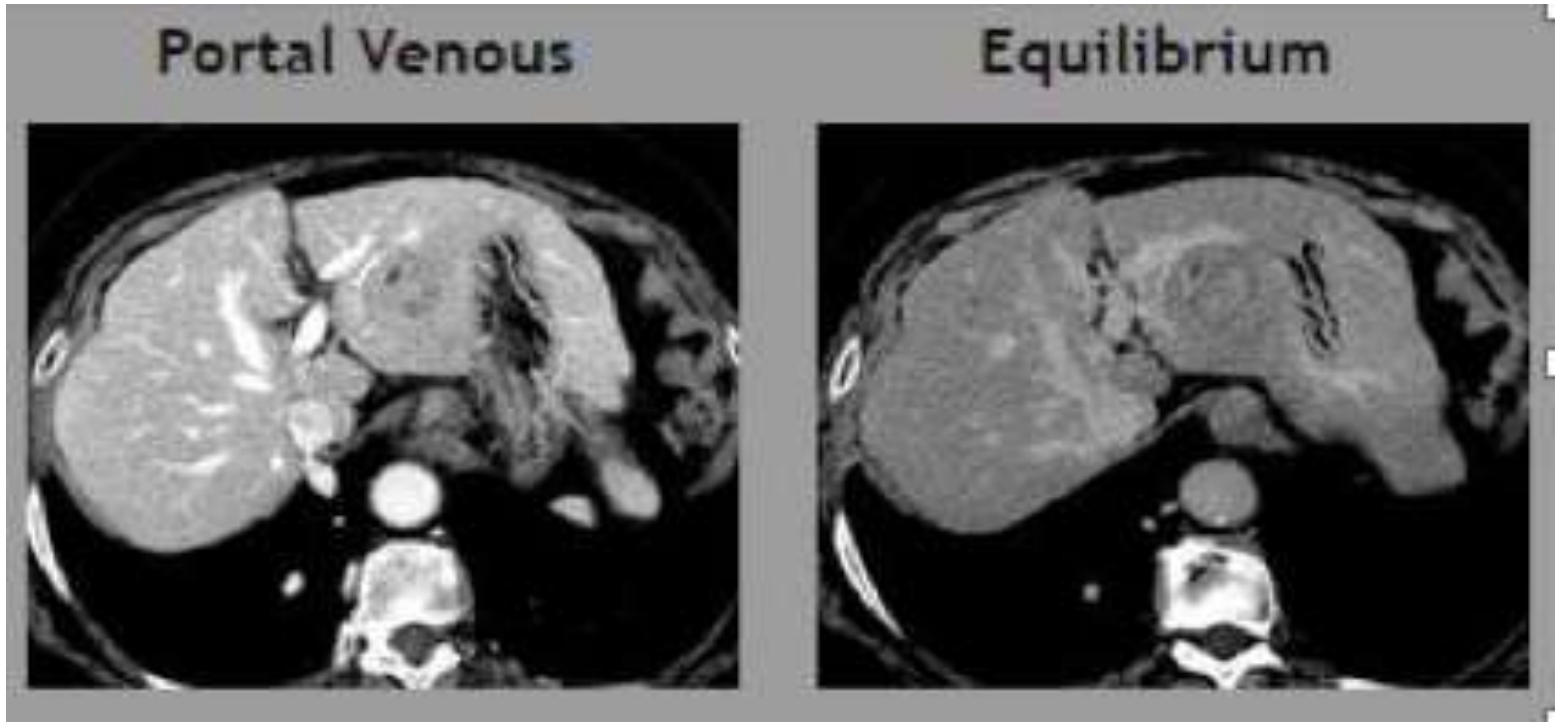


Fibrolamellar with central scar and no calcification

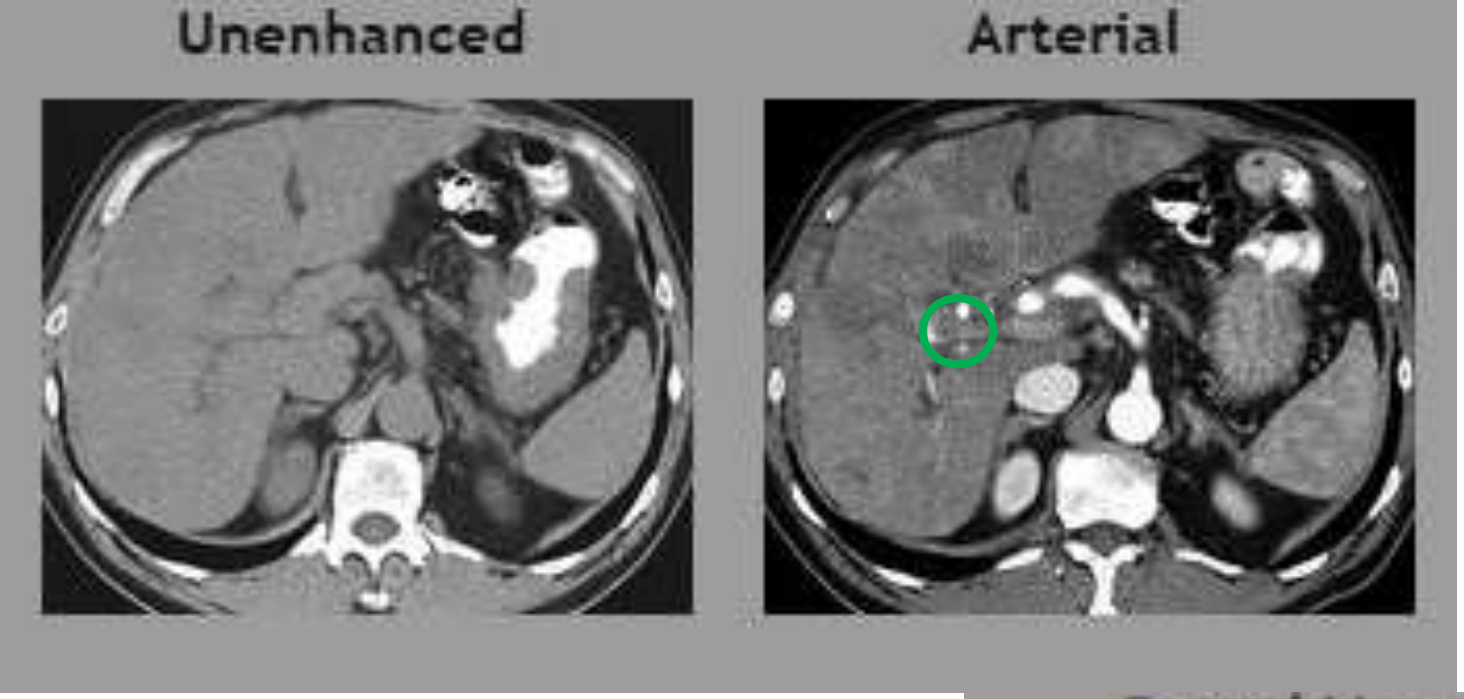
Nodule in nodule sign



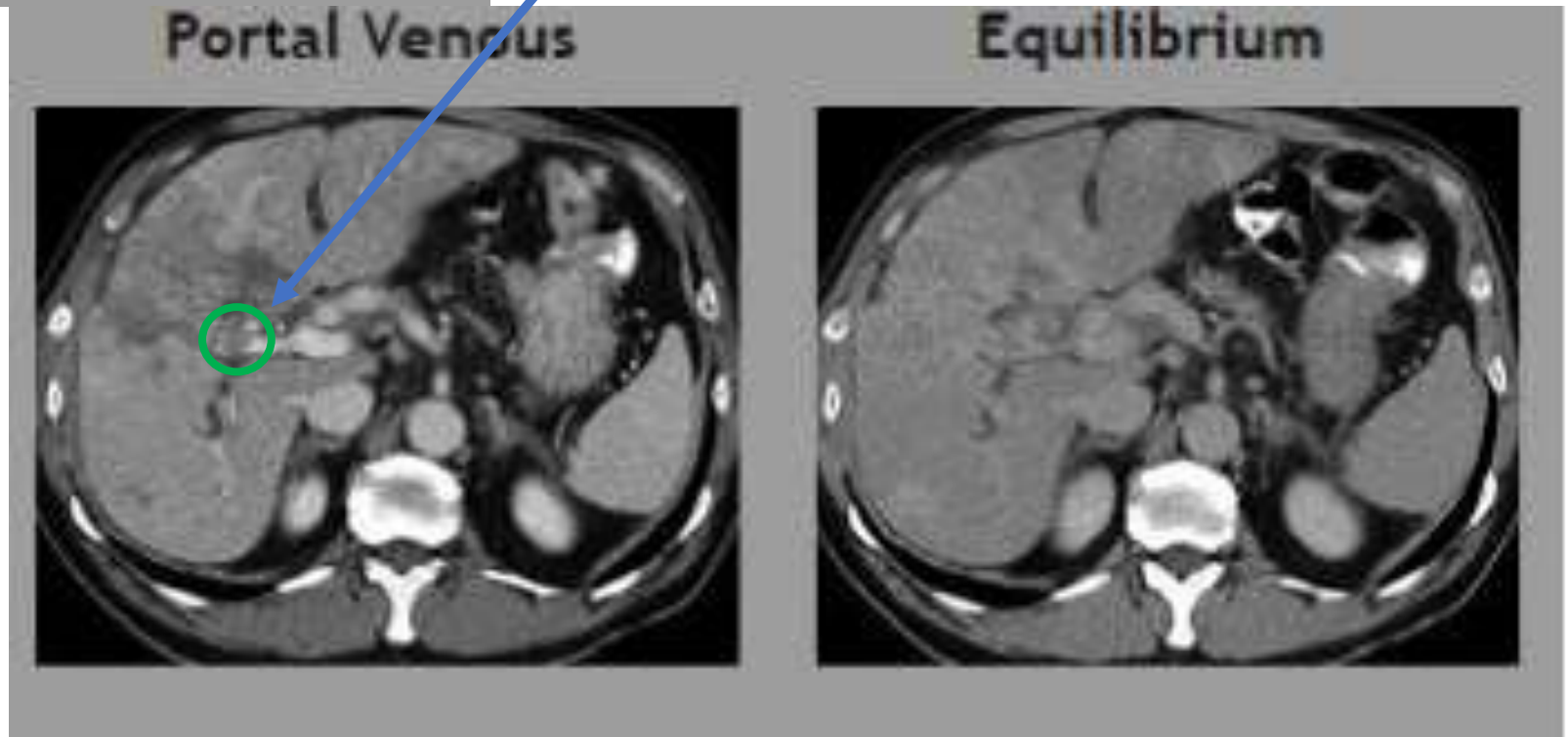


❖Dark mass on T1- and T2-weighted images-siderotic regenerative nodule or siderotic dysplastic nodule.

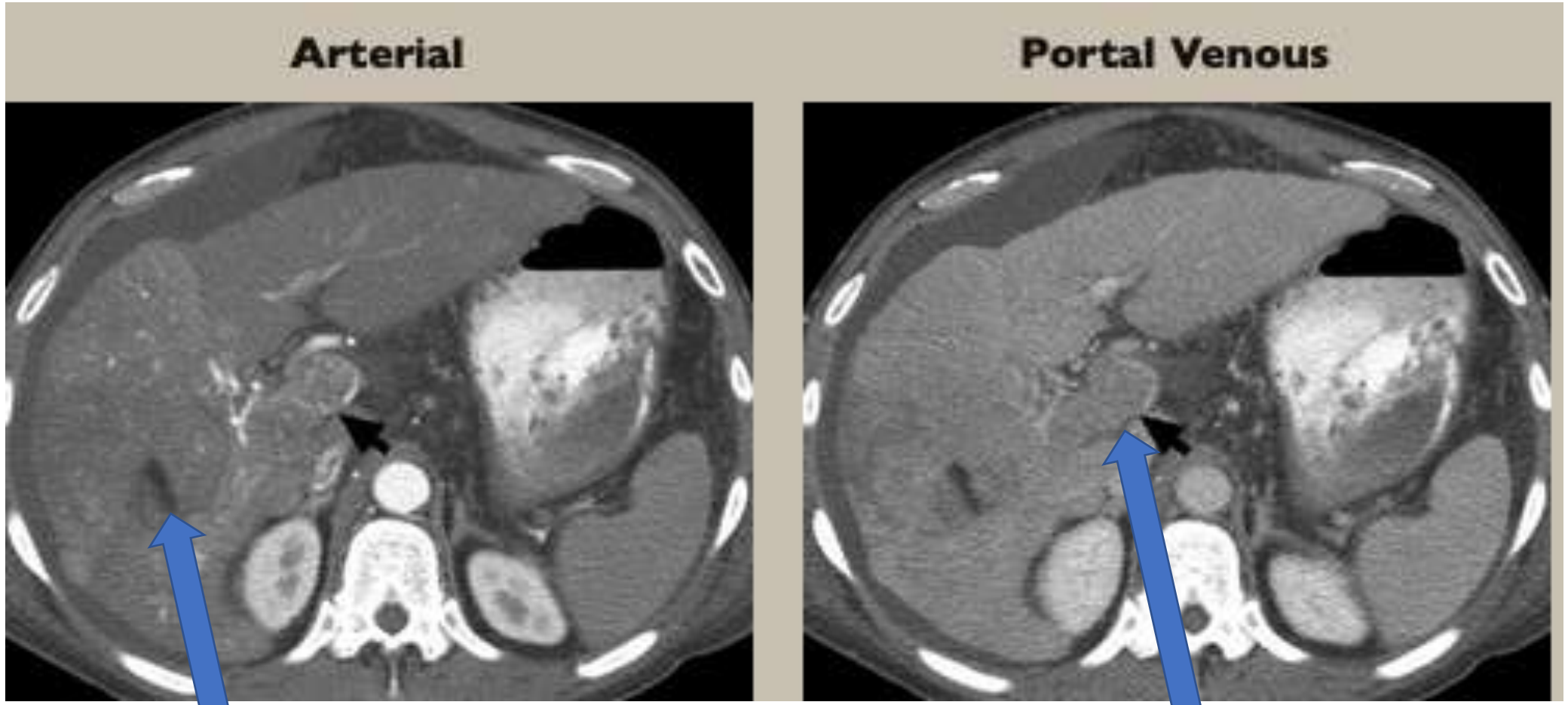
❖Bright mass on T1-weighted images and dark or isointense on T2-weighted images-dysplastic nodule or low-grade HCC.



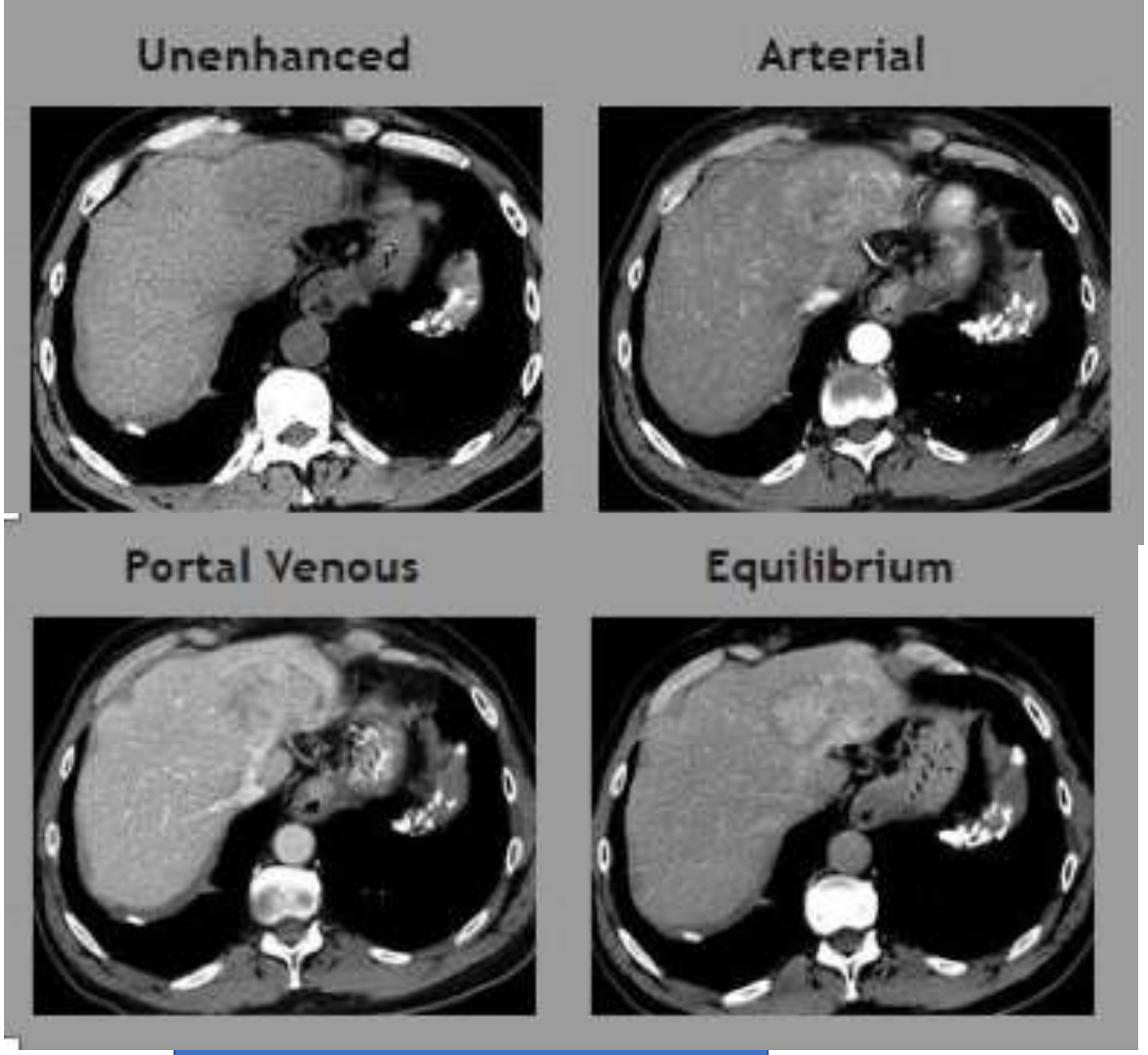
Vascular HCC thrombi are best seen on venous phase imaging as hypointensity relative to the contrast in the vessel



Fibrotic HCC with portal venous thrombus and bland thrombus

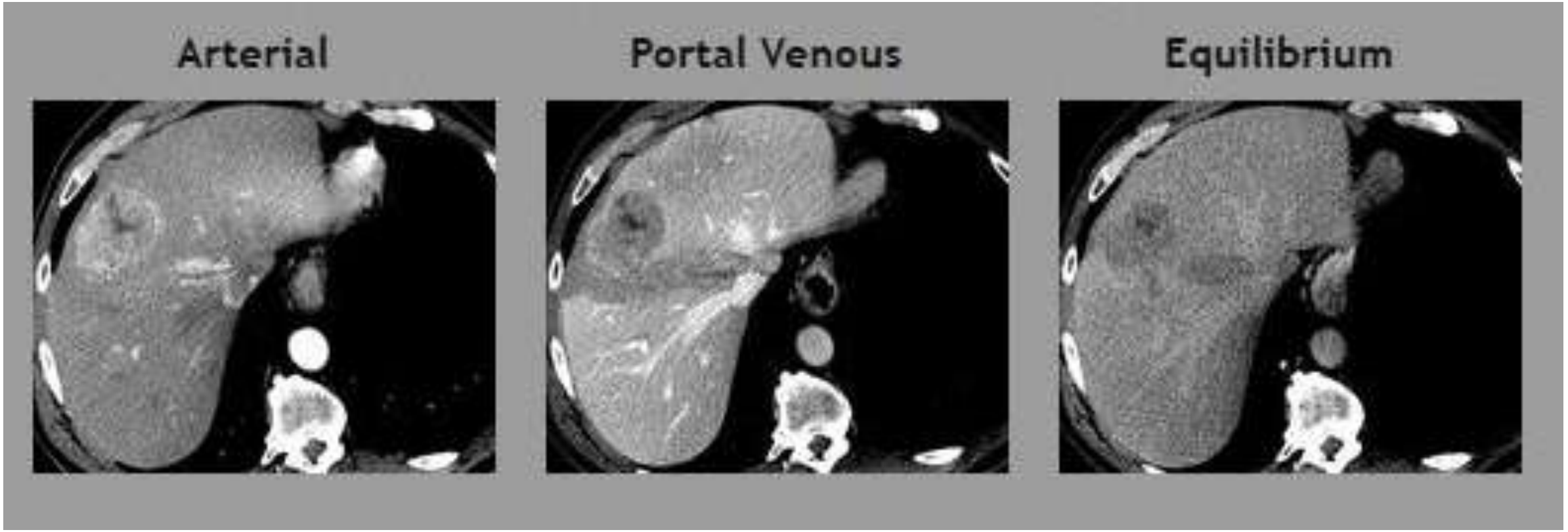


Fatty variant with portal venous thrombosis

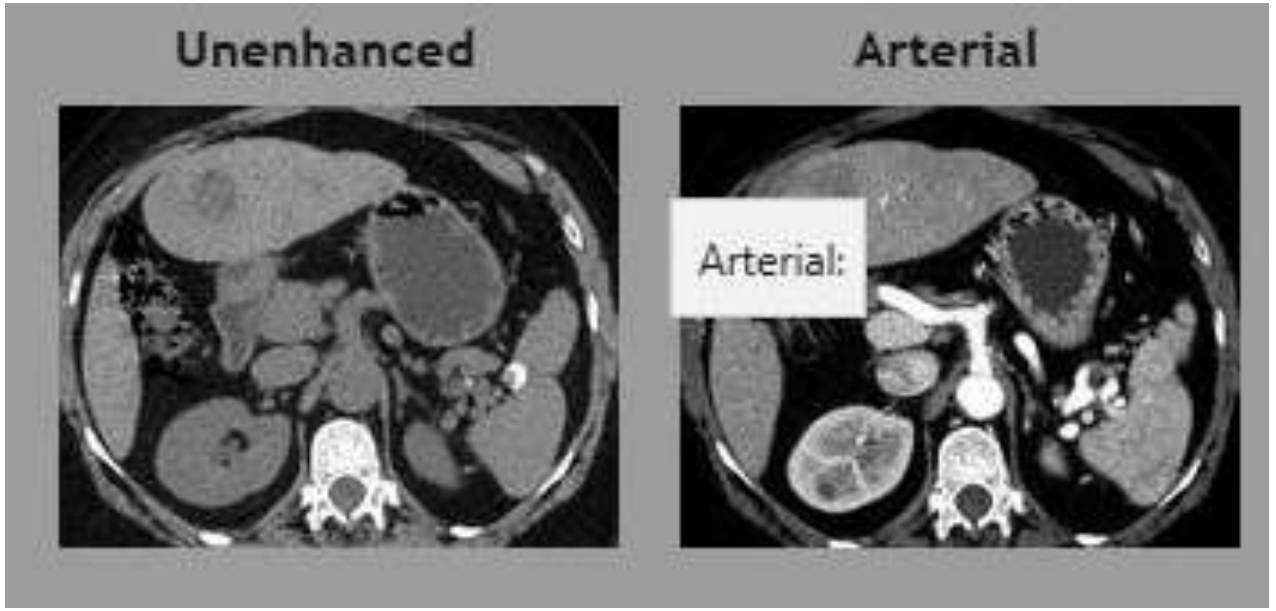


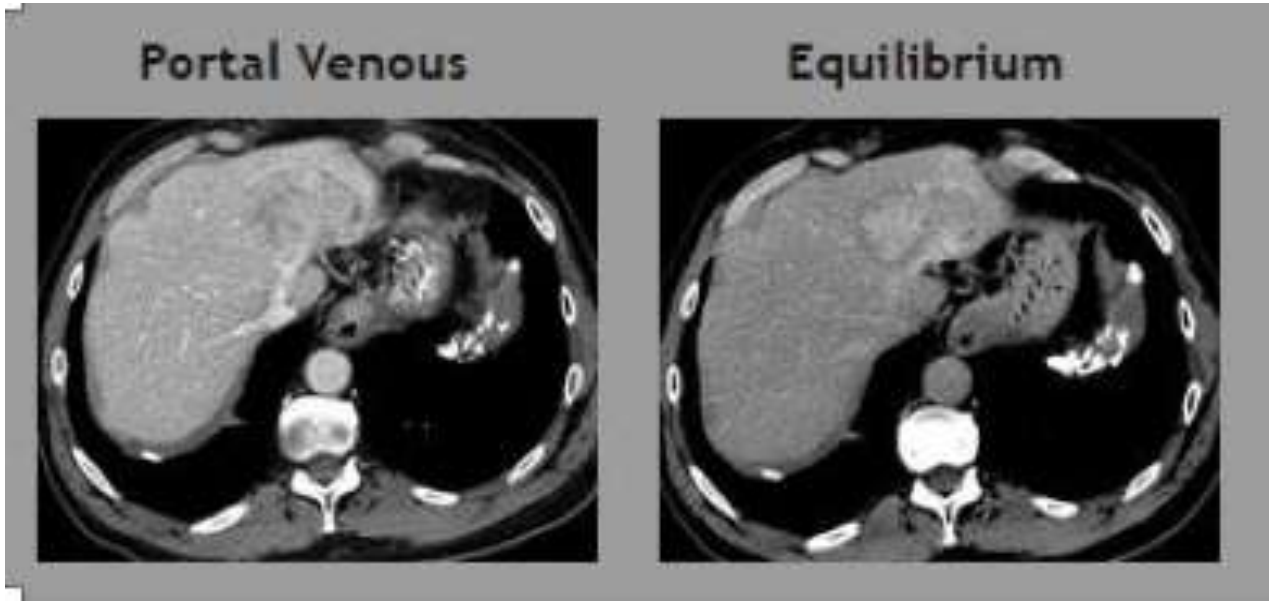
Sclerosing HCC

Right hepatic vein invasion with hypovascular transient hepatic attenuation difference

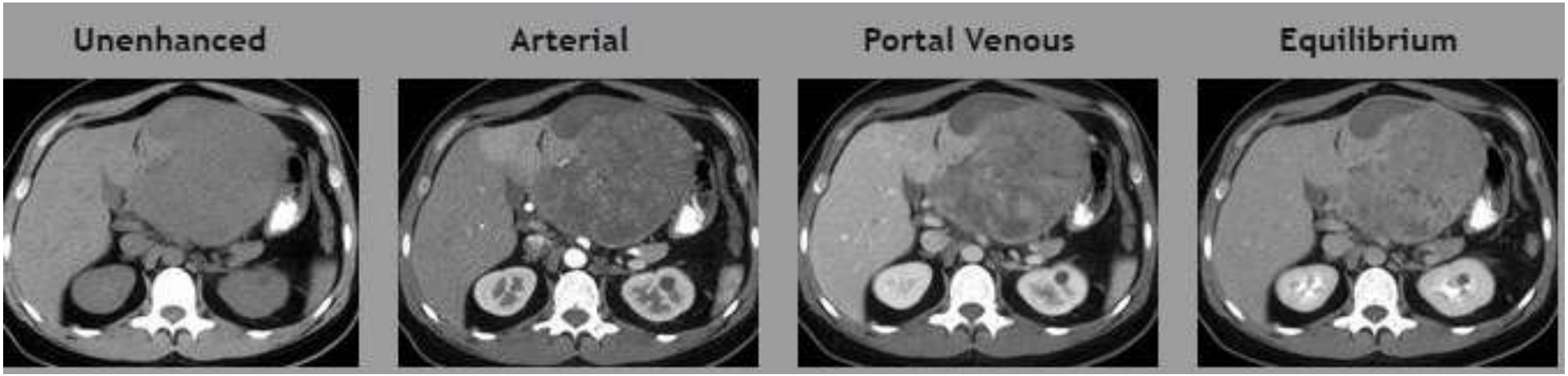


Hypovascular HCC





Haemorrhagic HCC

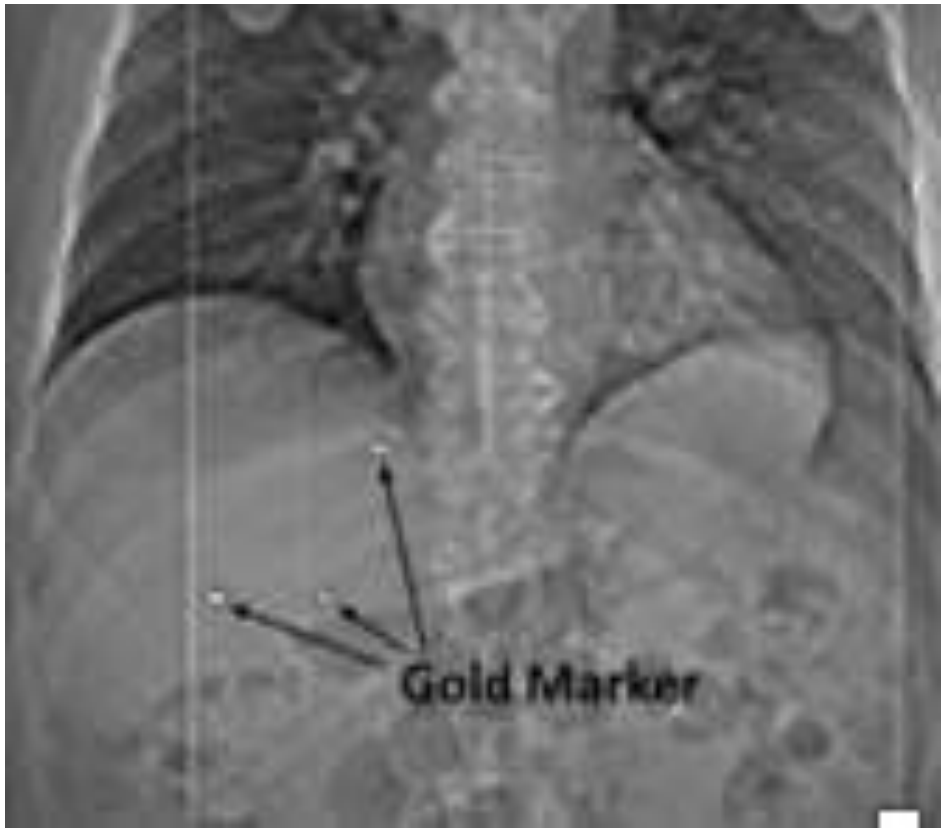


Assess Tumor motion

- **Intrafraction motion** -can potentially result in geographic miss
- **Assess Amplitude** of the respiratory motion -kV fluoroscopy ,4DCT or Cine MRI
- **Motion management -if breathing motion is > 5 mm.**
- Breathing motion assessed on 4DCT and adequately treated with PTV margins < 20mm is permitted.
- 4D CT: A 4D, or respiratory sorted, CT may be obtained for assessing motion if breath hold is not used for liver immobilization.

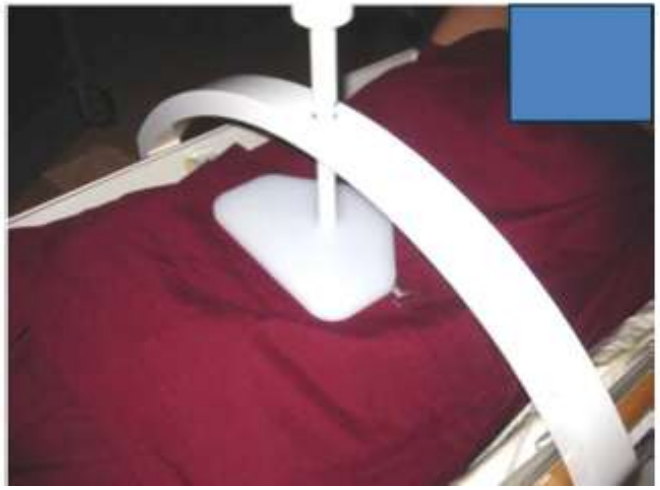
Fiducial placement

- Required in Cyberknife based treatment
- Performed in USG or CT guidance
- Ideally 4-6 fiducials are placed in close vicinity to tumour min. 2 cm spacing No farther than 5 cm from tumour
- At least 15° angle b/n grouping of 3 fiducials (should be non colinear)
- Allow 7 days in b/w fiducial insertion and planning CT scan
- Min. of 3 fiducials is required to track rotation during trt delivery
- Selection influenced by needle caliber and length, anatomy and characteristics of target lesion



Respiratory motion management

- Active Breath Control(can reduce motion to 5mm)
- Forced Shallow breathing with abdominal compression(can reduce motion to 5-10mm)
- Real time tracking /gating
  - Abdominal belt with inflatable bladder
  - Inflation: 15-40 mmHg



No Restriction in respiratory motion

- **Used if motion management means cannot be applied or tumour moves less than 5 mm.**
- It allows motion within margins of PTV(derived from ITV)
- A 4DCT set can be acquired allowing creation of and Internal target volume (ITV)with relative certainty of tumor respiratory motion

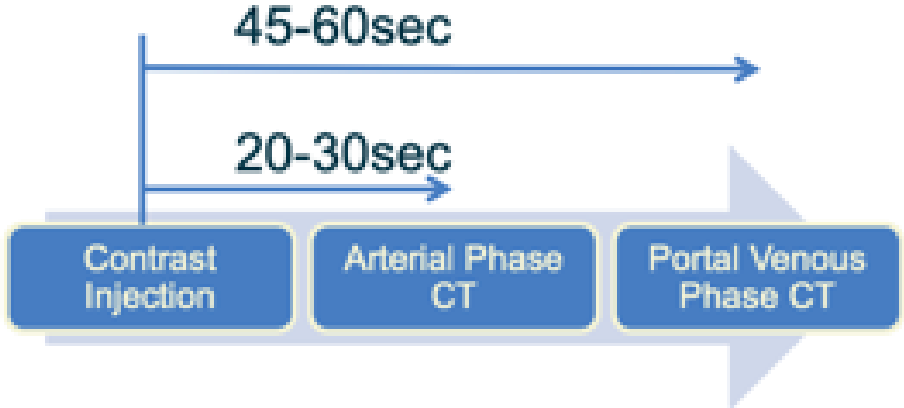
Patient positioning

- Reproducible
- Patient positioning- depends on SBRT delivery system being utilized
- Devices used- stereotactic frames/individualized vacuum moulds
- **Scan with arms above head or by side whichever is most comfortable**
- **Positioning should allow optimal range of beam angles**
- MRI should ideally be performed on the same day as the CT in treatment position

SIMULATION

CT scans used for target delineation - multi-phase IV contrast scans obtained in breath hold.

- Head-first-supine position
- Arterial imaging is important;-patients undergo both an early arterial-phase CT scan acquired **at end-expiration breath-hold** and a venous-phase CT scan also acquired at end expiration.
- **Slice thickness is generally 1.25 mm. Levels should be 20 cm above and below liver.**
- 4D CT scan obtained to capture respiratory motion as well as to serve as a delayed-phase scan.



Timing of imaging after IV contrast administration:

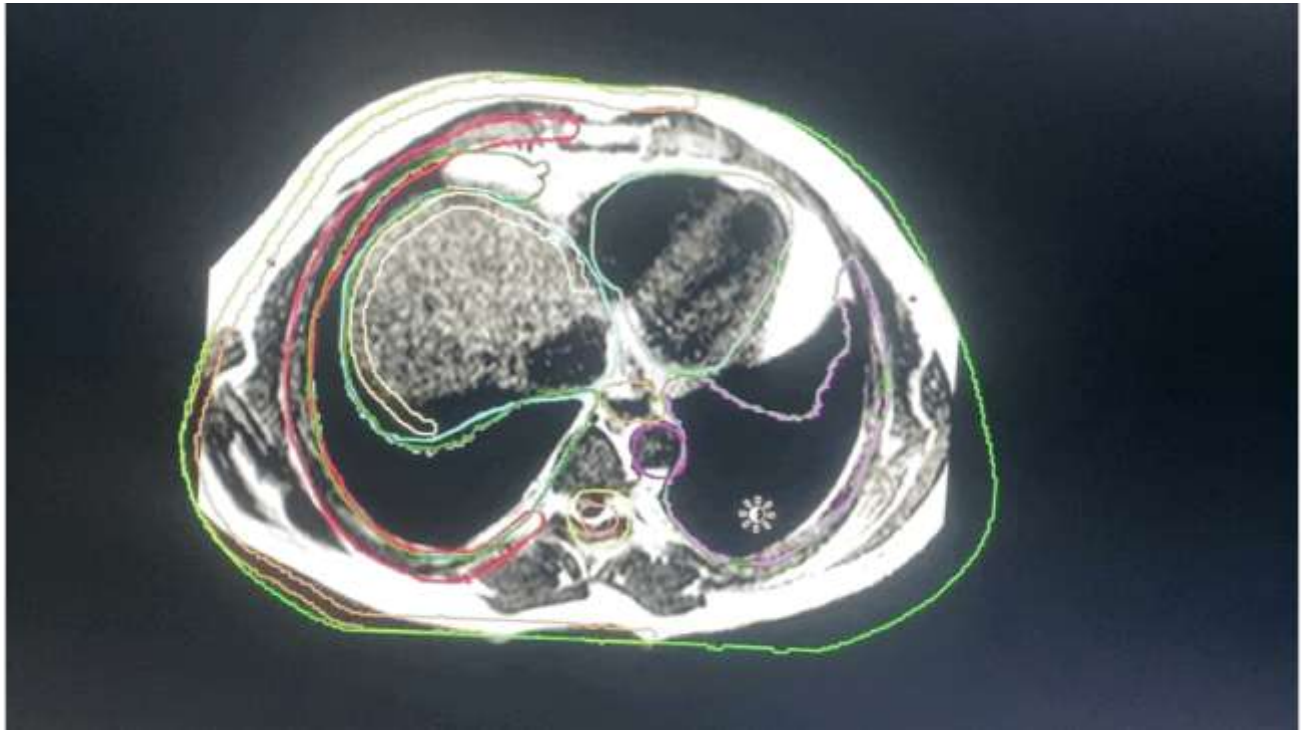
- Varies between 16 and 64 detector scanners
- **IV contrast 2cc/kg to a max of 180cc @ 3-5cc/second**
- **For 16-slice CT scan –**A phase imaging performed at 25 (35-50 s) seconds & D phase at 55 (45-60) seconds using 5 cc/s to a maximum dose of 200 cc) in exhale breath hold.
- **For a 64 detector scanner-** A, V and D phase scanning occurs 20, 60 and 180 seconds, respectively, after the 100HU threshold is reached.

Bolus Tracking technique

- IV bolus tracking- controls for variations in cardiac circulation time, to obtain images during correct phases of contrast enhancement.
- A cursor is placed in aorta at level of origin of the celiac axis & is used to detect when contrast arrives in abdominal aorta (100 HU)

Image Registration

- IV contrast contraindicated-multiphase CEMR
- MRI also is better in delineation of infiltrative lesions
- MR contrast contraindicated-non-contrast T1 weighted images(7mm)
- **Register with best fit liver- to-liver image registration, focusing on region of PTVs if deformation or rotation occurs between scans.**



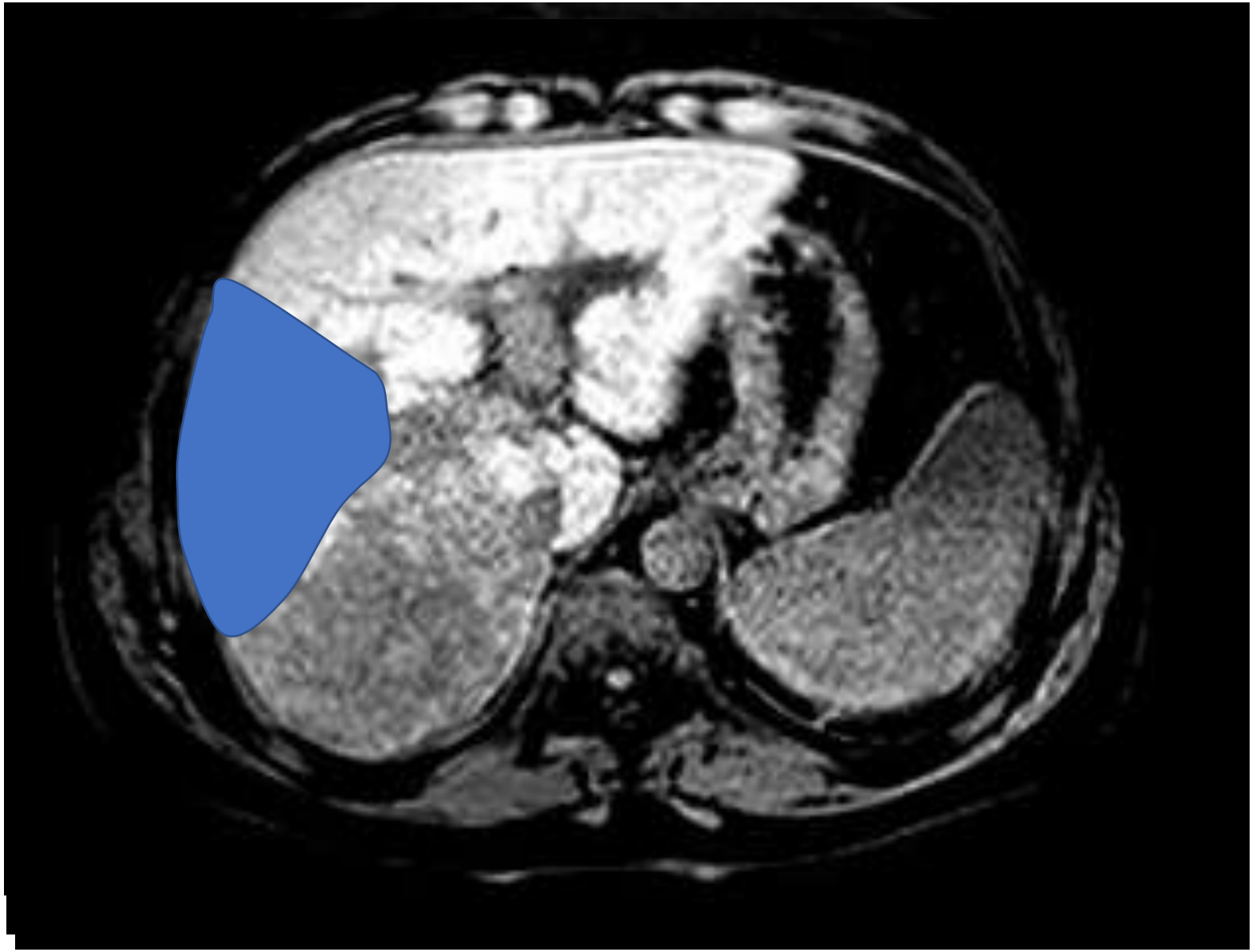
Volume definition

- **GTV is defined as all parenchymal & vascular HCC**
- **Radiographically apparent arterially enhancing(on arterial phase) &/or washed-out tumor (on venous phases) including any arterially enhancing vascular tumor thrombus.**
- **Vascular HCC thrombi (GTV v)** most often are best seen on venous phase imaging
- **Bland vascular thrombi** - **should be excluded** or may be included in CTV (RTOG1112)
- **Non-tumor extrahepatic vascular thrombi-** not be treated as GTV/ CTV.
- GTV should not extend beyond liver surface

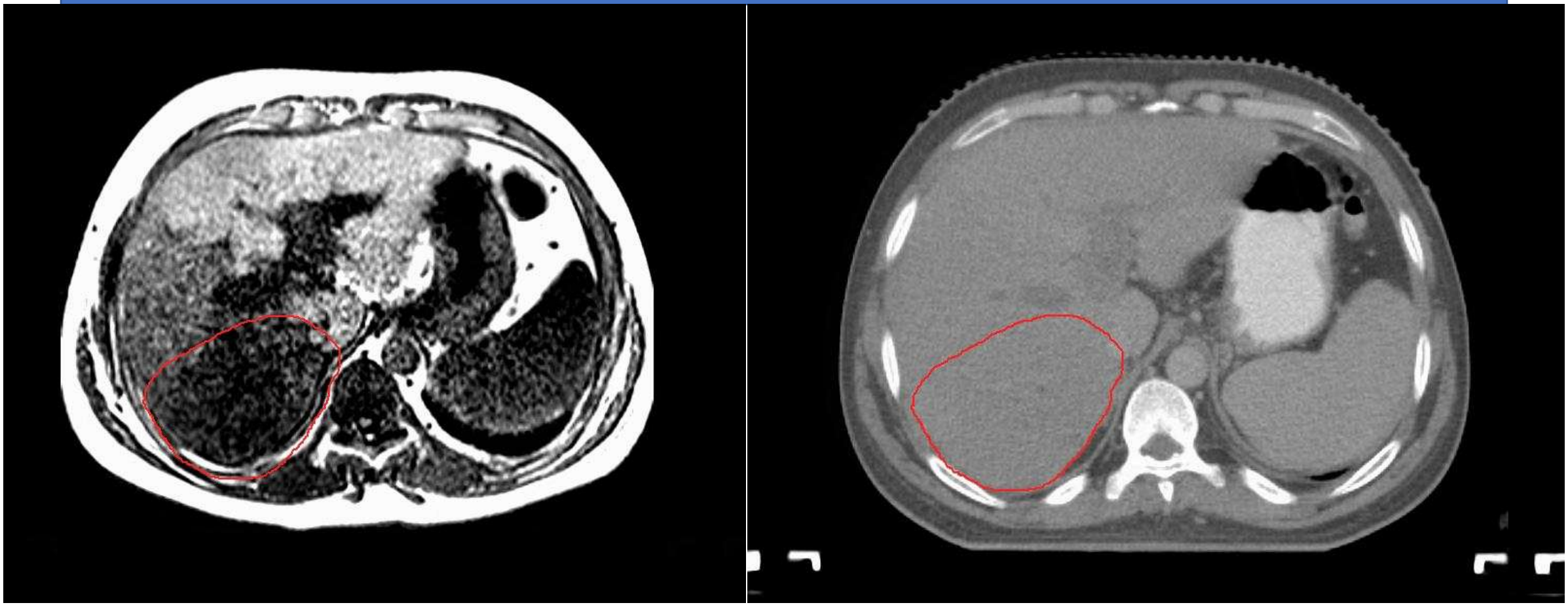
Tips for contouring

- **Over-contouring** →either a lower prescription dose →lower probability of local control or a higher risk of RILD
- Outline GTV on **images that best display** tumor target(MRI /CT) & review on NCCT
- Use **abdominal window** setting on CT
- **Avoid contouring perfusion abnormalities** wedge shaped arterial enhancement without washout
- **Review** in Coronal and sagittal plane
- **Review**: with diagnostic radiology & Obtain peer review

Verify contours with radiologist



GTV Delineation



Interobserver Variability in Target Definition for Hepatocellular Carcinoma With and Without Portal Vein Thrombus: Radiation Therapy Oncology Group Consensus Guidelines

Theodore S. Hong, MD[*], Walter R. Bosch, DSc[†], Sunil Krishnan, MD, PhD[‡], Tae K. Kim, MD[§], Harvey J. Mamon, MD, PhD[||], Paul Shyn, MD[¶], Edgar Ben-Josef, MD[#], Jinsil Seong, MD[**], Michael G. Haddock, MD[††], Jason C. Cheng, MD[‡‡], Mary U. Feng, MD[§§], Kevin L. Stephans, MD[||||], David Roberge, MD[¶¶], Christopher Crane, MD[‡], and Laura A. Dawson, MD[##]

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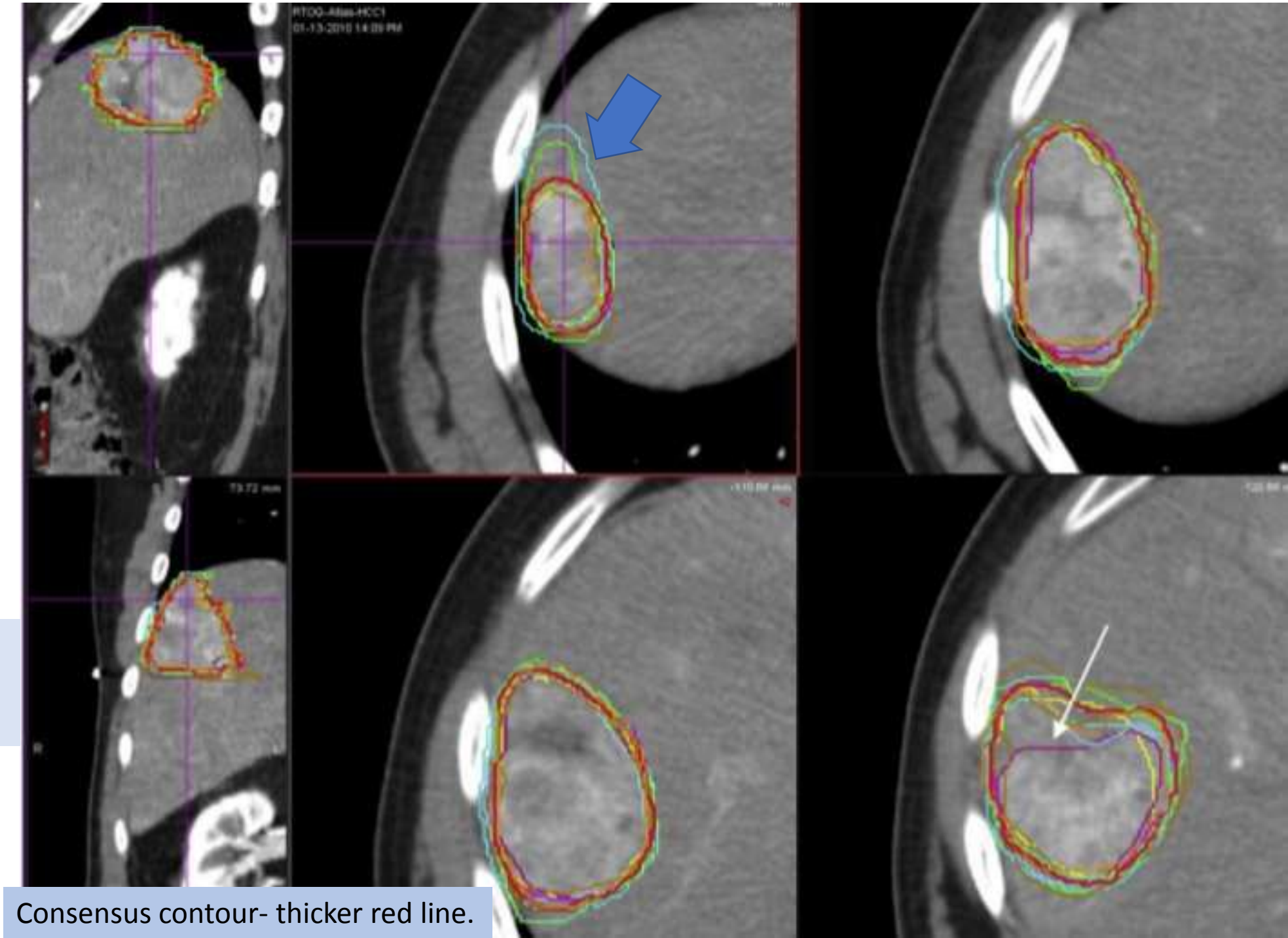
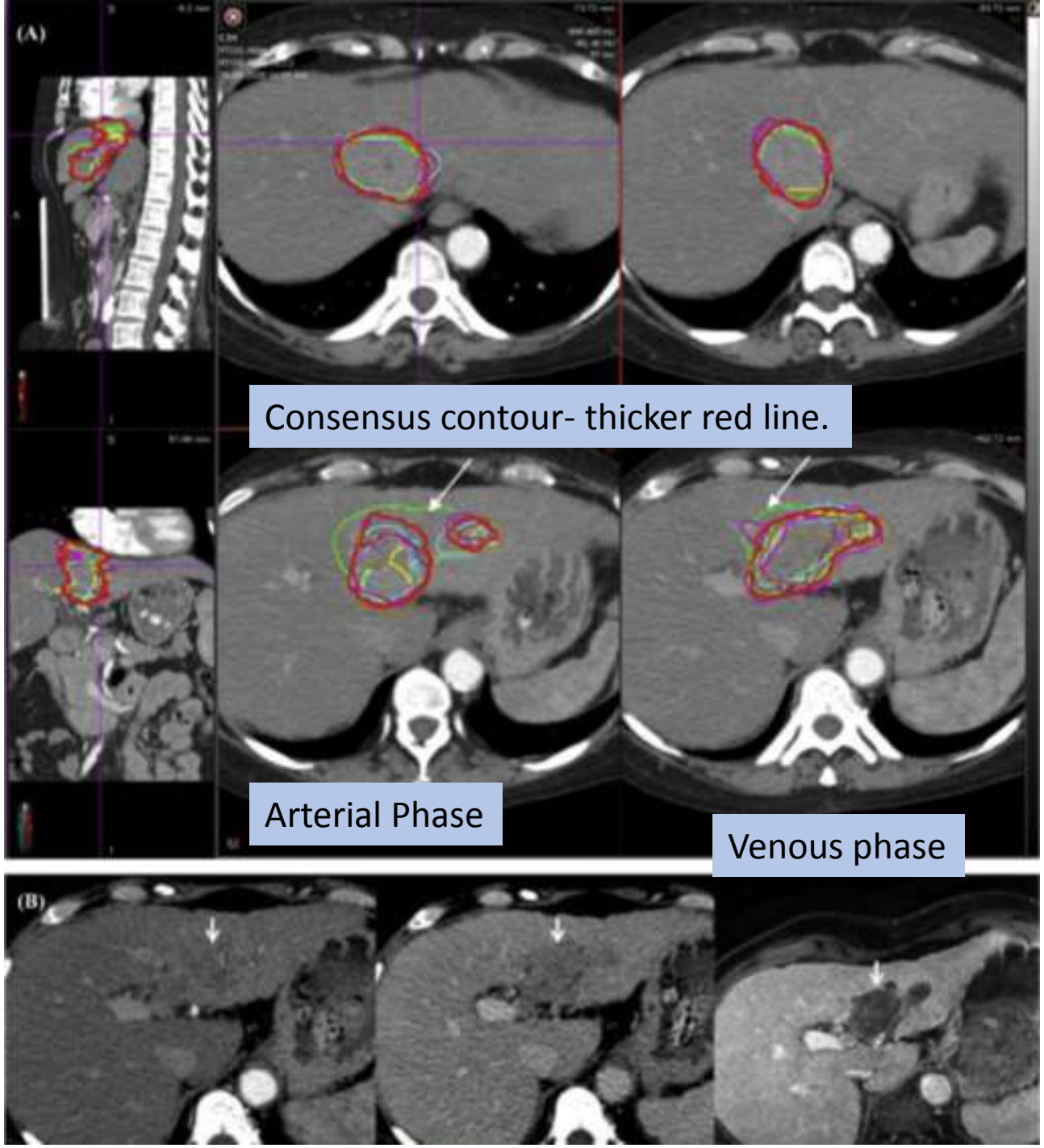
Int J Radiat Oncol Biol Phys. 2014 July 15; 89(4): 804–813.
doi:10.1016/j.ijrobp.2014.03.041.

HCC with no (TVT)

Misidentified an area of vascular arterial enhancement as HCC



Consensus contour- thicker red line.

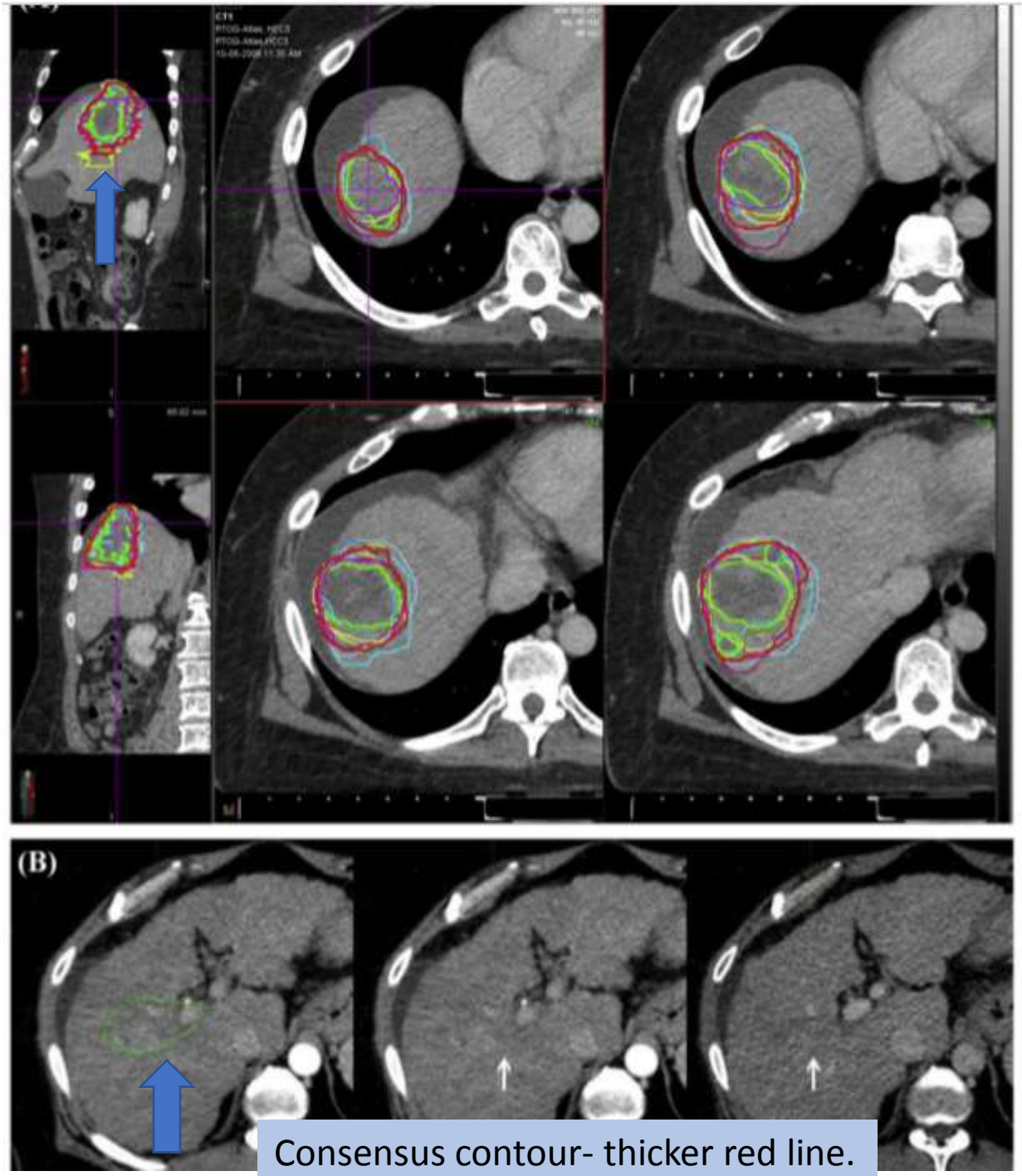


HCC with major (TVT).

Over contoured due to Fusional error

HCC with small TVT

Over contoured due to perfusion defect inclusion in PTV



Clinical Target Volume….is it required?

- CTV expansion to encompass microscopic ds is not routinely done.
- Sometimes defined on basis of GTV expansion by 3-5 mm.

RTOG 01112-CTVp -GTV with no expansion.

CTV expansions to include regions at high risk for microscopic ds-

- CTVv including non-tumor vascular (v) thrombi,
- CTVt prior TACE (t) sites
- CTVr adjacent RFA or other ablation sites

Treated to a lower dose than GTV

CTV for Liver SBRT

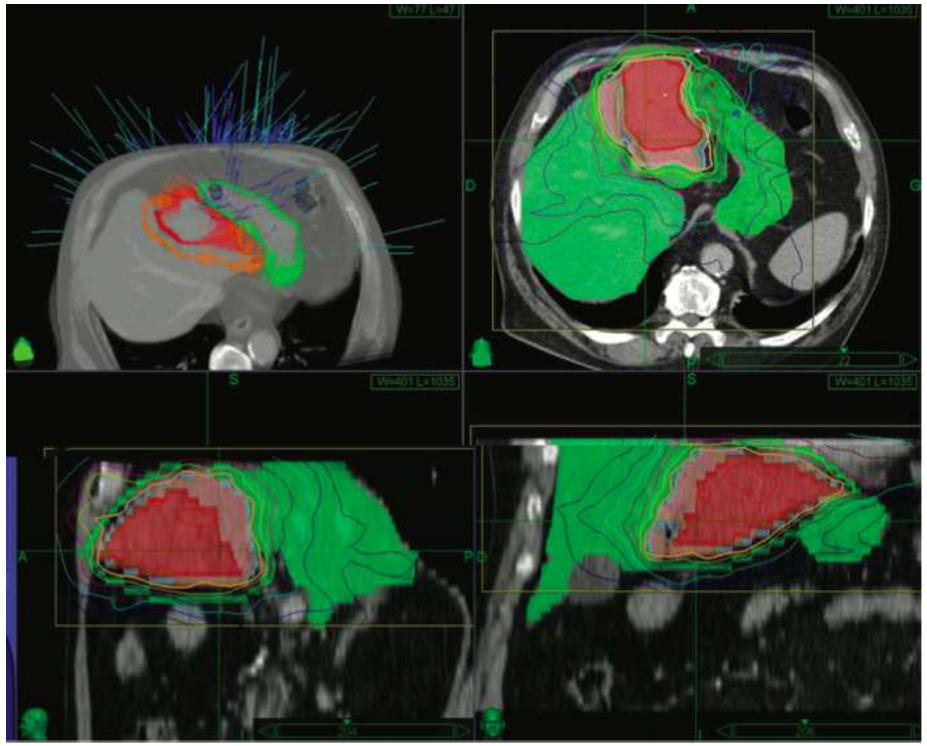


Table IV

Observed toxicity after SRT at various follow-up times based on the National Cancer Institute (NCI) Common Terminology Criteria for Adverse Events (CTCAE, v3.0).

Follow-up time	End of Treatment		3 Months		6 Months		9 Months		Late	
Toxicity Grade	Grade 1/2	Grade 3/4	Grade 1/2	Grade 3/4	Grade 1/2	Grade 3/4	Grade 1/2	Grade 3/4	Grade 1/2	Grade 3/4
Dermatitis										
Nausea			2		1				3	
Vomiting	3		1		1				2	
Gastritis			1						1	
Gastro duodenal ulcer					2	1			2	1
Hepatic toxicity				1						1
Dysphagia			1						1	
Hepatic/epigastric pain	1	1	3		1				4	
Hematoma										
Fatigue			1		1				2	
Anorexia	1									
Diarrhea			1		1				2	
Total (n/%)	5 (20%)	1 (4%)	10 (48%)	1 (5%)	7 (39%)	1 (6%)	0	0	17 (81%)	2 (10%)
Evaluable patients (n)	25		21		18		14		21	

Louis C et al **Stereotactic radiotherapy of hepatocellular carcinoma: preliminary results.***Technol Cancer Res Trea* 2010, **9:** 479-487.

Planning target volume

- PTV is defined as CTV with an expansion for organ motion and set up errors
- **Determined by**

➢Type of immobilization

➢Motion management strategy chosen

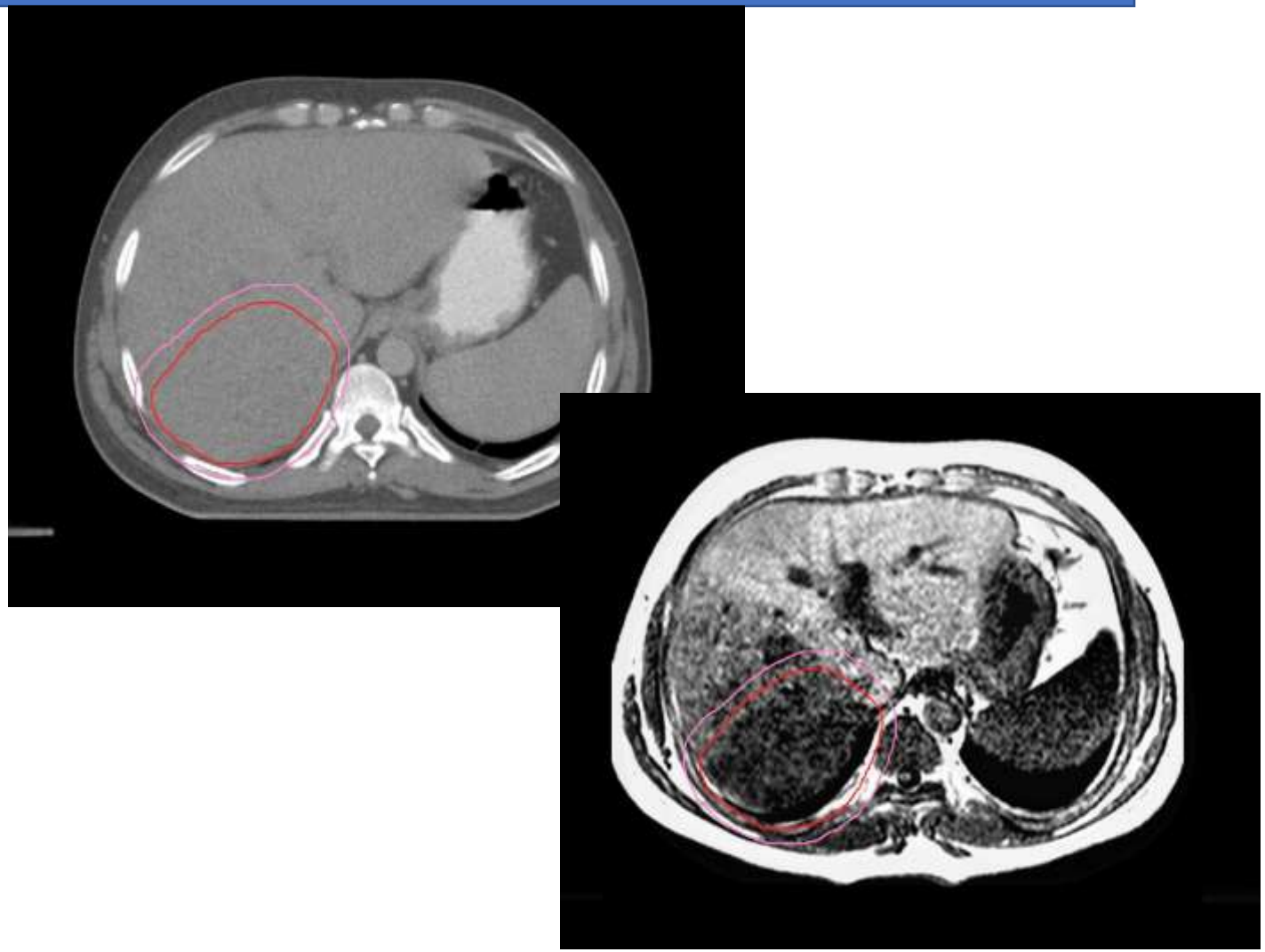
➢Frequency/type of on-board imaging

➢ Presence of fiducial markers.

- **Respiratory motion tracking-1.5-3mm**
- **If no breathing control/tracking methods employed -5 mm radially & 10 mm CC(ITV based)**
- **If 4DCT margins -3-5 mm.**

Planning Target Volume

- **Respiratory-gated treatments -** no/small adjustment for the ITV.
- **Free-breathing** ITV or use PTV margin (as per degree of tumor excursion)
- **PTV margins ≤ 10 mm are a goal.**
- Asymmetric PTV margins are permitted.
- **PTVs should not be manually modified due to proximity of adjacent OARs.**

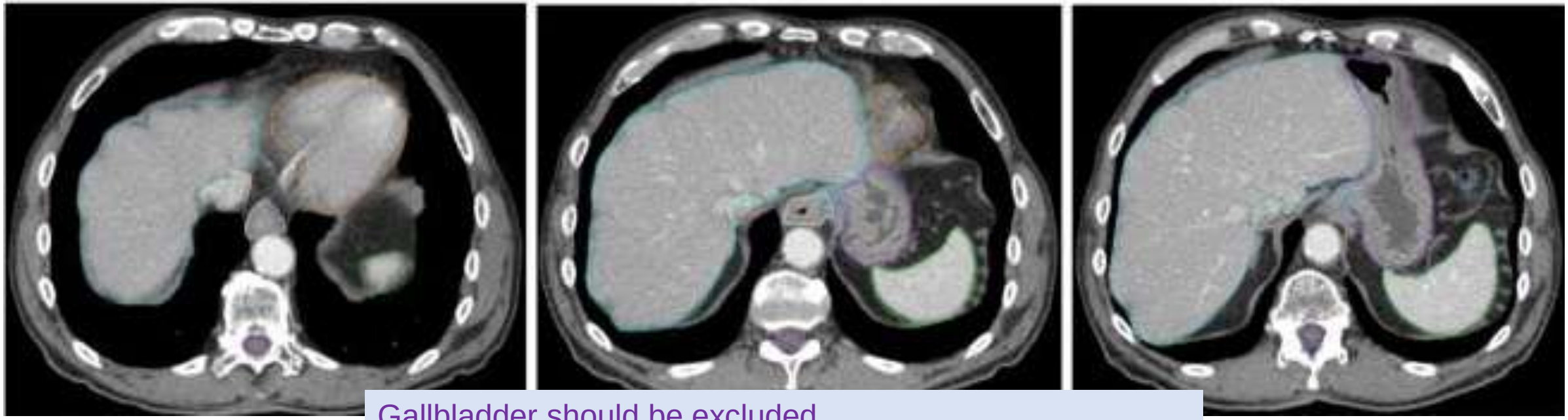


Delineation of organs at risk

- Normal liver parenchyma
- Spinal cord
- Heart
- Chest wall
- Esophagus
- Kidneys
- Stomach
- Small and large bowel
- Diaphragm
- Skin
- Vessels
- **Central hepatobiliary tract (cHBT)**

Organs at Risk -Liver

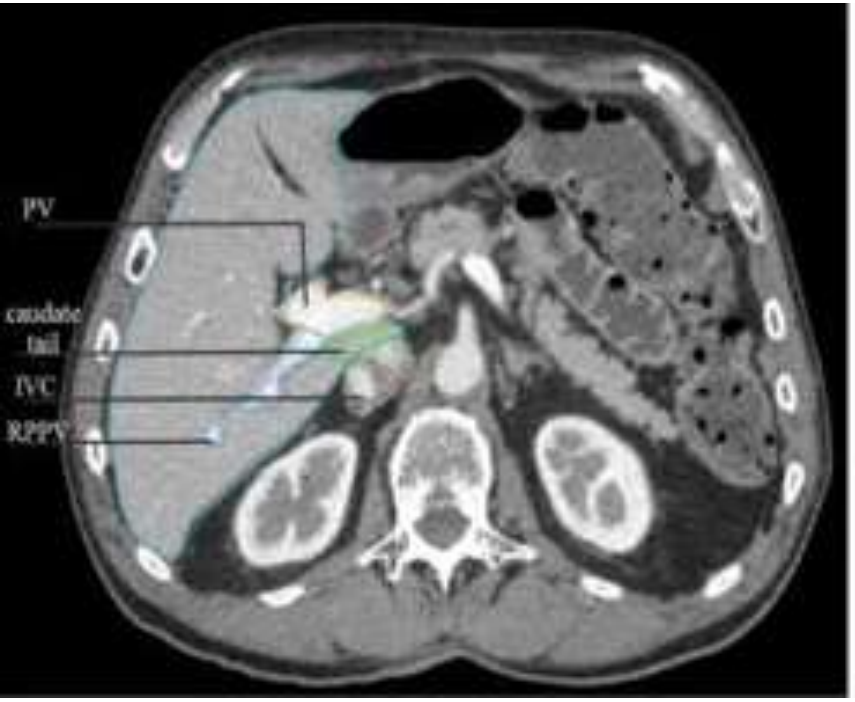
Whole liver should be contoured for dose calculation with volume minus PTV

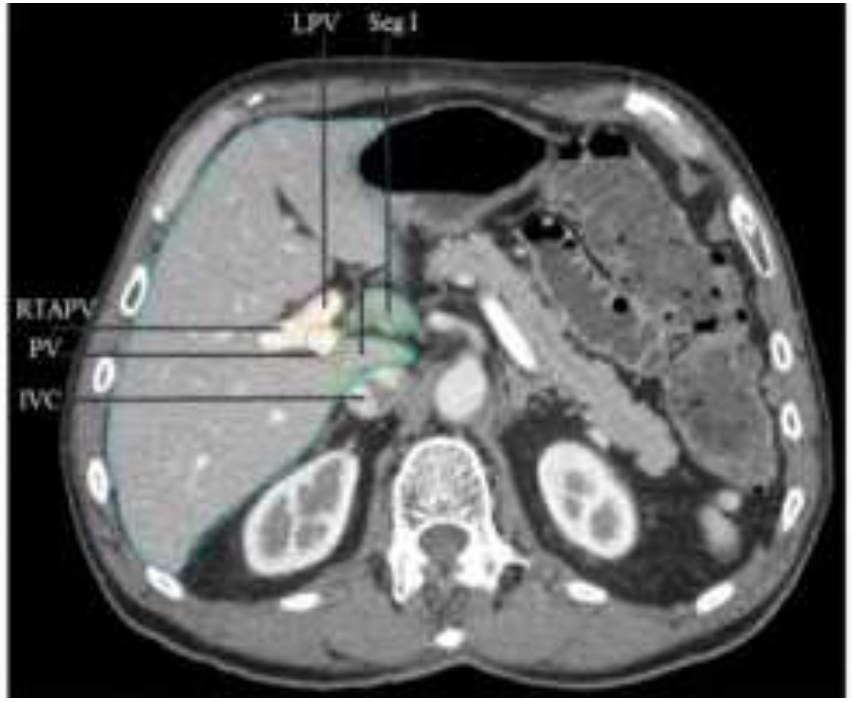


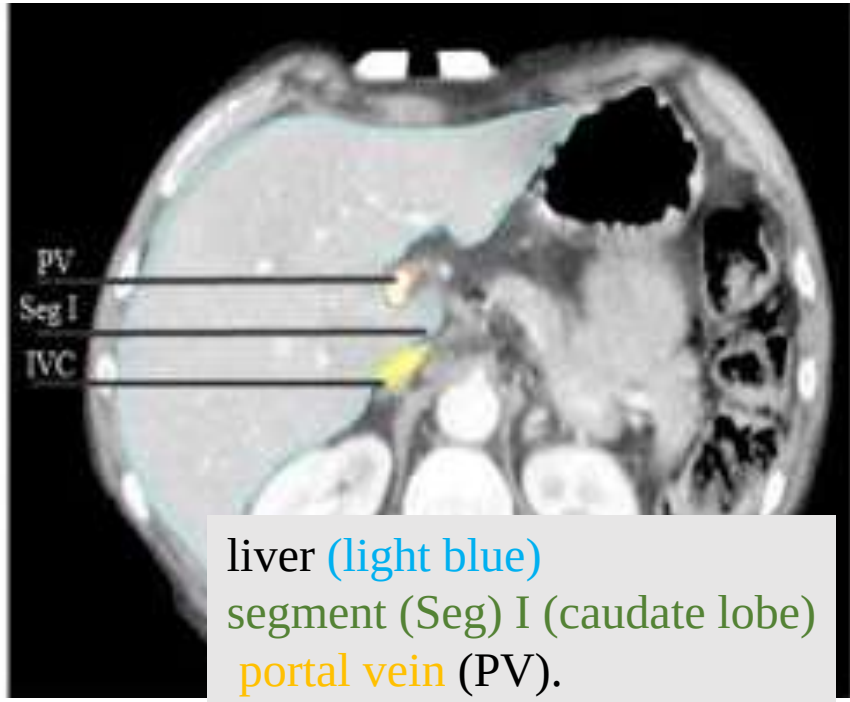
Gallbladder should be excluded
•IVC should be excluded when it is discrete from liver

liver (light blue), IVC (yellow), esophagus (white), heart (orange), spleen (green), stomach . spinal canal (purple), top of gastroesophageal junction (GEJ) light blue large bowel (2C).

Organs at Risk -Liver







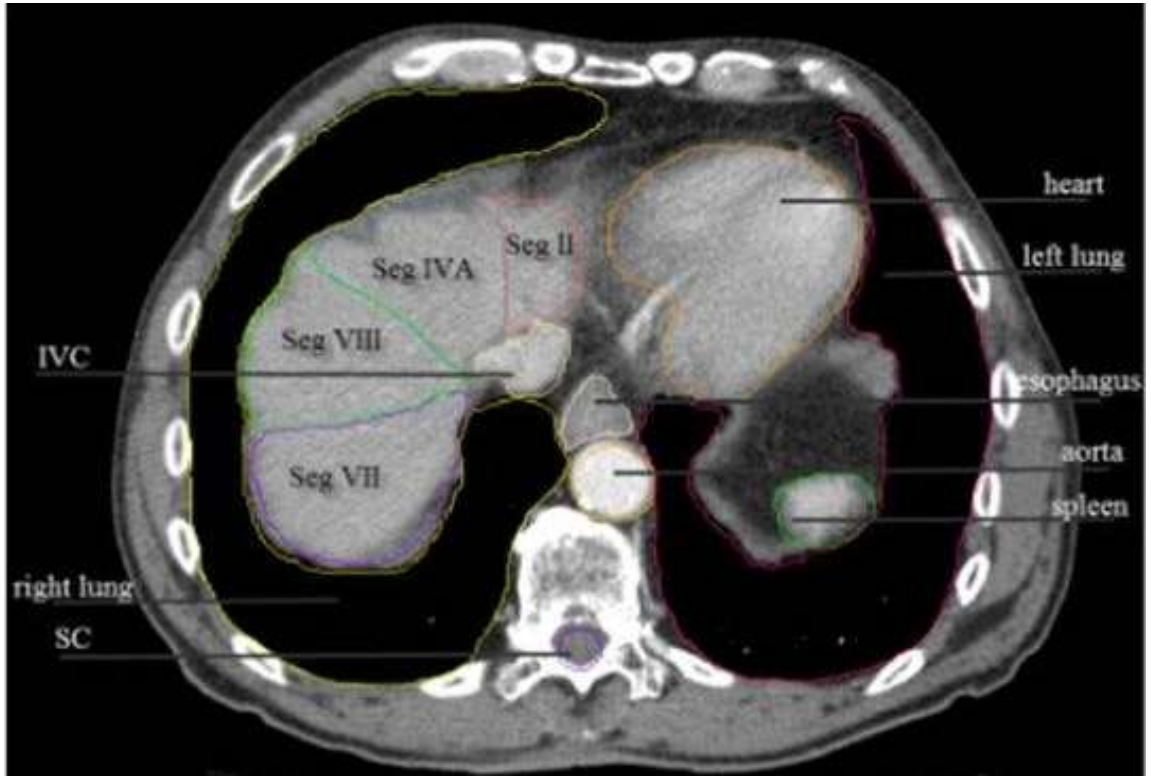
liver (light blue)
segment (Seg) I (caudate lobe)
portal vein (PV).

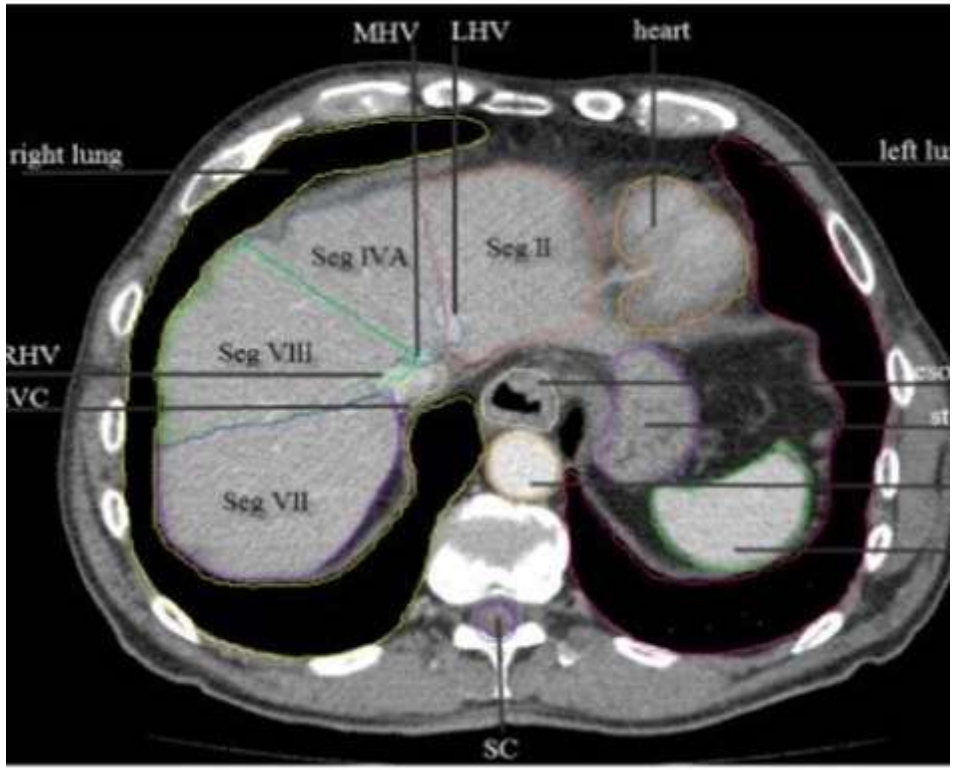
- Segment I, “caudate tail,” posterior to the PV
- liver contour should exclude the PV

- Segment I to left of the PV,
- Liver contour should include segment I and the PV.

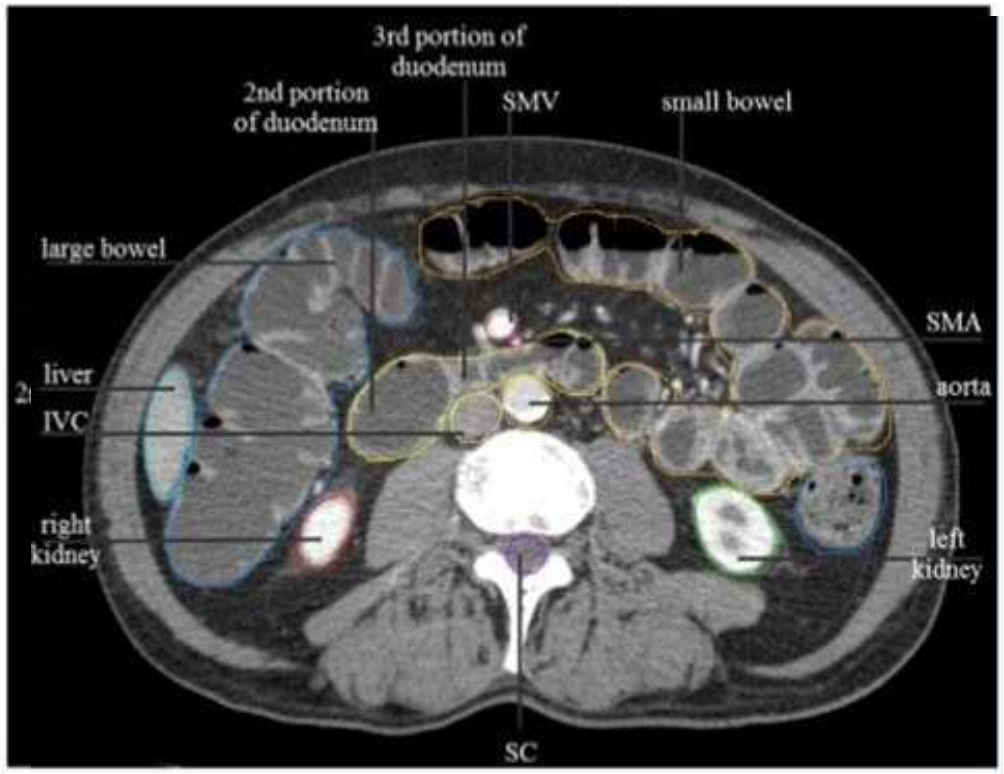
- Segment I does not fully extend to the left of the PV
- PV is excluded from liver contour.

Organs at Risk-lower thoracic



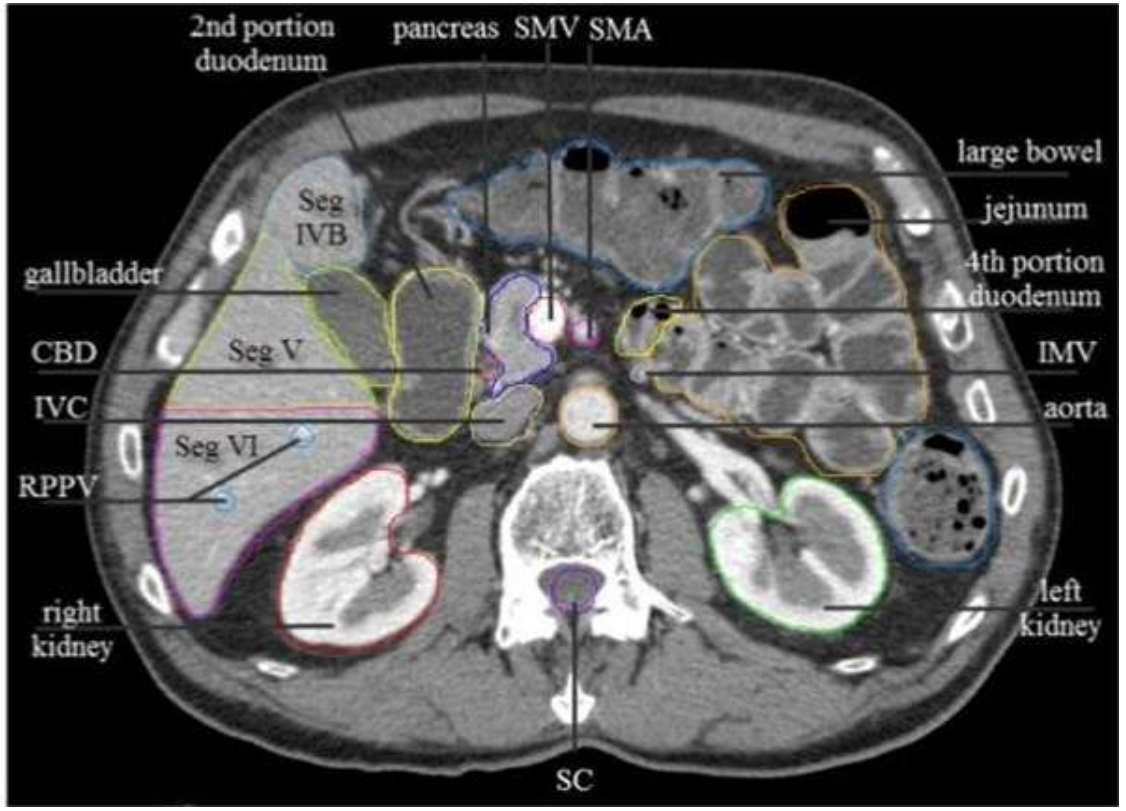


Organs at Risk



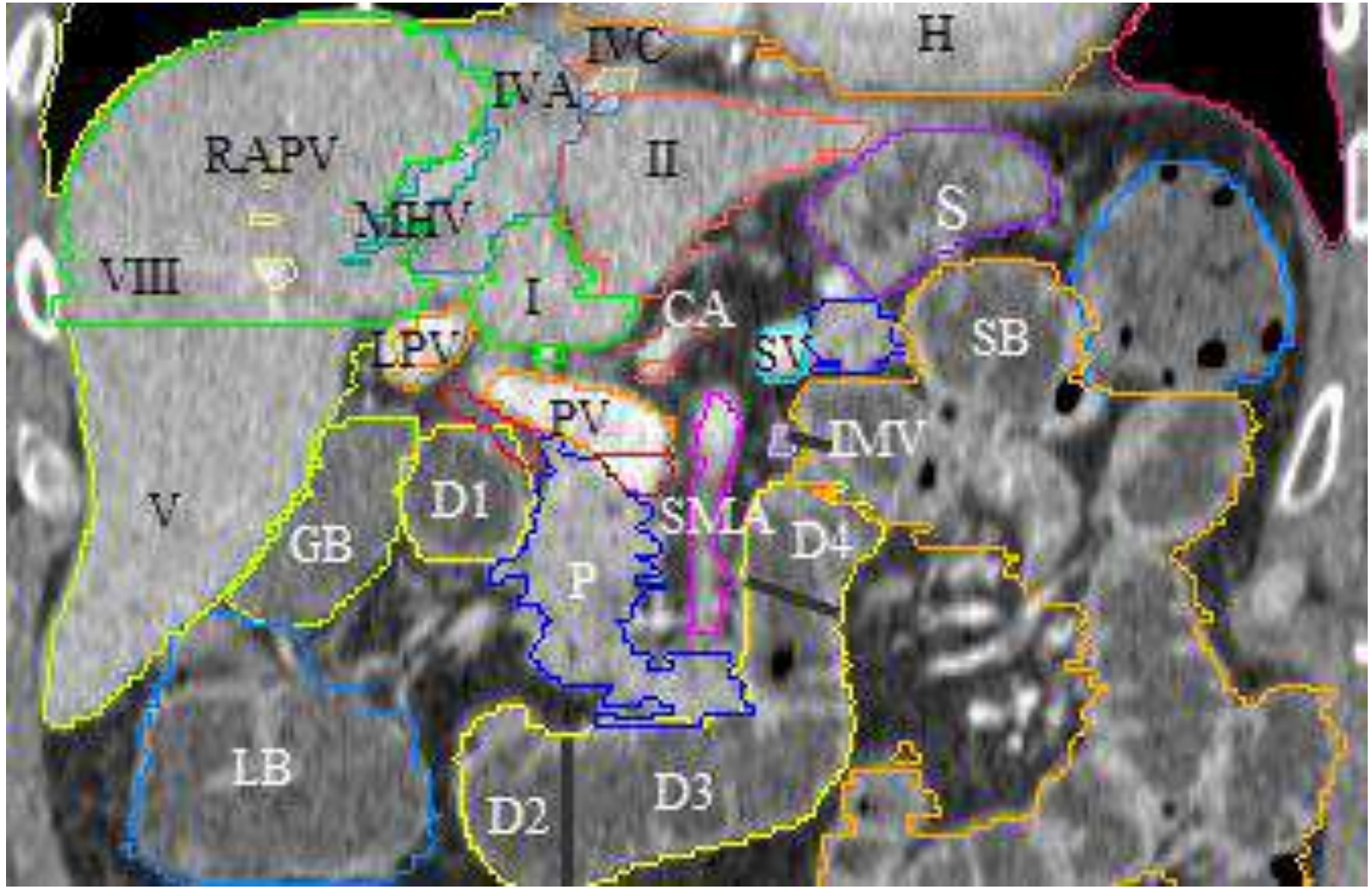
duodenum (shown in yellow).
DSplenic vein (SV)
portal vein (PV)
common bile duct (CBD)
inferior vena cava (IVC)
superior mesenteric artery (SMA),
SMV, spinal canal (SC).
IMV, inferior mesenteric vein,
RAPV, right anterior portal vein
MHV, middle hepatic vein
LPV, left portal vein
IVC (yellow)
H, heart
S, stomach
LB, large bowel
SB, small bowel
GB, gallbladder
P, pancreas
PV, portal vein,
CA, celiac artery,

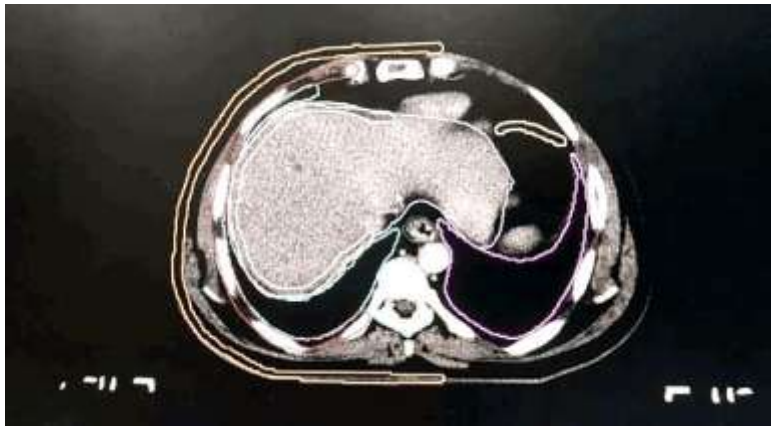
Organs at Risk



Resources for contouring OARS of upper abdomen
RTOG atlas

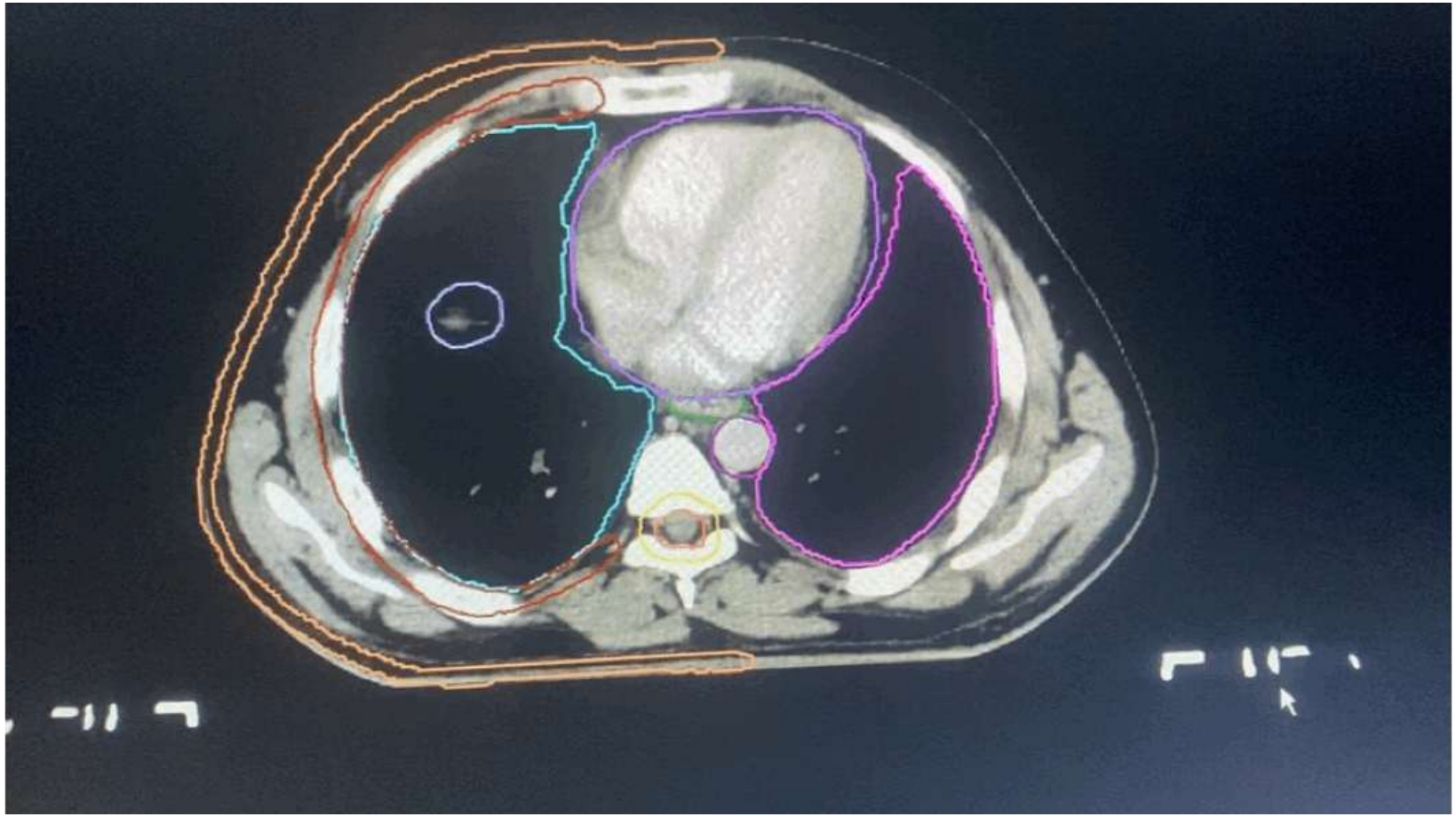
Duodenum


IVC
H
IVA
RAPV
II
MHV
S
VIII
I
CA
SV
SB
LPV
PV
IMV
V
D1
SMA
D4
GB
P
LB
D2
D3



Central hepatobiliary tract

Defined by a 15-mm expansion of the portal vein from the splenic confluence to the first bifurcation of left and right portal veins



DOSE PRESCRIPTION AND FRACTIONATION

- Various dose prescription and fractionation schedules
- No consensus guidelines exist for selecting an optimal dose.
- Prescription dose is limited by volume of normal liver, underlying liver function, and adjacent normal tissue constraints.
- Dose response relationship & BED >100 Gy(10) equivalent is important for tumour control
- 2 year LC- 90% are achieved with 54-60 Gy in 3 fractions compared to 59% (36-53.9Gy/3Fractions) & 8.1% in doses less than 36 Gy

Factors affecting dose prescription and fractionation

Commonly used fractions

- 10-30Gy in a single fraction
- 45-60Gy in 3 fractions over 3-10 days
- 50-60Gy in 5 fractions over 5-12 days
- 60Gy in 8 fractions over 10 days
- 50-60 in 10 fractions over 12 days

Treatment planning and dosimetric information for SBRT studies

Investigator	Total dose range (Gy) & fractions	Imaging modalities	Target margins	Prescription definition	Motion management	Liver planning guidelines
Barney et al	45–60 3,5	CT, MRI	GTV = CTV; ITV = CTV + motion margin using 4DCT; PTV = ITV + nonuniform 5-mm margin	Isodose line covers PTV based on tumor volume and proximity of OARs	Gating, Ac	≥700 cm^3 to ≤21 Gy
Tse et al	24–54 6	kV fluoroscopy, CT, MRI	CTV = GTV + 8 mm within liver; PTV = CTV + individualized margin (minimum 5 mm)	Isodose line covers PTV based on limiting RILD risk	Breath hold, AC	Based on V_{eff}
Huang et al	25–48 4,5	CT	With fiducial markers: PTV = GTV + 0– 8 mm (increased to 8–20 mm in caudocephalad direction if no fiducial markers)	70%–83% Isodose line covers PTV	CRTS, AC	≥700 cm^3 to ≤15 Gy
Kang et al	42–60 3	CT	ITV = GTV + motion margin using slow CT; PTV = ITV + 4 mm in longitudinal direction and 2 mm in all other directions	SBRT doses prescribed at isodose line (70%–80% of maximum dose) covering ≥97% of PTV	AC, CRTS	≥700 cm^3 to ≤17 Gy
Goodman et al	18–30 1	CT, MRI, PET/CT	ITV = GTV + motion margin using 4DCT; PTV = ITV + 3–5 mm for patients with 4DCT; PTV = ITV + 5–10 mm for patients with no 4DCT	65%-90% isodose covering PTV	CRTS	≥700 cm^3 to ≤15 Gy
Andolino et al	CP: A, 44 (30–48); B, 40 (24–48) 3,5	Dual-phase CT	PTV = GTV + 5 mm radially and + 10 mm superoinferiorly	80% Isodose line covering PTV	AC	CP A: 1/3 to ≤10 Gy and ≥500 cm^3 to <7 Gy; CP B: 1/3 to ≤18 Gy and ≥500 cm^3 to <12 Gy
Bujold et al	24–54 6	CT, MRI	CTV = GTV + 5–8 mm within liver; PTV = nonuniform expansion around CTV based on individual patient tumor motion and reproducibility of immobilization (≥5 mm)	Isodose line covering PTV based on limiting RILD risk	ABC,AC	Based on V_{eff}
Son et al	30–39 3	CT	PTV = GTV + 3–5 mm	PTV enclosed by 70%–85% isodose line	Breath hold + CRTS	V_{20Gy} ≤50%
Barney et al	28–60 1,3,5	CT, PET/CT	ITV = GTV + motion margin using 4DCT; PTV = ITV + 5 mm	95% coverage of PTV with prescription isodose line	NA	NA
Bae et al	30–60 3,4,5	CT, MRI, PET/CT	GTV = CTV; PTV = CTV + 4 mm in longitudinal direction and 2 mm in all other directions	56%–83% Isodose line of maximum dose in CyberKnife and 91%–100% in RapidArc to cover ≥95% of PTVs	NA	≥700 cm^3 to ≤17 Gy

AC- Abdominal compression,ABC- Active breathing control ,CRTS Cyberknife respiratory tracking system with fiducial markers

Montefiore-Einstein Cancer Center SBRT Registry Study Doses as per effective liver volume

- Five fractions: 30-50 Gy (depends on Veff)
- Veff Dose per fraction < 0.3 10 Gy x 5

  0.3 - 0.4 9 Gy x 5

  0.4 - 0.5 8 Gyx 5

  0.5 - 0.6 6 Gyx 5

$$V_{eff} = \sum_i \Delta v_i \left(\frac{d_i}{d_{ref}} \right)$$

Dref-prescribed dose
Di- dose per fraction
Vi- partial dose volume associated with ith dose bin
Veff- effective liver volume (Veff) irradiated is defined as the normal liver volume, minus all GTVs, which if irradiated uniformly to treatment dose would be associated with the same risk of toxicity as non-uniform dose distribution delivered

Lyman-Kutcher-Burman

Dawson LA et al Acta Oncol 45:856, 2006

Use of effective liver volume (Veff) to aid in dose allocation

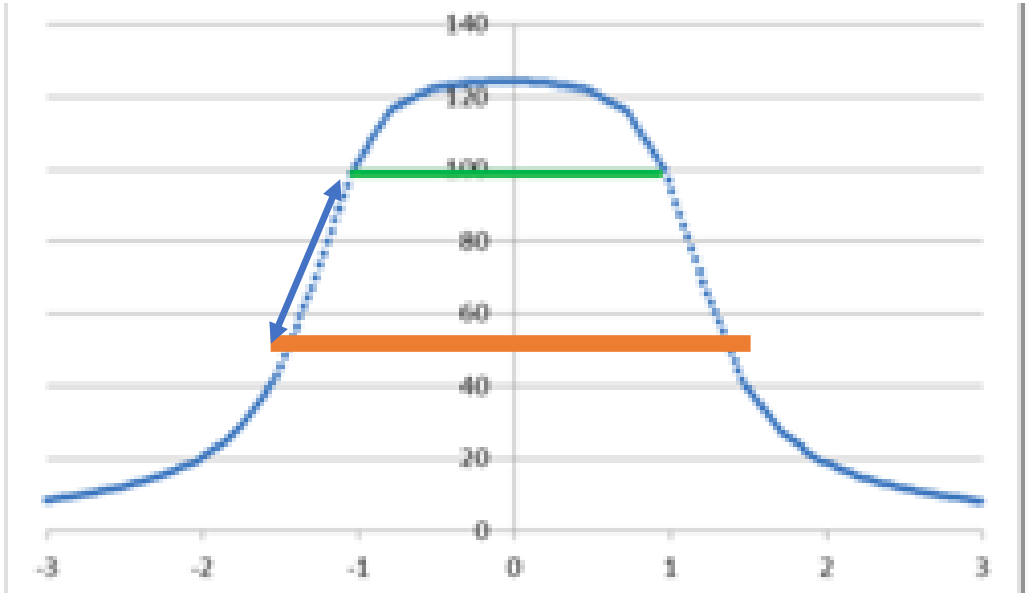
Optional Constraint	Priority Constraint	Prescription Dose	
Liver Veff	Allowed Mean Liver Dose [MLD] (Gy)	Planned Prescription Dose (Gy)	If the maximum allowed MLD is exceeded at this planned dose
< 25%	13.0	50	Reduce to 45 Gy and re-evaluate
25 - 29%	15.0	45	Reduce to 40 Gy and re-evaluate
30 - 34%	15.0	40	Reduce to 35 Gy and re-evaluate
35 - 44%	15.5	35	Reduce to 30 Gy and re-evaluate
45 - 54%	16.0	30	Reduce to 27.5 Gy and re-evaluate
55 - 64%	17.0	27.5	Ineligible

Dose values in this table should be read as physical dose for photons, or RBE-weighted dose for protons (assuming RBE = 1.1).

In absence of adjacent GI luminal structures that may limit dose, PTV dose prescription should be as high as possible based on mean liver dose (MLD, defined as mean dose to the liver minus all GTVs)

SBRT planning principles

- Inhomogeneous Dose inside PTV
- Sharp Dose Fall Off outside PTV
- Multiple non-coplanar beams or arcs are needed to create conformal dose distributions.



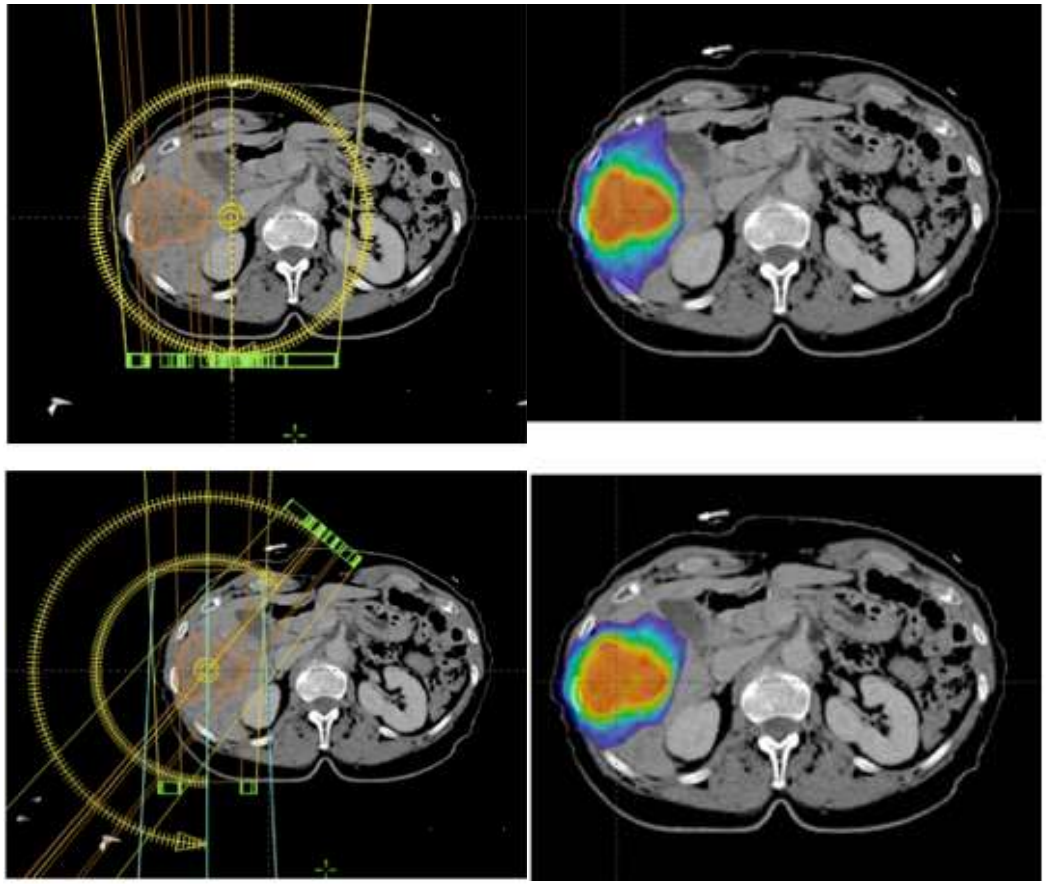
	conventional	SBRT
Dose Distribution	Homogeneous (maximum PTV dose ~ 110%)	Heterogeneous (maximum PTV dose up to 160%)
Dose Gradient outside PTV	Shallow slope	Steep slope

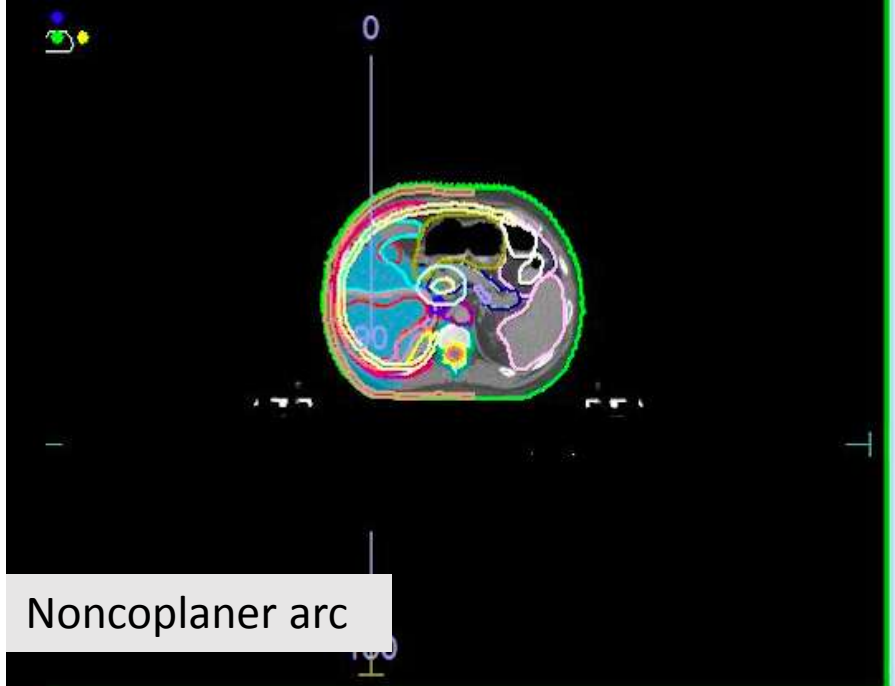
Planning priorities

- Maximize target volume dose ,maintain all normal tissue constraints
- **Dose inhomogeneity** inside PTV is potentially advantageous& but not considered a priority in plan design.
- Main objective of plan is to minimize volume of normal tissues outside PTV receiving high dose/ fraction
- **Reducing maximal dose to all luminal gastrointestinal normal tissues should be a planning priority**
- Beam angles-individualized to **minimize the pathlength** through liver & through adjacent OARS
- Conformality of 30 Gy isodose

Treatment Planning

- Increasing number of beams improves conformality of target dose & dose gradient
- No significant difference beyond 9 beams irrespective of target size
- Increasing VMAT is employed for planning
- Right lateral ,multiple partial arcs
- Keep beams /arcs on ipsilateral side

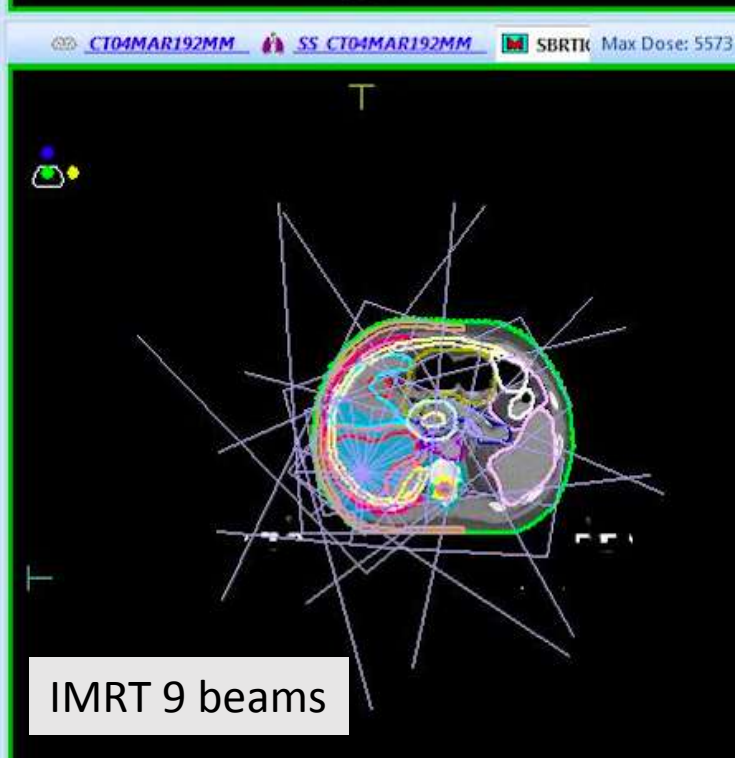




Noncoplaner arc

Partial Arc

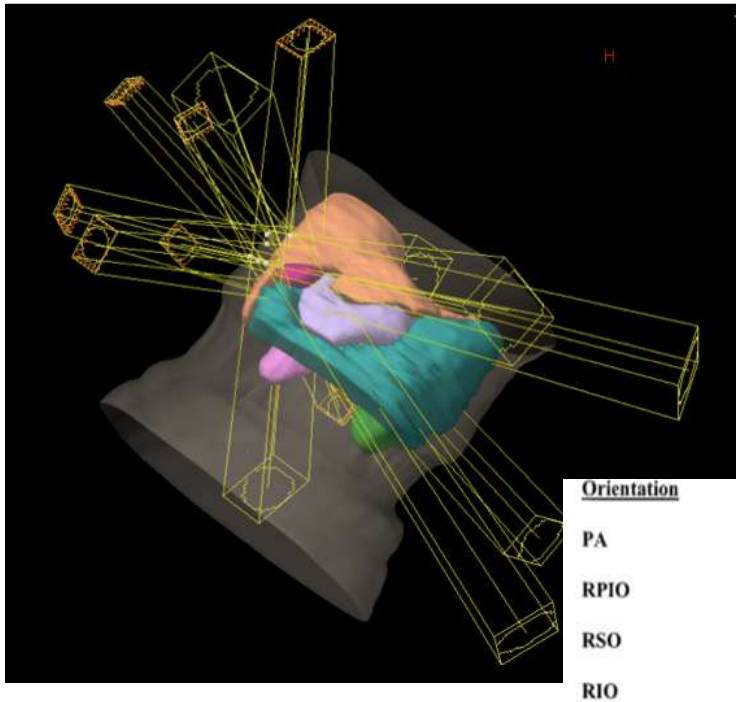
360 D ARC



IMRT 9 beams

RT Planning …know the limitations of the machines

- Non-coplanar beams could be used to compensate for lateral beams.
- If gating is used, only coplanar beams can be used for some machines, arms on side could further limits beams.
- VMAT can not be combined with gating for many machines
- Beam arrangement should consider collision possibility



Orientation	Gantry	Couch
PA	180	0
RPIO	220	20
RSO	270	330
RIO	270	30
RAO (OR LPO)	315 (135)	0
ASO	40	90
AIO	320	90
LAO (OR LAIO)	45	0 (320)
LT LAT	90	0
LPO	150	0

Planning Considerations

Beam Arrangement

- Isocentric vs Non isocentric
- Coplaner vs Non coplaner
- Conformal vs IMRT vs VMAR

Beam Modes

- Regular(500-600 MU/min
- SRS(1000 MU/min) low energy available
- Flattening filter free(1400-2400MU/min) in low and high energy

Other planning parameters

- Beam mode: Regular vs FFF
- Field shaping
- MLC size
- Dose optimization and calculation

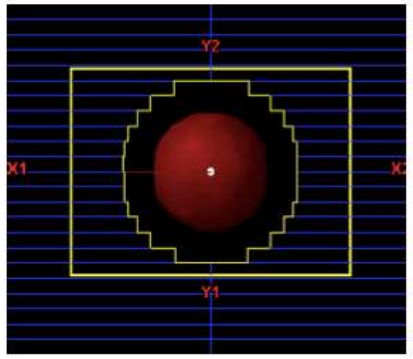
Dosemetric charactersitics of FFF

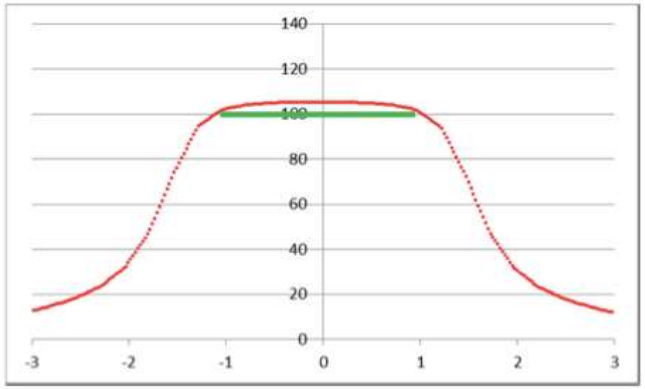
- Higher dose rate ,shorter delivery time
- Reduced energy variation across the field
- Increased surface dose

Kragl et. al. Rad Onc. V93, 2009

Beam Shaping Consideration

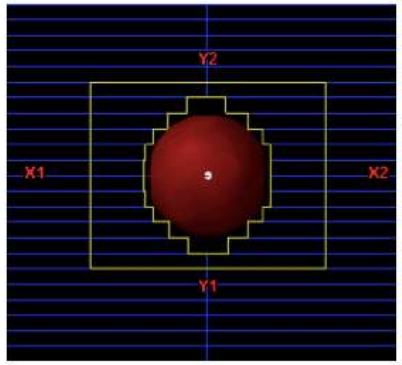
Beam margin approximate to beam penumbra (6-8mm)

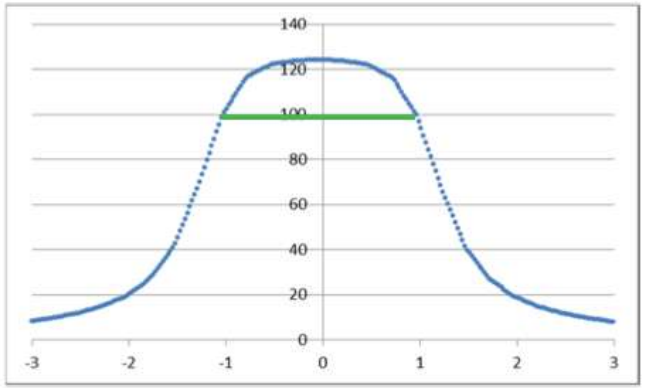




Homogenous dose inside PTV
Slow dose gradient outside target

Reduce beam margin < beam penumbra (2-3mm)





Hotspot inside PTV
Sharp dose gradient outside target

Heterogeneity Corrections

- All dose distributions should include corrections for tissue heterogeneities.
- Arterial vascular contrast from planning dataset is recommended to be converted to water equivalent density if used for planning.
- Planning datasets without IV contrast may be used for planning
- Corrections for the immobilisation devices.

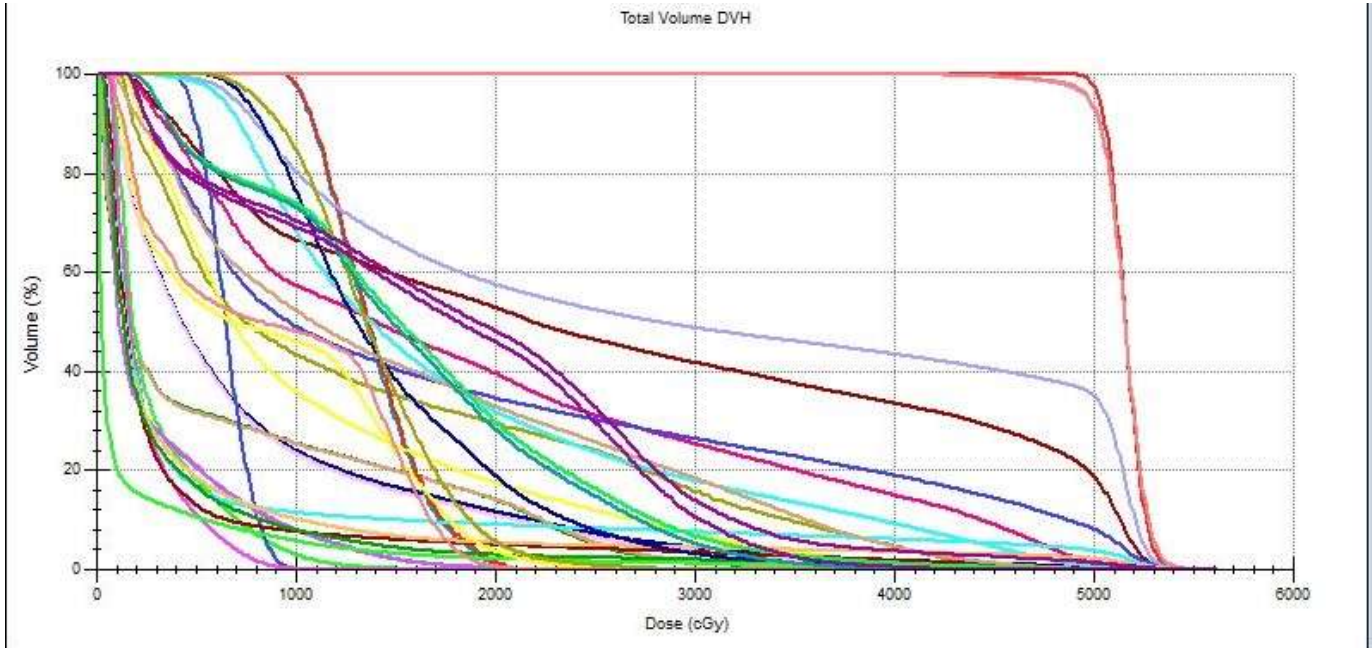
Plan Evaluation

- Target coverage
- Target dose heterogeneity
- Normal tissue constraints
- Dose conformity

❖High dose spill

❖Intermediate dose spill

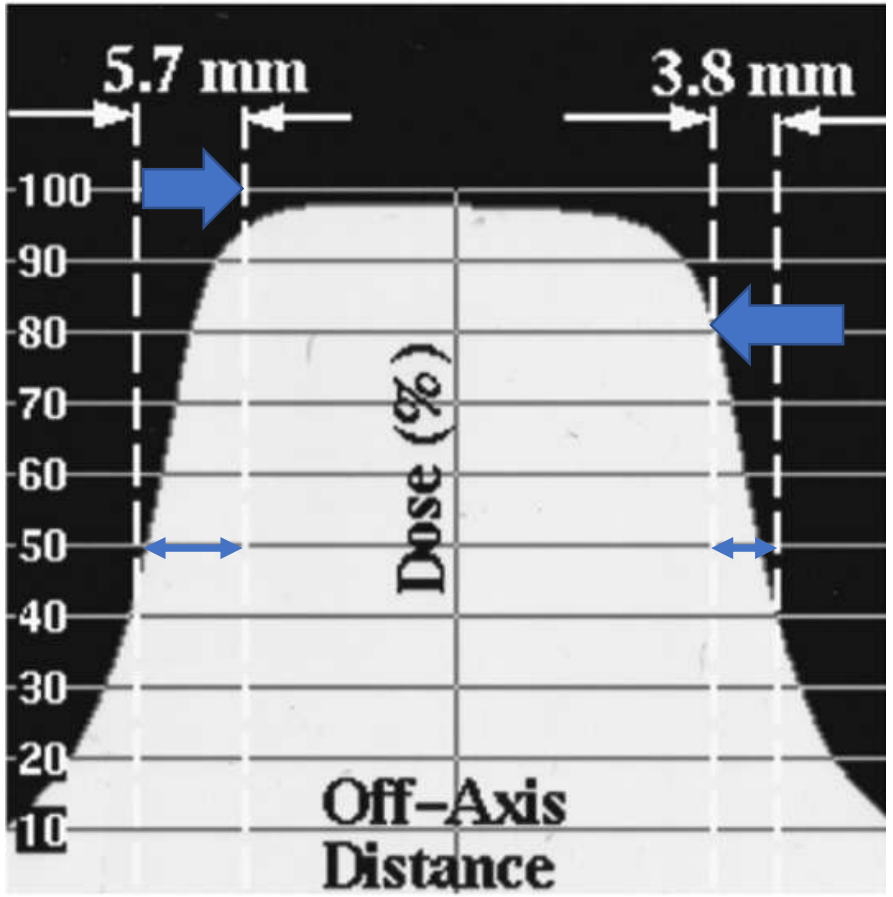
❖Low dose spill



Prescription Isodose

Prescription Isodose: must be ≥ 60% & < 90% of the max. dose

- Dose would conventionally be prescribed to 70-80% isodose.
- **Fall off from prescription Isodose to half of prescription dose occurs over shortest distance if dose is prescribed to 80 % Isodose shell with 100% as maximum dose**



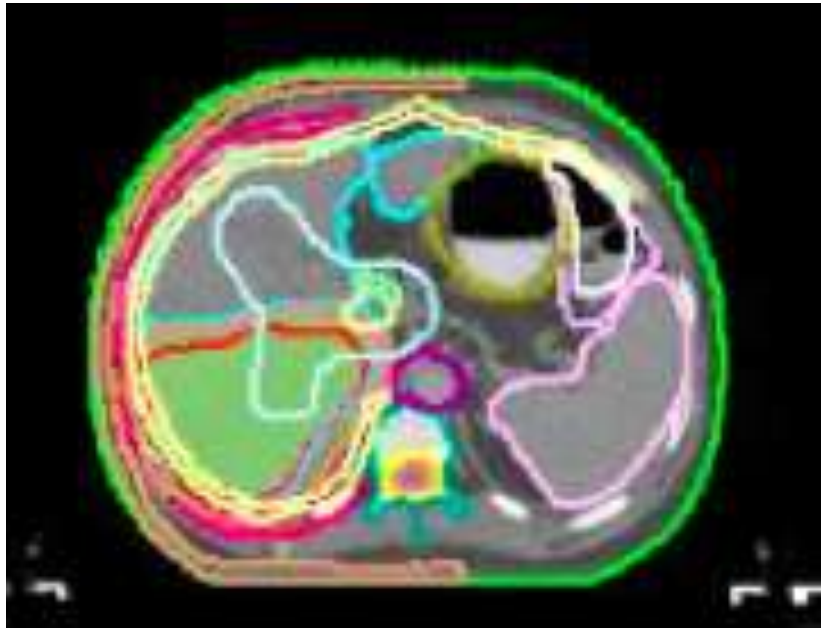
RTOG

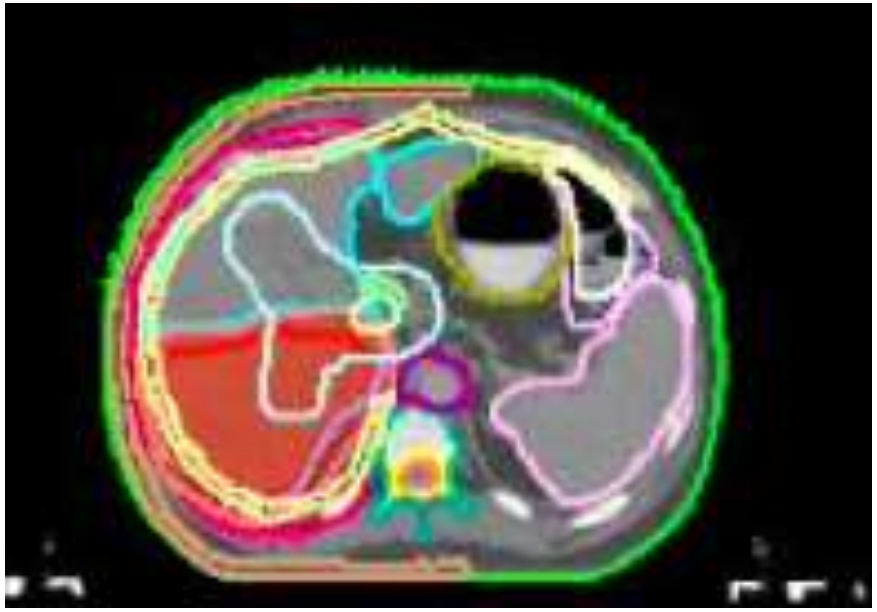
Prescription Isodose Surface Coverage

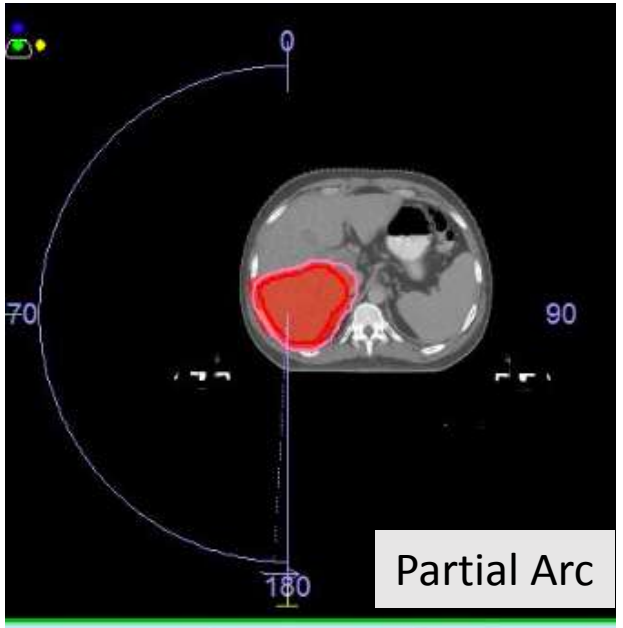
Evaluation of the dose–volume histogram and isodose levels

- At least 95% of target volume covered by 100% of prescribed dose.
- Minimum 95% prescribed dose covers 99% of PTV
- Rarely 99% of PTV receives a minimum of 90% of prescription dose
- GTV should covered by 100% of prescribed dose.
- **Max. Dose:** normalized to 100%, must be within PTV
- Global max. doses of 110% -130% of prescription dose are acceptable (if located within target volume, preferably within GTV)
- Hot spots should be within PTV ,not > 1 cc & max. dose should be <120%

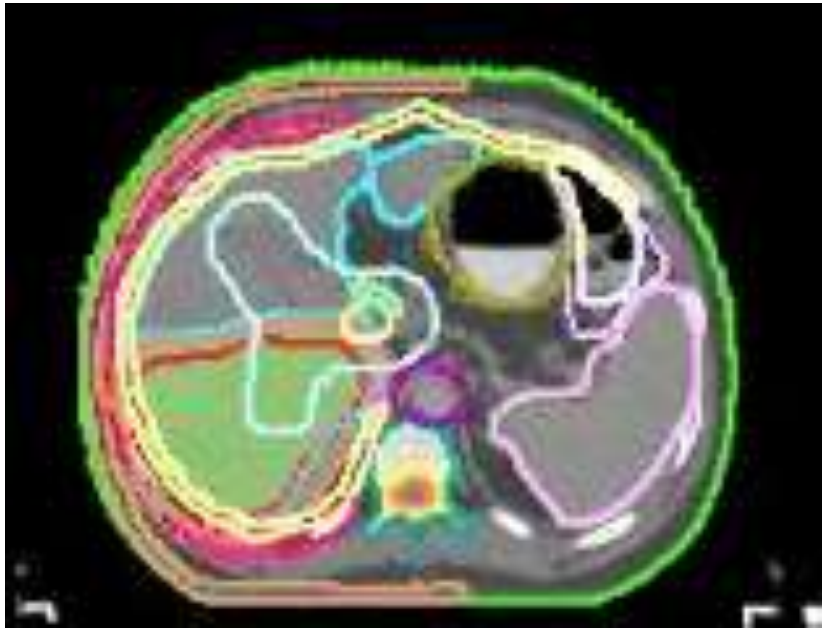
AAPM TG 101 report



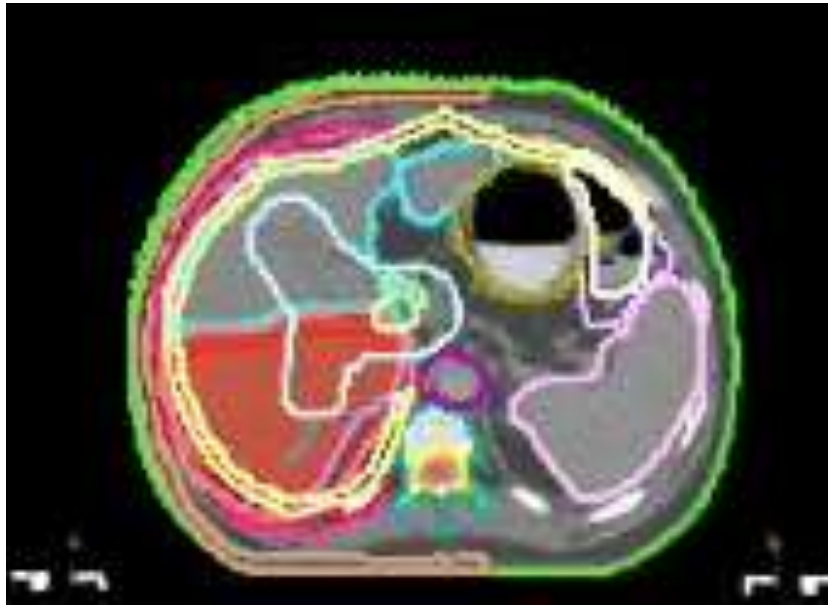




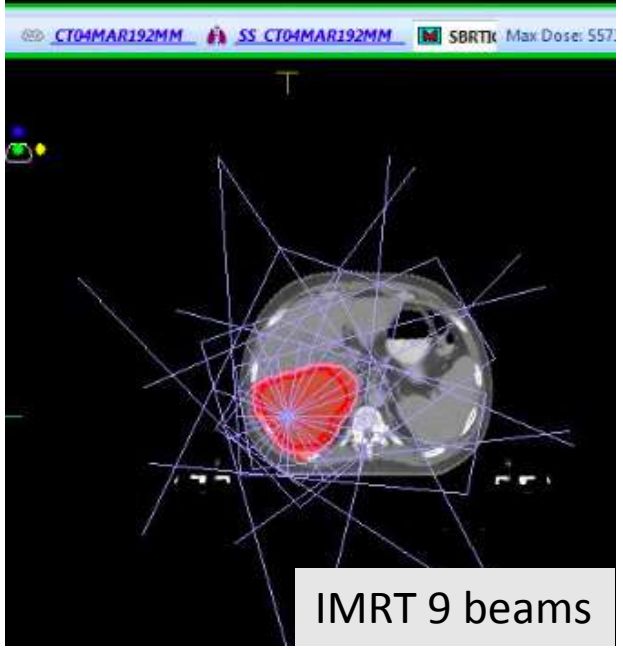
Partial Arc



95% Coverage



100% coverage



IMRT 9 beams

Common dose constraints

Organ at Risk	Dose Constraint
Liver—noncirrhotic	≥700 cm^3 of uninvolved liver <15 Gy (three fractions) ≥700 cm^3 of uninvolved liver <21 Gy (five fractions)
Liver—cirrhotic	**Child–Pugh class A** ≥700 cm^3 of uninvolved liver <15 Gy (in 3 or 5 fractions) Mean liver dose <15 Gy (in three or five fractions) **Child–Pugh class B** ≥700 cm^3 of uninvolved liver <15 Gy (five fractions) ≥500 cm^3 of uninvolved liver <7 Gy (five fractions) Mean liver dose <10 Gy (in five fractions)
Mean liver dose	≤15.4 Gy
Spinal cord	D_{max} <20 Gy (three fractions) D_{max} <15 Gy (three fractions) V16 < 1.2 cm3(three fractions) V18 < 0,25 cm3(three fractions) max 22 Gy(three fractions)
Heart	D_{mean} <12 Gy V_{15} <10% V24 < 15 cm3 max 30 Gy<15cc receives ≥32 Gy maximum point dose ≤52.5 Gy
Central hepatobiliary tree	V_{40} <37 cm^3 and V_{30} <45 cm^3 (five fractions)

D_{max}, maximum dose; D_{mean}, mean dose; $D_{n\ mL}$, dose received by *n* mL of tissue; *Vn*, volume of tissue receiving *n* Gray.

Dose Constraints cont….

Hepatocellular Carcinoma	**60–75 Gy in Four to Five Fractions**
Critical Structures	**Suggested Dose Limits**
Stomach Duodenum Bowel	D_{max} <40 Gy V_{25} <9 mL V_{30} <5 mL V_{35} <1 mL V_{30} <1 cm^3, $V_{24.5}$ <2 cm^3 (three fractions)
Kidney	V_5 <50 Gy Kidney (both): ≤1/3 volume receives ≥15 Gy V6 < 10%
Kidney (ipsilateral)	$V_{12.3Gy}$ <130 mL
Chest wall	V_{30} <30 mL $D_{2\ mL}$ <27 Gy
Ribs	D_{2mL} <27 Gy (recommended
Esophagus	V15 < 10 cm3 V21 < 5 cm3 V25 < 0,5 cm^2

Dose constraints for critical structures (treatment in three fractions)

Critical Structures	Suggested Dose Limits
Lungs (Right + Left)	V5 < 50 %
	V10 < 30 %
	(Vtotal - V11) > 1500 cm3 <1000 cc receives ≥11.4 Gy (3.8 Gy/fx)
Remaining healthy liver	V15 < 50 %
	V21 < 33%
	(Vtotal-V17) > 700 cm3 >700mL receive <15 Gy
Stomach	V19 < 10 cm3
	V21 < 5 cm3
	V25 < 0,5 cm3
Duodenum	V15 < 5 cm3
	V24 < 0,5 cm3
Small intestines	V16 < 5 cm3

Critical Structures	Suggested Dose Limits
Esophagus:	Maximal point dose is 27 Gy (9 Gy per fraction)
Stomach/Duodenum/Small Bowel:	Maximal point dose 30 Gy
Colon	Maximal dose 34 Gy to 0.5 cc
Skin:	Maximal point dose is 24 Gy (8 Gy per fraction
Vessels	V39 < 10 cm3

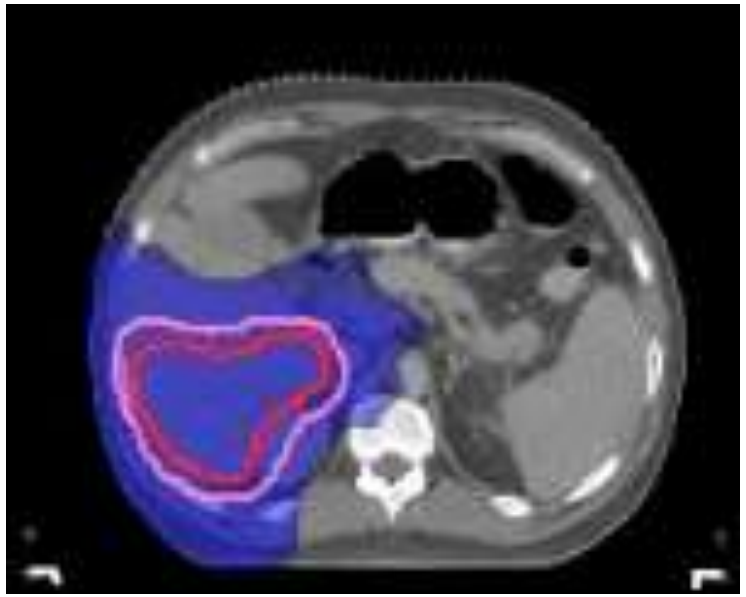
If constraints not met…

- Max prescription dose that allows meeting OAR constraints is chosen.
- If OAR constraints are not met then place higher priority on meeting OAR constraints & 95% isodose can be relaxed or total dose can be reduced as per clinical discretion
- Multiple PTVs, MLD should be evaluated with prescription dose corresponding to highest dose level that any PTV is treated.
- TVT dose should be same as HCC prescription dose but lower doses are acceptable if required to maintain normal tissue limits

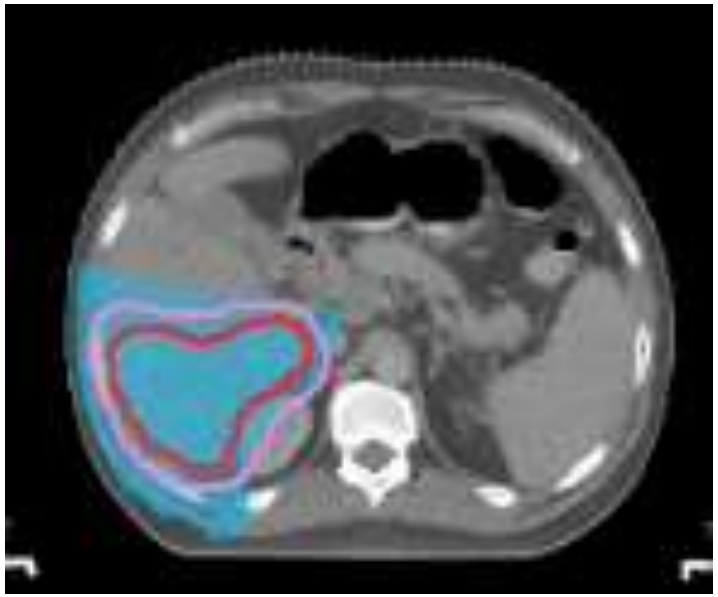
RTOG 1112

Spillage- Visual inspection/Quantify

- **High Dose Spillage**: Cumulative volume of all tissue outside PTV receiving a dose > 105% of prescription dose should be <15% of PTV volume
- **Intermediate Dose Spillage:** Falloff gradient beyond PTV extending into normal tissue structures must be rapid in all directions



20% Spill



50% Spill

(f RTOG 0813 &0915 protocols)

Minimum Standard for reporting

- Prescribed dose
- Prescription ICRU reference point or dose/volume e.g.% isodose covering PTV
- Number of treatment fractions
- Total treatment delivery period
- Target coverage

Plan conformity –ratio of prescription isodose volume to PTV

❖ **Conformity index-**Dose fall off outside target ratio of volume of the 50% isodose curve to PTV

❖**Heterogenity index-**ratio of highest dose received by 5% to PTV to lowest dose received by 95% of PTV)

Notable areas of high dose and low dose outside the PTV

Dose to OARS dose to 1 and 5 % volumes and mean doses

Mathematical definition of plan quality metrics

Statistics | Display

Structure	Volume (cm³)	Min. Dose (cGy)	Max. Dose (cGy)	Mean Dose (cGy)	Cold Ref. (cGy)	Volume < (cm³)	Volume < (%)	Hot Ref. (cGy)	Volume > (cm³)	Volume > (%)	% in Volume	Is in SS	Heterogeneity Index	Conformity Index
PTV	1088.672	3530.4	5607.3	5140.2				**4750.0**	1072.508	98.52	100.00	yes	1.07	0.87
Spinal cord	50.696	58.9	2203.3	877.7				1988.8	**0.350**	**0.69**	100.00	yes	17.41	
PRV	155.520	55.8	3140.7	867.7							100.00	yes		
kidney rt-PTV	162.512	120.6	4646.4	1082.4							100.00	yes	17.00	
Liver-PTV	1503.424	216.2	5423.6	1813.4				5303.1	**0.035**	**0.00**	100.00	yes	7.05	0.00
Lung rt-PTV	1221.928	25.5	5320.0	381.4							100.00	yes	38.84	0.00
chestwall-PTV	499.240	117.2	5497.9	1884.6				**3500.0**	100.076	20.05	100.00	yes	18.65	0.00
kidney rt	198.680	120.6	5607.3	1831.1				**1750.0**	74.096	37.29	100.00	yes	25.10	
Duodenum	44.024	103.6	4577.3	1368.4				4501.3	**0.035**	**0.08**	100.00	yes	25.62	
Esophagus-PTV	38.312	12.4	4211.8	645.2							100.00	yes	93.08	0.00
Stomach-PTV	503.768	481.2	3211.6	1377.4							100.00	yes	2.52	0.00
Bowel-PTV	1888.120	31.5	5225.8	757.3							100.00	yes	34.15	0.00
Gall bladder-PTV	16.552	924.8	2127.8	1386.9							100.00	yes	1.79	
Lt Kidney-PTV	185.960	43.0	1173.6	230.4							100.00	yes	9.18	
HEART-PTV	588.752	50.0	1937.9	292.5							100.00	yes	10.14	
Jejunum-PTV	61.320	331.1	1025.1	645.9							100.00	yes	1.84	
Lung lt-PTV	994.336	17.9	2506.8	297.7							100.00	yes	30.70	0.00
vessels-PTV	126.488	138.9	4583.2	1719.1							100.00	yes	15.41	0.00
Pancreas-PTV	136.976	487.7	4474.9	1476.0							100.00	yes	3.70	0.00
vert body-PTV	288.424	135.8	4262.5	1527.8							100.00	yes	10.10	
Liver	2375.136	216.2	5597.0	3063.8				5079.7	**700.000**	**29.47**	100.00	yes	7.59	0.09
LUNG TOTAL-PTV	2279.280	17.9	5320.0	348.3							100.00	yes	30.42	0.00
skin	663.904	69.9	5157.9	1538.2				**3700.0**	52.456	7.90	100.00	yes	26.20	0.00
patient(Unsp.Tiss.)	37436.456	0.0	5445.2	191.6							99.89	no	177.55	
Bowel	1871.584	31.5	5471.9	793.3				5381.3	**0.035**	**0.00**	100.00	yes	35.94	
Esophagus	34.984	12.4	4011.3	642.0				**2000.0**	4.908	14.03	100.00	no	97.72	
Gall bladder	15.832	905.7	2127.8	1376.3							100.00	yes	1.79	
HEART	577.856	50.4	1937.9	291.9				**3200.0**	0.000	0.00	100.00	yes	10.10	
Jejunum	59.016	340.4	1003.5	646.8				1003.5	**0.000**	**0.00**	100.00	yes	1.83	
LUNG TOTAL	2274.656	17.9	5604.4	466.7				**1250.0**	186.056	8.18	100.00	yes	49.67	
Lt Kidney	179.232	43.0	1147.9	229.2				**1250.0**	0.000	0.00	100.00	yes	9.08	
Lung lt	962.856	17.9	2506.8	294.4				**1250.0**	43.112	4.48	100.00	yes	30.31	
Lung rt	1240.256	25.5	5604.4	583.3				**1250.0**	131.340	10.59	100.00	yes	88.21	
Pancreas	130.064	489.0	4658.8	1479.0							100.00	yes	3.68	
Stomach	490.920	481.2	3188.2	1376.1				3108.1	**0.035**	**0.01**	100.00	yes	2.50	
chestwall	569.688	117.2	5568.7	2585.6				**5492.7**	0.024	0.00	100.00	yes	19.02	
vert body	273.448	135.8	5128.6	1581.7							100.00	yes	10.49	
vessels	122.840	138.9	5444.8	1834.0				**2300.0**	49.388	40.21	100.00	yes	16.93	

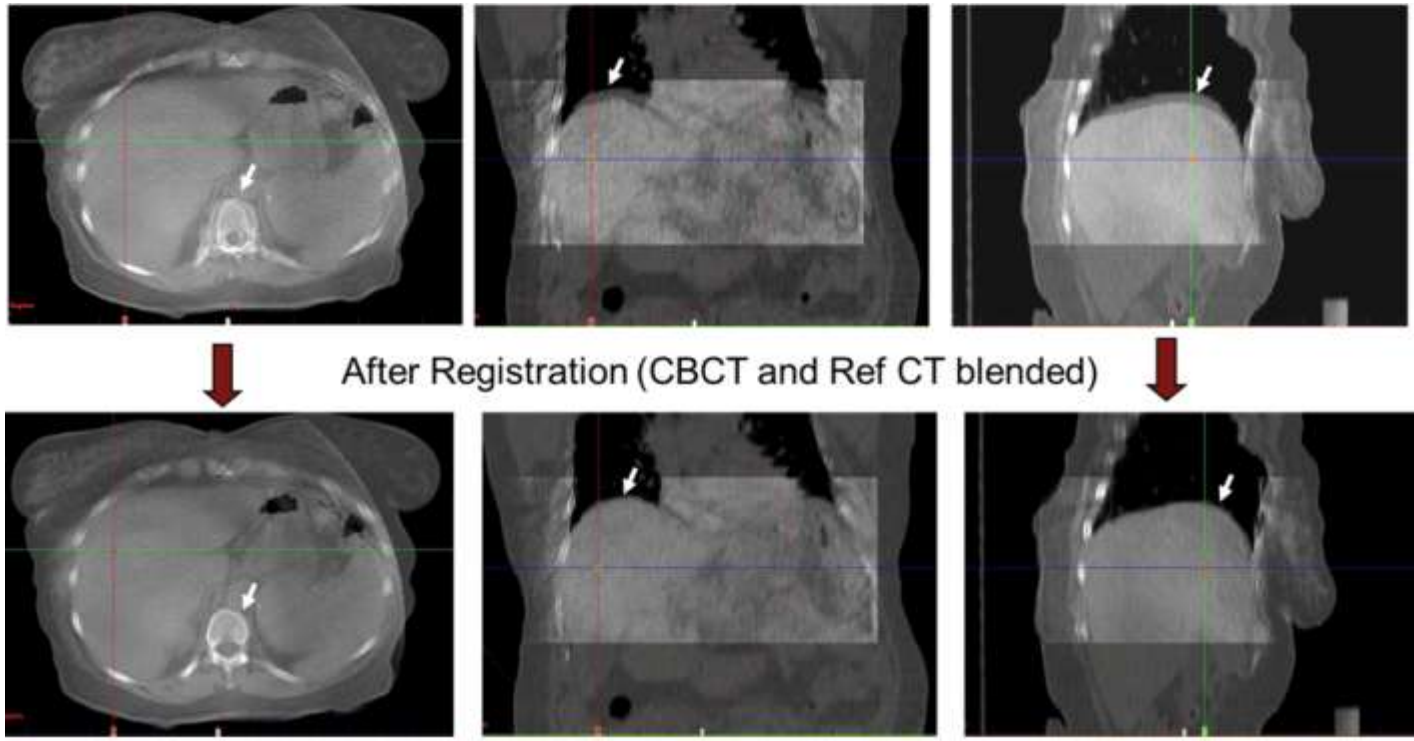
Dry Run can be fruitful

Treatment verification

- Reproduce setup
- Verify isocenter
- Clinically mode up each treatment field
- Check beam clearance (collision)
- Check any interlock
- MLC interlock?
- Potential MU problem?

Treatment delivery

- **Daily image guidance is mandatory**
- Ideal is **matching to soft tissues of liver** ,but matching of vertebral bodies is used as a surrogate although liver moves in between fractions relative to vertebrae
- Fiducials provide an alternative in matching
- Errors of 3 mm or above should be corrected
- When using CBCT a post trt scan is advised to assess intrafraction variation
- Flouro can alternatively be used



Summary

- Accurate localization, treatment planning technology and procedures are essential to performing SBRT for liver
- Judicious selection of the image set for contouring warranted
- Potential pitfall areas- Incorrect tumour identification

  Fusional errors
- Peer review /Radiology review
- Motion management is critical for the success of SBRT for liver
- Priority – achieve OAR constraints to hollow viscera
- Judicious selection of beam orientation /plan
- Dosimetry
- Vigilant execution

Narayana Health

Thank You

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