SBRT in Hepatocellular carcinoma:
Contouring & Planning

Dr. Kanika Sood Sharma
Clinical Lead and Senior Consultant
Radiation Oncology
Dharamshila Narayana Superspeciality Hospital
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

<table>
<thead>
<tr>
<th>Selection Factor</th>
<th>Ideal Parameters for Liver SBRT</th>
<th>Exclusion Criteria Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient immobilization</td>
<td>Able to tolerate immobilization</td>
<td>Unable to tolerate immobilization</td>
</tr>
<tr>
<td>Imaging</td>
<td>Tumor clearly defined on triphasic enhanced CT or MRI (HCC)</td>
<td></td>
</tr>
<tr>
<td>Eligibility for other therapies</td>
<td>Ineligible for resection or other local therapies because of technical considerations or concerns of efficacy and/or toxicity</td>
<td></td>
</tr>
<tr>
<td>Liver function</td>
<td>Child–Pugh class A or B7/8</td>
<td>Child–Pugh class C</td>
</tr>
<tr>
<td>Healthy liver volume</td>
<td>Ability to meet dose constraints</td>
<td>&lt;700 cm³ remaining healthy liver volume</td>
</tr>
<tr>
<td>Tumor location</td>
<td>&gt;1 cm from critical OARs, such as bowel, diaphragm, chest wall, or central liver</td>
<td>&lt;5 mm from critical OARs</td>
</tr>
<tr>
<td>Great vessel involvement</td>
<td>May be involved</td>
<td></td>
</tr>
<tr>
<td>Burden of extrahepatic disease</td>
<td>None</td>
<td>Uncontrolled or significant extrahepatic burden</td>
</tr>
</tbody>
</table>
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)
Obtain multi-phase 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
Vascular anatomy liver

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

https://liveratlas.org/diagnosis/14/
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.
• 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
- T2 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
Arterial Phase

PRECONTRAST

T2 FAT SAT

Arterial enhancement of tumour

3DGRE IMAGES

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

Diagn Interv Radiol 2014; 20:209-221
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

Fat within HCC

TVT in portal vein

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
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)
• 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##

*Department of Radiation Oncology, Massachusetts General Hospital and Harvard Medical School, Boston, Massachusetts

HCC with no (TVT)

Misidentified an area of vascular arterial enhancement as HCC

Consensus contour- thicker red line.
HCC with major (TVT).

Consensus contour - thicker red line.

Arterial Phase

Venous phase

Over contoured due to Fusional error
HCC with small TVT

Over contoured due to perfusion defect inclusion in PTV

Consensus contour - thicker red line.
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 -GTVO 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

Right: Treated to a lower dose than GTV

CTV for Liver SBRT
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(CTV 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 $\leq 10$ 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

- 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
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
• 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% (36-53.9 Gy/3 Fractions) & 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
<table>
<thead>
<tr>
<th>Investigator</th>
<th>Total dose range (Gy) &amp; fractions</th>
<th>Imaging modalities</th>
<th>Target margins</th>
<th>Prescription definition</th>
<th>Motion management</th>
<th>Liver planning guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barney et al</td>
<td>45–60 3,5</td>
<td>CT, MRI</td>
<td>GTV = CTV; ITV = CTV + motion margin using 4DCT; PTV = ITV + nonuniform 5-mm margin</td>
<td>Isodose line covers PTV based on tumor volume and proximity of OARs</td>
<td>Gating, Ac</td>
<td>≥700 cm³ to ≤21 Gy</td>
</tr>
<tr>
<td>Tse et al</td>
<td>24–54 6</td>
<td>kV fluoroscopy, CT, MRI</td>
<td>CTV = GTV + 8 mm within liver; PTV = CTV + individualized margin (minimum 5 mm)</td>
<td>Isodose line covers PTV based on limiting RILD risk</td>
<td>Breath hold, AC</td>
<td>Based on V&lt;sub&gt;eff&lt;/sub&gt;</td>
</tr>
<tr>
<td>Huang et al</td>
<td>25–48 4,5</td>
<td>CT</td>
<td>With fiducial markers: PTV = GTV + 0–8 mm (increased to 8–20 mm in caudocephal direction if no fiducial markers)</td>
<td>70%–83% Isodose line covers PTV</td>
<td>CRTS, AC</td>
<td>≥700 cm³ to ≤15 Gy</td>
</tr>
<tr>
<td>Kang et al</td>
<td>42–60 3</td>
<td>CT</td>
<td>ITV = GTV + motion margin using slow CT; PTV = ITv + 4 mm in longitudinal direction and 2 mm in all other directions</td>
<td>SBRT doses prescribed at isodose line (70%–80% of maximum dose) covering ≥97% of PTV</td>
<td>AC, CRTS</td>
<td>≥700 cm³ to ≤17 Gy</td>
</tr>
<tr>
<td>Goodman et al</td>
<td>18–30 1</td>
<td>CT, MRI, PET/CT</td>
<td>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</td>
<td>65%-90% Isodose covering PTV</td>
<td>CRTS</td>
<td>≥700 cm³ to ≤15 Gy</td>
</tr>
<tr>
<td>Andolina et al</td>
<td>CP: A, 44 (30–48); B, 40 (24–48) 3,5</td>
<td>Dual-phase CT</td>
<td>PTV = GTV + 5 mm radially and + 10 mm superoinferiorly</td>
<td>80% Isodose line covering PTV</td>
<td>AC</td>
<td>CP A: 1/3 to ≤10 Gy and ≥500 cm³ to &lt;7 Gy; CP B: 1/3 to ≤18 Gy and ≥500 cm³ to &lt;12 Gy</td>
</tr>
<tr>
<td>Bujold et al</td>
<td>24–54 6</td>
<td>CT, MRI</td>
<td>CTV = GTV + 5–8 mm within liver; PTV = nonuniform expansion around CTV based on individual patient tumor motion and reproducibility of immobilization (≥5 mm)</td>
<td>Isodose line covering PTV based on limiting RILD risk</td>
<td>ABC, AC</td>
<td>Based on V&lt;sub&gt;eff&lt;/sub&gt;</td>
</tr>
<tr>
<td>Son et al</td>
<td>30–39 3</td>
<td>CT</td>
<td>PTV = GTV + 3–5 mm</td>
<td>PTV enclosed by 70%–85% isodose line</td>
<td>Breath hold + CRTS</td>
<td>V&lt;sub&gt;20Gy&lt;/sub&gt; ≤50%</td>
</tr>
<tr>
<td>Barney et al</td>
<td>28–60 1,3,5</td>
<td>CT, PET/CT</td>
<td>ITV = GTV + motion margin using 4DCT; PTV = ITv + 5 mm</td>
<td>95% coverage of PTv with prescription isodose line</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Bae et al</td>
<td>30–60 3,4,5</td>
<td>CT, MRI, PET/CT</td>
<td>GTV = CTV; PTV = CTV + 4 mm in longitudinal direction and 2 mm in all other directions</td>
<td>56%–83% Isodose line of maximum dose in CyberKnife and 91%–100% in RapidArc to cover ≥95% of PTVs</td>
<td>NA</td>
<td>≥700 cm³ to ≤17 Gy</td>
</tr>
</tbody>
</table>

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 \( V_{\text{eff}} \))
- \( V_{\text{eff}} \) Dose per fraction < 0.3: 10 Gy x 5
  - 0.3 - 0.4: 9 Gy x 5
  - 0.4 - 0.5: 8 Gy x 5
  - 0.5 - 0.6: 6 Gy x 5

\[
V_{\text{eff}} = \sum_{i} \Delta v_i \left( \frac{d_i}{d_{\text{ref}}} \right)
\]

\( D_{\text{ref}} \)-prescribed dose
\( D_i \)- dose per fraction
\( V_i \)- partial dose volume associated with \( i \)th dose bin
\( V_{\text{eff}} \)- effective liver volume (\( V_{\text{eff}} \)) 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 ($V_{eff}$) to aid in dose allocation

<table>
<thead>
<tr>
<th>Optional Constraint</th>
<th>Priority Constraint</th>
<th>Prescription Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liver $V_{eff}$</td>
<td>Allowed Mean Liver Dose [MLD] (Gy)</td>
<td>Planned Prescription Dose (Gy)</td>
</tr>
<tr>
<td>&lt; 25%</td>
<td>13.0</td>
<td>50</td>
</tr>
<tr>
<td>25 - 29%</td>
<td>15.0</td>
<td>45</td>
</tr>
<tr>
<td>30 - 34%</td>
<td>15.0</td>
<td>40</td>
</tr>
<tr>
<td>35 - 44%</td>
<td>15.5</td>
<td>35</td>
</tr>
<tr>
<td>45 - 54%</td>
<td>16.0</td>
<td>30</td>
</tr>
<tr>
<td>55 - 64%</td>
<td>17.0</td>
<td>27.5</td>
</tr>
</tbody>
</table>

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.
• 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
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 (1400-2400 MU/min) in low and high energy

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

Dosemetric characteristics of FFF
- Higher dose rate, shorter delivery time
- Reduced energy variation across the field
- Increased surface dose
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 $\geq 60\%$ & $< 90\%$ 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
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 be 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
95% Coverage

100% coverage
### Common dose constraints

<table>
<thead>
<tr>
<th>Organ at Risk</th>
<th>Dose Constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liver—noncirrhotic</td>
<td>≥700 cm³ of uninvolved liver &lt;15 Gy (three fractions)</td>
</tr>
<tr>
<td></td>
<td>≥700 cm³ of uninvolved liver &lt;21 Gy (five fractions)</td>
</tr>
<tr>
<td>Liver—cirrhotic Child—Pugh class A</td>
<td>≥700 cm³ of uninvolved liver &lt;15 Gy (in 3 or 5 fractions)</td>
</tr>
<tr>
<td></td>
<td>Mean liver dose &lt;15 Gy (in three or five fractions)</td>
</tr>
<tr>
<td>Liver—cirrhotic Child—Pugh class B</td>
<td>≥700 cm³ of uninvolved liver &lt;15 Gy (five fractions)</td>
</tr>
<tr>
<td></td>
<td>≥500 cm³ of uninvolved liver &lt;7 Gy (five fractions)</td>
</tr>
<tr>
<td></td>
<td>Mean liver dose &lt;10 Gy (in five fractions)</td>
</tr>
<tr>
<td>Mean liver dose</td>
<td>≤15.4 Gy</td>
</tr>
<tr>
<td>Spinal cord</td>
<td>$D_{\text{max}}$ &lt;20 Gy (three fractions)</td>
</tr>
<tr>
<td></td>
<td>$D_{\text{max}}$ &lt;15 Gy (three fractions)</td>
</tr>
<tr>
<td></td>
<td>V16 &lt; 1.2 cm³ (three fractions)</td>
</tr>
<tr>
<td></td>
<td>V18 &lt; 0.25 cm³ (three fractions)</td>
</tr>
<tr>
<td></td>
<td>max 22 Gy (three fractions)</td>
</tr>
<tr>
<td>Heart</td>
<td>$D_{\text{mean}}$ &lt;12 Gy</td>
</tr>
<tr>
<td></td>
<td>$V_{15}$ &lt;10%</td>
</tr>
<tr>
<td></td>
<td>V24 &lt; 15 cm³</td>
</tr>
<tr>
<td></td>
<td>max 30 Gy &lt;15 cc receives ≥32 Gy</td>
</tr>
<tr>
<td></td>
<td>maximum point dose ≤52.5 Gy</td>
</tr>
<tr>
<td>Central hepatobiliary tree</td>
<td>$V_{40}$ &lt;37 cm³ and $V_{30}$ &lt;45 cm³ (five fractions)</td>
</tr>
</tbody>
</table>

$D_{\text{max}}$, maximum dose; $D_{\text{mean}}$, mean dose; $D_{n \text{ mL}}$, dose received by $n$ mL of tissue; $V_n$, volume of tissue receiving $n$ Gray.
### Dose Constraints cont....

<table>
<thead>
<tr>
<th>Hepatocellular Carcinoma</th>
<th>60–75 Gy in Four to Five Fractions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Critical Structures</strong></td>
<td><strong>Suggested Dose Limits</strong></td>
</tr>
<tr>
<td>Stomach</td>
<td>$D_{\text{max}} &lt; 40 \text{ Gy}$</td>
</tr>
<tr>
<td>Duodenum</td>
<td>$V_{25} &lt; 9 \text{ mL}$</td>
</tr>
<tr>
<td>Bowel</td>
<td>$V_{30} &lt; 5 \text{ mL}$</td>
</tr>
<tr>
<td></td>
<td>$V_{35} &lt; 1 \text{ mL}$</td>
</tr>
<tr>
<td></td>
<td>$V_{30} &lt; 1 \text{ cm}^3$, $V_{24.5} &lt; 2 \text{ cm}^3$ (three fractions)</td>
</tr>
<tr>
<td>Kidney</td>
<td>$V_5 &lt; 50 \text{ Gy}$</td>
</tr>
<tr>
<td></td>
<td>Kidney (both): $\leq 1/3$ volume receives $\geq 15 \text{ Gy}$</td>
</tr>
<tr>
<td></td>
<td>$V_6 &lt; 10%$</td>
</tr>
<tr>
<td>Kidney (ipsilateral)</td>
<td>$V_{12.3 \text{ Gy}} &lt; 130 \text{ mL}$</td>
</tr>
<tr>
<td>Chest wall</td>
<td>$V_{30} &lt; 30 \text{ mL}$</td>
</tr>
<tr>
<td></td>
<td>$D_{2 \text{ mL}} &lt; 27 \text{ Gy}$</td>
</tr>
<tr>
<td>Ribs</td>
<td>$D_{2 \text{ mL}} &lt; 27 \text{ Gy}$ (recommended)</td>
</tr>
<tr>
<td>Esophagus</td>
<td>$V_{15} &lt; 10 \text{ cm}^3$</td>
</tr>
<tr>
<td></td>
<td>$V_{21} &lt; 5 \text{ cm}^3$</td>
</tr>
<tr>
<td></td>
<td>$V_{25} &lt; 0.5 \text{ cm}^2$</td>
</tr>
</tbody>
</table>
### Dose constraints for critical structures (treatment in three fractions)

<table>
<thead>
<tr>
<th>Critical Structures</th>
<th>Suggested Dose Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lungs (Right + Left)</td>
<td>V5 &lt; 50 %</td>
</tr>
<tr>
<td></td>
<td>V10 &lt; 30 %</td>
</tr>
<tr>
<td></td>
<td>(V\text{total} - V11) &gt; 1500 cm\text{3}</td>
</tr>
<tr>
<td></td>
<td>&lt;1000 cc receives ≥11.4 Gy (3.8 Gy/\text{fx})</td>
</tr>
<tr>
<td>Remaining healthy liver</td>
<td>V15 &lt; 50 %</td>
</tr>
<tr>
<td></td>
<td>V21 &lt; 33%</td>
</tr>
<tr>
<td></td>
<td>(V\text{total}-V17) &gt; 700 cm\text{3}</td>
</tr>
<tr>
<td></td>
<td>&gt;700mL receive &lt;15 Gy</td>
</tr>
<tr>
<td>Stomach</td>
<td>V19 &lt; 10 cm\text{3}</td>
</tr>
<tr>
<td></td>
<td>V21 &lt; 5 cm\text{3}</td>
</tr>
<tr>
<td></td>
<td>V25 &lt; 0.5 cm\text{3}</td>
</tr>
<tr>
<td>Duodenum</td>
<td>V15 &lt; 5 cm\text{3}</td>
</tr>
<tr>
<td></td>
<td>V24 &lt; 0.5 cm\text{3}</td>
</tr>
<tr>
<td>Small intestines</td>
<td>V16 &lt; 5 cm\text{3}</td>
</tr>
<tr>
<td>Esophagus:</td>
<td>Maximal point dose is 27 Gy (9 Gy per fraction)</td>
</tr>
<tr>
<td>Stomach/Duodenum/Small Bowel:</td>
<td>Maximal point dose 30 Gy</td>
</tr>
<tr>
<td>Colon</td>
<td>Maximal dose 34 Gy to 0.5 cc</td>
</tr>
<tr>
<td>Skin:</td>
<td>Maximal point dose is 24 Gy (8 Gy per fraction)</td>
</tr>
<tr>
<td>Vessels</td>
<td>V39 &lt; 10 cm\text{3}</td>
</tr>
</tbody>
</table>
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
• **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

(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

❖ **Heterogeneity 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
<table>
<thead>
<tr>
<th>Structure</th>
<th>Volume (m³)</th>
<th>Min. Dose (Gy)</th>
<th>Max. Dose (Gy)</th>
<th>Mean Dose (Gy)</th>
<th>Mean/Cord (Gy)</th>
<th>Cold Ref. (Gy)</th>
<th>Volume &lt; (m³)</th>
<th>Volume &gt; (m³)</th>
<th>% in Volume</th>
<th>In Is %</th>
<th>Volumetric Index</th>
<th>Conformity Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>WITH</td>
<td>0.086</td>
<td>0.086</td>
<td>0.086</td>
<td>0.086</td>
<td>0.086</td>
<td>0.086</td>
<td>0.086</td>
<td>0.086</td>
<td>0.086</td>
<td>0.086</td>
<td>0.086</td>
<td>0.086</td>
</tr>
<tr>
<td>WW</td>
<td>0.086</td>
<td>0.086</td>
<td>0.086</td>
<td>0.086</td>
<td>0.086</td>
<td>0.086</td>
<td>0.086</td>
<td>0.086</td>
<td>0.086</td>
<td>0.086</td>
<td>0.086</td>
<td>0.086</td>
</tr>
</tbody>
</table>

**Mathematical definition of plan quality metrics**

**Volumetric Index**

\[ V = \frac{V_{\text{Plan}}}{V_{\text{Reference}}} \]

**Conformity Index**

\[ C = \frac{\text{Volume}_{\text{Plan}}}{\text{Volume}_{\text{Reference}}} \]
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?
• 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
Thank You

9899320923

kanika2sood@yahoo.co.in