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SBRT planning for liver metastases: A focus on immobilization, motion management and planning imaging techniques

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ABSTRACT

Aim: To evaluate the different techniques used for liver metastases Stereotactic Body Radiation Therapy (SBRT) planning. We especially focused on immobilization devices, motion management and imaging used for contouring.

Background: Although some guidelines exist, there is no consensus regarding the minimal requirements for liver SBRT treatments.

Materials and methods: We reviewed the main liver metastases SBRT publications and guidelines; and compared the techniques used for immobilization, motion management, margins and imaging.

Results: There is a wide variety of techniques used for immobilization, motion management and planning imaging.

Conclusions: We provide a subjective critical analysis of minimal requirements and ideal technique for liver SBRT planning.

1. Background

SBRT is an attractive option of local treatment for patients with liver metastases.[1–5] Liver SBRT relies on the same principle as intracranial stereotactic treatments, which are high dose per fraction, few fractions, high biological equivalent dose and very high precision. On the opposite, some differences are target volumes (usually much bigger) and the necessary motion management because liver tumors are moving targets.[6–9]

Despite a rapid development of the technique and a wide variety of tools available, there is a lack of consensus regarding those useful and/or necessary for planning. Especially, there is a wide heterogeneity regarding set up, dose prescription and contouring, although some guidelines are available.[10–12]

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Based on the published results, we will critically discuss in this paper the minimal requirements for liver mets SBRT planning.

All aspects regarding quality insurance and specific dosimetric considerations will not be the subject of this review.

2. Machine type and dose prescription

Most of the published studies reported treatments performed on linear accelerator (see Table 1).[13–25] Some other reported treatments on Cyberknife®[26–29] or other machines dedicated for SBRT treatments.[30,31]

There is a large heterogeneity in dose prescription and fractionation used. Number of fractions varied from 1 to 10, and dose prescription from 14 to 75 Gy. Most treatments were tridimensional conformal radiotherapy, performed with multiple coplanar beams,[13–19,24,25] but some used non coplanar beams[20,21,30] or volumetric modulated arctherapy.[22,23,31] Dose prescription varied also depending on the type of treatment: isocentric (prescription to an isodose line) vs. volumetric.

3. Immobilization and set up

As SBRT aims at delivering high biological equivalent dose to targets in close proximity to organs at risk, the use of a reproducible immobilization system enhances the security of the treatments and enables to decrease planning target volume margins.

There are basically 3 contention types used for liver SBRT: generic contentions, not different from the ones in use for conventional radiotherapy[23]; personalized noninvasive contentions, such as posterior vacuum based or Mold care contentions[31]; and stereotactic dedicated contentions, usually vacuum based "whole body".[22,25] The first ones might be less accurate and reproducible; while the last ones might be more difficult to use and might reduce patient tolerance to the treatment, especially if long fractions are expected. Customized immobilization devices are highly recommended to minimize intrafractional motion due to patient movement. Image guidance should be adapted to the type of immobilization used for treatment.[32]

4. Respiratory management

Motion management is a major challenge in abdominal SBRT.

There are 5 strategies for motion management in this setting, as described by Wolthaus et al.[33]

The first one is to treat patients in free breathing, but without specific knowledge of the respiratory motion, with margins taking into account the respiratory movement of the target. This results in large irradiated volumes, as margins have to be adapted to largely encompass this motion without really knowing it. The second is to treat on Internal Target Volume (ITV), which is the tumor volume on all respiratory phases plus additional set-up margins. This strategy requires an evaluation of tumor motion and its reproducibility over time by different means (4D CT, 4D PET CT, inhale and exhale phase's acquisitions, etc.). The third one is to achieve a reduction in the ITV by respiratory blockage or abdominal compression. Abdominal compression is widely used in liver SBRT.[13,15,17–22,24,25] Another way to reduce ITV is to identify all respiratory phases like in ITV basis treatment, but to choose the phases for treatment, either the most reproducible or the ones with the minimal movement. This requires to be able to identify the phases during planning and treatment; and to manage to stop the irradiation outside of these phases. The last strategy is to identify a time weighted average position, to apply margins and to treat on that volume, rather than on the whole ITV. With that strategy, the risk is to miss the target during a minimal time of the respiratory phase, which has to be insignificant in order not to have clinical consequences.

Respiratory management may use a variety of methods, including respiratory gating, tumor tracking, organ motion dampening, or patient-directed methods.[12]

5. Fiducials implants

Few teams chose to perform fiducial implants, maybe because patients referred for SBRT are usually frail and a complete non-invasive procedure might be more suitable for them.[19,25–29]

Nonetheless, the use of fiducials is a reliable way to evaluate respiratory motion during planning and/or treatment, as liver metastases are usually invisible without contrast injection. If present, surgical clips of previous surgery, bile duct prosthesis or chemotherapy catheters might play the same role as fiducials.[31] The use of fiducials (3–5 gold fiducials) seems to be mandatory when using Cyberknife® for liver SBRT.[26–29]

6. Imaging for contouring – multimodality imaging

Bi or triphasic CT scan with contrast seems to be mandatory for liver mets SBRT planning. Nearly all published series used PET/CT and/or MRI coregistration in order to improve contouring. Few teams used these last modalities in treatment position, although they might improve contouring.[13,23,31] Metabolic imaging seems to be of particular interest as MRI and CT scan have been shown to underestimate tumor size in a surgical cohort with radiographic to pathologic correlation.[34]

The use of four-dimensional computed tomography (4D CT), although not mandatory, helps with tumor motion evaluation in lung and abdominal SBRT.[35–37] It might be more physiologic than the use of end-expiratory and/or end-inspiratory acquisitions to evaluate liver motion. Some concerns remain on whether it may or may not adequately represent daily intrafractional motion of abdominal tumors.[38]

The use of 4D PET CT in treatment position may better define the respiratory movements of liver targets and improve SBRT planning for liver metastases.[39–41] Furthermore, non respiratory-gated PET exams can both misdiagnose liver metastases and underestimate the real internal target volumes.[39]

Table 1 – Overview of the main published studies of SBRT for liver mets and the corresponding techniques used for immobilization, motion management and planning imaging.

Authors	Year	Patients number	Lesions/ patient	RT technique	Dose	Fractions	PTV definition	RT planning technique	PET/CT fusion	MRI fusion	Contention	Fiducials	Motion management
Ambrosino	2009	27	N/A	Cyberknife	25–60	3	Tumor = GTV = CTV PTV = CTV + 5 mm (10 mm Cr-Ca) PTV → 80% isodose	CT scan with contrast	Yes	No	N/A	Yes	Synchrony® system
Andratschke	2015	74	1–4	Linac 3D-CRT	30–35	3–5	Tumor = GTV = CTV PTV = CTV + 5 mm (10 mm Cr-Ca) “Composite” ITV (2009) PTV = “composite” ITV + 5 mm (2009)	CT scan with contrast Sequential CTs 4D PET CT (2009) 4D CT (2009)	Yes	Yes	Vacuum couch Oxygen	No	Free breathing Abdominal compression 4D PET CT (2009) 4D CT (2009)
Dawson	2006	34	N/A	Linac 3D-CRT	24–57 (phase I–II)	6	Tumor = GTV CTV = GTV + 8 mm PTV = CTV + 5 mm	CT scan with contrast MRI simulation	No	Yes	Customized immobilization	No	Breath-hold Active breathing control 4D CT if not possible (free breathing)
Goodman	2010	19	N/A	Cyberknife	18–30	1	Tumor = GTV = CTV PTV = CTV + 5–10 mm	CT scan with contrast 4D CT	Yes	No	Alpha Cradle	Yes (3–5)	Synchrony® system 4D CT
Herfarth	2001	37	1–4	Linac 3D-CRT	14–26	1	Tumor = GTV = CTV PTV = CTV + 6 mm (10 mm Cr-Ca) PTV → 80% isodose	CT scan with contrast	No	No	Vacuum couch	No	Free breathing Abdominal compression
Hoyer	2006	44	1–5	Linac 3D-CRT	45	3	Tumor = CTV PTV = CTV + 5 mm (10 mm Cr-Ca) CTV → 95% isodose PTV → 67% isodose	CT scan with contrast	No	No	Stereotactic body frame (Aahrus) Custom-made vacuum pillow (Copenhagen)	No	Free breathing

Table 1 – (*Continued*)

Authors	Year	Patients number	Lesions/ patient	RT tech- nique	Dose	Fractions	PTV definition	RT planning technique	PET/CT fusion	MRI fusion	Contention	Fiducials	Motion management
Katz	2007	69	1–6	Novalis ExacTrac	30–55	10	Tumor = GTV = CTV PTV = CTV + 7 mm (10 mm Cr-Ca) PTV → 80% isodose	CT scan with contrast Relaxed end-expiratory breath holds	Yes	Yes	Vacuum cushion	No	External body fiducial markers ExacTrac® Respiratory gating
Kavanagh	2006	36 (21 evaluable)	1–3	Linac 3D-CRT	60	3	Tumor = GTV PTV = GTV + 5–10 mm PTV → 80–90% isodose	CT scan with contrast	Yes	Yes	Body frame with reference fiducial markers or Equivalent customized external vacuum-type or Synthetic body mold	No	Breath-holding or abdominal compression
Lee	2009	68	1–8	Linac 3D-CRT	27.7–60 (phase I)	6	Tumor = GTV CTV = GTV + 8 mm PTV = CTV + 5 mm minimum	CT scan with contrast MRI with contrast	No	No	Customized body mold	No	Active breathing control or abdominal compression
Llacer Moscardo	2016	41	1–10	Novalis TrueBeam STX VMAT	40–50 Gy	5–10	"Composite" ITV PTV = "composite" ITV + 5 mm	CT scan with contrast MRI simulation 4D PET CT 4D CT	Yes	Yes	Custom-made posterior pillow (mold care)	If no surgical clips	Adaptive gating 4D PET CT 4D CT
Mendez Romero	2006	17	1–4	Linac 3D-CRT	30 or 37.5	3	Tumor = CTV PTV = CTV + 5–10 mm PTV → 65% isodose	CT scan with contrast	No	No	Stereotactic body frame	Yes Gold fiducials	Abdominal compression
Rusthoven	2009	47	1–3	Linac 3D-CRT or conformal arcs	36–60 (phase I/II)	3	Tumor = GTV PTV = GTV + 7–15 mm	CT scan with contrast	Yes	Yes	External vacuum-type or synthetic body mold	No	Active breathing control or Abdominal compression or

							PTV → 80–90% isodose						Free breathing External body fiducial markers
Schefter	2005	18	1–3	Linac 3D-CRT or conformal arcs	36–60 (phase I)	3	Tumor = GTV = CTV PTV = CTV + 5 mm (10 mm Cr-Ca) PTV → 80–90% isodose	CT scan with contrast	Yes	Yes	Stereotactic body frame or equivalent customized external vacuum-type or synthetic body mold	No	Active breathing control or Abdominal compression or External body fiducial markers
Scorsetti	2013	61	1–3	Linac VMAT	75	3	Tumor = GTV = CTV PTV = CTV + 4–6 mm (7–10 mm Cr-Ca)	CT scan with contrast 4DCT (30%)	Yes	Yes	Thermoplastic body mask Stereotactic body frame	No	Abdominal compression 4DCT (30%)
Stintzing	2010	14	1–2	Cyberknife	24	1	Tumor = GTV PTV = GTV + 7 mm PTV → 70% isodose	CT scan with contrast MRI with contrast	No	No	N/A	Yes Gold fiducials	Synchrony® system
Van de Voorde	2015	33	1–3	Linac VMAT or IMRT	5–20 per fraction	3–10	Tumor = GTV PTV = GTV + 10 mm	4D PET CT with contrast CT scan or MRI	Yes	Yes if performed	Knee and feet support Breast board bilateral arm support	No	4D PET CT
Vautravers	2011	42	1–4	Cyberknife	40–45	3–4	Tumor = GTV CTV = GTV + 5 mm PTV = CTV + 3 mm	CT scan with contrast	No	Yes	N/A	Yes Gold fiducials	Synchrony® system
Wulf	2006	39	1–3	Linac 3D-CRT	26–37.5	1–4	Tumor = GTV CTV = GTV + 3 mm PTV = CTV + 5 mm (5–10 mm Cr-Ca) PTV → 65–80% isodose	CT scan with contrast	Yes	Yes	Stereotactic body frame	No	Abdominal compression

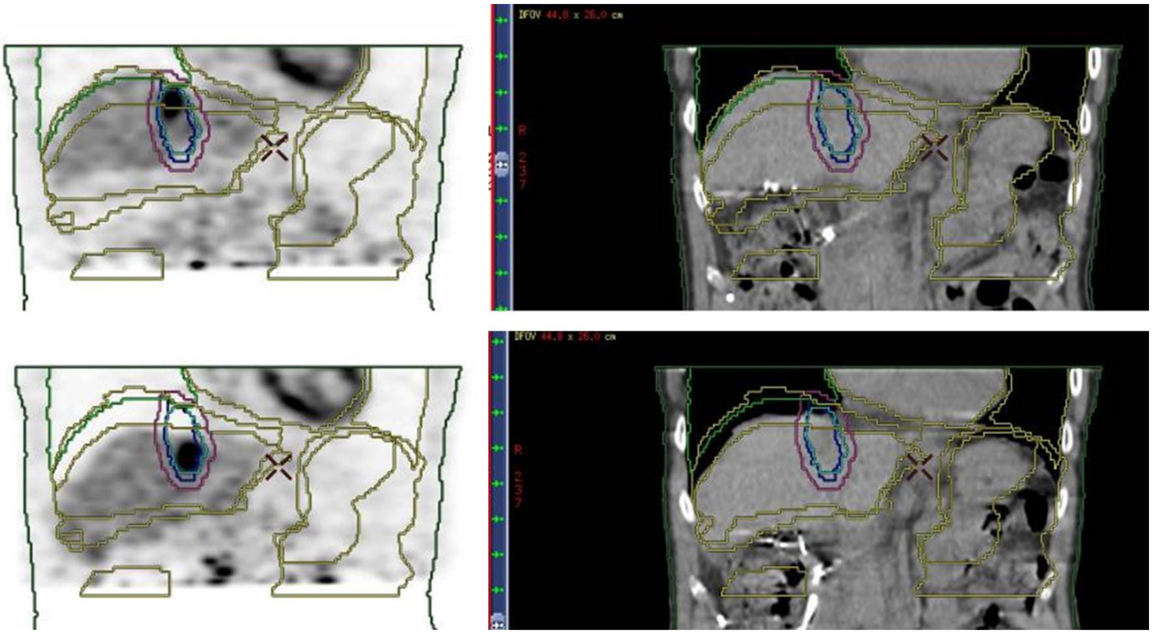

Fig. 1 – Coronal view of 4D CT (right side) and 4D PET CT (left side) in end expiratory (upper part) and end inspiratory (lower part) phases in a patient with liver met referred for SBRT. The respiratory cycle of the patient is divided in ten phases acquired for 4D CT and 4D PET CT. The volume is set by contouring each one of the ten phases and overlaps the contours to create an internal target volume. Only the end expiratory and end inspiratory phases of these ten phases are shown.

The ideal imaging technique for liver SBRT could thus incorporate triphasic CT Scan, 4D CT, MRI and 4D PET CT, all in treatment position (Fig. 1).

7. Contouring and margins

Gross tumor volume (GTV) is the tumor volume seen on the planning exams. No additional clinical target volume (CTV) margin is added. An internal target volume (ITV) is created to account for tumor motion if it is evaluated on the planning exams. Breathing-related liver motion may be assessed by four-dimensional CT, cine-magnetic resonance imaging, or two-dimensional kilovoltage (kV) fluoroscopy to determine appropriate planning target volume margins.[9]

A planning target volume (PTV) margin is then added to encompass set up margins. A 5 mm radial and a 10 mm craniocaudal margin are widely chosen in the published studies on liver metastases SBRT,[42–45] although some teams reported smaller setup errors in this setting.[46–48]

Image guidance should be performed before each fraction of treatment and during beam delivery if possible.

All margins should be adapted to the whole technique of treatment used including contentions and their accuracy, motion management for planning and treatment and the precision of image guidance before and during treatment delivery.[1]

8. Conclusion

SBRT is a complex procedure that requires adapted methods for planning. Many different methods can be used, provided they result in a sufficient level of precision. Multimodality imaging is necessary to improve the accuracy of contouring. Margins should be adapted to the methodology of contouring, respiratory management, contention and set-up reproducibility. Special care should be taken to immobilization, respiratory management and imaging for contouring and guidance.

Conflict of interest

None declared.

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