4D Target definition for SBRT: how to deal with moving targets, a practical approach

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From 3D to 4D Target Definitions (ICRU50/62)

3D CT

4D CT

ICRU 50

Target movement, immobilization, imaging resolution.

Treated Volume
Clinical Target Volume (CTV)
Gross Tumor Volume (GTV)
Planning Target Volume (PTV)

Risk statistics, clinical judgment, biological images

ICRU62
- ITV
- PRV
Geometric error (AAPM TG101)

- **planning**
  - inter and intra-observer variations in GTV/CTV contouring
  - motion artifacts on imaging
- **patient related**
  - breathing pattern
  - compliance
- **physiological factors:**
  - respiratory motion, heart beat, peristaltic
  - daily changes in organ volume
- **treatment related changes:**
  - changes in atelectasis
  - tumour growth and shrinkage
- **inaccuracy/reproducibility in positioning and alignment beams**
  - set-up errors (3-5 mm)
  - mechanical uncertainties
  - transfer errors etc.
Organs at risk definition in 4D radiotherapy for SBRT (ICRU62)

PRV = planning organ at risk volume

- takes into consideration the movement of the Organs at Risk during the treatment.
- An integrated margin must be added to the Organ at Risk to compensate for the variations and uncertainties, using the same principle as PTV and is known as the Planning Organ at Risk volume (PRV).
- A PTV and PRV may occasionally overlap.
Heart motion impacts on target movement
AAPM TG 76 and 101

- Respiratory motion assessment necessary, but respiratory management individualized

- describe method for respiratory motion management

- > 5mm motion – respiratory management is recommended

3D solution

Encompass the entire range of motion

4D solution

Breath-hold Tracking Gating
Stereotactic body radiotherapy (SBRT)/stereotactic ablative body radiotherapy (SABR)

- treats relatively small targets, using large, ablative doses delivered in a short period of time – little room for error

- Tight therapeutic ratio
  - target/OAR must be accurately defined, and localized before and during treatment – **image guidance essential**

  - tightly conformal dose distribution increase risk of geographic miss – **motion management**

- require skill and training

- SABR may involve delivering small fields, specialized collimators, especially high dose rate beam – careful commissioning
Imaging for GTV/OAR definition in SBRT
Imaging and GTV/OAR delineation

Agreement

- high resolution images
- evaluation of internal motion
- multimodality co-registered imaging

No standardization

- use of imaging
- delineation
- margins
## Multimodality imaging for SBRT

<table>
<thead>
<tr>
<th>Modality</th>
<th>Details</th>
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<tbody>
<tr>
<td><strong>CT</strong></td>
<td>• accurate geometry, good delineation of bone, lung &lt;br&gt; • tissue density information &lt;br&gt; • 4DCT available for targets that move &lt;br&gt; • need for 1.5mm slicing or less &lt;br&gt; • windowing can impact on GTV delineation</td>
</tr>
<tr>
<td><strong>MRI</strong></td>
<td>• better soft tissue contrast &lt;br&gt; • T1-T2 sequences with contrast usually used &lt;br&gt; • special sequences might be required &lt;br&gt; • image spacing – 1.5mm or less(special request) &lt;br&gt; • images might have geometric distortion &lt;br&gt; • ideally scan on flat couch</td>
</tr>
<tr>
<td><strong>PET-CT</strong></td>
<td>• metabolic imaging not visible on CT/MRI &lt;br&gt; • PET-CT images automatically coregistered &lt;br&gt; • windowing level setting may strongly affect apparent size of the tumor</td>
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Multimodality imaging

• small “slicing”, longer scanning time

• co-registration accuracy should be checked near target-use natural landmark or implanted fiducials

• clinical judgement
  
  o additional information from MRI/PET should guide delineation, but contouring on CT
  
  o MRI, PET to guide delineation - careful when used to guide contouring on a respiratory correlated CT scan
## Imaging for moving target

<table>
<thead>
<tr>
<th>Type</th>
<th>Advantages</th>
<th>Disadvantage</th>
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<tbody>
<tr>
<td>CT slow</td>
<td>ability to capture tu motion</td>
<td>• motion artifacts- blurring of images</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• loss of resolution</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• errors in delineation</td>
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<tr>
<td>CT at extreme phases of respiratory cycle</td>
<td>• theoretically – captures the entire range of motion</td>
<td>• unreliable for small tumors with wide range of motion</td>
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<tr>
<td></td>
<td>• lower workload</td>
<td></td>
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<tr>
<td>4DCT – gold standard</td>
<td>• captures respiratory motion over few respiratory cycles</td>
<td>• does not take into account the daily variation breathing pattern</td>
</tr>
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<td></td>
<td>• inform about shape and mobility synchronously acquired</td>
<td>• requires regular breathing /ability to be coached</td>
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<tr>
<td>Breath-hold</td>
<td>• smallest GTV</td>
<td>• patient compliance</td>
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<td>• lung protection (DIBH)</td>
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GTV/OAR delineation
Choice of imaging for delineation depends on the location of target – high resolution

CT50 and MIP CT image of lung lesion-MIP image shows extent of motion of dense lesion in lung

MinIP for Hypodense liver lesion

MIP/MinIP images cannot be used for dose calculation
Lung windowing is recommended to delineate GTV in lung SBRT (Eclipse 250, -1000)
Mediastinal setting might be useful when delineating tumors central/near chest wall
GTV contouring – avoid “jagged” contouring and verify transverse with coronal and sagittal views

Smooth contours that “make sense” in all planes

Should “spiculations” be included?
Metabolic imaging: to guide delineation, but GTV should be based on CT imaging

Identifies extent disease not visible on CT

Changes volume GTV

<table>
<thead>
<tr>
<th>Scientific Abstract 3064; Table</th>
<th>Differences in GTV by tumor location</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>GTV CT</td>
</tr>
<tr>
<td>Peripheral:</td>
<td>2.95 (1.78-7.5)</td>
</tr>
<tr>
<td>Median (range)</td>
<td>2.95 (1.78-7.5)</td>
</tr>
<tr>
<td>Chest wall:</td>
<td>9.6 (0.5-66.25)</td>
</tr>
<tr>
<td>Median (range)</td>
<td>9.6 (0.5-66.25)</td>
</tr>
<tr>
<td>Central:</td>
<td>16.56 (14.02-49.78)</td>
</tr>
<tr>
<td>Median (range)</td>
<td>16.56 (14.02-49.78)</td>
</tr>
</tbody>
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Metabolic imaging - challenges

Mis-registration if free breathing PET/CT

W/L setting impacts on the delineation: incorrect setting reduces the apparent size of GTV

There is no consensus in the method to use for GTV delineation

Images courtesy of Ron Lalonde, UPCI
OAR delineation for SBRT

• Important to establish clear guidelines about how to contour normal tissues - promote consistency
  
  o E.g. contouring spinal cord - contour cord, not canal, add 3 mm margin ± 1 cm from target
  o use of atlases

• Again, pay attention to 3-dimensional contour - avoid ‘jagged’ volumes

• Consider adding margin to small OARs near tumor volume (PRV)
ITV and PTV definition - what margins?
ITV and PTV definitions

- Conventional free breathing
- ITV
- Gated at exhale
- Mid-position

- Maximum exhale
- Time-weighted average position
- Geometrical average position
- Maximum inhale

Source: Expert Rev Anticancer Ther © 2009 Expert Reviews Ltd
ITV and PTV definition for lung tumors

CT 50 (end expiration)  MIP  Extreme  All phases

GTV 50
Generate ITV: adapted margins based on magnitude of motion

not for planning use needs coregistration

not for small tumors with large motion

workload

generate ITV

PTV = ITV + set-up error
Which method better for GTV-ITV definition?
Wu J et al – ASTRO 2012

Comparison of Lung Cancer Target Definition Strategies in Stereotactic Body Radiotherapy
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\(^2\)Department of Radiation Medicine, Oregon Health and Science University, Portland, OR
\(^3\)Nuclear Engineering & Radiation Health Physics, Oregon State University, Corvallis, OR

Fig. 2 Normalized target and PTV volumes with respect to GTV\(_{FB}\) and PTV\(_{FB}\) respectively.

Fig. 3 Tumor D100 (Gy) and V60 (%).

Fig. 4 Total lung and ipsilateral lung V20 (%).

Geometric parameters

Dosimetric parameters
Set up margins and PTV

- majority: PTV = GTV + 1 cm CC, 0.5 cm other directions

- PTV = ITV + 0.3 - 0.5 cm (set-up variation)
Requirement....

- standardization protocols for imaging and contouring methods
- training
Beacon Hospital - protocol for respiratory motion assessment and management
Protocol of SABR = accuracy, precision, reproducibility

Retrospective 4DCT
VarianRPM + GE lightspeed
Intelligence Bodyfix

Target delineation
on the 50% EE phase
using CT+PET-CT info

Analysis target motion
GE Advantage Sim Medical

Planning
Eclipse Varian
Dynamic IMRT
D3 Pittsburgh

Verification
OBI-CBCT-Fluoro
before treatment

Delivery
TrilogyTx microMLC
1000MU/min
Beacon - motion assessment workflow

4DCT-RPM monitoring

- Images Courtesy from UPMC Cancer Center, Dept. Rad. Oncology

Transfer to Adv Sim and Motion analysis

- No
- Regular cycle?

< 5mm

Adapt PTV = GTV + motion + 3-5mm

> 5mm

Active management

Coach Patient
Breathing assessment session - introduced summer 2010 - RTT and physicist present

- review of patients treated
- in 10% of the patients required rescan and replan because of:
  - inability of patients to reproduce the respiratory management at CT
  - irregular breathing, small gating window – not practical
  - time to review of 4DCT scan by consultants and decision about management was too long

- aims:
  - assess respiratory pattern
  - assess the ability of the patient to follow commands
  - assess ability of breath-hold
  - assess needs of the patient - oxygen, painkillers etc.

- immobilization

- decision about the individualized respiratory management
Breathing assessment- mini 4DCT through the tumor

- mini-4DCT and breathing assessment information reviewed by physician+
  physicist

- decision about the type of active management-
  - what can patient do?
  - artefacts?
Evaluation of motion and definition on the target – full 4DCT acquired during a second visit

- **GTV**
  - contouring of GTV in Eclipse on 50% EE phase (most stable)
  - PET for guidance

- add 5mm circumferential margin (5mm threshold for active management)

- export to ADW for analysis
  - gated?/non-gated?
  - measure motion on each phase
Evaluation of internal motion, determination ITV, adaptation PTV – on full 4DCT scan

<table>
<thead>
<tr>
<th>Target Phase</th>
<th>Phase Error</th>
<th>Motion ≤ 5 mm from E.E</th>
<th>Evaluation Structure Name:</th>
<th>Treatment Decision:</th>
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<tbody>
<tr>
<td></td>
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<td>() USE GATING FOR THE TREATMENT</td>
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<td>0%</td>
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<td>Phases for Treatment (Motion≤5mm) _____% to _____%</td>
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<td>10%</td>
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<td></td>
<td>( ) DO NOT USE GATING FOR TREATMENT</td>
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<tr>
<td>20%</td>
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<tr>
<td>30%</td>
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<td>90%</td>
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Comments:

Physician
Radiation Oncologist
Physics Check
4D management - non gated treatment

Motion <5mm inf/post direction

Final target definition

ITV = GTV + 5 mm I-P
PTV = ITV +3 mm circumferential
4D management—gated treatment

Motion >5mm inf direction

Gate = 30-70%

\[ \text{ITV} = \text{GTV} + 5 \text{ mm Inf} \]
\[ \text{PTV} = \text{ITV} + 3 \text{ mm circumferential} \]
4D management – coaching

Free breathing - irregular

Monophasic coaching

Monophasic coached 4DCT, gated treatment
TOD - Significant motion, irregular breathing, unable to follow commands or to breathhold, MIP for contouring, 3DSBRT

4DCT free breathing

Free breathing - irregular

MIP used for GTV delineation
GTV=ITV
PTV=GTV+0.3cm (SE)

Biphasic coaching – unable to follow

Breath- hold – significant baseline shifts
Breathhold technique

- Regular, reproducible
- Minimises residual motion
- Patient compliance

Current indications – DIBH
- tu lower lobes lung (>1cm, small gating window)
- abdominal tumours if fiducials cannot be inserted
Pre-SBRT PET-CT

4DCT shows significant motion (>3cm SI)

BH respiratory tracing

PTV = GTV +5mm
5mm = 3mm set-up error, 2mm residual motion
Summary

- Respiratory motion impacts significantly on target volume definition, therefore individualized and standardized respiratory management is essential.

- Clear protocols for method of image guidance for target volumes definition are required.

- Guidelines for delineation of target and organ at risk volumes are necessary to promote consistency, accuracy and reproducibility.
Thank you for your attention!

• Acknowledgments:

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