Stereotactic Body Radiation Therapy (SBRT) I: Radiobiology and Clinical Experience

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Stereotactic Body Radiation Therapy (SBRT) II: Physics and Dosimetry Considerations

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AAPM 2008 50th Annual Meeting, Houston, Texas
Therapy Continuing Education Course: SBRT: I & II
Monday, July 28, 2008: 7:30 – 9:25AM

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Stereotactic Body Radiation Therapy II: Physics and Dosimetry

Educational Objectives

- 1. Understand the issues related to the clinical implementation and technical aspects of SBRT techniques and technology and become familiar with the preliminary reporting of AAPM Task Group 101.
- 2. Understand the importance of QA procedures, guidelines, and reporting requirements for SBRT.
- 3. Understand the practical aspects of SBRT treatment planning for paraspinal, lung, liver, and abdominal tumors and recognize the critical issues related to each site.

AAPM Task Group 101: Stereotactic Body Radiation Therapy

The AAPM RTC approved the following charges of the task group:

- Charge (1): To review the literature and identify the range of historical experiences, reported clinical findings and expected outcomes
- Charge (2): To review the relevant commercial products and associated clinical findings for an assessment of system capabilities, technology limitations, and patient related expectations and outcomes.
- Charge (3): Determine required criteria for setting-up and establishing an SBRT facility, including protocols, equipment, resources, and QA procedures.
- Charge (4): Develop consistent documentation for prescribing, reporting, and recording SBRT treatment delivery.

SBRT TG101 Members

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Overview of the 9 Tables in the TG101: SBRT

Clinical:
- Prescribed doses/fractionation schemes for SBRT trials
- Selected spinal SBRT clinical trials
- Summary of tolerance doses for various critical organs

Relocalization Management:
- Stereotactic localization methods and delivery systems
- Setup and positioning accuracy of several anatomical sites
- Errors and management strategies for patient positioning
- Summary of literature involving implanted fiducials

Bioeffect treatment planning:
- Tumor and normal tissue NTD for SBRT

QA:
- Summary of QA recommendations

Providing TG 101 readers with SBRT Dose Schemes

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Tables summarizing prescribed doses and fractionation schemes for various clinical trials for SBRT

1- Body
2- Spine

Clinical Trials for SBRT

Institution	Reference	SBRT dose and fractionation	Results
Indiana University	47	24-66 Gy 3 fractions	Phase I study; maximum tolerated dose (MTD) not reached for T1 lesions; MTD 66 Gy for T2 lesions
Indiana University	70	60-66 Gy 3 fractions	1 yr local control 98%
Aarhus University	40	45 Gy 3 fractions	2 yr local control 85%
Kyoto University	45	48 Gy/4 fractions	2 yr local control 95%
Air Force General Hospital, Beijing	43	50 Gy / 10 fractions	1 yr local control 95%
University of Marburg	33	30 Gy 1 fraction	1 yr local control 94%
Radiation Therapy Oncology Group (RTOG) 0236	70	60 Gy 3 fractions	1 yr local control 98%

Spinal SBRT clinical trials

Institution (Reference)	N	Dose (No. fractions)	Comment
Henry Ford Hospital (Ryu, 2004)	49	10-16 Gy (1)	Pilot study, SBRT as boost Good palliation reported
MD Anderson (Chang, 2004)	15	30 Gy (5)	10 Gy point dose max to cord CT-on-rails setup for verification
MSKCC (Yamada, 2004)	16	Variable	Custom body frame used Typically 20 Gy/5 fxns for re-treat
Georgetown U (Degen, 2005)	51	Variable	Avg 6.5 Gy x 3.6 fxns Significant pain reduction observed
Stanford (Dodd, 2006)	51	16-30 Gy (1-2)	1 case of toxicity noted

Providing TG 101 readers with tolerance doses for various organs

A Table summarizing critical organ tolerance doses including

- Volume
- Cumulative dose
- Toxicity
- No. of fractions

Organ	Volume	Cumulative dose (Gy)*	Toxicity	No. fractions
Spinal cord	Any point	18	myelopathy	3
Main Bronchus	Whole circumference	6	Lobar atelactasis	3-4
Trachea and ipsilateral bronchus	Any point	30-36		3
Lung	<35%	23	Radiation pneumonitis	3
Ipsilateral brachial plexus	Any point	24	brachialplexopathy	3
Heart/great vessels	Any point	24-36	Pericarditis / arrhythmia / cardiac arrest	3
Skin	Any point	18-23 (11-15 if in a skin fold)		3
Mediastinal targets	25% circumference	21	chronic cough or chronic dysphagia	3
Esophagus	Any point	20-27	esophagitis	3
Stomach/Duodenum	<5cc	17-21	ulceration	3
Jejunum / Ileum	<10cc	17	Ulceration / bowel obstruction	3
Colon	<20cc	17	Ulceration / bowel obstruction	3
Kidney	4-10 cm	40	Kidney failure	5
	<4 cm	30		3
Liver	Any part	21	Liver failure	3

Providing TG 101 readers with SBRT localization and delivery methods

A Table summarizing localization methods including

- Co-ordinate system
- Commercial system
- IGRT and Tretment Delivery System

Stereotactic Coordinate System Definition	Commercial System	Image guidance and Treatment Delivery
Physical Fiducial Coordinate system	Elekta Body frame Leibinger Body frame Medical Intelligence BodyFIX	Any accelerator Any accelerator Any accelerator
Virtual IR Coordinate System	Accuray Cyberknife BrainLAB ExacTrac	Robotic assisted linear accelerator Any gantry based accelerator
Virtual image-based coordinate system	Elekta Synergy Varian Trilogy Tomotherapy Accuray Cyberknife BrainLAB ExacTrac	Elekta linear accelerator Varian linear accelerator Tomotherapy accelerator Robotic assisted linear accelerator Any gantry based accelerator
Image-guided with Physical Stereotactic Fiducial System	Medical Intelligence BodyFIX/ Radionics Localization Device with GE or Siemens CT on rails	Varian Exact Target LINAC/CT-on-rails Siemens LINAC/CT-on-rails

Providing TG 101 readers with SBRT localization and delivery methods:

Cone Beam CT Localization of Lung Tumors

- Cone beam imaging is increasingly being used for localization of lung tumors taking into account respiratory motion.
- Cone beam scans can have an acquisition time 60 seconds or more. They may therefore span 15 or more breathing cycles, so the resulting image is effectively time averaged over the breathing cycle.
- Thus the object seen at the position of the target corresponds to the volume swept out by the gross tumor volume (GTV) as it moves through the respiratory cycle, providing an estimate of internal target volume (**ITV).**

Reference:

- T. G. Purdie, J. P. Bissonnette, K. Franks, A. Bezjak, D. Payne, F. Sie, M. B. Sharpe and D. A. Jaffray, "Cone-beam computed tomography for on-line image guidance of lung stereotactic radiotherapy: localization, verification, and intrafraction tumor position," Int J Radiat Oncol Biol Phys **68**, 243-252 (2007).

Providing TG 101 readers with reported set-up and positioning accuracy

A Table summarizing set-up/positioning including

- Author/Reference
- Immobilization and repositioning method
- Reported accuracy

Author-Year	Site	Immobilization/Repositioning	Reported accuracy
Lax-1994	Abdomen	Wood Frame/Stereotactic coordinates on box to skin marks	3.7mm Lat 5.7mm Long
Hamilton-1995	Spine	Screw fixation of spinous processes to box	2mm
Tokunoye-1997	Liver	Prone position/jaw and arm straps	5mm
Murphy-1997	Spine	Frameless/ Implanted fiducial markers with real time imaging and tracking	1.6mm radial
Sato-1998	Abdomen	Frameless/ Combination CT, X-ray, and linac	Not Reported
Lohr-1999	Spine	Body cast with stereotactic coordinates	≤ 3.6mm mean vector
Wulf-2000	Lung, liver	Elekta™ body frame	3.3mm Lat. 4.4mm Long.
Nakagawa-2000	Thoracic	Megavoltage CT on linac	Not Reported
Herfarth-2001	Liver	Leibinger body frame	1.8-4.4 mm
Nagata-2002	Lung	Elekta™ body frame	2mm
Fukumoto-2002	Lung	Elekta™ body frame	Not Reported
Hara-2002	Lung	Custom bed transferred to treatment unit after confirmatory scan	2mm
Hof-2003	Lung	Leibinger body frame	1.8-4 mm
Timmerman-2003	Lung	Elekta™ body frame	approx 5mm
Yenice – 2003	Spine	Custom stereotactic frame and In-room CT guidance	1.5 mm- system acc. 2-3mm –positioning accuracy
Chang-2004	Spine	MI™ BodyFix with Stereotactic Frame/LINAC CT-on-rail with	1 mm (syst. accuracy)

Providing TG 101 readers with set-up error management strategies

A Table summarizing set-up error strategies including

- Set-up errors
- Set-up aids
- Off-line and on-line strategy
- Organ motion considerations

		STRATEGY		
		Immobilization/Setup Aids	Off-line	On-line
Setup Errors	Inter-fraction	Alignment/Constraint Standard procedures Lasers/Light Field on Tattoos Thermoplast masks Tape Bite Blocks	Conventional weekly port film practice Statistical Approaches: i) Population-based thresholds. ii) Individual-based thresholds.	MV-Radiographs (conventional pre-ports) EPID MV-Radiographs On-line kV Radiographs (with/without markers) Optical Video Monitoring
	Intra-fraction	Vacu-Form molds/casts Thermoplast Body Casts Stereotactic Head Frame Stereotactic Body Frame	(see note **)	MV Fluoroscopic kV Fluoroscopic Optical Video Monitoring Optical Reflectors/Markers
Organ Motion	Inter-fraction	Breath-hold Consistent Time-of-Day Active Breathing Control Specifications (bladder/rectum, full/empty) Patient position (prone/supine)	Off-line strategies based on repeat CT scans.	On-line Computed Tomography (CT-on-a-rail, Cone-Beam CT, Tomotherapy) Ultrasound Other imaging modalities (MRI, Ultrasound)

Providing TG 101 readers with set-up error management strategies

Range of tumor motion

Motion of the tumor/target area, if not explicitly accounted for, can cause artifacts during CT imaging and treatment delivery and thereby limit the geometric accuracy demanded for SBRT.

Respiratory motion of lung tumors have been demonstrated in ranges up to **50 mm**.

Reference: Q. S. Chen, M. S. Weinhous, F. C. Deibel, J. P. Ciezki and R. M. Macklis, "Fluoroscopic study of tumor motion due to breathing: facilitating precise radiation therapy for lung cancer patients," Med Phys **28**, 1850-1856 (2001).

Providing TG 101 readers with review on implanted fiducials

A Table summarizing implanted fiducials including

- Institution/Author
- anatomical site/location
- Method of implantation
- Results

Study	Location	Method	Results
Chung, et al. [295-297]	Prostate	3 gold markers inserted transrectally under ultrasound guidance	At least 2 of 3 markers seen in 99% of images; no marker migration in 6 years of use
Koong et al. [102, 103]	Pancreatic tumors	3-5 gold markers with a breath-hold technique on Cyberknife	
Wurm et. al. [298]	Liver	Gold coil [Visicoil – Radiomed Tyngsboro, MA] implanted into the liver for high-dose hypo-fractionated treatments	
Shirato et al. [299]	Lung	2mm diameter gold sphere using fiberoptics	Successful in peripheral lesions in a series of 34 patients where marker was lodged in bronchial tree of <2mm diameter. Failed in central lesions due to marker loss.
Imura et al. [300]	Lung	2mm diameter gold sphere using fiberoptics	25% marker loss from time of insertion to end of treatment. 95% placement stability (<2mm migration) in remaining markers.
Whyte et al [26]	Lung	Percutaneous marker insertion for single-fraction Cyberknife treatment	3 of 23 patients developed pneumothorax
de Mey et al. [301]	Lung	Percutaneous insertion of platinum helical coils	3 of 25 patients developed pneumothorax
Willoughby et al [302]	Lung	Percutaneous insertion of gold coils	30% pneumothorax rate
Medin et al. [303]	Spine	Implanted gold markers in swine	Largest inter-merker separation on one vertebra < 0.42mm
Murphy and coworkers [304]	Spine	4 stainless steel surgical tacks implanted under	RMS targeting error under kV image guidance =1.5mm

Bio-effect–based treatment planning

- SBRT involves the application of individual high doses in a range not studied in prior decades
- It is unlikely that normal tissue tolerance doses derived from the study of conventionally fractionated radiation therapy will apply in the context of SBRT.
- One way to evaluate the possible biological effect of an SBRT treatment plan in terms of its potential local tumor control and its potential normal tissue effects is to convert its associated physical dose distribution to a biologically normalized dose distribution.
- Using the biologically normalized dose distribution, bioeffect measures can be calculated to rank and compare the SBRT treatment plan with others. Examples of such bioeffect measures are the biologically effective dose (BED) concept, the normalized total dose (NTD) concept, and the equivalent uniform dose (EUD) concept.

Providing TG 101 readers with tumor and normal tissue NTD for SBRT

Tumor and normal tissue NTDs for some Stereotactic Body Radiotherapy schedules that have been employed in Non Small Cell Lung Cancer (NSCLC).

The tumor and normal tissue NTDs were calculated using an α/β-ratio of 10 Gy and 3 Gy, respectively.

The Progression-free survival of patients with NSCLC at 30 months was estimated from Martel et al. (1) for the schedules marked with a * and from Fowler et al. (2) when rapid re-proliferation can be neglected.

Total Physical Dose (Gy)	Ref	NTD_{10} (Gy)	Log_{10} Cell Kill	Estim. Progress'n Free Survival 30 months	NTD_3 (Gy)
30 x 2 = 60* in 6 weeks		65	9.9	16 % * with repop	60
35 x 2 = 70* in 7 weeks		72	10.9	26 % * " "	70
4 x 12 = 48	(3)	83	12.6	82 % no repop	144
3 x 15 = 45	(4)	94	14.2	95 % " "	162
5 x 12 = 60	(5)	110	16.7	>99% " "	180
3 x 20 = 60	(6,7)	150	22.7	>99% " "	276
3 x 22 = 66	(6,7)	176	26.7	>99% " "	330

Providing TG 101 readers with a summary of QA recommendations

A Table summarizing SBRT related QA recommendations from….

Quality Assurance of Radiation Therapy:
The Challenges of Advanced Technologies Symposium,
Dallas, TX, 20-22 February 2007

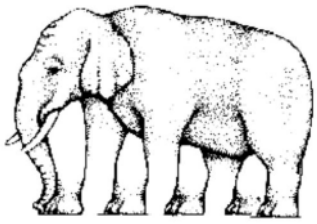
Edited by Jeffrey F. Williamson and Bruce R. Thomadsen

American Society for Therapeutic Radiology and Oncology, American Association of Physicists in Medicine and National Cancer Institute

Int Jo Rad Onc Biol Physics
Volume 71, Issue 1, Supplement 1, Pages S1-S214 (1 May 2008)

Source	Purpose	Proposed Test	Proposed Tolerence	Proposed Frequency
Galvin et al., 2008[105]	Overall positioning accuracy, including image registration (frame-based systems)	Winston-Lutz test	<=2mm for multiple couch angles	At initial commissioning and then monthly
Galvin et al., 2008[105]	Overall positioning accuracy, including image registration (frame-based systems)	Winston-Lutz test modified to make use of the in-room imaging systems	<=2mm for multiple couch angles	At initial commissioning and then monthly
Palta et al, 2008[106]	MLC accuracy	Light field, radiographic film, or EPID	<0.5mm (especially for IMRT delivery)	Annually
Solberg et al, 2008[94]	Dosimetric verification	Film and ionization chamber	±3% absolute dose difference, ±3mm dose distribution distance	Before each frameless SBRT session
Jiang et al, 2008[107]	Respiratory motion tracking and gating in 4D CT	Phantoms with cyclical motion	N/A	N/A
Bissonnette et al, 2008[108]	CBCT geometric accuracy	Portal image vs. CBCT image isocenter coincidence	±2mm	daily

In the end, all SBRT requires diligence in commissioning and … memory from experience



How many legs does this elephant have?

CBCT can have an acquisition time of 60 seconds, and span 15 or more breathing cycles. Thus the object seen at the position of the target corresponds to an estimate of what volume?

25% 1. GTV
25% 2. CTV
25% 3. PTV
25% 4. ITV

Respiratory motion of lung tumors can range up to how many mm?

25% 1. 5 mm
25% 2. 10 mm
25% 3. 20 mm
25% ➡ 4. 50 mm

10

The normalized total dose (NTD) concept, when applied to an SBRT delivery of 3 fractions of 22 Gy can yield a bioeffect equivalent to:

25% 1. 66 Gy
25% 2. 100 Gy
25% 3. 200 Gy
25% ➡ 4. >300 Gy

10