PHOTON VS. PROTON SBRT DEBATE

CLINICAL DEBATE WITH

KRISTIN HIGGINS, MD, VS. CHARLES SIMONE, MD

PHYSICS DEBATE WITH

FANG-FANG YIN, PHD, VS. LIYONG LIN, PHD

DISCLOSURE

- NIH research grant
- Research funding from Varian Medical Systems

KEY TECHNICAL/CLINICAL PARAMETERS FOR SBRT

Characteristic	3D/IMRT	SBRT
Dose/fraction	1.8–3 Gy	6–30 Gy
No. of fractions	10–30	1–5
Target definition	CTV/PTV (gross disease+clinical extension): Tumor may not have a sharp boundary.	GTV/CTV/ITV/PTV (well-defined tumors: GTV=CTV)
Margin	Centimeters	Millimeters
Physics/dosimetry monitoring	Indirect	Direct
Required setup accuracy	TG40, TG142	TG40, TG142
Primary imaging modalities used for treatment planning	CT	Multimodality: CT/MR/PET-CT
Redundancy in geometric verification	No	Yes
Maintenance of high spatial targeting accuracy for the entire treatment	Moderately enforced (moderate patient position control and monitoring	Strictly enforced (sufficient immobilization and high frequency position monitoring through integrated image guidance)
Need for respiratory motion management	Moderate—Must be at least considered	Highest
Staff training	Highest	Highest+special SBRT training
Technology implementation	Highest	Highest
Radiobiological understanding	Moderately well understood	Poorly understood
Interaction with systemic therapies	Yes	Yes

Benedict *et al.*: Stereotactic body radiation therapy: AAPM TG101 2010

PUBLISHED QA RECOMMENDATIONS FOR SBRT AND SBRT-RELATED TECHNIQUES

Source	Purpose	Proposed test	Reported achievable tolerance	Proposed frequency
Ryu *et al.*, 2001[a]	End-to-end localization accuracy	Stereo x ray/DRR fusion	1.0 to 1.2 mm root mean square	Initial commissioning and annually thereafter
Ryu *et al.*, 2001[a]	Intrafraction targeting variability	Stereo x ray/DRR fusion	0.2 mm average, 1.5 mm maximum	Daily (during treatment)
Verellen *et al.*, 2003[b]	End-to-end localization accuracy	Hidden target (using stereo x ray/DRR fusion)	0.41 ± 0.92 mm	Initial commissioning and annually thereafter
Verellen *et al.*, 2003[b]	End-to-end localization accuracy	Hidden target (using implanted fiducials)	0.28 ± 0.36 mm	Initial commissioning and annually thereafter
Yu *et al.*, 2004[c]	End-to-end localization accuracy	Dosimetric assessment of hidden target (using implanted fiducials)	0.68 ± 0.29 mm	Initial commissioning and annually thereafter
Sharpe *et al.*, 2006[d]	CBCT mechanical stability	Constancy comparison to MV imaging isocenter (using hidden targets)	0.50 ± 0.5 mm	Baseline at commissioning and monthly thereafter
Galvin *et al.*, 2008[e]	Overall positioning accuracy, including image registration (frame-based systems)	Winston–Lutz test modified to make use of the in-room imaging systems	≤2 mm for multiple couch angles	Initial commissioning and monthly thereafter
Palta *et al.*, 2008[f]	MLC accuracy	Light field, radiographic film, or EPID	<0.5 mm (especially for IMRT delivery)	Annually
Solberg *et al.*, 2008[g]	End-to-end localization accuracy	Hidden target in anthropomorphic phantom	1.10 ± 0.42 mm	Initial commissioning and annually thereafter
Jiang *et al.*, 2008[h]	Respiratory motion tracking and gating in 4D CT	Phantoms with cyclical motion	N/A	N/A
Bissonnette *et al.*, 2008[i]	CBCT geometric accuracy	Portal image vs CBCT image isocenter coincidence	±2 mm	daily

Benedict *et al.*: Stereotactic body radiation therapy: AAPM TG101 2010

ACHIEVABLE ACCURACIES CATEGORIZED BY BODY SITE AND IMMOBILIZATION/REPOSITIONING DEVICE

Author, year	Site	Immobilization/repositioning	Reported accuracy
Lax, 1994[a]	Abdomen	Wood frame/stereotactic coordinates on box to skin marks	3.7 mm Lat, 5.7 mm Long
Hamilton, 1995[b]	Spine	Screw fixation of spinous processes to box	2 mm
Murphy, 1997[c]	Spine	Frameless/implanted fiducial markers with real-time imaging and tracking	1.6 mm radial
Lohr, 1999[d]	Spine	Body cast with stereotactic coordinates	≤3.6 mm mean vector
Yenice, 2003[e]	Spine	Custom stereotactic frame and in-room CT guidance	1.5 mm system accuracy, 2–3 mm positioning accuracy
Chang, 2004[f]	Spine	MIT™ BodyFix with stereotactic frame/linac/CT on rails with 6D robotic couch	1 mm system accuracy
Tokuuye, 1997	Liver	Prone position jaw and arm straps	5 mm
Nakagawa, 2000[g]	Thoracic	MVCT on linac	Not reported
Wulf, 2000[h]	Lung, liver	Elekta™ body frame	3.3mm lat,4.4 mm long
Fuss, 2004[i]	Lung, liver	MIT™ BodyFix	Bony anatomy translation 0.4, 0.1, 1,6 mm (mean X, Y, Z); tumor translation before image guidance 2.9, 2.5, 3.2 mm (mean X, Y, Z)
Herfarth, 2001[j]	Liver	Leibinger body frame	1.8–4.4 mm
Nagata, 2002[k]	Lung	Elekta™ body frame	2 mm
Fukumoto, 2002[l]	Lung	Elekta™ body frame	Not reported
Hara, 2002[m]	Lung	Custom bed transferred to treatment unit after confirmatory scan	2 mm
Hof, 2003[n]	Lung	Leibinger body frame	1.8–4 mm
Timmerman, 2003[o]	Lung	Elekta™ body frame	Approx. 5 mm
Wang, 2006[p]	Lung	Medical Intelligence body frame stereotactic coordinates/CT on rails	0.3 ± 1.8 mm AP, -1.8 ± 3.2 mm Lat, 1.5 ± 3.7 mm SI

Benedict *et al.*: Stereotactic body radiation therapy: AAPM TG101 2010

CURRENT STATUS FOR PHOTON SBRT

Well established clinical procedures

- History of ~ 30 years
- Technology: almost all sites in US
- Acceptable clinical standard procedures/protocols/guidelines
- Credentialing (NRG, IROC, etc.)
- Quality assurance programs
- Widely accepted with defined reimbursement
- Excellent clinical outcomes

SOME REPORTED TRIALS AND PROCEDURES

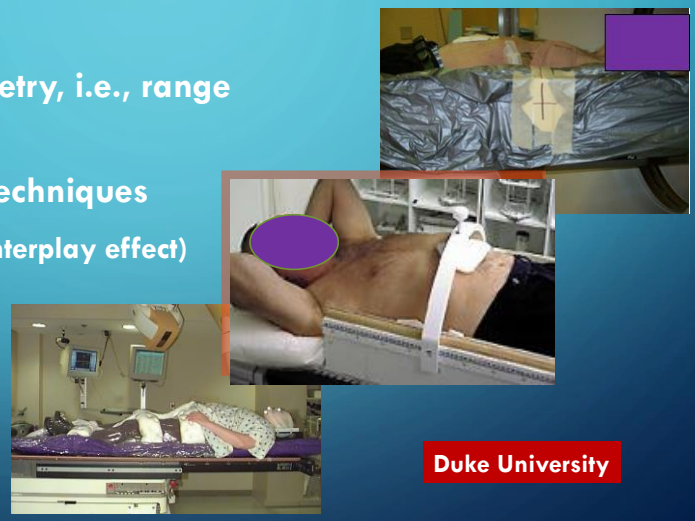
- 2007 - RTOG 0618: Stereotactic body radiation therapy (SBRT) to treat operable early-stage lung cancer patients.
- 2008 - Stereotactic Body Radiation Therapy in Treating Patients With Stage I Non-Small Cell Lung Cancer
- 2004 - RTOG0236 A Phase II Trial of Stereotactic Body Radiation Therapy (SBRT) in the Treatment of Patients with Medically Inoperable Stage I/II Non-Small Cell Lung Cancer
- 2009 - RTOG-0915: A Randomized Phase 2 Study Comparing 2 Stereotactic Body Radiation Therapy (SBRT) Schedules for Medically Inoperable Patients With Stage I Peripheral Non-Small Cell Lung Cancer
- 2009 - NRG Oncology/RTOG 0813 was a phase I/II study designed to determine the maximum tolerated dose (MTD), efficacy, and toxicity of stereotactic body radiotherapy (SBRT) for centrally located NSCLC
- NRG-BR001: A Phase 1 Study of Stereotactic Body Radiotherapy (SBRT) for the Treatment of Multiple Metastases
- 2015 - NRG-BR002: A Phase IIR/III Trial of Standard of Care Therapy with or without Stereotactic Body Radiotherapy (SBRT) and/or Surgical Ablation for Newly Oligomets
- 2022 – ASTRO External Beam Radiation Therapy for Primary Liver Cancers: An ASTRO Clinical Practice Guideline Practical Radiation Oncology (2022) 12,28–51

- 2019 ACR–ASTRO PRACTICE PARAMETER FOR THE PERFORMANCE OF STEREOTACTIC BODY RADIATION THERAPY
- 2017 - AAPM-RSS Medical Physics Practice Guideline 9.a. for SRS-SBRT. Appl Clin Med Phys2017;18:5:10–21
- 2012 - Quality and safety considerations in stereotactic radiosurgery and stereotactic body radiation therapy: Executive summary Pract Radiat Oncol. 2012 Jan; 2(1): 2–9.
- 2020 - ACR–AAPM TECHNICAL STANDARD FOR THE PERFORMANCE OF RADIATION ONCOLOGY PHYSICS FOR EXTERNAL-BEAM THERAPY

CURRENT STATUS FOR PHOTON SBRT

Immobilization

- Less effect on dosimetry, i.e., range uncertainty
- Variety of delivery techniques
  - 3DCRT (minimize interplay effect)
  - IMRT/VMAT



Duke University

CURRENT STATUS FOR PHOTON SBRT

Planning – dosimetry/optimization

- Optimization – both manual and automatic
- Simulation imaging: CT, PET/CT, MRI – both 3-D and 4D
- Dose calculation – both convolution/superposition and MC
- Established target prescription, OAR tolerances
- Potential more conformal using more beams/large arcs

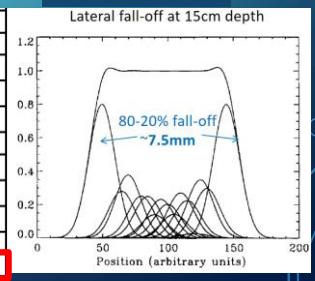
- Less sensitive to HU variation for dose calculation
- More robust to intra-fractional motion
- Less affected by RBE

Paganetti PMB 2012

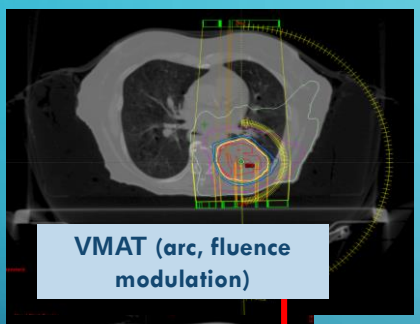
Patient setup	mm	± 0.7 mm
Dose calculation:		
Biology (always positive) ^	+ ~0.8% [g]	+ ~0.8% [g]
CT imaging and calibration	± 0.5% [b]	± 0.5% [b]
CT conversion to tissue (excluding I-values)	± 0.5% [a]	± 0.2% [d]
CT grid size	± 0.3%	± 0.3%
Mean excitation energy (I-values) in tissues	± 1.5% [c]	± 1.5% [c]
Range degradation; complex inhomogeneities	– 0.7% [e]	± 0.1 %
Range degradation; local lateral inhomogeneities *	± 2.5% [f]	± 0.1 %
Total (excluding *, ^)	2.7% + 1.2 mm	2.4% + 1.2 mm
Total (excluding ^)	4.6% + 1.2 mm	2.4% + 1.2 mm

Myths and realities of range uncertainty

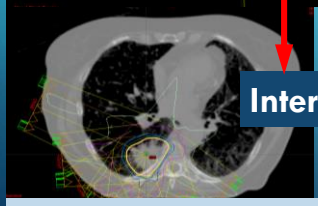
Lomax BJR 2020



PHOTON SBRT DELIVERY TECHNIQUES

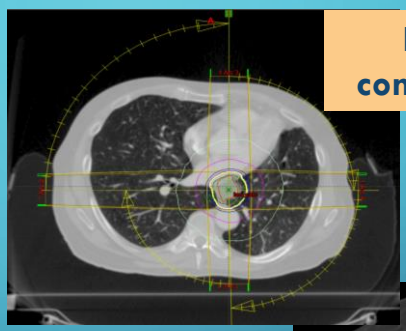


VMAT (arc, fluence modulation)



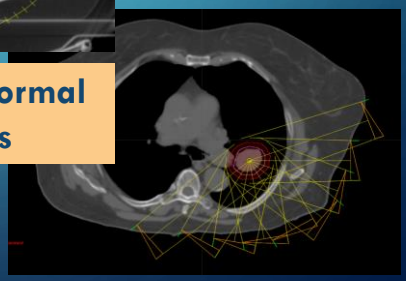
Interplay?

IMRT (static, fluence modulation)



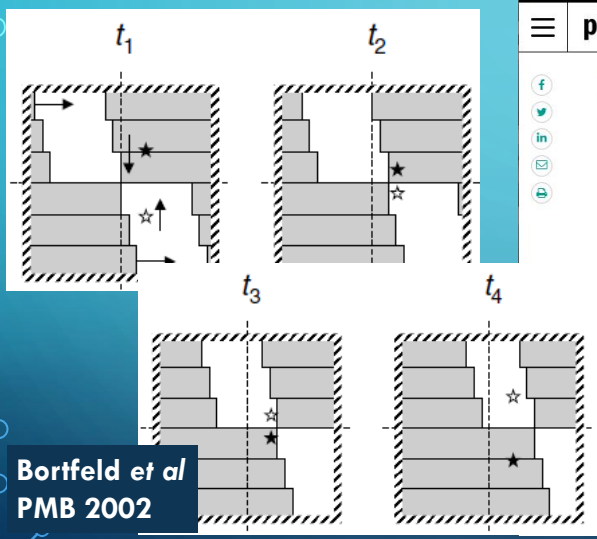
Dynamic conformal arcs

Static conformal beams

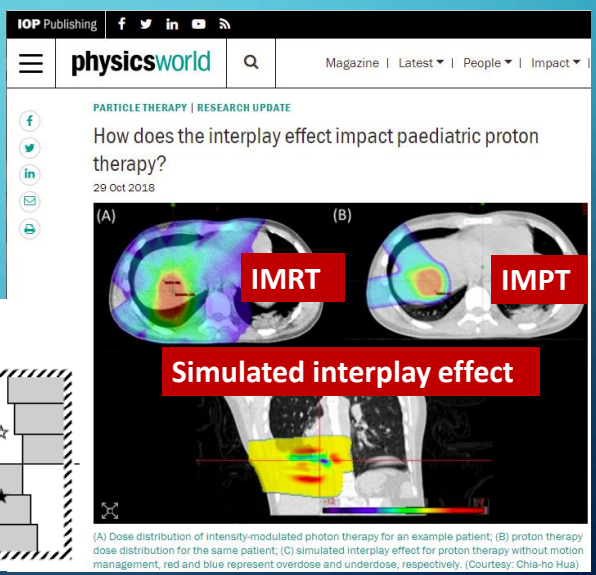


Duke University

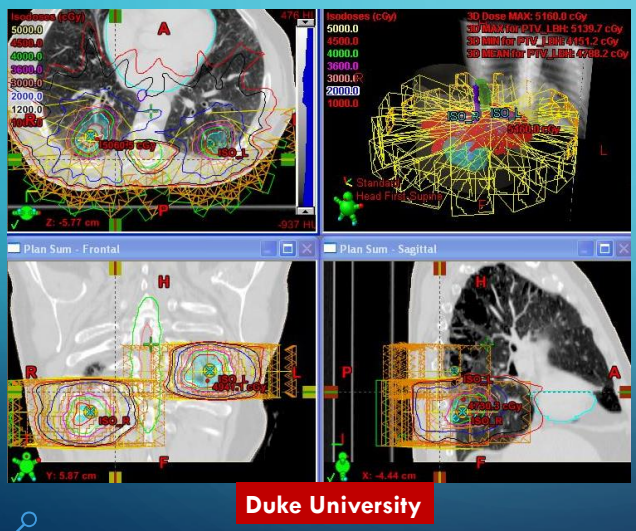
INTERPLAY EFFECT WITH IMRT/SCANNING BEAMS



Bortfeld *et al* PMB 2002



PHOTON SBRT DELIVERY TECHNIQUES

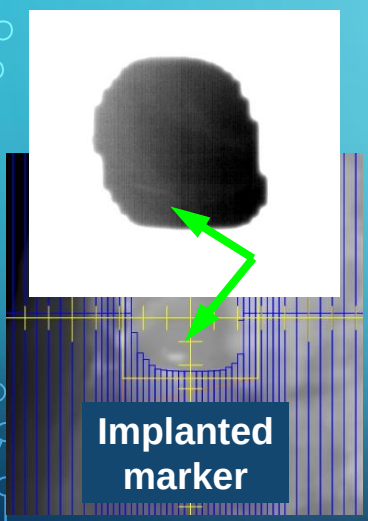


Duke University

Single isocenter multiple targets to improve the delivery efficiency

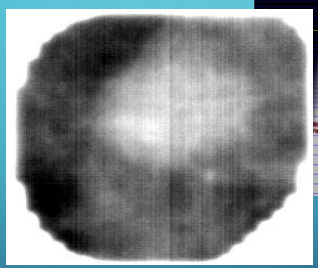
Localization: stereo x-ray, onboard CT/CBCT, optical onboard MRI, etc.

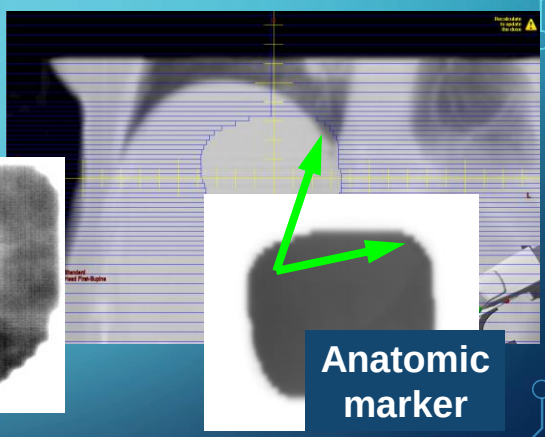
REAL-TIME FLUOROSCOPIC VERIFICATION IMAGING



Implanted marker

Duke University





Anatomic marker

Real-time imaging: x-ray, MRI, optical and PET?

SUMMARY

- Photon SBRT
  - is a widely accepted treatment option for majority radiation oncology centers in US
  - clinical outcomes are extremely promising
  - is a well established procedure including reimbursement
- Proton SBRT
  - is being explored only in limited radiation centers and needs time to be mature
  - clinical advantage is still to be seen
  - has bright future but the road to the future is uneven

Thank organizers for having me in the debate

Thank you for your attentions