



Aspectos práticos para planejamento - SBRT em Pulmão, Fígado e Pâncreas

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Exigência da RDC Nº 96/08 da ANVISA



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Treatment planning optimization with beam motion modelling for dynamic z [Med Phys. 2019]
Early Exploratory Analysis for Patient-reported Quality of Life and Dosim [Am J Clin Oncol. 2019]
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Stereotactic Body Radiotherapy (SBRT) for Oligometastatic Spine Metastases: An Overview.
Zeng KL et al. Front Oncol. (2019)

Stereotactic body radiation therapy (SBRT) for high-risk prostate cancer: Where are we now?
Gonzalez-Motta A et al. Pract Radiat Oncol. (2018)

Organs at risk in lung SBRT.
De Rose F et al. Phys Med. (2017)

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Pasqualetti F, Panichi M, Sollini M, Sainato A, Galli L, Morganti R, Chiacchio S, Marciano A, Zanca R, Mannelli L, Coraggio G, Sbrana A, Cocuzza P, Montrone S, Baldaccini D, Gonnelli A, Molinari A, Cantarella M, Mazzotti V, Ricci S, Palai F, Erba PA.
Eur J Nucl Med Mol Imaging. 2019 Oct 16. doi: 10.1007/s00259-019-04482-6. [Epub ahead of print]
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2. [Current status of stereotactic body radiotherapy for the treatment of hepatocellular carcinoma.](#)
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Yeungnam Univ J Med. 2019 Aug 12;36(3):192-200. doi: 10.12701/yujm.2019.00269. eCollection 2019 Sep. Review.
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3. [Radiotherapy for pelvic nodal recurrences after radical prostatectomy: patient selection in clinical practice.](#)
Panje C, Zilli T, Pra AD, Arnold W, Brouwer K, Garcia Schuler HI, Gomez S, Herrera F, Khanfir K, Papachristofilou A, Pesce G, Reuter C, Vees H, Zwahlen D, Putora PM.
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PMID: 31619296 [Free Article](#)
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Best matches for sbirt lung cancer:

[Stereotactic body radiotherapy \(SBRT\) for Stage I lung cancer.](#)
Nagata Y et al. Jpn J Clin Oncol. (2018)

[Stereotactic body radiation therapy \(SBRT\) for early-stage lung cancer in the elderly.](#)
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[Organs at risk in lung SBRT.](#)
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Bai X, Shan G, Chen M, Wang B.
Biomed Eng Online. 2019 Oct 18;18(1):101. doi: 10.1186/s12938-019-0721-7.
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2. [Illustration of a fatal radiation-induced lung aneurysm: Is central lung stereotactic radiotherapy to be banned?](#)
Ledoux B, Dupont M, Duplaquet F, Pirard L, Ocak S, Wanet M, Remouchamps V.
Cancer Radiother. 2019 Oct 11. pii: S1278-3218(19)30392-0. doi: 10.1016/j.canrad.2019.05.016. [Epub ahead of print]
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3. [A Large, Multicenter, Retrospective Study on Efficacy and Safety Of Stereotactic Body Radiotherapy \(SBRT\) in Oligometastatic Ovarian Cancer \(MITO RT1 Study\): A Collaboration of MITO, AIRO GYN, and MaNGO Groups.](#)
Macchia G, Lazzari R, Colombo N, Laiscia C, Capelli G, D'Agostino GR, Deodato F, Maranzano E, Ippolito E, Ronchi S, Paia F, Scorsetti M, Cilla S, Ingargiola R, Huscher A, Cerrotta AM, Fodor A, Vicenzi L, Russo D, Borghesi S, Perrucci E, Pignata S, Aristei C, Morganti AG, Scambia G, Valentini V, Jereczek-Fossa BA, Ferrandina G.
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Severe and Fatal Multilobar Nonclassic Radiation Pneumonitis following [Case Rep Pulmonol. 2019]

Pleural contact decreases survival in clinical T1N0M0 lung cancer pa [Radiother Oncol. 2019]

Anemia is a poor prognostic factor for stage I non-small cell lu [Clin Transl Radiat Oncol. 2019]

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Best matches for sbrt liver cancer:

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[Stereotactic body radiotherapy for colorectal cancer liver metastases: A systematic review.](#)
Petrelli F et al. Radiother Oncol. (2018)

[Phase II trial on SBRT for unresectable liver metastases: long-term outcome and prognostic factors of survival after 5 years of follow-up.](#)
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2. [Role of stereotactic body radiation therapy in the treatment of liver metastases: clinical results and prognostic factors.](#)
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Liver Cancer. 2019 Jul;8(4):281-294. doi: 10.1159/000490260. Epub 2018 Jul 12. Erratum in: Liver Cancer. 2019

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Titles with your search terms

The role of SBRT in oligometastatic patients with liver metastas: [Rep Pract Oncol Radiother. 2017]

[Availability of using diaphragm matching in stereotactic [Nihon Hoshasen Gijutsu Gakkai ...]

Individualized image guided iso-NTCP based liver cancer SBRT. [Acta Oncol. 2006]

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Best matches for sbrt pancreatic cancer:

[Stereotactic body radiotherapy for unresected pancreatic cancer: A nationwide review.](#)
de Geus SWL et al. **Cancer.** (2017)

[Systematic review on the treatment of isolated local recurrence of pancreatic cancer after surgery: re-resection, chemoradiotherapy and SBRT.](#)
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[SBRT in pancreatic cancer: what is the therapeutic window?](#)
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☐ [A model-based patient selection tool to identify who may be at risk of exceeding dose tolerances during pancreatic SBRT.](#)

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☐ [EUS-guided placement of fiducial markers for the treatment of pancreatic cancer.](#)

2. Coronel E, Singh BS, Cazacu IM, Moningi S, Romero L, Taniguchi C, Herman JM, Bhutani MS. **VideoGIE.** 2019 Jul 3;4(9):403-406. doi: 10.1016/j.vgie.2019.05.007. eCollection 2019 Sep. No abstract available. PMID: 31517161 [Free PMC Article](#) [Similar articles](#)

☐ [Phase I/II Trial of Neoadjuvant Oregovomab-based Chemoinmunotherapy Followed by Stereotactic Body Radiotherapy and Nelfinavir For Locally Advanced Pancreatic Adenocarcinoma.](#)

3. Lin C, Verma V, Lazenby A, Ly QP, Berim LD, Schwarz JK, Madiyalakan M, Nicodemus CF, Hollingsworth MA, Meza JL, Are C, Padussis J, Grem JL. **Am J Clin Oncol.** 2019 Oct;42(10):755-760. doi: 10.1097/COC.0000000000000599. PMID: 31513018 [Similar articles](#)

☐ [The role of biological dose-escalation for pancreatic cancer.](#)

4. Bruynzeel AME, Lagenwaard FJ. **Clin Transl Radiat Oncol.** 2019 Apr 25;18:128-130. doi: 10.1016/j.cro.2019.04.020. eCollection 2019 Sep. Review.

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Chemotherapy in combination with stereotactic body radiation therapy (SE [BMJ Case Rep. 2018]

SBRT for pancreatic cancer: In regard of Bohoudi et al. [Radiother Oncol. 2018]

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Best matches for sabr:

[Stereotactic ablative radiotherapy versus standard of care palliative treatment in patients with oligometastatic cancers \(SABR-COMET\): a randomised, phase 2, open-label trial](#)
Palma DA et al. Lancet. (2019)

[Stereotactic ablative radiotherapy \(SABR\) for early-stage central lung tumors: New insights and approaches](#)
Tekatli H et al. Lung Cancer. (2018)

[Stereotactic Ablative Body Radiotherapy \(SABR\) for Oligometastatic Prostate Cancer: A Prospective Clinical Trial](#)
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☐ [Non-coplanar VMAT plans for lung SABR to reduce dose to the heart: a planning study](#)
1. Kim ST, An HJ, Kim JI, Yoo JR, Kim HJ, Park JM.
Br J Radiol. 2019 Oct 18;20190596. doi: 10.1259/bjr.20190596. [Epub ahead of print]
PMID: 31625759 [Similar articles](#)

☐ [Local ablative radiotherapy for oligometastatic non-small cell lung cancer](#)
2. Suh YG, Cho J.
Radiat Oncol J. 2019 Sep;37(3):149-155. doi: 10.3857/roj.2019.00514. Epub 2019 Sep 30.
PMID: 31591862 **Free Article** [Similar articles](#)

☐ [Treatment planning optimization with beam motion modelling for dynamic arc delivery of SBRT using Cyberknife with multileaf collimation](#)
3. Bedford JL, Tsang HS, Nill S, Oelfke U.
Med Phys. 2019 Oct 6. doi: 10.1002/mp.13848. [Epub ahead of print]
PMID: 31587322 [Similar articles](#)

☐ [Predicting 5-Year Progression and Survival Outcomes for Early-Stage Non-Small Cell Lung Cancer Treated with Stereotactic Ablative Radiotherapy: Development and Validation of Robust Prognostic Nomograms](#)
4. [Treated with Stereotactic Ablative Radiotherapy: Development and Validation of Robust Prognostic Nomograms](#)

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On the use of AAA and AcurosXB algorithms for three different [Rep Pract Oncol Radiother. 2019]

Comparison of treatment plan quality among MRI-based IMRT with a linac, I [PLoS One. 2019]



Tópicos abordados

- Documentos de Referência
- Prescrição e esquemas de fracionamento
- Parâmetros técnicos do planejamento
- Dicas para o planejamento
- Tolerâncias de dose
- Considerações finais



Não é escopo desta apresentação

- Sistemas de imobilização para SBRT
- Simulação e aquisição de imagens
- Fusão de imagens para o planejamento
- Delimitação de PTV e OAR
- QA para verificação dos planos
- Métodos de localização por imagem para ttos



Referências – para começar

- **Benedict *et al.*, 2010: Stereotactic body radiation therapy: The report of TG101**
- **RTOG 0813 - SEAMLESS PHASE I/II STUDY OF STEREOTACTIC LUNG RADIOTHERAPY (SBRT) FOR EARLY STAGE, CENTRALLY LOCATED, NON-SMALL CELL LUNG CANCER (NSCLC) IN MEDICALLY INOPERABLE PATIENTS, act. 2009**
- **RTOG 0915 (NCCTG N0927) - A RANDOMIZED PHASE II STUDY COMPARING 2 STEREOTACTIC BODY RADIATION THERAPY (SBRT) SCHEDULES FOR MEDICALLY INOPERABLE PATIENTS WITH STAGE I PERIPHERAL NON-SMALL CELL LUNG CANCER, act. 2009**
- **NRG-BR001 - A Phase 1 Study of Stereotactic Body Radiotherapy (SBRT) for the Treatment of Multiple Metastases, act. 2014**



Study	Name	Status	Phase
NRG-LU001	Randomized Phase II Trial of Concurrent Chemoradiotherapy +/- Metformin HCL in Locally Advanced NSCLC	Closed to Accrual	II R
NRG-LU002	Maintenance Systemic Therapy Versus Local Consolidative Therapy (LCT) Plus Maintenance Systemic Therapy For Limited Metastatic Non-Small Cell Lung Cancer (NSCLC): A Randomized Phase II/III Trial	Open to Accrual	II R / III
NRG-LU003	A Biomarker-Driven Protocol for Previously Treated ALK-Positive Non-Squamous NSCLC Patients: The NCI-NRG ALK Master Protocol	Open to Accrual	II
NRG-LU004	Phase I Trial of Accelerated or Conventionally Fractionated Radiotherapy Combined With MEDI4736 (durvalumab) in PD-L1 High Locally Advanced Non-Small Cell Lung Cancer (NSCLC) (ARCHON-1)	Open to Accrual	I
NRG-LU005	Limited Stage Small Cell Lung Cancer (LS-SCLC): A Phase II/III Randomized Study of Chemoradiation Versus Chemoradiation Plus Atezolizumab	Open to Accrual	II R / III
RTOG-0617	A Randomized Phase III Comparison of Standard- Dose (60 Gy) Versus Highdose (74 Gy) Conformal Radiotherapy with Concurrent and Consolidation Carboplatin/Paclitaxel +/- Cetuximab (IND #103444) in Patients with Stage IIIA/IIIB Non-Small Cell Lung Cancer	Closed to Accrual	III
RTOG-0618	A Phase II Trial of Stereotactic Body Radiation Therapy (SBRT) in the Treatment of Patients with Operable Stage I/II Non-Small Cell Lung Cancer	Terminated	II
RTOG-0813	Seamless Phase I/II Study of Stereotactic Lung Radiotherapy (SBRT) for Early Stage, Centrally Located, Non-Small Cell Lung Cancer (NSCLC) in Medically Inoperable Patients	Closed to Accrual	I / II
RTOG-0839	Randomized Phase II Study of Pre-Operative Chemoradiotherapy +/- Panitumumab (IND #110152) Followed By Consolidation Chemotherapy In Potentially Operable Locally Advanced (Stage IIIA, N2+) Non-Small Cell Lung Cancer	Closed to Accrual	II
RTOG-0915	A Randomized Phase II Study Comparing 2 Stereotactic Body Radiation Therapy (SBRT) Schedules for Medically Inoperable Patients with Stage I Peripheral Non-Small Cell Lung Cancer	Terminated	II
RTOG-1106	RTOG 1106/ACRIN 6697, Randomized Phase II Trial of Individualized Adaptive Radiotherapy Using During-Treatment FDG-PET/CT and Modern Technology in Locally Advanced Non-Small Cell Lung Cancer (NSCLC)	Closed to Accrual	II R
RTOG-1306	A Randomized Phase II Study of Individualized Combined Modality Therapy for Stage III Non-Small Cell Lung Cancer (NSCLC)	Terminated	II R
RTOG-1308	Phase III Randomized Trial Comparing Overall Survival After Photon Versus Proton Chemoradiotherapy for Inoperable Stage II-IIIB NSCLC	Open to Accrual	III

Study	Name	Status	Phase
NRG-BR001	A Phase 1 Study of Stereotactic Body Radiotherapy (SBRT) for the Treatment of Multiple Metastases	Closed to Accrual	I



Referências – para começar

- **Stereotactic Ablative Radiotherapy for the Comprehensive Treatment of Oligometastatic Tumors (SABR-COMET): A Randomized Phase II Trial, 2019**
- **RTOG 0236 - 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, act. 2004**



Referências – para começar - Fígado

- **RTOG 0438 - A PHASE I TRIAL OF HIGHLY CONFORMAL RADIATION THERAPY FOR PATIENTS WITH LIVER METASTASES, act. 2005**

Study Name	Status	Phase
0013 A Phase II Trial of Conventional Radiation Therapy followed by Intratumoral Bleomycin Delivered using a Refillable Sustained Device (IND#46,592) for the Treatment of Supratentorial Glioblastoma	Terminated	II
0212 A Phase II/III Randomized Trial of Two Dose Schedules for Delivering Prophylactic Cranial Irradiation for Patients with Limited Disease Small Cell Lung Cancer (Companion Study to the International Cranial Irradiation Trial, PCI 01EULINT1)	Terminated	II/III
0438 Phase I Trial of Highly Conformal Radiation Therapy for Patients with Liver Metastases	Terminated	I



Referências – para começar - Pâncreas

Study Name	Status	Phase
0020 A Randomized Phase II Trial of Weekly Gemcitabine, Paclitaxel and External Irradiation (50.4 Gy) Followed by the Farnesyl Transferase Inhibitor R115777 (NSC #702818) for Locally Advanced Pancreatic Cancer	Terminated	II
0411 A Phase II Study of Bevacizumab with Concurrent Capecitabine and Radiation Followed by Maintenance Gemcitabine and Bevacizumab for Locally Advanced Pancreatic Cancer	Terminated	II
1102 A Phase I Study of Induction Ganitumab (IND #113278) and Gemcitabine, Followed by Ganitumab, Capecitabine, and 3D-Conformal Radiation Therapy (3D-CRT) With Subsequent Maintenance Therapy for Locally Advanced Pancreatic Cancer	Terminated	I
1201 A Phase II Randomized Trial of High Versus Standard Intensity Local or Systemic Therapy for Unresectable Pancreatic Cancer	Terminated	II R
9704 A Phase III Study of Pre and Post Chemoradiation 5-FU Vs. Pre and Post Chemoradiation Gemcitabine for Postoperative Adjuvant Treatment of Resected Pancreatic Adenocarcinoma	Terminated	III
9812 A Phase II Trial of External Irradiation (50.4 GY) and Weekly Paclitaxel (Taxol) for Non-Metastatic, Unresectable Pancreatic Cancer	Terminated	II

- Astro Guideline – ASTRO RT for Pancreatic Cancer, 06/2019
- Goto et al. Radiation Oncology (2018) 13:118 – Clinical evaluation of intensity-modulated radiotherapy for locally advanced pancreatic cancer
- Stereotatic Body Radiotherapy for Unresected Pancreatic Cancer: a National Review, 2017

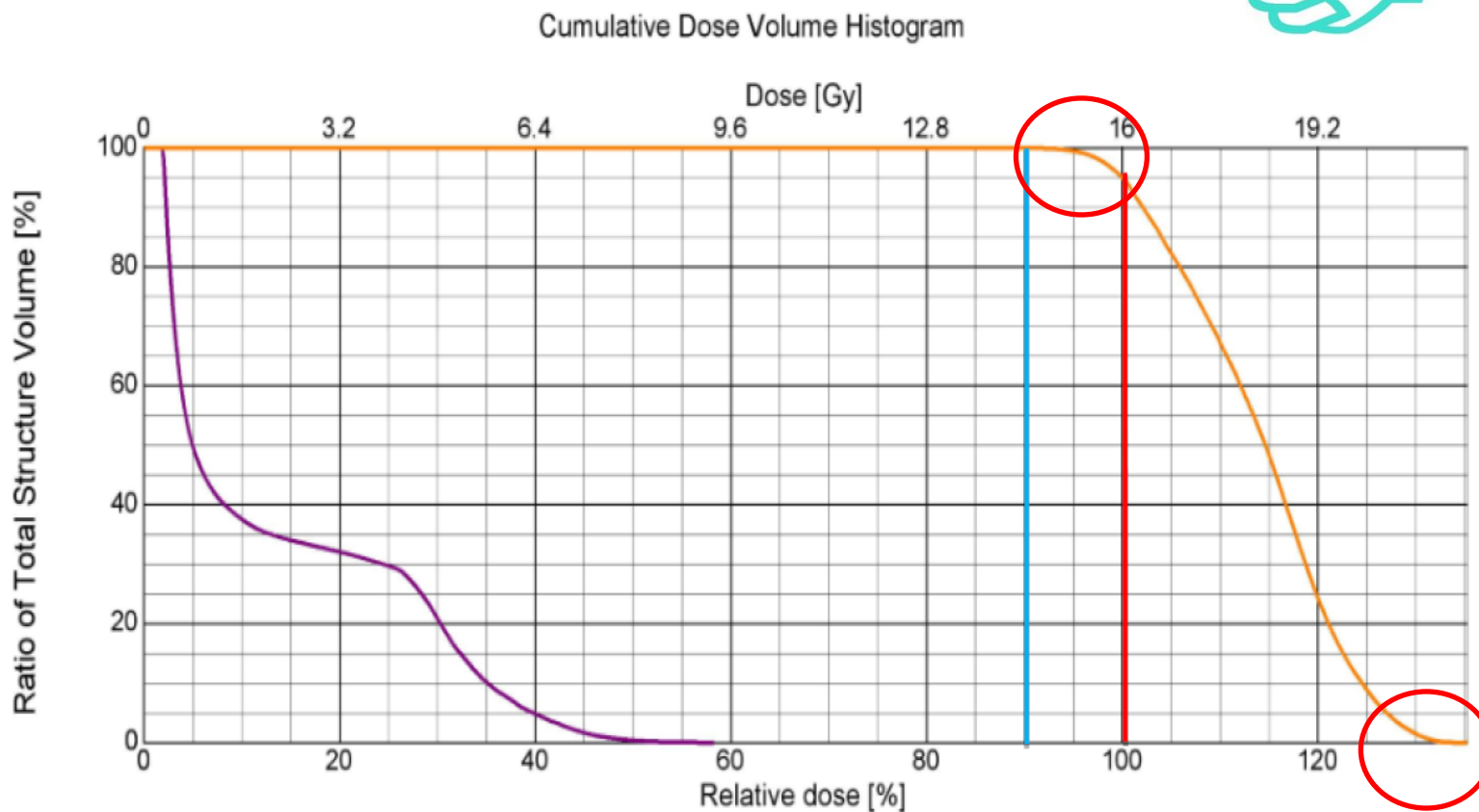


SBRT/SABR – conceitos importantes

- Objetivo: ablação dos tecidos dentro do PTV
- OAR são prioritários!!!
- Dose $\geq 5\text{Gy/fr}$
- Máximo de 5apl (???)
- Margens pequenas de conformação do PTV
- Rápido fall-off de dose fora do PTV
- Altos gradientes de dose dentro do PTV (110-160%)
- Low/Intermediate dose spillage



Plano de SBRT



Esquemas de dose/fração

Radiotherapy and Oncology 77 (2005) 83-87
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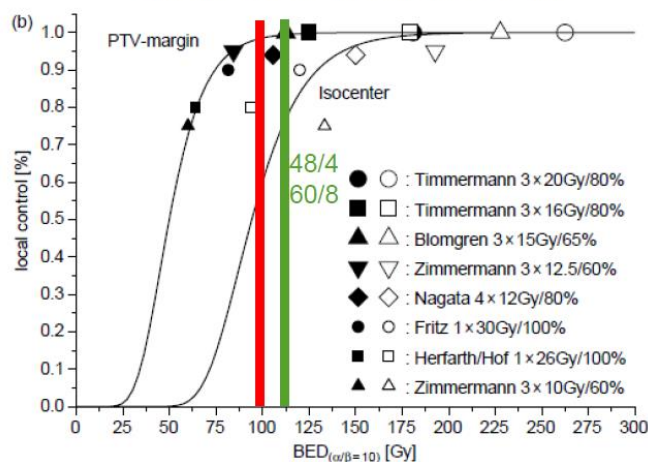
Extracranial stereotactic RT

Dose-response in stereotactic irradiation of lung tumors

Joern Wulf^{a,b}, Kurt Baier^a, Gerd Mueller^a, Michael P. Flentje^{a,*}

^aDepartment of Radiotherapy, University of Wuerzburg, Wuerzburg, Germany,

^bDepartment of Radiotherapy, Lindenhofspital, Bern, Switzerland



Local Control Rate of Early-Stage Non-Small Cell Lung Cancer Treated with SBRT

Investigator	Dose, Prescription	Approximate minimal total dose delivered to PTV (Gy)	SFED (Gy)	BED (Gy)	SED (Gy)
Timmerman, et al. (2006)	20-22 Gy x 3 (80% isodose)	60-66	56.4-62.4	132-147	107-119
Timmerman, et al. (2003)	18-20 Gy x 3 (80% isodose)	54-60	50.4-56.4	118-132	95-107
Nyman, et al. (2006)	15 Gy x 3 (PTV periphery)	45	41.4	96	78
Xia, et al (2006)	5 Gy x 10 (50% isodose)	50	34.3*	78	63
Zimmermann, et al. (2006)	12.5 Gy x 3 (80% isodose)	37.5	33.9	78	63
Wulf, et al. (2005)	12.5 Gy x 3 (65% isodose)	37.5	33.9	78	63
Hara, et al. (2006)	30-34 Gy x 1 (minimal dose to CTV or PTV)	30-34	30-34	68-78	55-63
Fritz, et al. (2006)	30 Gy x 1 (isocenter)	24	24	68	55
Hof, et al. (2003)	19-26 Gy x 1 (isocenter)	15.2-20.8	15.2-20.8	32-46	34-48
Nagata, et al. (2005)	48 Gy to isocenter	42.6 to isocenter	99	80 to isocenter	

Abbreviations: SBRT = stereotactic body radiotherapy; PTV = planning target volume; SFED = single fraction equivalent dose; BED = biologically effective dose; SED = standard effective dose; CTV = clinical target volume; CFRT = conventionally fractionated radiotherapy
*Because dose per fraction is smaller than transition dose (D_t), this was calculated using $SFED_{cfrt}$



RT09 0915

Ex.:

6.1.2 Dose Fractionation

Patients will receive 5 fractions of radiation, on an every 2-day basis i.e., 2-3 treatments per week, so that the SBRT schedule is completed within 1.5-2 weeks. There should be a minimum of 40 hours between treatments.

The starting dose level will be dose level 5: 10 Gy x 5 fractions, i.e., 50 Gy/5 fractions. The dose per fraction for each patient will be provided at the time of registration based on the toxicity experience of the previous patients on study.

The dose per fraction is to be prescribed to the prescription line at the edge of the PTV.

Dose Level	Dose per Fraction	Total Dose
1	8 Gy	40 Gy
2	8.5 Gy	42.5 Gy
3	9 Gy	45 Gy
4	9.5 Gy	47.5 Gy
5	10 Gy†	50 Gy
6	10.5 Gy	52.5 Gy
7	11 Gy	55 Gy
8	11.5 Gy	57.5 Gy
9	12 Gy	60 Gy

†Protocol treatment begins at Level 5, 10 Gy. Levels 1-4 will be employed if dose-limiting toxicity is seen with the Level 5 (10 Gy) dose.

RTOG 0813, June 8, 2015

NRG-BR001 version date 11/13/15

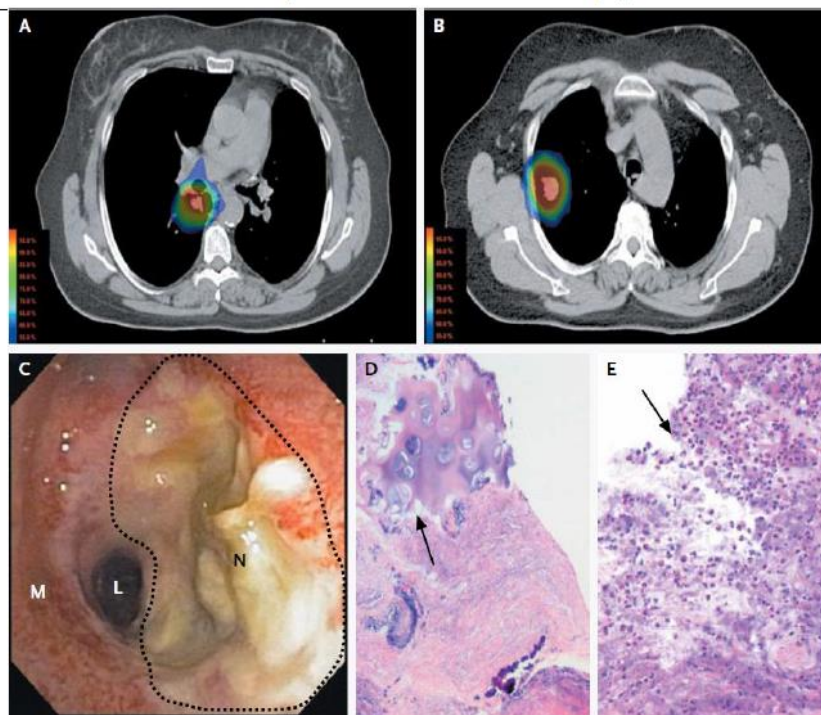
Table 6-1

Prescription Doses		
Metastatic Locations	Initial Starting Dose	Decreased DLT Dose
Lung--Peripheral	45 Gy (3 fractions)	42 Gy (3 fractions)
Lung—Central	50 Gy (5 fractions)	47.5 Gy (5 fractions)
Mediastinal/Cervical Lymph Node	50 Gy (5 fractions)	47.5 Gy (5 fractions)
Liver	45 Gy (3 fractions)	42 Gy (3 fractions)
Spinal/Paraspinal	30 Gy (3 fractions)	27 Gy (3 fractions)
Osseous	30 Gy (3 fractions)	27 Gy (3 fractions)
Abdominal-pelvic metastases (lymph node/adrenal gland)	45 Gy (3 fractions)	42 Gy (3 fractions)



Cautela

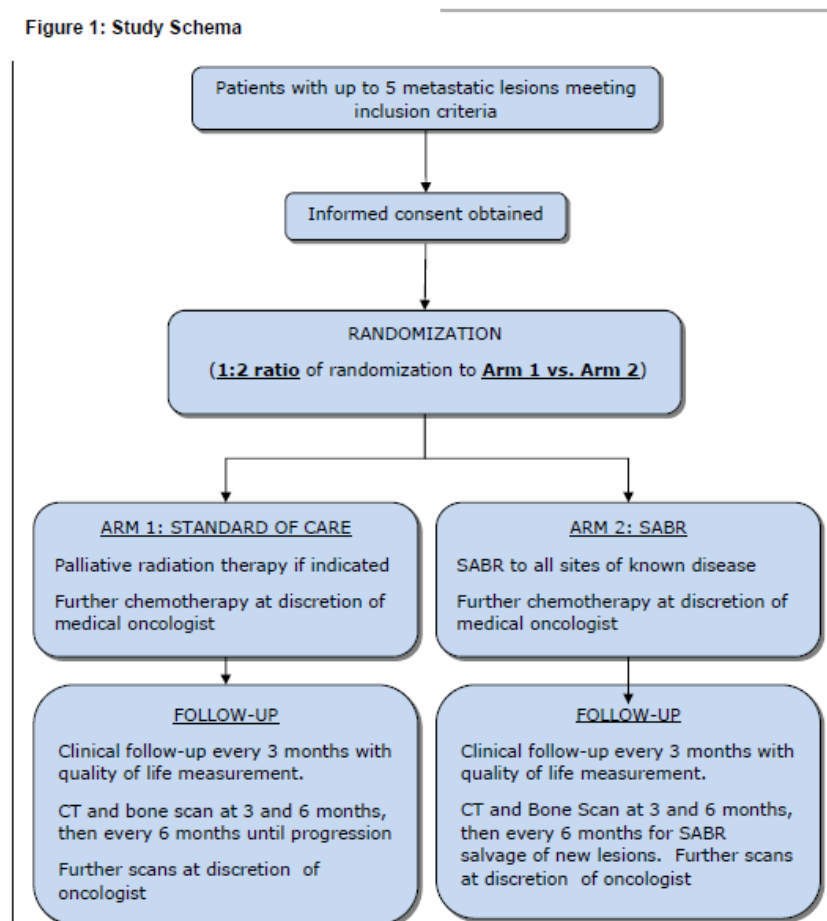
Central-Airway Necrosis after Stereotactic Body-Radiation Therapy



Corradeeti, Haas, Rengan NEJM 2012

Stereotactic Ablative Radiotherapy for Comprehensive Treatment of Oligometastatic Tumors (SABR-COMET): A Randomized Phase II Trial

Figure 1: Study Schema



6.0.1 Standard Arm (Arm 1)

Radiotherapy for patients in the standard arm should follow the principles of palliative radiotherapy as per the individual institution, with the goal of alleviating symptoms or preventing imminent complications. Patients in this arm should not receive stereotactic doses or radiotherapy boosts.

Treatment recommendations are as follows:

Brain: Whole brain radiotherapy
i.e. 20 Gy in 5 fractions, 30 Gy in 10 fractions

Lung: Palliative radiotherapy as per 2011 consensus guidelines.¹⁵
i.e. 8 Gy in 1 fraction, 20 Gy in 5 fractions, 30 Gy in 10 fractions

Bone: Palliative radiotherapy as per 2011 consensus guidelines.¹⁶
i.e. 8 Gy in 1 fraction (most common), 20 Gy in 5 fractions, 30 Gy in 10 fractions

Liver: 20 Gy in 5 fractions if standard institutional practice

Stereotactic Ablative Radiotherapy for Comprehensive Treatment of Oligometastatic Tumors (SABR-COMET): A Randomized Phase II Trial

6.1 Experimental Arm (Arm 2)

All treatments in this study are based on current protocols in clinical use at the LRCP and VUmc for treatment of lung,¹⁷ liver,¹⁸ brain,^{19,20} and spinal cord²¹ metastases. The guiding principle for radiotherapy is to achieve disease control but to minimize any potential adverse impact on quality of life. Concurrent chemotherapy or targeted therapy at the time of radiotherapy is not permitted within the 4 weeks prior to SABR. Hormone therapy is permitted.

6.1.1 Dose/Fractionation

Doses and fractionations by tumor site are shown in Table 1.

Tumor Location	Description	Total Dose (Gy)	Number of fractions	Dose per fraction (Gy)	Frequency
Lung	Tumors 3 cm or less surrounded by lung parenchyma	54	3	18	Every second day
	Abutting chest wall or >3 cm	55	5	11	Every second day
	Within 2 cm of mediastinum or brachial plexus	60	8*	7.5	Every second day
Bone	Any bone except femur	35 Gy	5	7	Daily
	Vertebral body: additional options	16-20 Gy OR	1	16-20	Single dose
		30 Gy	3	10	Every second day
Brain Metastases	Non-radiosurgical	40 Gy to metastases	5	8 Gy to lesion	Daily
	(If whole brain treated, then simultaneous boost to each lesion)	20 Gy whole brain (optional)	5	4 Gy WBRT	Daily
	Radiosurgical ≤1 cm	22-24 Gy	1	22-24 Gy	Single dose
	>1 and ≤2 cm	20-22 Gy	1	20-22 Gy	Single dose
	>2 and ≤3 cm	18-20 Gy	1	18-20 Gy	Single dose
Liver	Optional whole brain to follow (see text)				
	LRCP site: Dose is based on calculated normal tissue probability of <5%				Every second day
	Other sites	45-60	3-8	7.5-15	Every second day
Adrenal		60 Gy	8	7.5	Every second day

*If esophageal dose constraints cannot be met, 12 fractions should be used.

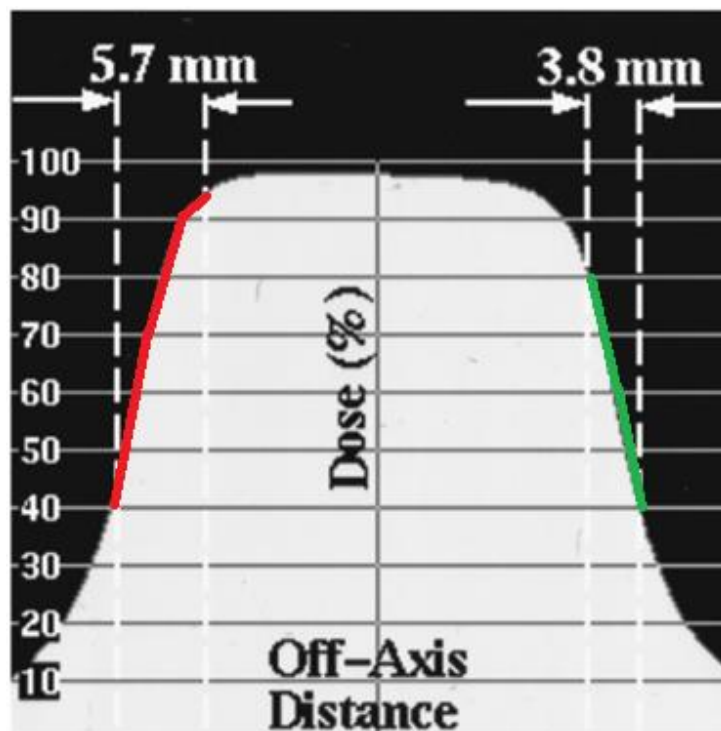


Planejamento em SBRT – alguns conceitos

- **Conformação do PTV**
- **Prescrição de Dose**
- **Heterogeneidade**
- **Fatores técnicos**
- **Constraints de dose OAR**
- **Clearance**



Margem de conformação do PTV

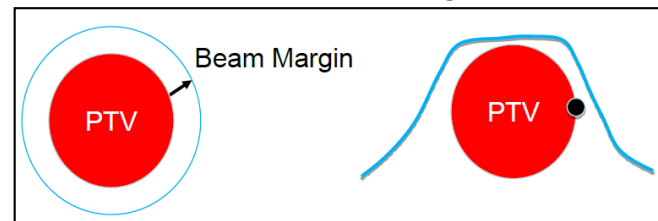


Sanford L. Meeks et al Int. J. Radia. Onc. Biol. Phys., Vol. 41, No. 1, pp. 183–197, 1998

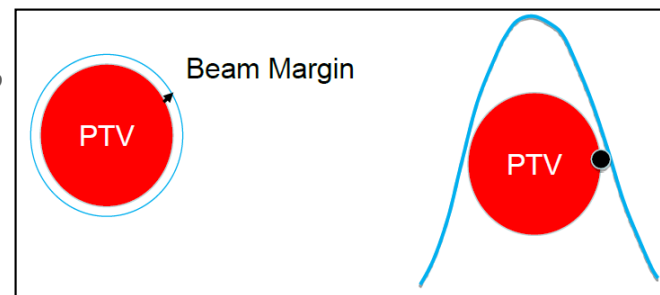


Margem de conformação do feixe

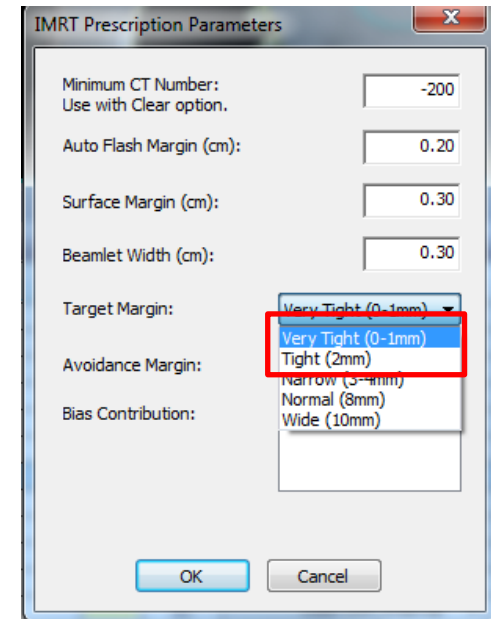
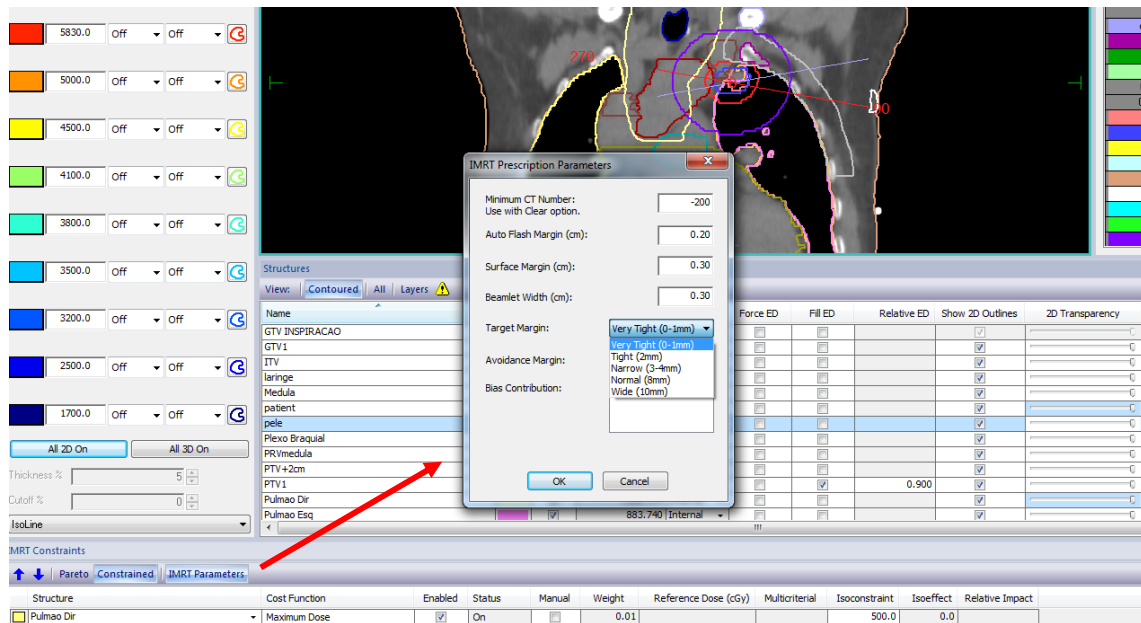
- Margem p/ feixe $\cong$ penumbra (5-6mm)
 - Dose Homogênea PTV / Dose máx $\cong$ 110% da Dose de Prescrição (PD)
 - Fall off de dose fora do PTV $\rightarrow$ “lento”



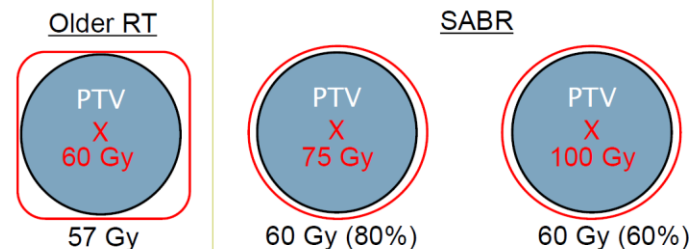
- Margem p/ feixe $\ll$ penumbra (0-2mm)
 - Dose Inomogênea PTV / Dose máx $\cong$ 110-160% da Dose de Prescrição (PD)
 - Fall off de dose fora do PTV $\rightarrow$ “rápido”



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Prescrição de dose (PD)



20Gy x 3 plan is different from 2Gy x 30 plan
a small lung lesion example (PTV volume 33cc)

	SBRT	Conventional	
# of Beams	11	11	3
Beam Margin (mm)	1	5	5
PD per fraction	20 Gy	2 Gy	2 Gy
Max PTV Dose (%)	124.2%	110.8%	110.0%
V _{100%}	38.6 cc	44.3 cc (5.7 cc more)	87.5 cc (48.9 cc more)
V _{50%} (R _{50%})	146.3 cc (4.4)	212.4 cc (6.4) (66cc more)	417.3 cc (12.6) (271 cc more)
V _{25%}	630.4 cc	799.2 cc (169 cc more)	756.8 cc (126 cc more)
50% PD	10 Gy	1 Gy	1 Gy

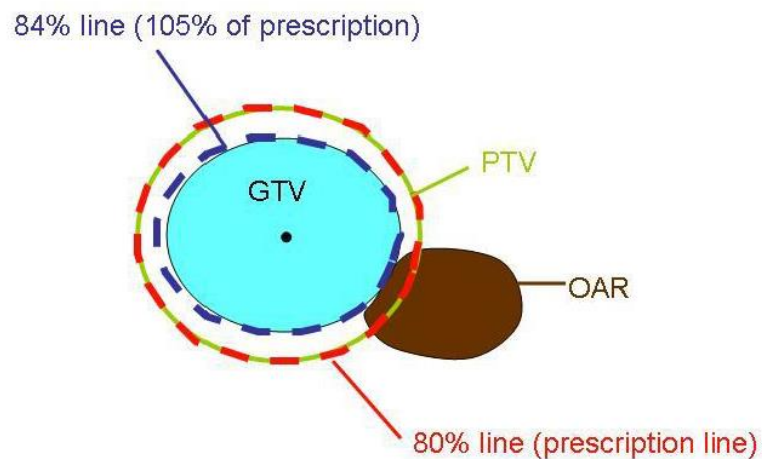
Senan, Palma, Lagerwaard, J Thorac Dis 2011

All Plans normalized to PTV V100% = 95%



Prescrição de dose (PD)

Figure 2

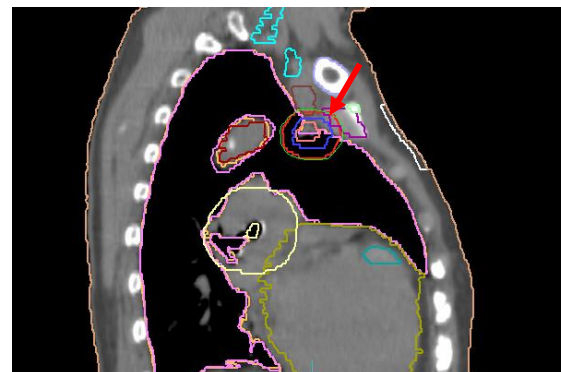
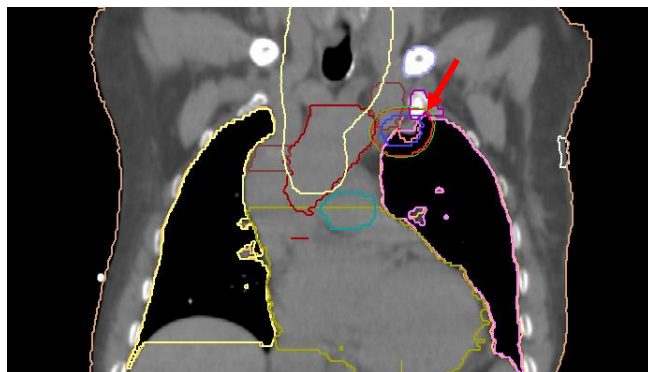
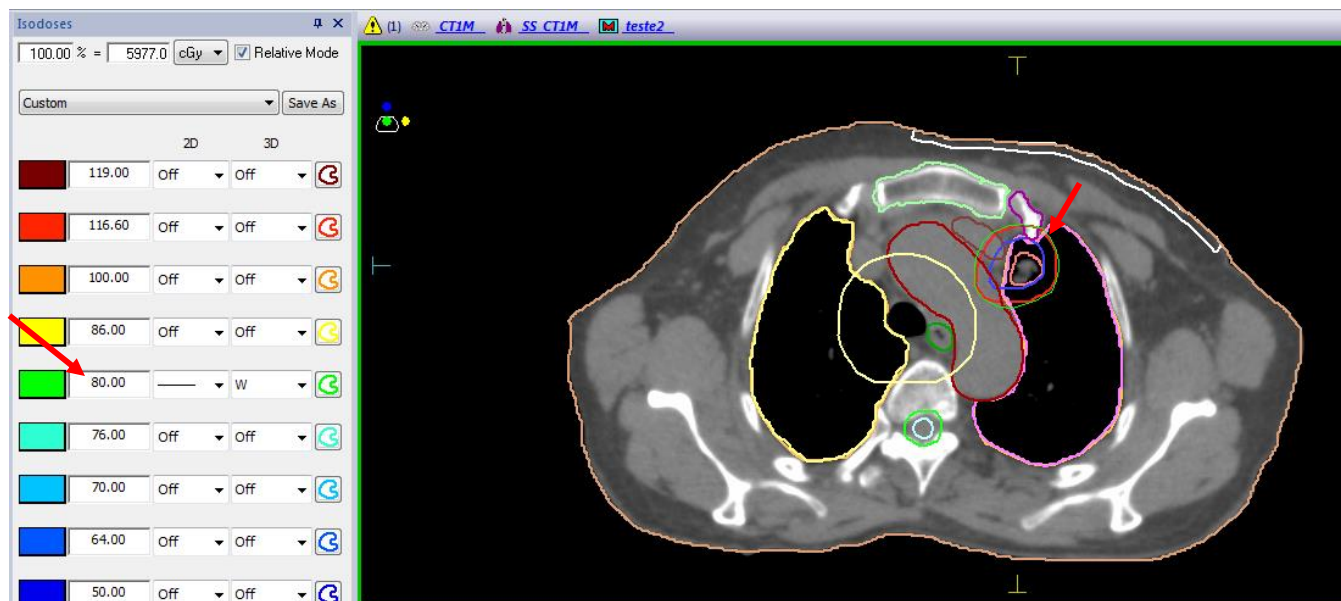


1. Prescription dose 50 Gy
2. Prescription isodose 80%
3. 105% of prescription dose
52.5 Gy (corresponds to 84%
isodose line)
4. Maximum dose (normalization)
at isocenter is 62.5 Gy

RTOG 0813, June 8, 2015

NRG-BR001 version date 11/13/15





Heterogeneidade

- RTOG 0236 não permitia

- Deve ser utilizada nos cálculos (RTOG 0813, 0915, SABR-COMET)

- ~~PBC~~

Patient	Tumor site and position	Plans with tissue heterogeneity corrections				Plans without tissue heterogeneity corrections			
		%PTV volume receiving prescribed dose	minimum dose (Gy)	mean dose (Gy)	maximum dose (Gy)	%PTV volume receiving prescribed dose	minimum dose (Gy)	mean dose (Gy)	maximum dose (Gy)
1	RUP	95.20	56.71	62.70	66.89	61.00	47.58	58.53	64.59
8		95.00	56.85	62.48	65.54	0.00	48.17	54.54	57.98
10		95.50	56.11	63.08	66.74	35.70	48.84	58.43	63.64
11		95.10	57.13	63.20	67.79	56.10	49.82	60.15	66.17
14		95.80	56.83	63.64	67.35	28.70	51.89	58.52	62.97
15	LUP	95.20	56.74	62.75	67.00	27.60	49.72	57.97	62.91
5		99.00	58.93	63.34	67.12	38.10	51.84	58.88	63.19
7		95.10	57.29	62.72	67.04	34.50	48.50	57.92	62.74
9		95.50	56.61	62.58	65.53	26.00	49.46	57.83	62.91
12	LUC	95.50	58.30	62.85	68.21	70.20	55.34	61.37	66.96
4		95.20	57.03	62.72	65.92	16.10	51.90	58.11	61.59
6		95.00	56.63	63.19	68.38	23.60	50.37	57.88	63.11
13	RLP	95.10	58.06	62.44	66.57	34.70	51.33	58.63	63.16
2	LLP	95.70	57.20	62.63	66.70	5.30	46.45	55.64	61.46
3		95.00	58.43	62.27	64.71	0.00	50.47	55.04	57.74

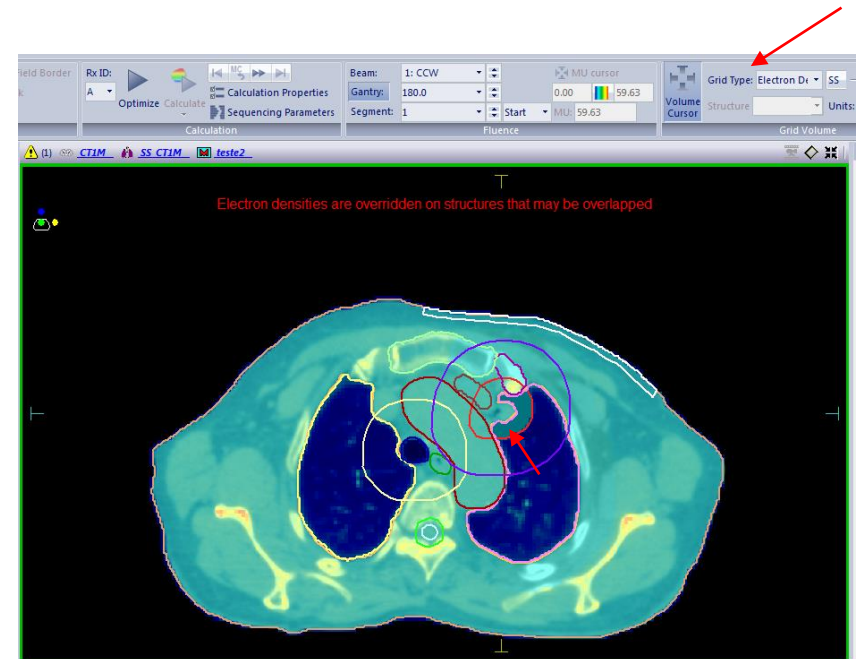
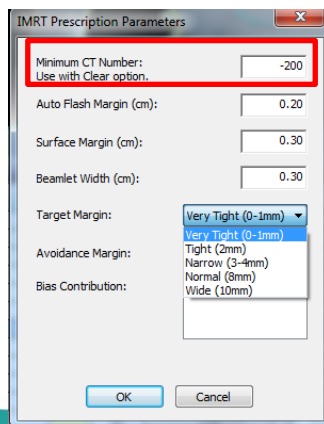
(RUP (right-upper-peripheral), LUP (left-upper-peripheral), LUC (left-upper central), RLP (right-lower peripheral), and LLP (left-lower-central)). The percentages of PTV volume receiving the prescription dose, and minimum, mean, and maximum PTV doses are presented for plans calculated with and without tissue heterogeneity

Impact of tissue heterogeneity corrections in stereotactic body radiation therapy treatment plans for lung cancer

Tania De La Fuente Herman, Heather Gabrish, Terence S. Herman, Maria T. Vlachaki,¹ and Salahuddin Ahmad



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Fatores técnicos

6.2 Technical Factors

6.2.1 Physical Factors

Only photon (x-ray) beams with photon energies 4-10 MV will be allowed. Cobalt-60 and charged particle beams (including electrons, protons, and heavier ions) are not allowed. Photon beam energies > 10 MV but not > 15 MV will be allowed only for a limited number (≤ 2) beams that must travel more than a cumulative distance of 10 cm through soft tissue (not lung) to reach the isocenter.

6.2.2 Minimum Field Aperture (Field Size) Dimension

Because of uncertainties in beam commissioning resulting from electronic disequilibrium within small beam apertures, a minimum field dimension of 3.5 cm is required for any field used for treatment delivery. It is understood that this may exceed the technical requirements listed in Section 6.4 for small lesions (< 2.5 cm axial GTV dimension or < 1.5 cm craniocaudal GTV dimension). In such cases, the prescription dose is still prescribed to the edge of the defined PTV. This minimum field dimension does not apply to centers using tomotherapy or multiple pencil beam delivery systems.

6.2.3 Dose Verification at Treatment

Personal dosimeter measurements (e.g., diode, TLD) may be obtained for surface dose verification for accessible beams as per institutional preference. This information is not required by the protocol.

RTOG 0813, June 8, 2015



Fatores técnicos

6.2 Technical Factors

6.2.1 Physical Factors

Only photon (x-ray) beams produced by linear accelerators, betatrons, or microtron accelerators with photon energies of 4-10 MV will be allowed. Cobalt-60 and charged particle beams (including electrons, protons, and heavier ions) are not allowed. Photon beam energies > 10 MV but not > 15 MV will be allowed only for a limited number (≤ 2) beams that must travel more than a cumulative distance of 10 cm through soft tissue (not lung) to reach the target.

6.2.2 Minimum Field Aperture (Field Size) Dimension

Because of uncertainties in beam commissioning resulting from electronic disequilibrium within small beam apertures, a minimum field dimension of 3.5 cm is required for any field used for treatment delivery for sites using standard 3-D conformal techniques where nearly all of the PTV is encompassed for each beam. It is understood that this may exceed the technical requirements listed in Section 6.4 for small lesions (< 2.5 cm axial GTV dimension or < 1.5 cm craniocaudal GTV dimension). In such cases, the prescription dose is still prescribed to the edge of the defined PTV. This minimum field dimension does not apply to centers using IMRT with a standard multileaf collimator or Tomotherapy or for the CyberKnife® unit where by design the entire PTV is not encompassed for each beam.

6.2.3 Dose Verification at Treatment

In-vivo dosimeter measurements (e.g., diode, TLD) may be obtained for surface dose verification for accessible beams as per institutional preference. This information is not required by the protocol.

6.2.4 Treatment Platforms

The trial allows most commercially available photon producing treatment units except the exclusion of units described in Section 6.2.1 (e.g., cobalt units and charge particle accelerators). As such, conventional linear accelerators, specialized linear accelerators with image guidance (e.g., Novalis, Trilogy, Synergy, Artiste) are allowed. These units can be used with conformal dose delivery or IMRT. Other specialized accelerators (e.g., the CyberKnife® or Tomotherapy) are allowed as long as they meet the technical specifications of the protocol and are used in a fashion that passes the accreditation tests required by the protocol.

RTOG 0915



Critérios (RTOG 0915)

- Dose máxima: normalizada para 100%, DENTRO do PTV
- Isodose de prescrição (PS): deve ser $\geq 60\%$ e $< 90\%$ da D_{máx}
- Cobertura da PS: $PTV_{V100\%PS} = 95\%$ e $PTV_{V90\%PS} \geq 99\%$ (idem SABR-COMET)
- High dose spillage: D_{cum} de todos os tecidos fora do PTV recebendo $D > 105\%PD$ não pode ser maior que 15% do vol. PTV
- Intermediate dose spillage: O gradiente de falloff de dose do PTV para os tecidos normais deve ser rápido e respeitar a tabela 1
- TODOS os constraints de dose dos OAR devem ser respeitados



(11/1/12) Table 1: Conformality of Prescribed Dose for Calculations Based on Deposition of Photon Beam Energy in Heterogeneous Tissue

PTV Volume (cc)	Ratio of Prescription Isodose Volume to the PTV Volume		Ratio of 50% Prescription Isodose Volume to the PTV Volume, $R_{50\%}$		Maximum Dose (in % of dose prescribed) @ 2 cm from PTV in Any Direction, D_{2cm} (%)		Percent of Lung Receiving 20 Gy Total or More, V_{20} (%)	
	Deviation		Deviation		Deviation		Deviation	
	None	Minor	None	Minor	None	Minor	None	Minor
1.8	<1.2	<1.5	<5.9	<7.5	<50.0	<57.0	<10	<15
3.8	<1.2	<1.5	<5.5	<6.5	<50.0	<57.0	<10	<15
7.4	<1.2	<1.5	<5.1	<6.0	<50.0	<58.0	<10	<15
13.2	<1.2	<1.5	<4.7	<5.8	<50.0	<58.0	<10	<15
22.0	<1.2	<1.5	<4.5	<5.5	<54.0	<63.0	<10	<15
34.0	<1.2	<1.5	<4.3	<5.3	<58.0	<68.0	<10	<15
50.0	<1.2	<1.5	<4.0	<5.0	<62.0	<77.0	<10	<15
70.0	<1.2	<1.5	<3.5	<4.8	<66.0	<86.0	<10	<15
95.0	<1.2	<1.5	<3.3	<4.4	<70.0	<89.0	<10	<15
126.0	<1.2	<1.5	<3.1	<4.0	<73.0	<91.0	<10	<15
163.0	<1.2	<1.5	<2.9	<3.7	<77.0	<94.0	<10	<15

Note 1: For values of PTV dimension or volume not specified, linear interpolation between table entries is required.

Note 2: Protocol deviations greater than listed here as "minor" will be classified as "major" for protocol compliance (see Section 6.7).

Boa prática utilizar $R_{50\%}$ e D_{2cm} para outros sítios anatômicos



SABR-COMET

Table 5. Dose conformity parameters for lung SABR treatments
From Hurkmans *et al*, 2010¹⁷

Radiation Oncology 2009, 4:1

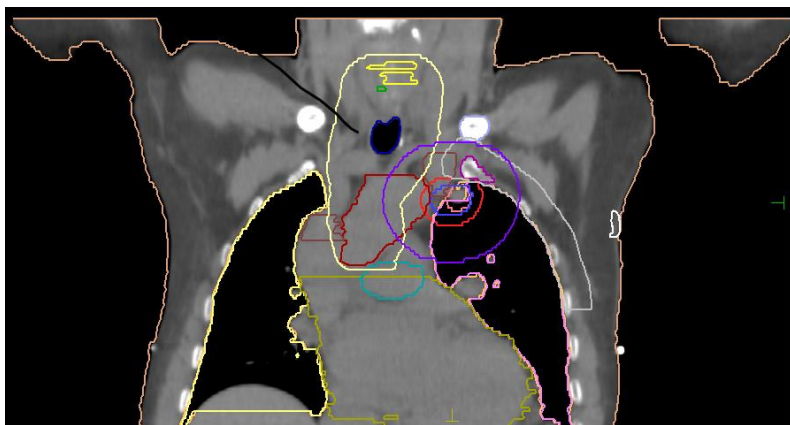
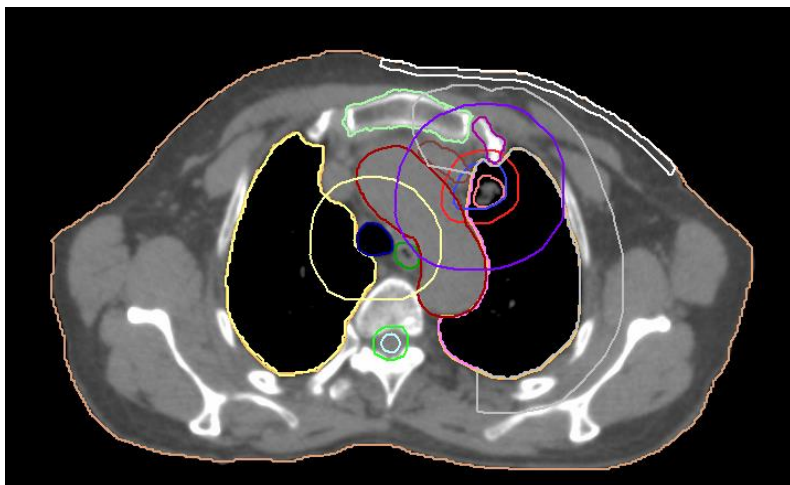
<http://www.ro-journal.com/content/4/1/1>

Table 1: Dose conformity requirements and definition of protocol deviations. $R_{100\%}$ and $R_{50\%}$ = ratio of respectively the 100% and 50% Prescription Isodose Volume to the PTV. $D_{2\text{ cm}}$ = dose maximum at 2 cm from the PTV as percentage of the prescribed dose. $V_{20\text{ Gy}}$ = Percent of lung receiving 20 Gy or more (both lungs minus GTV).

Type A models (standard algorithms)								
$R_{100\%}$		$R_{50\%}$		$D_{2\text{ cm}} (\%)$		$V_{20\text{ Gy}} (\%)$		PTV (cc)
Deviation		Deviation		Deviation		Deviation		
None	Minor	None	Minor	None	Minor	None	Minor	
<1.15	1.15–1.25	<8	8–10	<55	55–60	<4	4–6	0–20
<1.15	1.15–1.25	<7	7–8	<65	65–70	<6	6–8	20–40
<1.10	1.10–1.20	<6	6–6.5	<65	65–75	<8	8–10	>40
Type B models (more advanced algorithms)								
$R_{100\%}$		$R_{50\%}$		$D_{2\text{ cm}} (\%)$		$V_{20\text{ Gy}} (\%)$		PTV (cc)
Deviation		Deviation		Deviation		Deviation		
None	Minor	None	Minor	None	Minor	None	Minor	
<1.25	1.25–1.40	<12	12–14	<65	65–75	<5	5–8	0–20
<1.15	1.15–1.25	<9	9–11	<70	70–80	<6	6–10	20–40
<1.10	1.10–1.20	<6	6–8	<70	70–80	<10	10–15	>40



Algumas dicas para estes contornos



- PTV+2cm
- Pele
- PTVsoma - GTV
- Parede Torácica (usar função bólus no Pulmão Ipsilateral)

Técnicas de planejamento – campos estáticos

- Arranjos de campos coplanares ou não-coplanares
- Dar preferência para campos não-coplanares e não paralelos opostos (evitar sobreposição de campos)
- Campos coplanares recomendados para ttos com respiratory-gated (SABR-COMET)
- Mínimo de 7 campos! $\uparrow$ Alvo $\rightarrow \uparrow$ campos
- Restringir a dose de entrada de cada campos $\leq 30\%$ D_{tot} (TG101)
- Otimização de ângulo de colimador para melhor conformação
- Energia 4-10MV (RTOGs 0813/0915) e 6-10MV (SABR-COMET)
- Máx 2 campos 10-15MV (percurso total ≤ 10 cm em tecido mole) – RTOGs 0813/0915
- IMRT: segunda opção (RTOGs 0813/0915) ou alternativa (SABR-COMET)
- Dimensão mínima de campo = 3,5cm (RTOGs 0813/0915)
- Grid de cálculo ≤ 3 mm – Recomendação ≤ 2 mm (TG101)



Técnicas de planejamento – arcoterapia

- Modulada ou não modulada, no mínimo conformação dinâmica
- Mínimo de 340° (soma dos arcos) – RTOGs 0813/0915
- Preferência para arcos não-coplanares e parciais
- Arranjos de campos coplanares ou não-coplanares ($\leq 20^\circ \rightarrow$ clearance)
- Evitar irradiação circunferencial de: esôfago, traqueia, e brônquio ipsilateral (Timerman et al,2008)
- Lesões periféricas $\rightarrow$ checar clearance
- Otimização de ângulo de colimador para melhor conformação
- 1-2 arcos VMAT (SABR-COMET)
- VMAT: optar por arcos parciais
- Campos coplanares recomendados para ttos com respiratory-gated (SABR-COMET)
- IMRT: segunda opção (RTOGs 0813/0915) ou alternativa (SABR-COMET)
- Rotina Radialis – VMAT é a primeira opção
- Grid de cálculo $\leq 3\text{mm}$ – Recomendação $\leq 2\text{mm}$ (TG101)



Conheça o seu TPS

- Limitações e potencialidades do sistema
- Algoritmos de cálculo
- Correção de heterogeneidades
- Mecanismo de otimização para modulação
- Funções otimização para alvo e OAR
- Possibilidade de inclusão da mesa e dos acessórios de posicionamento no cálculo (TG176)
- Definição de protocolos institucionais para utilização



Monaco® - Target EUD x Target Penalty

Target EUD

This **biological** cost function is an objective (not a constraint) and is the primary cost function for targets. This cost function defines a structure as a target volume. It expresses the probability that a target cell survives a given dose. The field size for each beam or sequence is automatically designed to encompass the target volume.

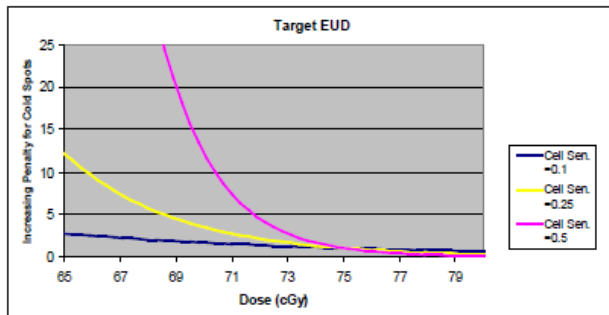
Required Parameters

Prescription (Gy):

Cell Sensitivity:

EUD (Equivalent Uniform Dose)

EUD is a homogeneous dose that, when applied to an organ, has the same clinical effect as any given, inhomogeneous dose distribution. The concept of EUD assumes that any two dose-distributions are assumed equivalent if they cause the same radiobiological effect.



Target Penalty

This **physical** cost function is the 'objective' version of the Quadratic Underdose constraint for targets (Figure 7-18). The isoeffect is a DVH based physical parameter. The Target Penalty is a quadratic penalty which starts at the threshold dose.

Target Penalty

Required Parameters

Prescription (Gy):

Minimum Volume (%):

Figure 7-18: Required parameters for the Target Penalty constraint

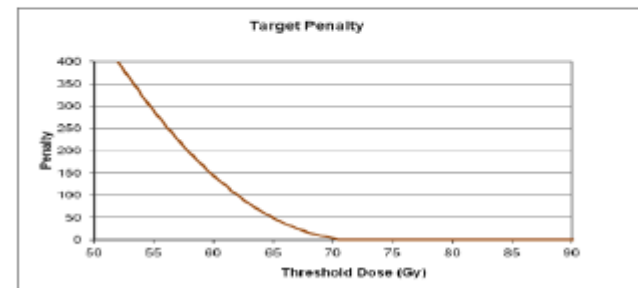
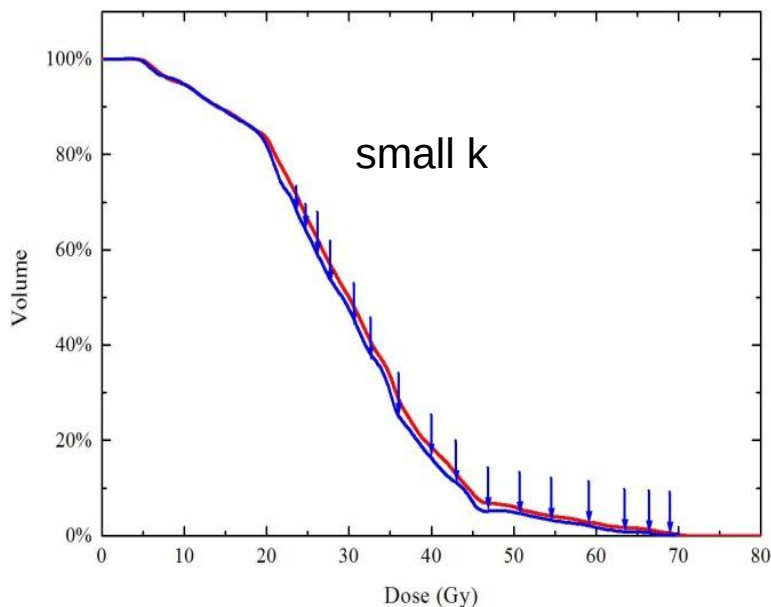


Figure 7-19: Target Penalty a Prescription of 72 Gy.

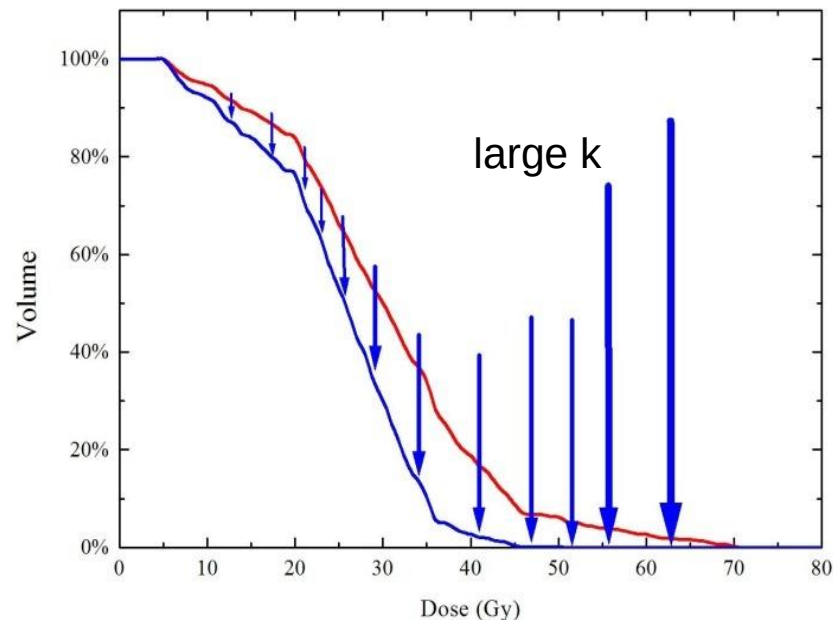
Monaco® Training Guide
Document ID: LTGMON0510



Monaco - Função Otimização - Serial



Efeito uniforme no DVH



Altas doses são penalizadas no DVH

Serial OAR	Common k Value	Common Isoconstraint Values (Gy)
Rectum	12	64
Bladder	8	60
Spinal Cord	12-14	29-36
Brainstem	12-14	36-40
Optic Nerve, Chiasm	12-16	32-48
Heart	6	21-24
Eye	2	25
Inner Ear	12	38
Mandible, Mouth, Larynx	8	40-46
Parotid Gland	1	22
Brain	1	12
Plexus	5	55

Examples of common k values for delivery of 2 Gy/fraction

Serial

Required Parameters

Equivalent Uniform Dose (cGy):

3600.0

Power Law Exponent:

12.00

Optional Physical Parameters

Shrink Margin (cm):

0.00

Optimize over all voxels in volume:

☒

Multicriteria:

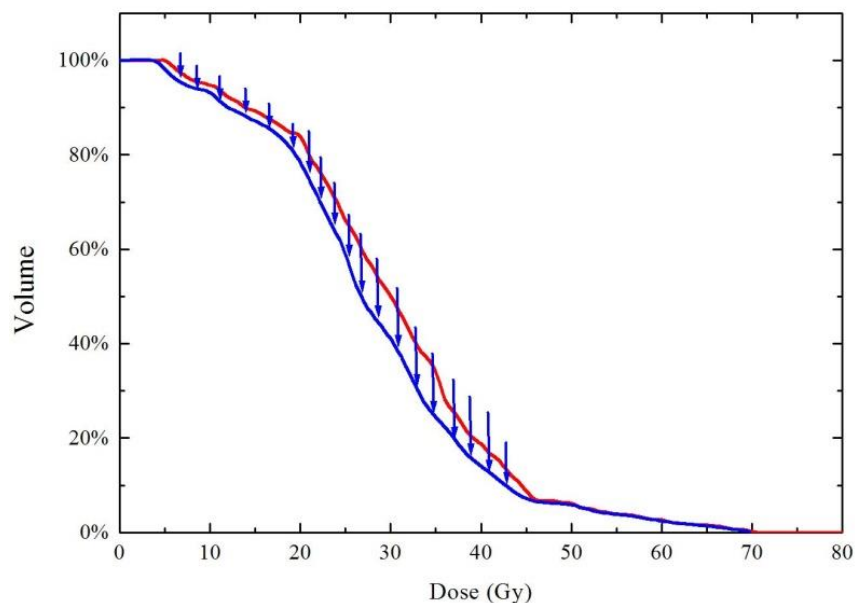
☐

OK

Cancel

Monaco® Training Guide
Document ID: LTGMON0510

Monaco - Função Otimização - Parallel



Effective Parallel cost function on a DVH

Parallel

Required Parameters

Reference Dose (cGy): 2600.0

Mean Organ Damage (%): 50.00

Power Law Exponent: 3.50

Optional Physical Parameters

Shrink Margin (cm): 0.00

Optimize over all voxels in volume: ☒

Multicribial: ☐

OK Cancel

Parallel OAR	Ref Dose (Gy)	Common k Value	Mean Organ Damage (%)
Lung	20	3	20
Parotid	26	3.9	40
Kidney	14	2.1	20
Liver	30	4.0	33

Monaco® Training Guide
Document ID: LTGMON0510



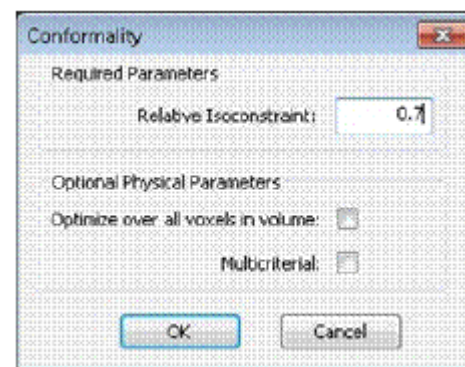
Monaco - Função Otimização - Conformality

Conformality

The Conformality cost function is a hybrid cost function. It controls undefined normal tissue instead of organs at risk. The Conformality cost function shapes the high dose volume tightly around one or more target volumes without being too restrictive to the optimum dose. The cost function decreases the need for extra contouring and cost functions (Quadratic Overdose) to control normal tissue dose levels.

Elimina ou minimiza a utilização de estruturas anéis

Minimiza a utilização da função *quadratic overdose* para o *patient*



The Relative Isoconstraint ranges from 0.01 to 1.00. Values less than 0.5 can start to restrict target coverage. Monaco applies a stronger penalty to voxels when you use a lower value for the Relative Isoconstraint. The default distance Monaco applies the Conformality Cost function is 4cm from the edge of the target. When you select **Optimize over all voxels in volume**, Monaco applies the cost function up to 8.0 cm from the edge of the target. You can also select Multicriterial to make this a secondary objective.

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Constraints OAR

**TODOS os
constraints
devem ser
respeitados!**

Arm 1: One Fraction (34 Gy)				
Serial Tissue	Volume	Volume Max (Gy)	Max Point Dose (Gy)	Endpoint (≥Grade 3)
Spinal Cord	<0.35 cc <1.2 cc	10 Gy 7 Gy	14 Gy	myelitis
Esophagus*	<5 cc	11.9 Gy	15.4 Gy	stenosis/fistula
Brachial Plexus	<3 cc	14 Gy	17.5 Gy	neuropathy
Heart/Pericardium	<15 cc	16 Gy	22 Gy	pericarditis
Great vessels	<10 cc	31 Gy	37 Gy	aneurysm
Trachea and Large Bronchus*	<4 cc	10.5 Gy	20.2 Gy	stenosis/fistula
Rib**	<1 cc	22 Gy	30 Gy	Pain or fracture
Skin	<10 cc	23 Gy	26 Gy	ulceration
Stomach	<10 cc	11.2 Gy	12.4 Gy	ulceration/fistula
Parallel Tissue	Critical Volume (cc)	Critical Volume Dose Max (Gy)		Endpoint (≥Grade 3)
Lung (Right & Left)	1500 cc	7 Gy		Basic Lung Function
Lung (Right & Left)	1000 cc	7.4 Gy		Pneumonitis

(11/12) Arm 2: Four Fractions (4 x 12 Gy)				
Serial Tissue	Volume	Volume Max (Gy)	Max Point Dose (Gy)	Endpoint (≥Grade 3)
Spinal Cord	<0.35 cc <1.2 cc	20.8 Gy (5.2 Gy/fx) 13.6 Gy (3.4 Gy/fx)	26 Gy (6.5 Gy/fx)	myelitis
Esophagus*	<5 cc	18.8 Gy (4.7 Gy/fx)	30 Gy (7.5 Gy/fx)	stenosis/fistula
Brachial Plexus	<3 cc	23.6 Gy (5.9 Gy/fx)	27.2 Gy (6.8 Gy/fx)	neuropathy
Heart/Pericardium	<15 cc	28 Gy (7 Gy/fx)	34 Gy (8.5 Gy/fx)	pericarditis
Great vessels	<10 cc	43 Gy (10.75 Gy/fx)	49 Gy (12.25 Gy/fx)	aneurysm
Trachea and Large Bronchus*	<4 cc	15.6 Gy (3.9 Gy/fx)	34.8 Gy (8.7 Gy/fx)	stenosis/fistula
Rib**	<1 cc	32 Gy (8 Gy/fx)	40 Gy (10 Gy/fx)	Pain or fracture
Skin	<10 cc	33.2 Gy (8.3 Gy/fx)	36 Gy (9 Gy/fx)	ulceration
Stomach	<10 cc	17.6 Gy (4.4 Gy/fx)	27.2 Gy (6.8 Gy/fx)	ulceration/fistula
Parallel Tissue	Critical Volume (cc)	Critical Volume Dose Max (Gy)		Endpoint (≥Grade 3)
Lung (Right & Left)	1500 cc	11.6 Gy (2.9 Gy/fx)		Basic Lung Function
Lung (Right & Left)	1000 cc	12.4 Gy (3.1 Gy/fx)		Pneumonitis

*Avoid circumferential irradiation

**Rib limit may be exceeded if rib structure lies within PTV; see Section 6.5.1.1 below.

6.5 Critical Structures

6.5.1 Critical Organ Dose-Volume Limits (3/4/10)

The following table lists maximum dose limits to a point or volume within several critical organs. Except for the rib, these are absolute limits, and treatment delivery that exceeds these limits will constitute a protocol violation (See Section 6.7). The dose is listed as total delivered. These limits were formulated with the approval of the study committee (Principal Investigators and Co-Chairs) using tolerance data, historical data as listed in section 1 with special weighting to the RTOG experience (in reference to the 34 Gy dose) and that of Chang, et al. from MD Anderson (in reference to the 12 Gy times 4 fractions arm).



RTOG 0915

Constraints de Dose (SABR-COMET)

Table 2. Normal tissue dose constraints for 1-3 fractions SABR regimens.
From Timmerman *et al*, 2008²²

Serial Tissue	Volume (mL)	Volume Max (Gy)	Max Point Dose (Gy)	Endpoint (≥Grade 3)
SINGLE-FRACTION TREATMENT				
Optic pathway	<0.2	8	10	Neuritis
Cochlea			12	Hearing loss
Brainstem	<1	10	15	Cranial neuropathy
Spinal cord	<0.25	10	14	Myelitis
	<1.2	7		
Cauda equina	<5	14	16	Neuritis
Sacral plexus	<3	14.4	16	Neuropathy
Esophagus*	<5	14.5	19	Stenosis/fistula
Ipsilateral brachial plexus	<3	14.4	16	Neuropathy
Heart/pericardium	<15	16	22	Pericarditis
Great vessels	<10	31	37	Aneurysm
Trachea and ipsilateral bronchus*	<4	8.8	22	Stenosis/fistula
Skin	<10	14.4	16	Ulceration
Stomach	<10	13	16	Ulceration/fistula
Duodenum*	<5	8.8	16	Ulceration
Jejunum/ileum*	<5	8.8	19	Enteritis/obstruction
Colon*	<20	11	22	Colitis/fistula
Rectum*	<20	11	22	Proctitis/fistula
Bladder wall	<15	8.7	22	Cystitis/fistula
Penile bulb	<3	14	34	Impotence
Femoral heads (right and left)	<10	14		Necrosis
Renal hilum/vascular trunk	<2/3 volume	10.6		Malignant hypertension
Parallel Tissue				
	Critical Volume (mL)	Critical Volume Dose Max (Gy)	Endpoint (≥Grade 3)	
Lung (right and left)	1,500	7	Basic lung function	
Lung (right and left)	1,000	7.4	Pneumonitis	
Liver	700	9.1	Basic liver function	
Renal cortex (right and left)	200	8.4	Basic renal function	
Serial Tissue				
THREE-FRACTION TREATMENT				
Optic pathway	<0.2	15 (5 Gy/fx)	19.5 (6.5 Gy/fx)	Neuritis
Cochlea			20 (6.67 Gy/fx)	Hearing loss
Brainstem	<1	18 (6 Gy/fx)	23 (7.67 Gy/fx)	Cranial neuropathy
Spinal cord	<0.25	18 (6 Gy/fx)	22 (7.33 Gy/fx)	Myelitis
	<1.2	11.1 (3.7 Gy/fx)		
Cauda equina	<5	21.9 (7.3 Gy/fx)	24 (8 Gy/fx)	Neuritis
Sacral plexus	<3	22.5 (7.5 Gy/fx)	24 (8 Gy/fx)	Neuropathy
Esophagus*	<5	21 (7 Gy/fx)	27 (9 Gy/fx)	Stenosis/fistula
Ipsilateral brachial plexus	<3	22.5 (7.5 Gy/fx)	24 (8 Gy/fx)	Neuropathy
Heart/pericardium	<15	24 (8 Gy/fx)	30 (10 Gy/fx)	Pericarditis
Great vessels	<10	39 (13 Gy/fx)	45 (15 Gy/fx)	Aneurysm
Trachea and ipsilateral bronchus*	<4	15 (5 Gy/fx)	30 (10 Gy/fx)	Stenosis/fistula
Skin	<10	22.5 (7.5 Gy/fx)	24 (8 Gy/fx)	Ulceration
Stomach	<10	21 (7 Gy/fx)	24 (8 Gy/fx)	Ulceration/fistula
Duodenum*	<5	15 (5 Gy/fx)	24 (8 Gy/fx)	Ulceration
Jejunum/ileum*	<5	16.2 (5.4 Gy/fx)	27 (9 Gy/fx)	Enteritis/obstruction
Colon*	<20	20.4 (6.8 Gy/fx)	30 (10 Gy/fx)	Colitis/fistula
Rectum*	<20	20.4 (6.8 Gy/fx)	30 (10 Gy/fx)	Proctitis/fistula
Bladder wall	<15	15 (5 Gy/fx)	30 (10 Gy/fx)	Cystitis/fistula
Penile bulb	<3	21.9 (7.3 Gy/fx)	42 (14 Gy/fx)	Impotence
Femoral heads (right and left)	<10	21.9 (7.3 Gy/fx)		Necrosis
Renal hilum/vascular trunk	<2/3 volume	18.6 (6.2 Gy/fx)		Malignant hypertension
Parallel Tissue				
	Critical Volume (mL)	Critical Volume Dose Max (Gy)	Endpoint (≥Grade 3)	
Lung (right and left)	1,500	10.5 (3.5 Gy/fx)	Basic lung function	
Lung (right and left)	1,000	11.4 (3.8 Gy/fx)	Pneumonitis	
Liver	700	17.1 (5.7 Gy/fx)	Basic liver function	
Renal cortex (right and left)	200	14.4 (4.8 Gy/fx)	Basic renal function	

Table 3. Normal tissue dose constraints for FIVE-fraction SABR regimens.
From Timmerman *et al*, 2008²²

Serial Tissue	Volume (mL)	Volume Max (Gy)	Max Point Dose (Gy)	Endpoint (≥Grade 3)
FIVE-FRACTION TREATMENT				
Optic pathway	<0.2	20 (4 Gy/fx)	25 (5 Gy/fx)	Neuritis
Cochlea			27.5 (5.5 Gy/fx)	Hearing loss
Brainstem	<1	26 (5.2 Gy/fx)	31 (6.2 Gy/fx)	Cranial neuropathy
Spinal cord	<0.25	22.5 (4.5 Gy/fx)	30 (6 Gy/fx)	Myelitis
	<1.2	13.5 (2.7 Gy/fx)		
Cauda equina	<5	30 (6 Gy/fx)	34 (6.8 Gy/fx)	Neuritis
Sacral plexus	<3	30 (6 Gy/fx)	32 (6.4 Gy/fx)	Neuropathy
Esophagus*	<5	27.5 (5.5 Gy/fx)	35 (7 Gy/fx)	Stenosis/fistula
Ipsilateral brachial plexus	<3	30 (6 Gy/fx)	32 (6.4 Gy/fx)	Neuropathy
Heart/pericardium	<15	32 (6.4 Gy/fx)	38 (7.6 Gy/fx)	Pericarditis
Great vessels	<10	47 (9.4 Gy/fx)	53 (10.6 Gy/fx)	Aneurysm
Trachea and ipsilateral bronchus*	<4	18 (3.6 Gy/fx)	38 (7.6 Gy/fx)	Stenosis/fistula
Skin	<10	30 (6 Gy/fx)	32 (6.4 Gy/fx)	Ulceration
Stomach	<10	28 (5.6 Gy/fx)	32 (6.4 Gy/fx)	Ulceration/fistula
Duodenum*	<5	18 (3.6 Gy/fx)	32 (6.4 Gy/fx)	Ulceration
Jejunum/ileum*	<5	19.5 (3.9 Gy/fx)	35 (7 Gy/fx)	enteritis/obstruction
Colon*	<20	25 (5 Gy/fx)	38 (7.6 Gy/fx)	colitis/fistula
Rectum*	<20	25 (5 Gy/fx)	38 (7.6 Gy/fx)	proctitis/fistula
Bladder wall	<15	18.3 (3.65 Gy/fx)	38 (7.6 Gy/fx)	cystitis/fistula
Penile bulb	<3	30 (6 Gy/fx)	50 (10 Gy/fx)	Impotence
Femoral heads (right and left)	<10	30 (6 Gy/fx)		Necrosis
Renal hilum/vascular trunk	<2/3 volume	23 (4.6 Gy/fx)		Malignant hypertension
Parallel Tissue				
	Critical Volume (mL)	Critical Volume Dose Max (Gy)	Endpoint (≥Grade 3)	
Lung (right and left)	1,500	12.5 (2.5 Gy/fx)	Basic lung function	
Lung (right and left)	1,000	13.5 (2.7 Gy/fx)	Pneumonitis	
Liver	700	21 (4.2 Gy/fx)	Basic liver function	
Renal cortex (right and left)	200	17.5 (3.5 Gy/fx)	Basic renal function	

*Avoid circumferential irradiation.

It is strongly recommended that the doses to organs at risk are not to be exceeded – in some specific cases, this may require lower doses or higher fractionations than listed here. Such changes in dose will require approval of one of the local principal investigators. (see section 6.2)



Constraints de Dose (SABR-COMET)

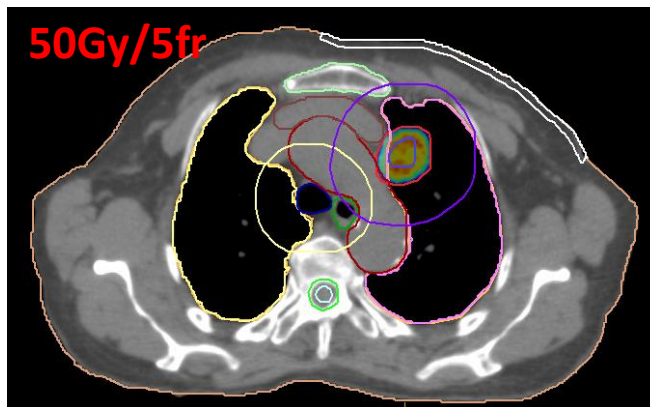
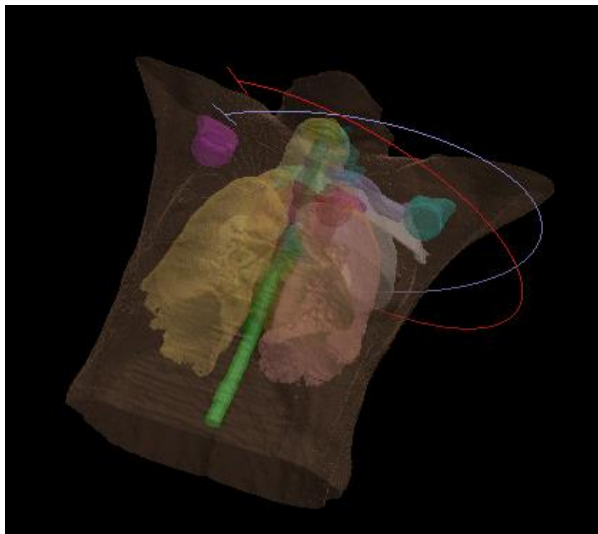
Table 4. Additional normal tissue dose constraints for EIGHT-fraction SABR regimens. Dose conformity requirements from Table 5 also apply for lung lesions. Note: for targets overlapping the stomach or esophagus, 12 fractions should be used, with a maximum dose of 48 Gy in 12 fractions for either organ. For any organs not listed, or for OARs for 12 fraction regimens, a biologically effective dose can be calculated using an alpha-beta ratio of 2.

<u>Structure</u>	<u>Maximum Dose</u>
Liver	At least 700 cc below 22 Gy (unless using NTCP calculation method)
Kidney (right and left)	At least 200 cc below 21 Gy
Spinal Cord	32 Gy point dose V(27 Gy) < 0.25 cc V(16 Gy) < 1.25 cc
Stomach	40 Gy point dose V(34 Gy) < 10 cc
Esophagus	40 Gy point dose V(33 Gy) < 5 cc
Great Vessels	65 Gy point dose V(58 Gy) < 10 cc
Trachea and Ipsilateral Mainstem Bronchus	40 Gy point dose V(21.5 Gy) < 4 cc
Ipsilateral Brachial Plexus	39 Gy point dose V(36.5 Gy) < 3 cc
Heart/Pericardium	46 Gy point dose V(39 Gy) < 15 cc
Duodenum	39 Gy point dose V(21.5 Gy) < 5 cc
Jejunum/Ileum	40 Gy point dose V(23 Gy) < 5 cc

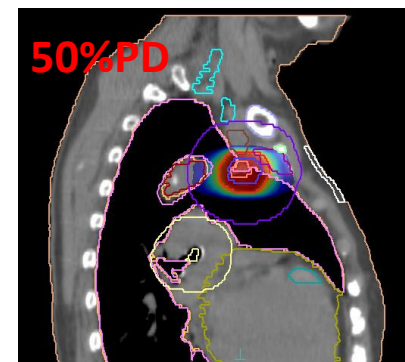
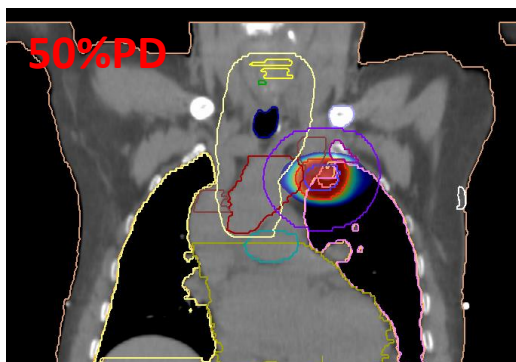
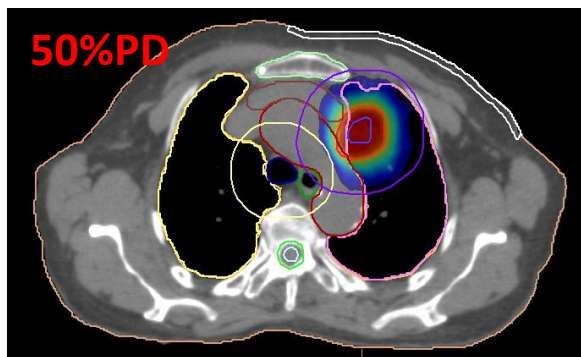
V(X) Gy: volume of structure receiving X Gy or more (i.e. for the stomach, V34 Gy is the volume of stomach receiving 34 Gy or more).



Caso clínico – Radialis



$V_{PTV} = 16,9cc$
 $V_{95\%} = 95,3\%$
 $V_{90\%} = 99,9\%$
 $Grad = +118\%$
 $R_{100\%} = 1,05$
 $R_{50\%} = 4,5$
 $D_{2cm} = 48,5\%$
 $V_{20Gy} = 2,5\%$



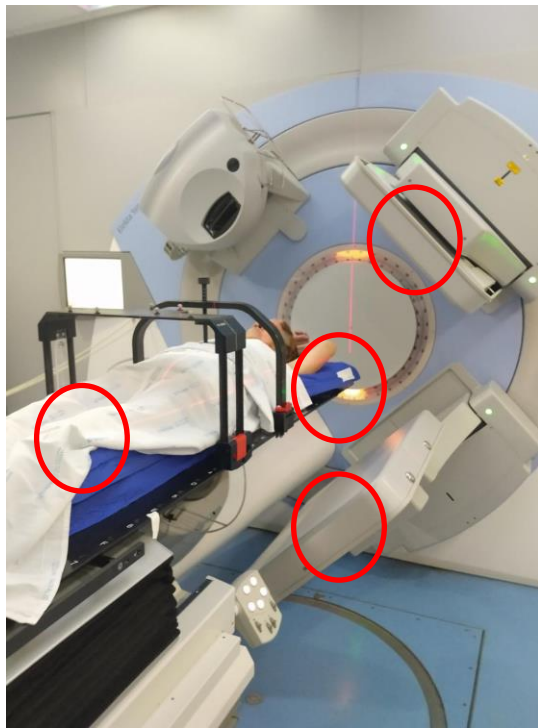
Clearance

- CT Simulação

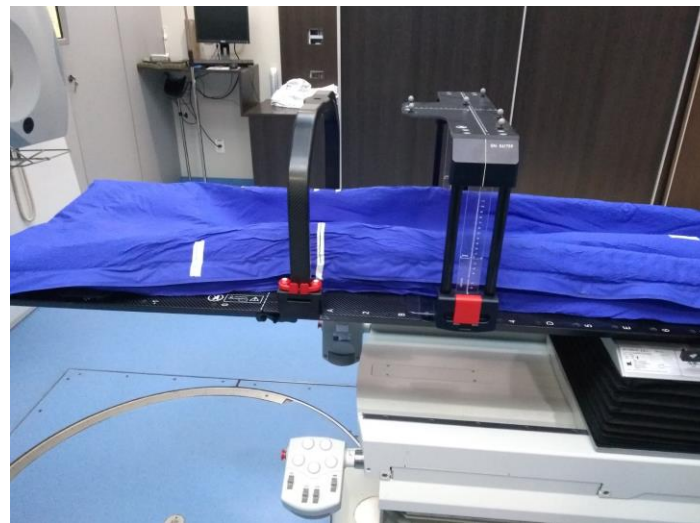
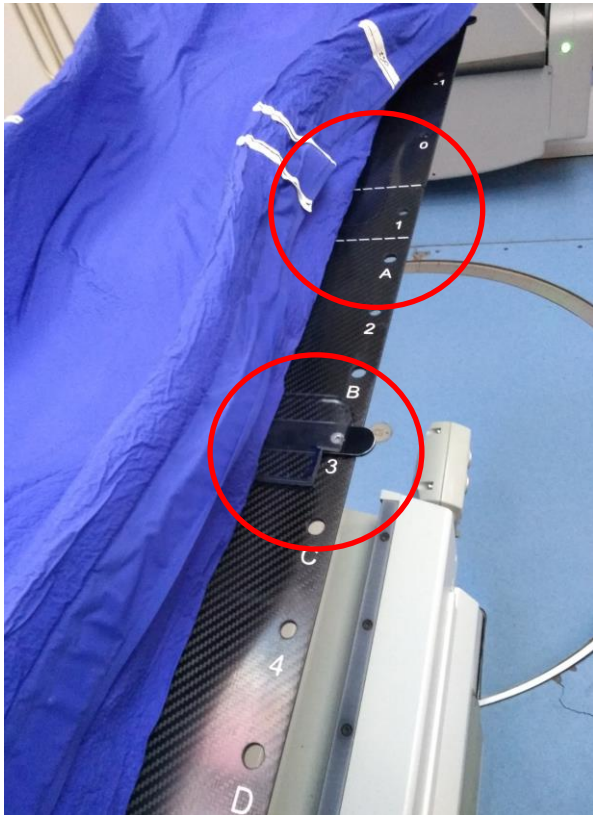


Clearance

- Tratamento



Clearance



SBRT - Fígado

6.1 Dose Specification (8/7/07)

6.1.1 The target dose is determined based on the study dose level and the volume of normal liver excluded from radiation (using the liver DVH) see Section 6.5. Treatment at the allocated dose level is only permitted if the normal tissue criteria in Section 6.5 are maintained. If the normal tissue criteria are not met at that dose, treatment at a lower dose level is permitted, as long as the normal tissue constraints are met at the lower dose level.

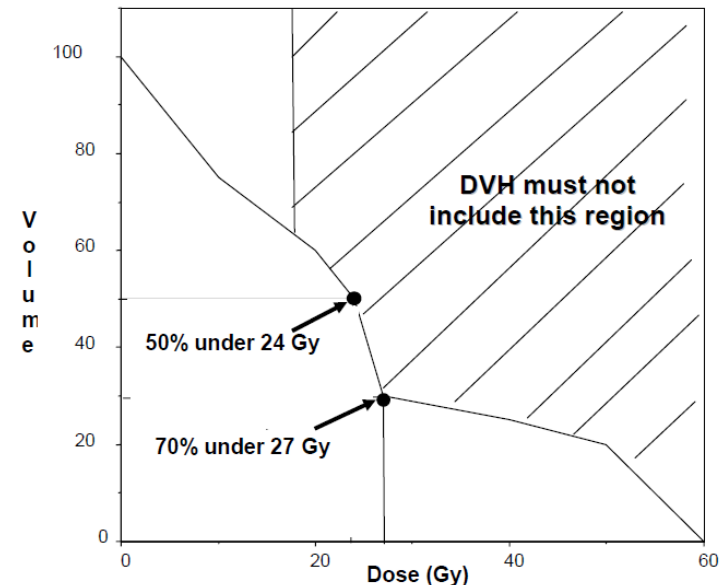
6.5 Critical Structures

6.5.1 Normal Liver: The normal liver is defined as that portion of liver not radiographically involved by gross tumor (Normal liver volume minus GTV). In all patients, it is required that there is at least 1000 cc of normal liver. No more than 30% of the normal liver may receive more than 27 Gy, and no more than 50% of normal liver may receive over 24 Gy. See figure below:

6.1.5 Table of permitted doses (in Gy)

Level	Total Dose (Gy)	Dose/fraction (100%)	PTV dose	
			Maximum (120%)	Minimum (90%)
I	35	3.5	4.2	3.15
II [†]	40	4.0	4.8	3.6
III	45	4.5	5.4	4.05
IV	50	5.0	6.0	4.5

[†] Protocol treatment begins at level II



RTOG 0438



SBRT - Fígado

- 6.1.3** Doses will be prescribed to a peripheral covering isodose covering the PTV. Assuming dose is normalized to this isodose at 100%, the maximal dose can be 120% and the minimum PTV dose 90%. Any dose > 110% must be within the PTV (except for adjacent tumors, in which the maximum dose outside the PTV must be < 115%). Minor variation is defined as minimum PTV dose falling between 85 and 90% (of the required 100% isodose prescription). Major variation (unacceptable) is defined as minimum PTV dose < 85 % (for the required 100% isodose prescription).
- 6.1.4** Maximum doses described in Section 6.1.3 are defined at 1 cc of volume. Minimum dose to the PTV is defined as minimum dose to 99.0% of the PTV.

6.1.5 Table of permitted doses (in Gy)

Level	Total Dose (Gy)	Dose/fraction (100%)	PTV dose	
			Maximum (120%)	Minimum (90%)
I	35	3.5	4.2	3.15
II [†]	40	4.0	4.8	3.6
III	45	4.5	5.4	4.05
IV	50	5.0	6.0	4.5

[†] Protocol treatment begins at level II

RTOG 0438



Planejamento

- Cobertura: $PTV_{V95\%PS} = 95\%$ (SABR-COMET)
- Arranjos de campos não-coplanares e não paralelos opostos (evitar sobreposição de campos)
- Mínimo de 7 campos! $\uparrow$ Alvo $\rightarrow \uparrow$ campos
- Restringir a dose de entrada de cada campos $\leq 30\%$ D_{tot} (TG101)
- Otimização de ângulo de colimador para melhor conformação
- Energia 6-25MV (RTOG 0438) e 6-10MV (SABR-COMET)
- IMRT: NÃO permitido no RTOG 0438
- IMRT: permitido no SABR-COMET – 1-2 VMAT arcos
- Rotina Radialis – VMAT é a primeira opção
- Grid de cálculo $\leq 3\text{mm}$ – Recomendação $\leq 2\text{mm}$ (TG101)



Constraints

Metastasis

If lesions > 2cm from Porta Hepatis/Bile Duct: Three Fractions 20Gy x 3

If lesions ≤ 2cm from Porta Hepatis/Bile Duct: Five Fractions 10Gy x 5

Liver minus-GTV: >700mL receive <15 Gy

Heart: <15cc receives ≥32 Gy; maximum point dose ≤52.5 Gy

Lung: <1000 cc receives ≥11.4 Gy (3.8 Gy/fx)

Esophagus: Maximal point dose is 27 Gy (9 Gy per fraction)

Stomach/Duodenum/Small Bowel: Maximal point dose 30 Gy

Kidney: ≤1/3 volume (sum of left and right) receives ≥15 Gy; V6 < 10%

Colon/Rectum: Maximal dose 34 Gy to 0.5 cc

Spinal Cord: Maximal point dose is 18 Gy (6 Gy per fraction)

Skin: Maximal point dose is 24 Gy (8 Gy per fraction)



Constraints

Hepatocellular Carcinoma

Five Fractions

- Normal Liver: defined as liver minus GTV
 - ≥ 700 cc liver volume must be outside of the PTV
 - Mean liver-GTV dose < 18 Gy
- Heart: Maximal dose in 40 Gy to 0.1 cc.
- Kidney: For patients with only one functioning kidney (as demonstrated by renal scan) or when one kidney is irradiated to mean dose > 12 Gy:
 - $> 80\%$ of the opposite kidney must receive < 12 Gy and volume receiving 6 Gy (V6) must be $< 10\%$.
 - Ideally $2/3$ of the combined kidney volume will receive < 15 Gy
- Spinal Cord: Maximal dose is 27 Gy to 0.1 cc.
- Duodenum: Maximal dose is 30 Gy to 0.5 cc.
- Small Bowel: Maximal dose is 30 Gy to 0.5 cc.
- Stomach: Maximal dose is 30 Gy to 0.5 cc.
- Large bowel: Maximal dose is 34 Gy to 0.5 cc.
- Esophagus: Maximal permitted dose is 30 Gy to 0.5 cc.
- Rib: Maximal point dose is 54 Gy.
- Liver capsule (5 mm within outer contour): Maximal point dose is 54 Gy.
- Skin (surface rim of 5 mm): Maximal point dose is 48 Gy.



SBRT - Pâncreas

Study	Number patients	Dose	Number fractions	Local control (%)	Median survival (mo)
Koong et al., 2005	16	25	1	94	8.25
Hoyer et al., 2005	22	45	3	57	5.7
Mahadevan et al., 2010	36	24-36	3	78	14.3
Schellenberg et al., 2011	12	25	1	94	11.8
Goyal et al., 2012	20	22-30	1-3	81	14.4
Lin et al., 2015	20	35-45	5	80	20
Moningi et al., 2015	88	25-33	5	61	14.4-18.4
Shaib et al., 2016	13	36-45	3	NR	11

Adapted from Kim et al., J Gastro Onc, 2016

All studies on unresectable patients, except Moningi, which included borderline resectable as well

- Astro Guideline – ASTRO RT for Pancreatic Cancer, 06/2019
- Goto et al. Radiation Oncology (2018) 13:118 – Clinical evaluation of intensity-modulated radiotherapy for locally advanced pancreatic cancer
- Stereotatic Body Radiotherapy for Unresected Pancreatic Cancer: a National Review, 2017



Planejamento

- Cobertura: $PTVV95\%PS = 95\%$ (SABR-COMET)
- Arranjos de campos não-coplanares e não paralelos opostos (evitar sobreposição de campos)
- Mínimo de 7 campos! $\uparrow$ Alvo $\rightarrow \uparrow$ campos
- Restringir a dose de entrada de cada campos $\leq 30\%$ D_{tot} (TG101)
- Otimização de ângulo de colimador para melhor conformação
- Energia 6-10MV (SABR-COMET)
- IMRT: permitido no SABR-COMET – 1-2 VMAT arcs
- Rotina Radialis – VMAT é a primeira opção
- Grid de cálculo $\leq 3mm$ – Recomendação $\leq 2mm$ (TG101)
- Prescrição:
 - 25-33Gy / 5fr
 - Considerar SIB 35-50Gy em áreas de acometimento de vasos



Constraints

Organ	Constraint	Organ	Constraint
Duodenum		Kidneys (combined)	
V30	<0.5 cc	Mean dose	<10 Gy
V18	<5 cc	Spinal Cord	
V12.5	<10 cc	V30	<0.035 cc
Stomach		Spinal Cord +5 mm	
V30	<0.5 cc	V25	<0.5 cc
V25	<5 cc		
Liver			
Mean dose	<15 Gy		

**These are institutional constraints for 5 fraction treatment created as an amalgam of published constraints (Moffitt, JHU) and those used in an institutional trial.*



Considerações Finais

- Seja **SEMPRE** cauteloso! Tenha sempre “medo” (no bom sentido)
- Defina os protocolos de SBRT (fracionamento/ esquemas de tto, prioridades, técnicas de planejamento e otimização, níveis de ação, constraints de dose,...)
- **SIGA O PROTOCOLO!!!**
- Revise periodicamente, com **TODA** a equipe, o protocolo
- Conheça bem o seu TPS, o seu AL e demais sistemas
- Faça sempre QA
- Crie uma cultura de segurança em todos os processos



OBRIGADO!



angel_s_martinez@yahoo.com.br