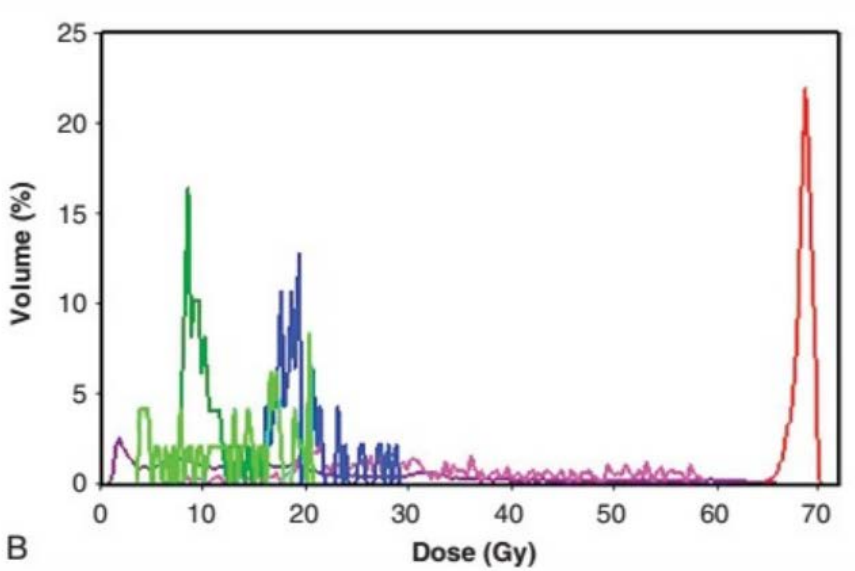
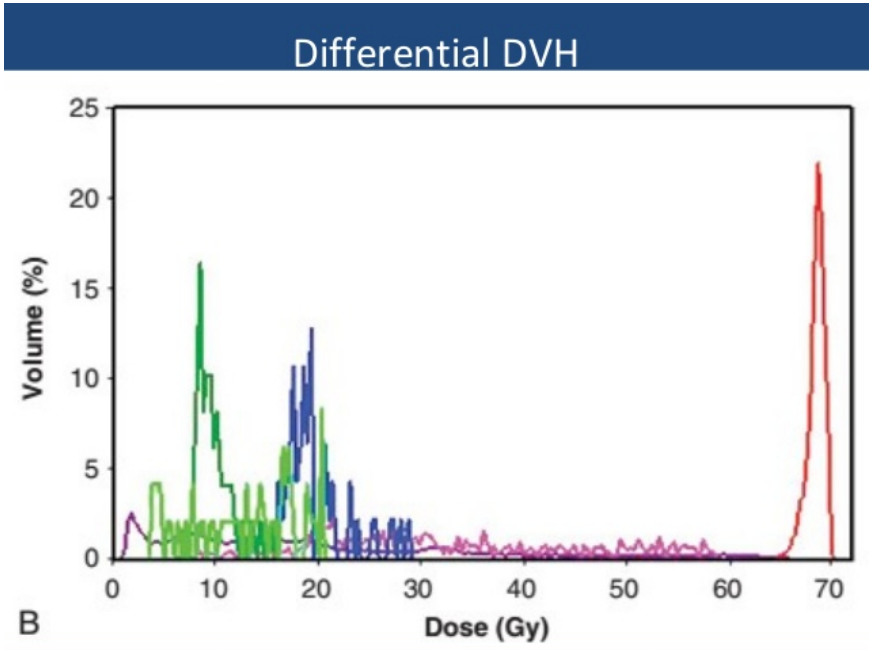
What is this figure?



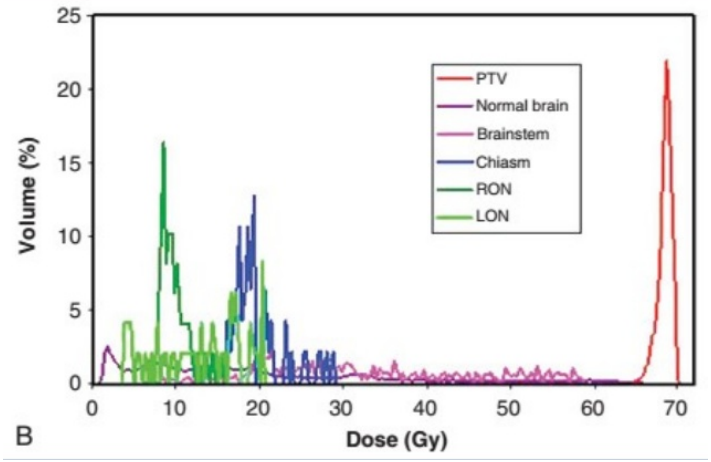
Which is the target in this figure?



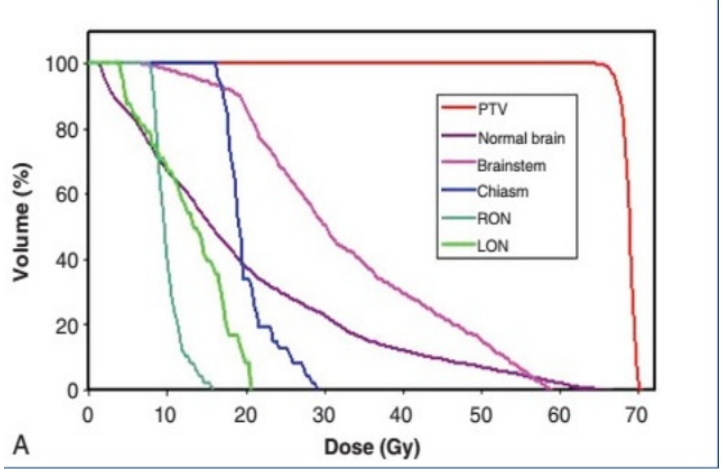
In a differential DVH, bar or column height indicates the volume of structure receiving a dose given by the bin. Bin doses are along the horizontal axis, and structure volumes (either percent or absolute volumes) are on the vertical.

What is the drawback of DVH?

Differential DVH



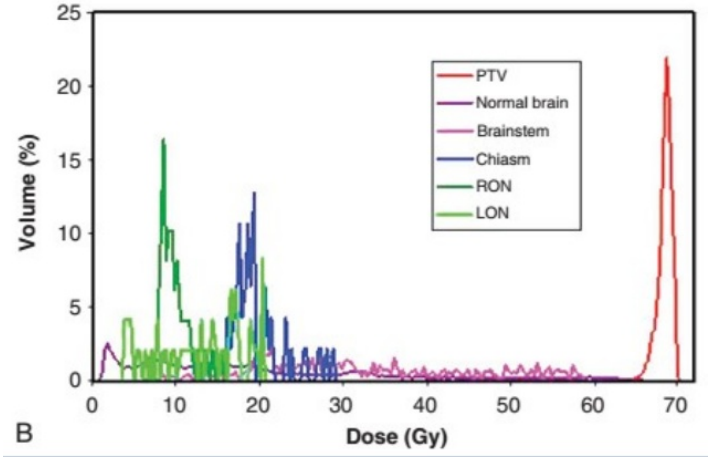
Cumulative DVH



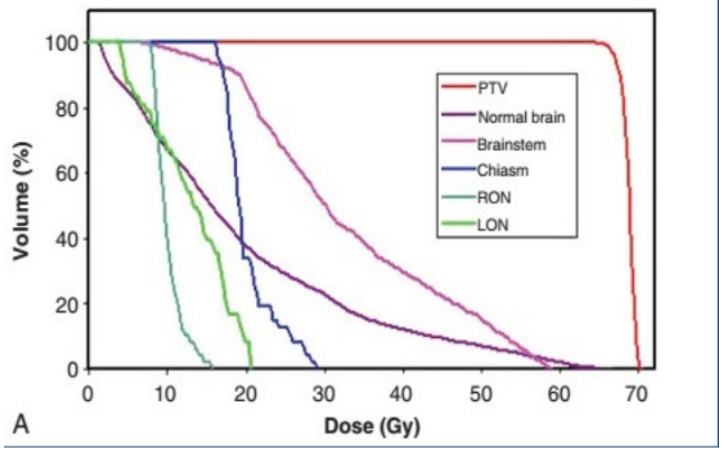
The cumulative DVH is plotted with bin doses along the horizontal axis, as well. However, the column height of the first bin (0-1 Gy, e.g.) represents the volume of structure receiving greater than or equal to that dose.

What is the drawback of DVH?

Differential DVH



Cumulative DVH



No spatial information; i.e., a DVH does not show where within a structure a dose is received

What other metrics we can calculate from DVH?

What other metrics we can calculate from DVH?

- Equivalent Uniform dose (EUD)

$$\mathrm{gEUD} = \left(\sum_i v_i D_i^a \right)^{1/a},$$

- Tumor control probability (TCP)

$$\mathrm{TCP} = \prod_{i=1}^{M} P(D_i)^{v_i},$$

$$P(D_i) = \exp\left(-\exp\left(e\gamma - \alpha D_i - \beta \frac{D_i^2}{n} \right) \right).$$

$$P(D_i) = \frac{1}{1 + (D_{50}/D_i)^k},$$

- Normal tissue complication probability (NTCP)

$$\mathrm{NTCP} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{t} e^{\frac{x^2}{2}} dx$$

$$t = \frac{D_{eff} - TD_{50}}{mTD_{50}}$$

$$D_{eff} = \left(\sum_i v_i D_i^{1/n} \right)^n,$$

● *Original Contribution*

DOSE-VOLUME HISTOGRAMS

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A plot of a cumulative dose-volume frequency distribution, commonly known as a dose-volume histogram (DVH), graphically summarizes the simulated radiation distribution within a volume of interest of a patient which would result from a proposed radiation treatment plan. DVHs show promise as tools for comparing rival treatment plans for a specific patient by clearly presenting the uniformity of dose in the target volume and any hot spots in adjacent normal organs or tissues. However, because of the loss of positional information in the volume(s) under consideration, it should not be the sole criterion for plan evaluation. DVHs can also be used as input data to estimate tumor control probability (TCP) and normal tissue complication probability (NTCP). The sensitivity of TCP and NTCP calculations to small changes in the DVH shape points to the need for an accurate method for computing DVHs. We present a discussion of the methodology for generating and plotting the DVHs, some caveats, limitations on their use and the general experience of four hospitals using DVHs.

Dose-volume histograms, Radiation therapy, Computerized treatment planning.

INTRODUCTION

total volume of a structure receiving dose within each

Clinical Investigations

Clinical dose–volume histogram analysis for pneumonitis after 3D treatment for non-small cell lung cancer (NSCLC)

Mary V Graham, M.D.[a], James A Purdy, Ph.D.[a], Bahman Emami, M.D.[a], William Harms, B.S.[a], Walter Bosch[a] (D.Sc.), Mary Ann Lockett[a] (M.B.A.), Carlos A Perez, M.D.[a]

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http://dx.doi.org/10.1016/S0360-3016(99)00183-2

Abstract

Purpose: To identify a clinically relevant and available parameter upon which to identify non-small cell lung cancer (NSCLC) patients at risk for pneumonitis when treated with three-dimensional (3D) radiation therapy.

Methods and Materials: Between January 1991 and October 1995, 99 patients were treated definitively for inoperable NSCLC. Patients were selected for good performance status (96%) and absence of weight loss (82%). All patients had full 3D treatment planning (including total lung dose–volume histograms [DVHs]) prior to treatment delivery. The total lung DVH parameters were compared with the incidence and grade of pneumonitis after treatment.

Results: Univariate analysis revealed the percent of the total lung volume exceeding 20 Gy (V_{20}), the effective volume (V_{eff}) and the total lung volume mean dose, and location of the tumor primary (upper versus lower lobes) to be statistically significant relative to the development of ≥ Grade 2 pneumonitis. Multivariate analysis revealed the V_{20} to be the single independent predictor of pneumonitis.

Conclusions: The V_{20} from the total lung DVH is a useful parameter easily obtained from most 3D treatment planning systems. The V_{20} may be useful in comparing competing treatment plans to evaluate the risk of pneumonitis for our individual patient treatment and may also be a useful parameter upon which to stratify patients or prospective dose escalation trials.

Technical note

A free program for calculating EUD-based NTCP and TCP in external beam radiotherapy

Hiram A. Gay[a], Andrzej Niemierko[b]

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[b] Department of Radiation Oncology, Massachusetts General Hospital, Boston, MA, USA

Received 18 July 2007, Accepted 23 July 2007, Available online 7 September 2007

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http://dx.doi.org/10.1016/j.ejmp.2007.07.001

Abstract

Purpose

Provide a simple research tool that may be used to calculate the NCTP or TCP of a particular treatment plan. Illustrate the implementation of the EUD-based NTCP and TCP models as a research tool.

Methods and materials

A high-level computing language was chosen to implement Niemierko's EUD-based NTCP and TCP mathematical models. The necessary treatment planning software requirements were clearly defined.

Results

The computer code is presented and explained. Six simple examples were created to quickly troubleshoot the reader's code implementation. A table of model parameters based on the Emami data was generated.

Tolerance dose

Fractionated radiotherapy

1. Rubin

Overview: Rubin 1967-

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Conventional	SBRT
Rubin	

- Very round numbers
- No volumes mentioned
- Vague endpoints

- Does provide both TD5/5 and TD50/5 !!

Tolerance doses (TD(5/5)-TD(50/5)) to whole-organ irradiation

Single dose (Gy)		Fractionated dose (Gy)	
Lymphoid	2–5	Testes	1–2
Bone marrow	2–10	Ovary	6–10
Ovary	2–6	Eye (lens)	6–12
Testes	2–10	Lung	20–30
Eye (lens)	2–10	Kidney	20–30
Lung	7–10	Liver	35–40
Gastrointestinal	5–10	Skin	30–40
Colorectal	10–20	Thyroid	30–40
Kidney	10–20	Heart	40–50
Bone marrow	15–20	Lymphoid	40–50
Heart	1–20	Bone marrow	40–50
Liver	15–20	Gastrointestinal	50–60
Mucosa	5–20	VCTS	50–60
VCTS	10–20	Spinal cord	50–60
Skin	15–20	Peripheral nerve	65–77
Peripheral nerve	15–20	Mucosa	65–77
Spinal cord	15–20	Brain	60–70
Brain	15–25	Bone and cartilage	>70
Bone and cartilage	>30	Muscle	>70
Muscle	>30		

Rubin P. Law and order of radiation sensitivity: absolute versus relative. In: Vaeth JM, Meyer JL, eds. Frontiers of radiation therapy and oncology. Basel: Karger; 1989:7–40

Textbooks from 1967 onward

TD5/5: 5% Tolerance Dose for 5 years
TD50/5: 50% Tolerance Dose for 5 years

http://www.tmedphys.wepassed.com/lectures/review/28

Fractionated radiotherapy

2. Emami's paper

Overview: Emami et al. 1991

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Conventional	SBRT
Rubin	
Emami	

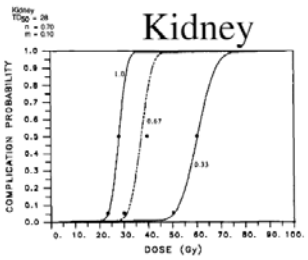

Fig. A12. Complication probability vs. dose for the kidney.

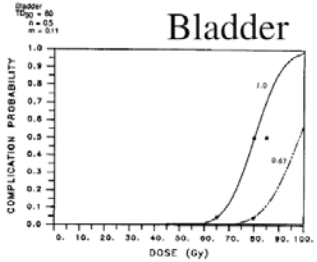

Fig. A1. Complication probability vs. dose for the bladder.

Table 1. Normal tissue tolerance to therapeutic irradiation

Organ	TD 5/5 Volume $\frac{1}{3}$	TD 5/5 Volume $\frac{2}{3}$	TD 5/5 Volume $\frac{3}{3}$	TD 50/5 Volume $\frac{1}{3}$	TD 50/5 Volume $\frac{2}{3}$	TD 50/5 Volume $\frac{3}{3}$	Selected endpoint
Kidney I	5000	3000*	2300	—	4000*	2800	Clinical nephritis
Kidney II							
Bladder	N/A	8000	6500	N/A	8500	8000	Symptomatic

Emami B, Lyman J, Brown A, Coia L, Goitein M, Munzenrider JE, Shank B, Solin LJ, Wesson M. Tolerance of normal tissue to therapeutic radiation.
Int J Radiat Oncol Biol Phys. 1991:21;109-122.

The most widely cited Red Journal paper of all time!!!

3. QUANTEC (QUANTATIVE ANALYSIS OF NORMAL TISSUE EFFECTS IN THE CLINIC)

Overview: QUANTEC

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Conventional	SBRT
Rubin	
Emami	
QUANTEC	

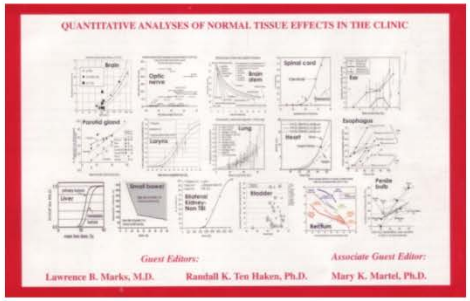


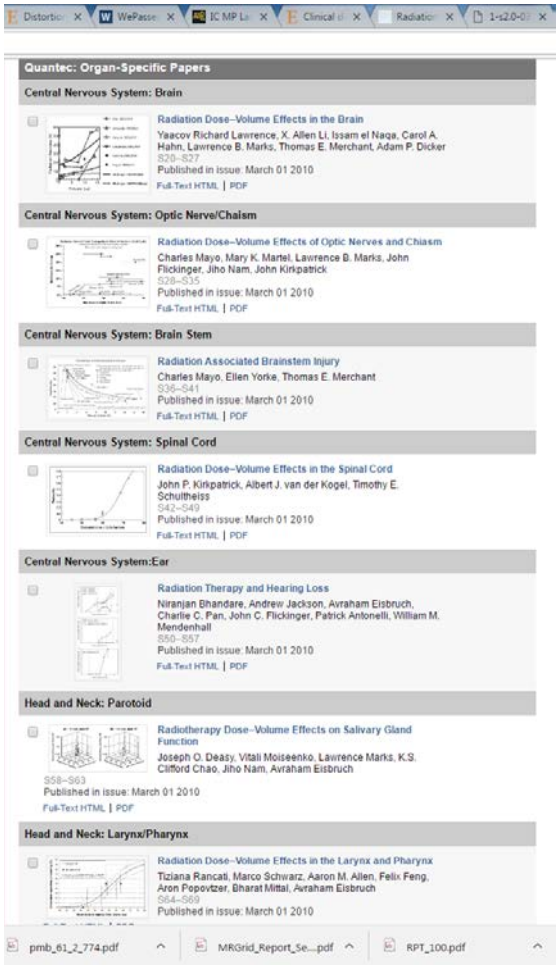
Table 1. QUANTEC Summary: Approximate Dose/Volume/Outcome Data for Several Organs Following Conventional Fractionation (Unless Otherwise Noted)*

Organ	Volume segmented	Irradiation type (partial organ unless otherwise stated)†	Endpoint	Dose (Gy), or dose/volume parameters†	Rate (%)	Notes on dose/volume parameters
Brain	Whole organ	3D-CRT	Symptomatic necrosis	Dmax <60	<3	Data at 72 and 90 Gy, extrapolated from BED models
	Whole organ	3D-CRT	Symptomatic necrosis	Dmax = 72	5	
	Whole organ	3D-CRT	Symptomatic necrosis	Dmax = 90	10	
	Whole organ	SRS (single fraction)	Symptomatic necrosis	V12 <5–10 cc	<20	Rapid rise when V12 > 5–10 cc
Brain stem	Whole organ	Whole organ	Permanent cranial neuropathy or necrosis	Dmax <54	<5	
	Whole organ	3D-CRT	Permanent cranial neuropathy or necrosis	D1–10 cc‖ ≤59	<5	

3. QUANTEC (QUANTATIVE ANALYSIS OF NORMAL TISSUE EFFECTS IN THE CLINIC)

Conventional fractionated 3D-CRT

Critical Structure	Volume	Dose/Volume	Max Dose	Toxicity Rate	Toxicity Endpoint
Brain			<60 Gy	<3%	Symptomatic necrosis
Brain			72 Gy	5%	Symptomatic necrosis
Brain			90 Gy	10%	Symptomatic necrosis
Brain stem			<54 Gy	<5%	Neuropathy or necrosis
Brain stem	D1-10 cc	<= 59 Gy		<5%	Neuropathy or necrosis
Brain stem			<64 Gy	<5%	Neuropathy or necrosis
Optic nerve/chiasm			<55 Gy	<3%	Optic neuropathy
Optic nerve/chiasm			55-60 Gy	3-7%	Optic neuropathy
Optic nerve/chiasm			>60 Gy	>7-20%	Optic neuropathy
Spinal cord			50 Gy	0.2%	Myelopathy
Spinal cord			60 Gy	6%	Myelopathy
Spinal cord			69 Gy	50%	Myelopathy
Cochlea	Mean	<=45 Gy		<30%	Sensory-neural hearing loss
Parotid, bilateral	Mean	<=25 Gy		<20%	Long-term salivary function <25%
Parotid, bilateral	Mean	<=39 Gy		<50%	Long-term salivary function <25%
Parotid, unilateral	Mean	<=20 Gy		<20%	Long-term salivary function <25%
Pharyngeal constrictors	Mean	<=50 Gy		<20%	Symptomatic dysphagia and aspiration
Larynx			<66 Gy	<20%	Vocal dysfunction
Larynx	Mean	<50 Gy		<30%	Aspiration
Larynx	Mean	<44 Gy		<20%	Edema
Larynx	V50	<27%		<20%	Edema
Lung	V20	<=30%		<20%	Symptomatic pneumonitis
Lung	Mean	7 Gy		5%	Symptomatic pneumonitis
Lung	Mean	13 Gy		10%	Symptomatic pneumonitis
Lung	Mean	20 Gy		20%	Symptomatic pneumonitis
Lung	Mean	24 Gy		30%	Symptomatic pneumonitis
Lung	Mean	27 Gy		40%	Symptomatic pneumonitis
Esophagus	Mean	<34 Gy		5-20%	Grade 3+ esophagitis
Esophagus	V35	<50%		<30%	Grade 2+ esophagitis
Esophagus	V50	<40%		<30%	Grade 2+ esophagitis
Esophagus	V70	<20%		<30%	Grade 2+ esophagitis
Heart (Pericardium)	Mean	<26 Gy		<15%	Pericarditis
Heart (Pericardium)	V30	<46%		<15%	Pericarditis
Heart	V25	<10%		<1%	Long term cardiac mortality



3. QUANTEC (QUANTATIVE ANALYSIS OF NORMAL TISSUE EFFECTS IN THE CLINIC)

1) Based on QUANTEC estimates for conventional fractionation, what is the 1% risk level for spinal cord:
   a) 45 Gy
   b) 50 Gy
   c) 54 Gy
   d) 60 Gy
   e) 61 Gy

3. QUANTEC (QUANTATIVE ANALYSIS OF NORMAL TISSUE EFFECTS IN THE CLINIC)

1) Based on QUANTEC estimates for conventional fractionation, what is the 1% risk level for spinal cord:

a) 45 Gy very low risk
b) 50 Gy 0.2% risk
c) **54 Gy 1% risk**
d) 60 Gy 6% risk
e) 61 Gy 10% risk

Endpoint: Myelopathy

SBRT tolerance dose

- **AJCO 2007**: Chang BK, Timmerman RD. Stereotactic Body Radiation Therapy: A Comprehensive Review. Am J Clin Oncol 2007;30:637-644.
- **Seminars 2008**: Timmerman RD. An overview of hypofractionation and introduction to this issue of seminars in radiation oncology. Semin Radiat Oncol. 2008;18:215-222.
- **TG101**: Benedict S , Yenice KM, Followill D, Galvin JM, Hinson W, Kavanagh B, Keall P, Lovelock M, Meeks S, Papiez L, Purdie T, Sadagopan R, Schell MC, Salter B, Schlesinger DJ, Shiu AS, Solberg T, Song DY, Stieber V, Timmerman R, Tomé WA, Verellen D, Wang L, Yin FF. Stereotactic body radiation therapy: The report of **AAPM Task Group 101**. Med. Phys. 2010 Aug;37(8):4078-4101.

- **NRG / RTOG / SABR Protocols**

SBRT tolerance dose

1) Which of the following contain NTCP estimates of risk for each dose tolerance limit:
   a) Rubin and Emami
   b) QUANTEC
   c) TG 101
   d) Seminars in Radiation Oncology April 2016

SBRT tolerance dose

1) Which of the following contain NTCP estimates of risk for each dose tolerance limit:
   a) Rubin and Emami
   b) QUANTEC
   c) TG 101
   d) Seminars in Radiation Oncology April 2016

a, b, d

TG 101 is a foundational landmark, but NTCP still needed

NTCP for SBRT

NTCP for SBRT, 60 authors from 15 institutions:

Dose Tolerance for Stereotactic Body Radiation Therapy
Seminars in Radiation Oncology, April 2016, NTCP for SBRT

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Introduction and Clinical Overview of the DVH Risk Map
Sucha O Asbell, MD, Jimm Grimm, PhD, Jinyu Xue, PhD, Meng-Sang Chew, PhD, and Tamara A LaCouture, MD

Optic Pathway
Stanford Data

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Iris C Gibbs, MD
Steven L Hancock, MD
Gordon Li, MD
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Cochlea
Georgetown Data

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Esophagus
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Chest Wall
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Aorta
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Bronchi
Erasmus MC Data

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Duodenum
CK Centre London Data

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Sucha O Asbell, MD

Spinal Cord
Stanford Data

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