Three Dimensional Intensity Modulated Brachytherapy (IMBT): Dosimetry Algorithm and Inverse Treatment Planning

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Clinical Challenges for Brachytherapy

➢ **Anatomy Limitation**

  ❖ **Critical structures are too close to the target**

  ❖ **Narrow physical space will not allow to put in larger equipment**

➢ **Source Limitation**

  ❖ **Radiation source will irritate radiation in 4π geometry**

  ❖ **Source is hard to modulate**
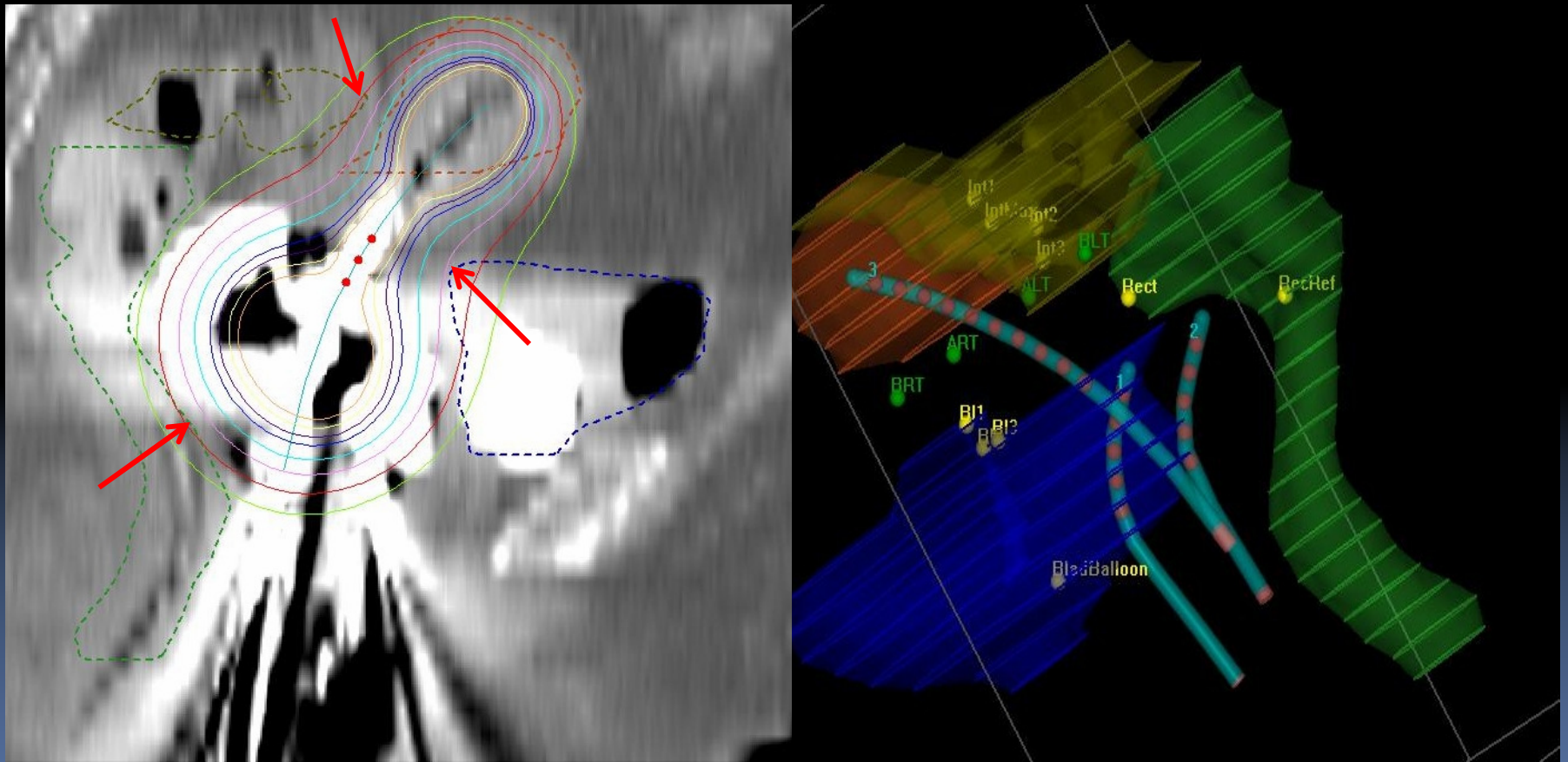
  ❖ **Source will decay**

➢ **Time Limitation**

  ❖ **Allow short time for planning**

➢ **Applicator Limitation**

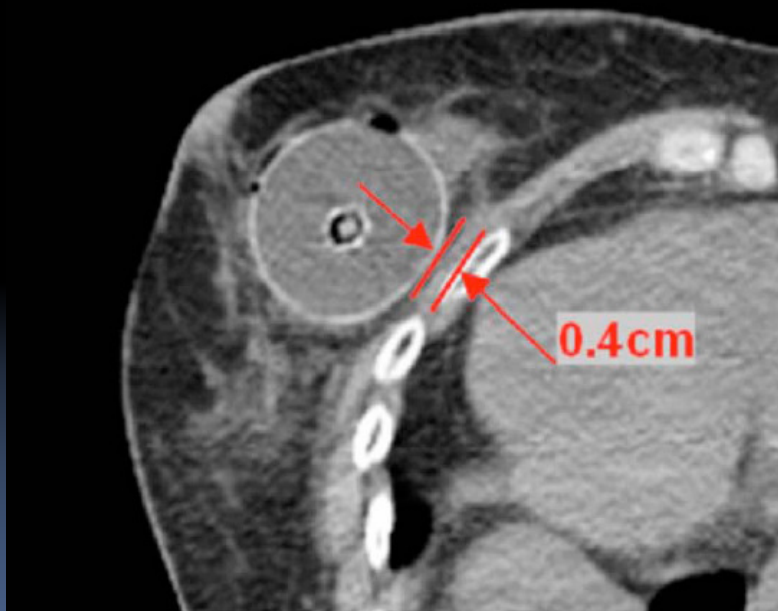 ❖ **Limited applicators available**

Introduction

- Scenario that you may want to use IMBT
  - To reduce the dose to adjacent normal tissue

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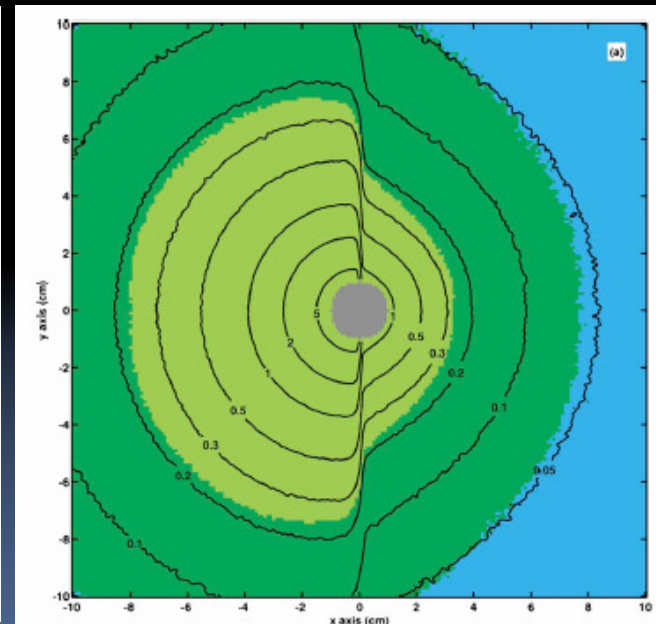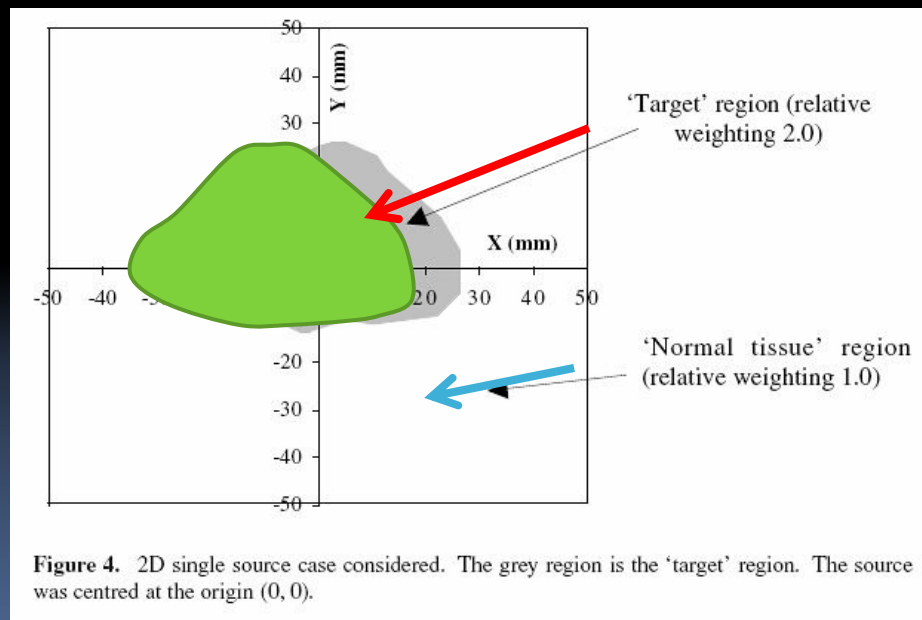 - To reduce the dose to adjacent normal tissue

Introduction

- ## Current approaches of IMBT
  - No commercial TPS
  - Directional sources
    - Use partial blocks to create a "fan beam" irradiation

Figure 4. 2D single source case considered. The grey region is the 'target' region. The source was centred at the origin (0, 0).

'Target' region (relative weighting 2.0)

'Normal tissue' region (relative weighting 1.0)
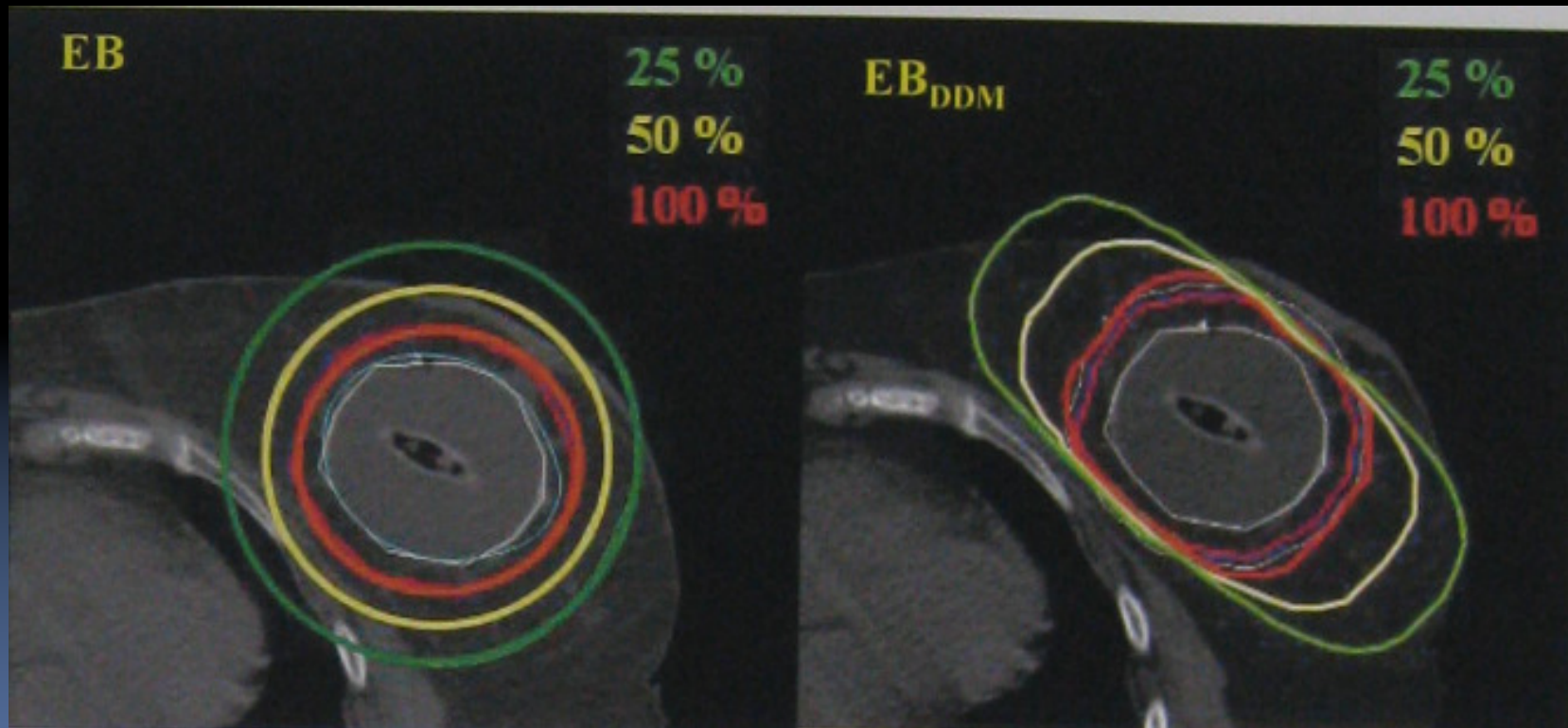
M A Ebert, Phy. Med. Biol. 47:2495-2509. 2002   Petrokokkinos etc. Med. Phys. 38(4) 2011

Introduction

- Current approaches of IMBT
  - Directional sources
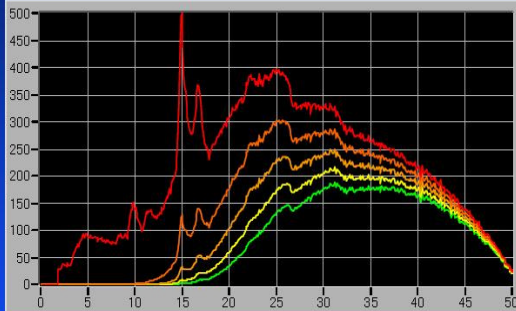   - Use partial blocks to create a "fan beam" irradiation

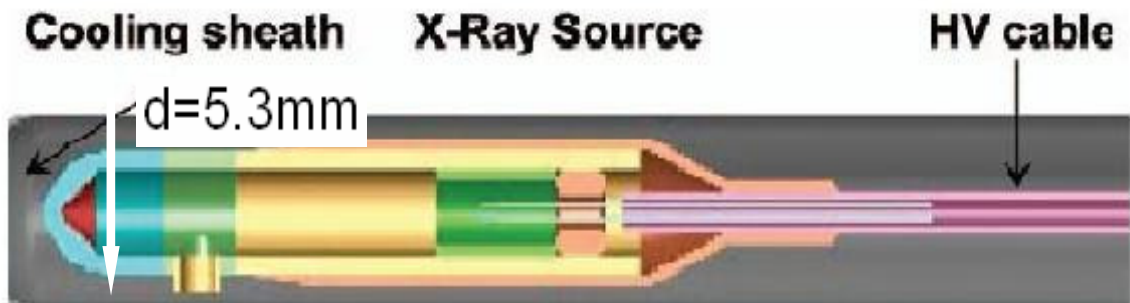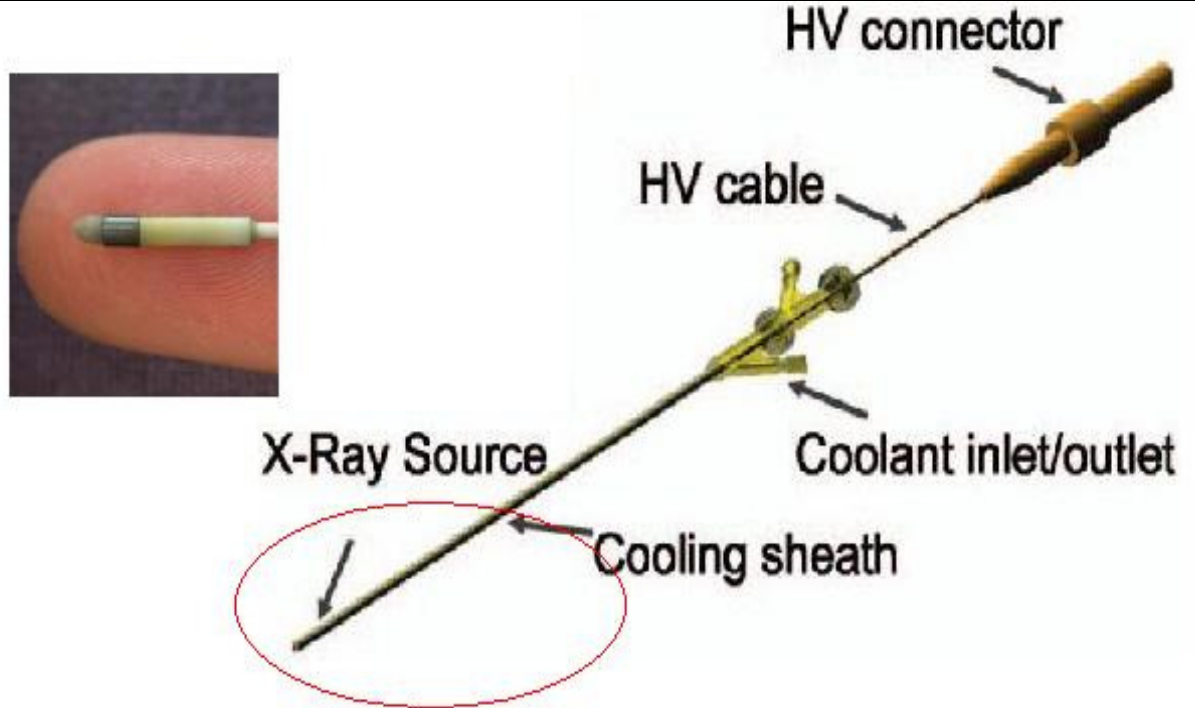*J Hiatt et al, Medical Physics. 36(6):2423, 2009*

Xoft Axxent^{TM} X-ray source

Tube spectra (counts vs. energy) during 50kVp operation through 0, 1, 2, 3 and 4 cm of water

Average energy: 26.7, 31.0, 32.6, 33.6 and 34.5 keV "Beam Quality", and therefore RBE, is similar to ^{125}I (28 keV average)

HV connector

HV cable

X-Ray Source

Coolant inlet/outlet

Cooling sheath

Cooling sheath   X-Ray Source   HV cable

d=5.3mm

Objectives

- The aims of this study are:

    - Propose a standardized dosimetry algorithm for 2D intensity modulated sources and a source characterization method for the application of this dosimetry algorithm

    - Develop a treatment planning system prototype utilizing this dosimetry method

    - Use this system to study the feasibility of 3D IMBT in improving plan quality

Materials and Methods

Characterization

1. How to define the intensity map of a source?
2. How to calibrate a intensity modulated source?

Planning

1. Forward planning
2. Inverse planning
   1) Define optimization criteria
   2) Optimization algorithms

Dosimetry

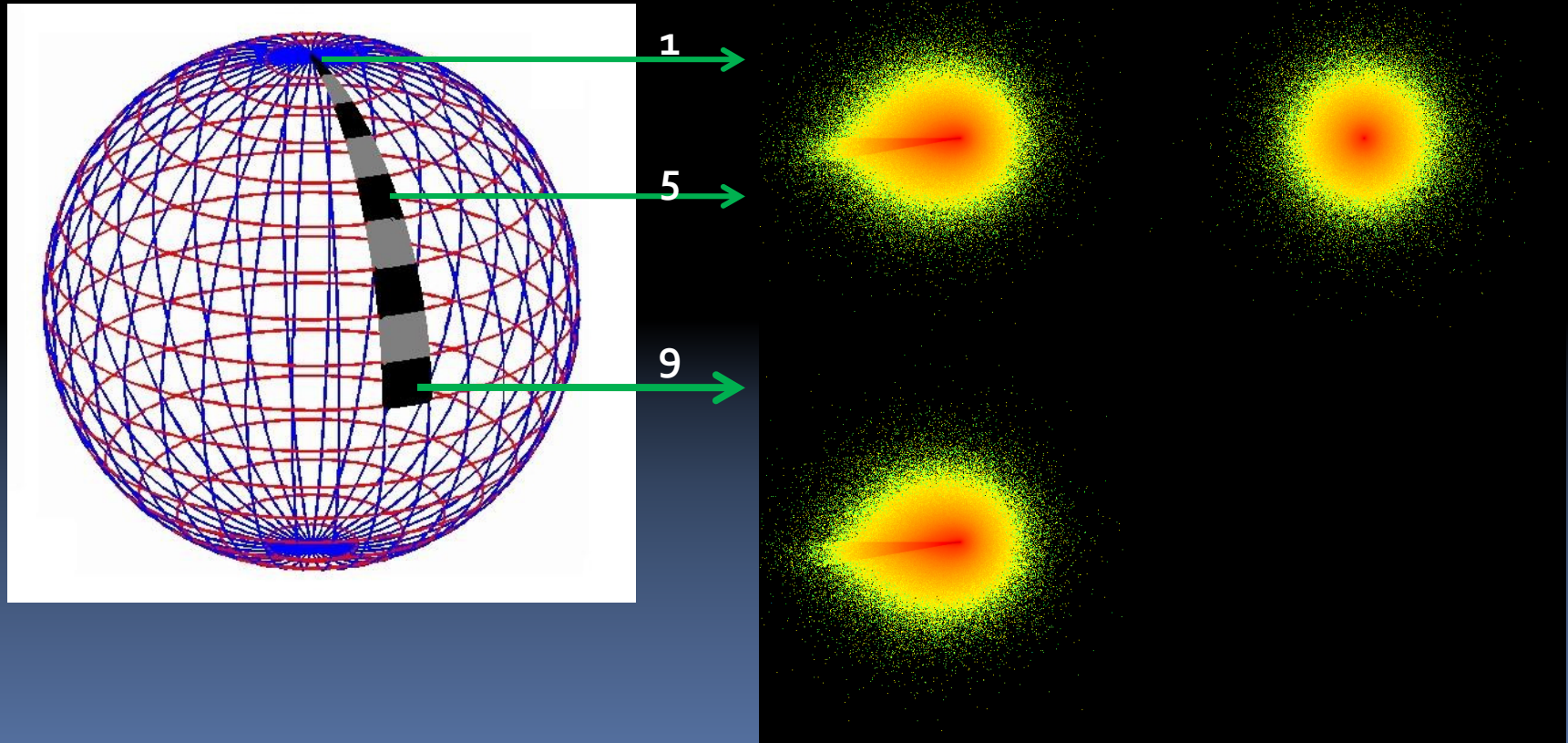1. Source intensity modulation correction: TG43 formulism?
2. Monte Carlo method?

Materials and Methods

- How to define the intensity distribution of a source
  - Divide into 18*36 segments, each 10^0 x 10^0
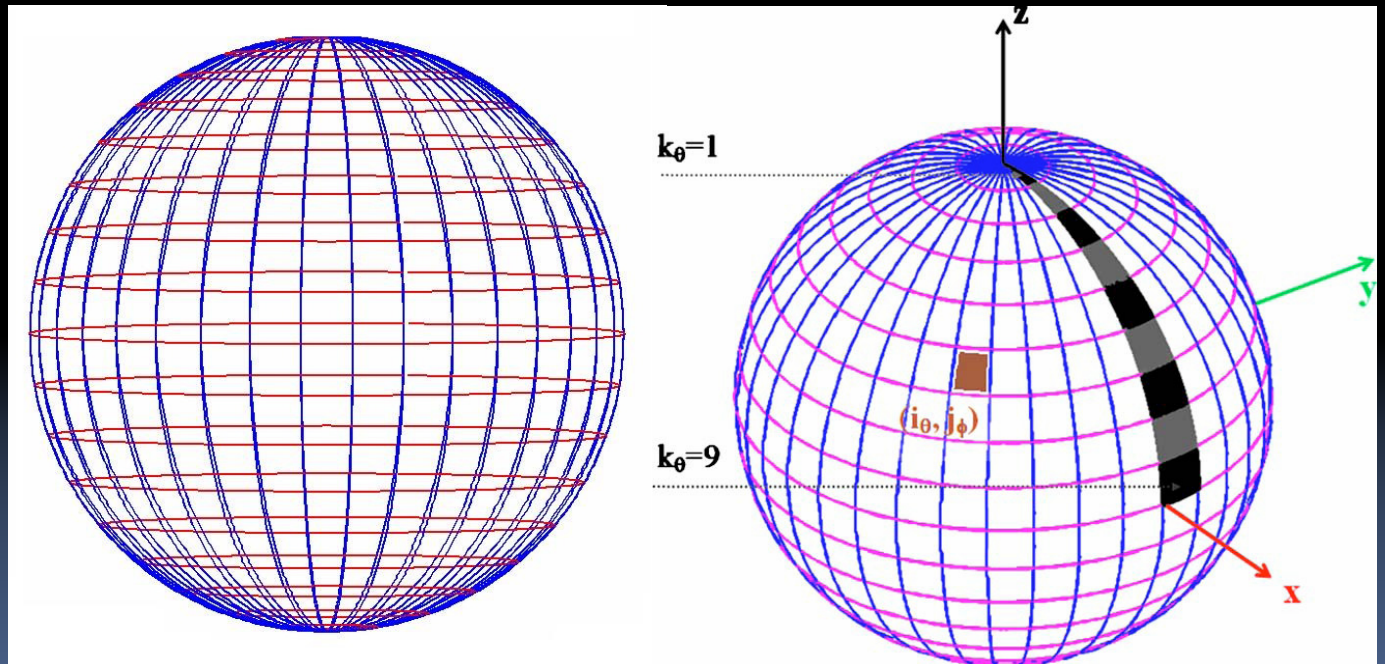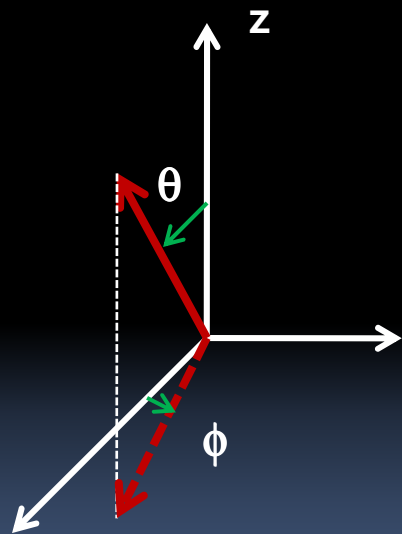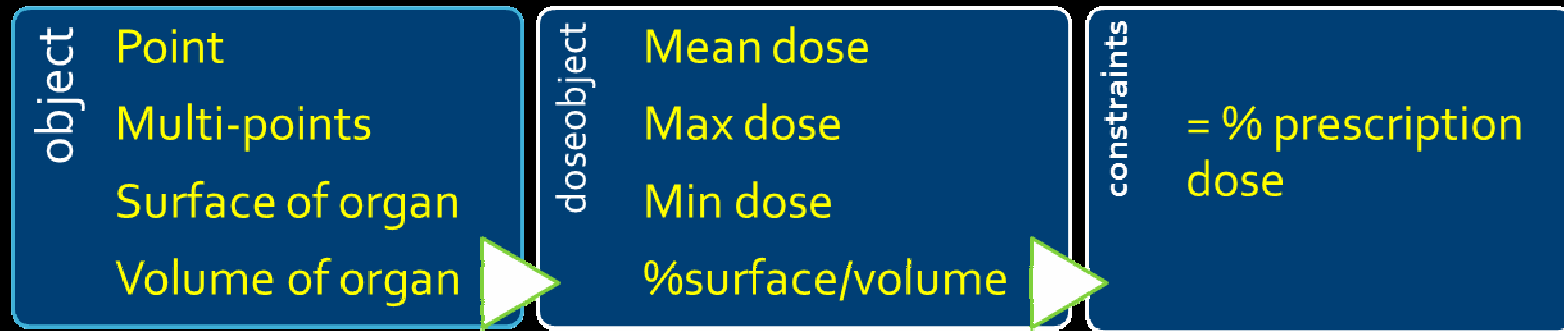
Materials and Methods

- ## How to calibrate a IMBT source?
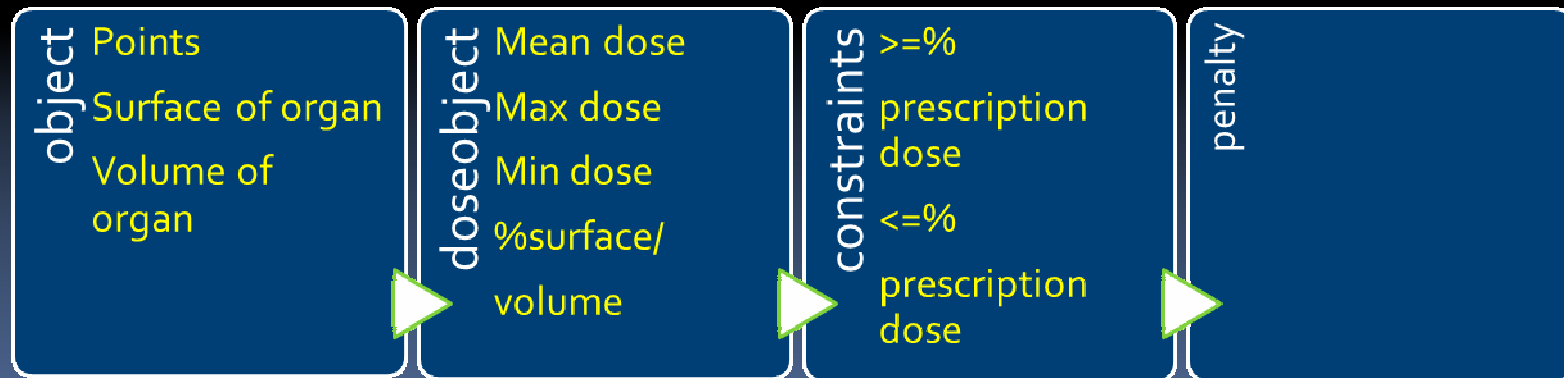 - Total 9 "beamlets", 1/72 of the total sphere

Materials and Methods

- ## Treatment planning
  - Inverse IMBT planning-optimization criteria
  - Prescribe to:

object	doseobject	constraints
Point	Mean dose	= % prescription dose
Multi-points	Max dose	
Surface of organ	Min dose	
Volume of organ	%surface/volume	

  - Optimization criteria

object	doseobject	constraints	penalty
Points	Mean dose	>=% prescription dose	
Surface of organ	Max dose		
Volume of organ	Min dose	<=% prescription dose	
	%surface/volume		

Materials and Methods

$$\dot{D}(r) = (S_k \wedge /r^2) g(r) \phi_{an}(r).$$

Air kerma strength

Dose rate constant

Geometry factor

Radial dose function

Anisotropy factor

$$\phi_{an}(r, \theta, \phi, I_{i_\theta j_\phi}) = \sum_{i_\theta=1}^{18} \sum_{j_\phi=1}^{36} I_{i_\theta j_\phi} \times \phi_{an,segment}^{i_\theta j_\phi}(r, \theta, \phi),$$
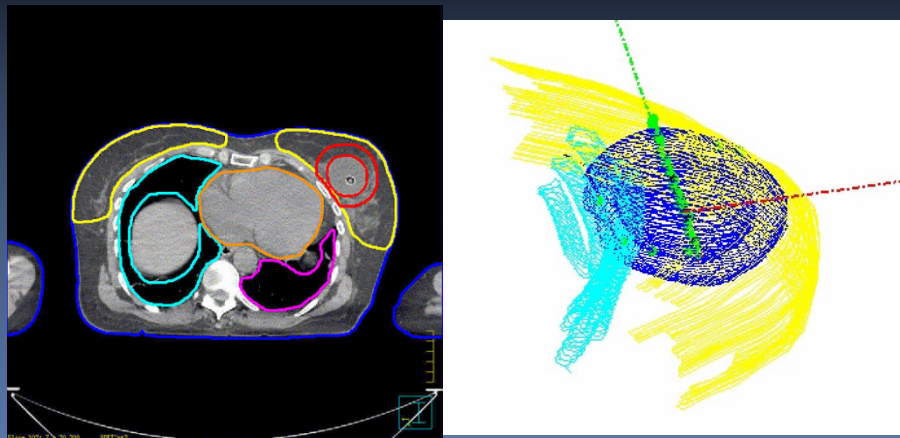
$$\text{where} \quad \phi_{an,segment}^{i_\theta j_\phi}(r, \theta, \phi) = \Phi^{k_\theta}(r, \theta', \phi') \quad \text{and}$$

$$\left\{ \begin{array}{ll} (k_\theta = i_\theta \quad \text{and} \quad \theta' = \theta) & \text{if } i_\theta \leq 9 \\ (k_\theta = 19 - i_\theta \quad \text{and} \quad \theta' = 180 - \theta) & \text{if } i_\theta > 9 \end{array} \right\},$$

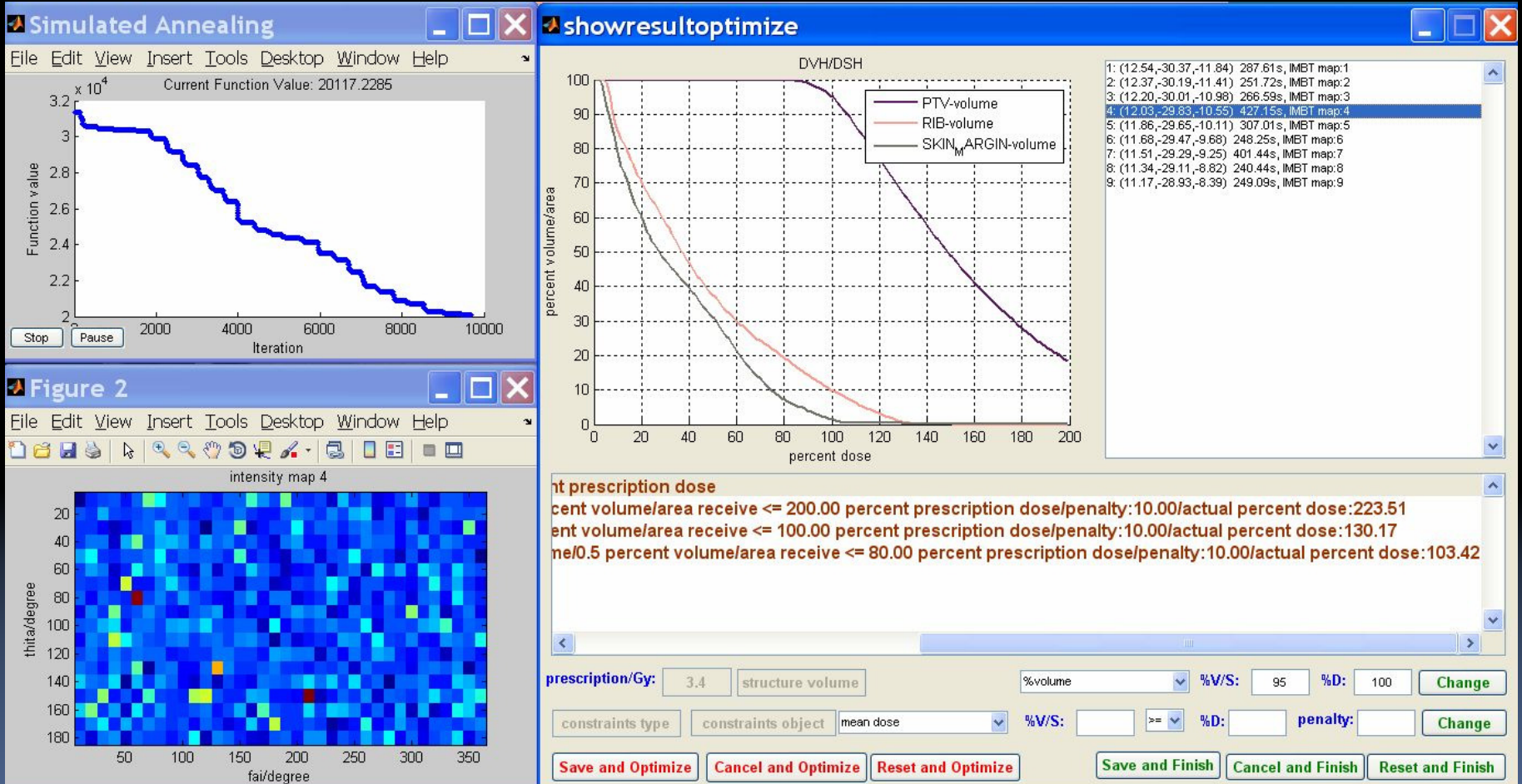$$\phi' = \phi - 10 \times (j_\phi - 1).$$

Materials and Methods

- Dosimetry
  - Monte Carlo
    - Previous study have showed that for low energy brachytherapy sources, the presence of tissue inhomogeneities and patient boundary will cause large dose discrepancies

    - Previous, we developed a Monte Carlo based dose calculation and evaluation system for brachytherapy, this system has recently upgraded to include IMBT simulation capability
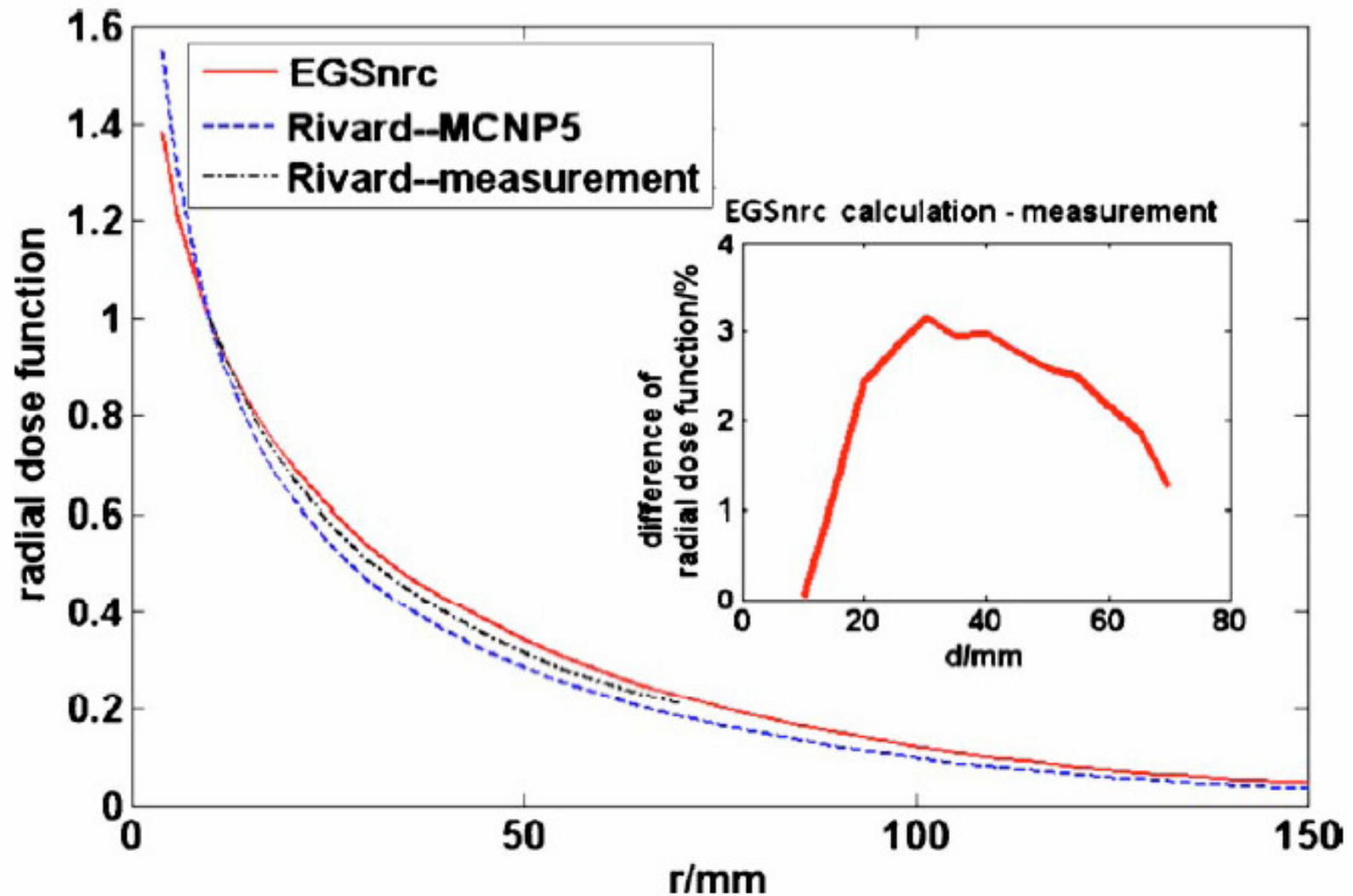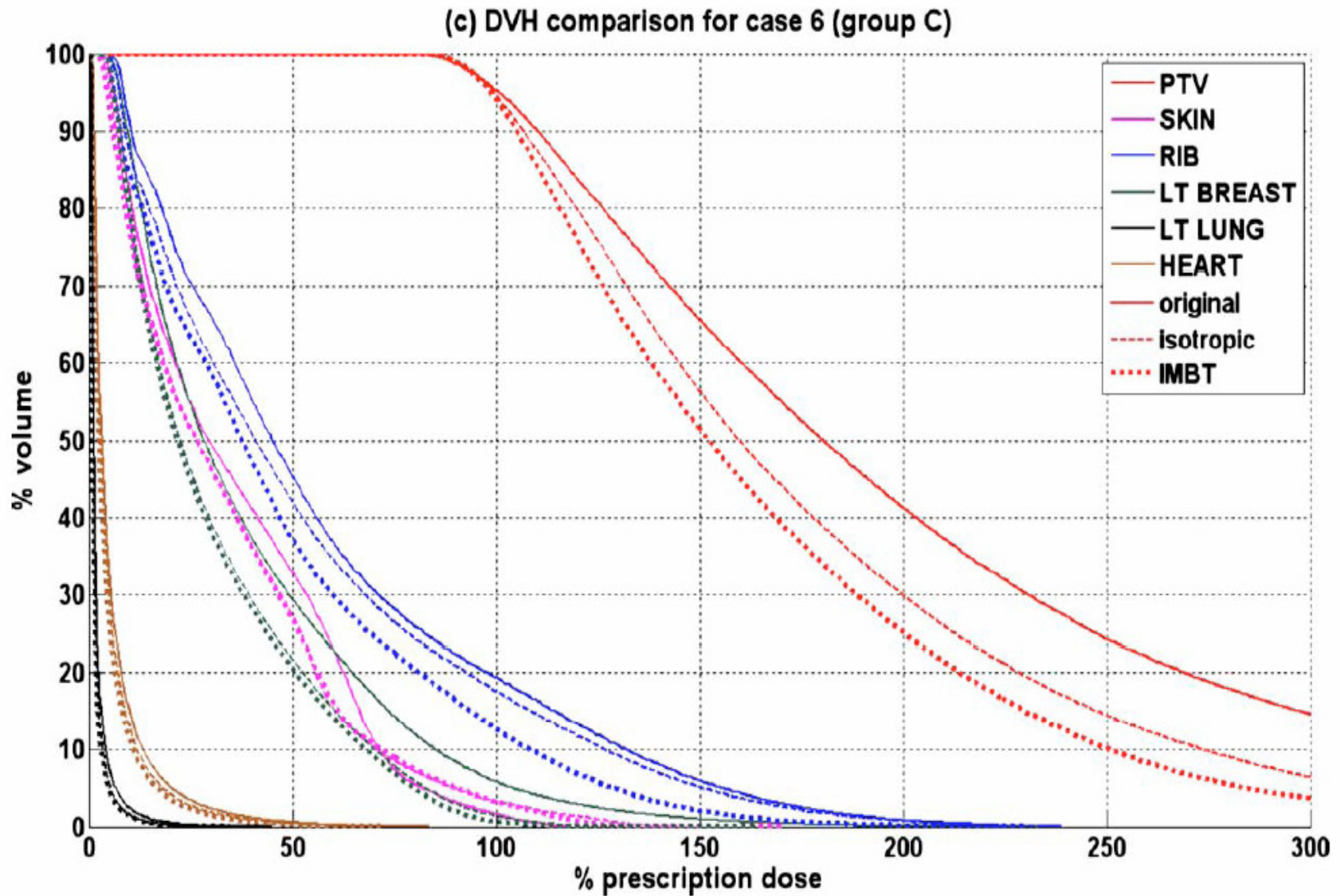
Materials and Methods
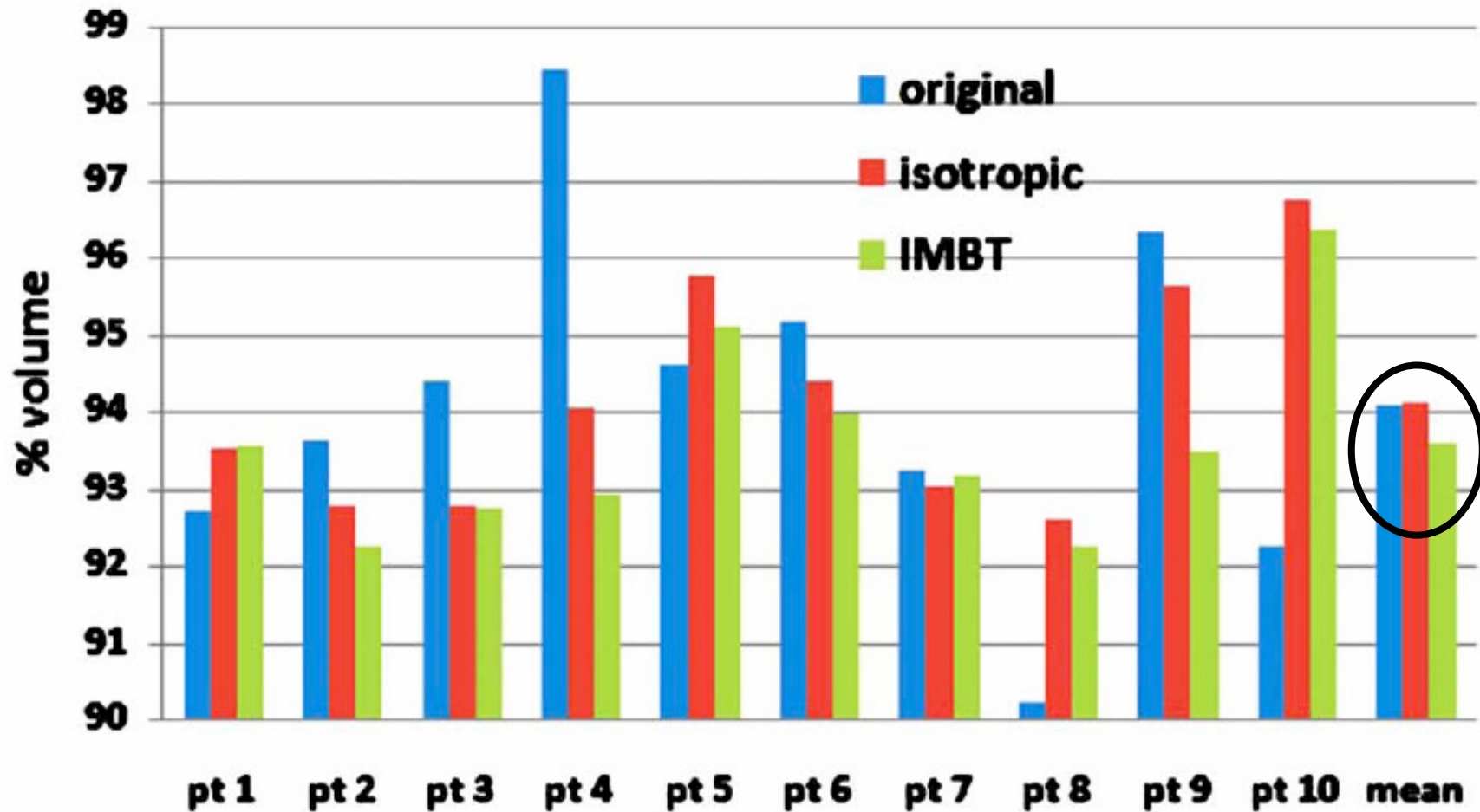
Results and Discussions

Results and Discussions

(a) DVH comparison for case 3 (group E)

Results and Discussions

(c) DVH comparison for case 6 (group C)

Legend:
- PTV
- SKIN
- RIB
- LT BREAST
- LT LUNG
- HEART
- original
- isotropic
- IMBT

Y-axis: % volume
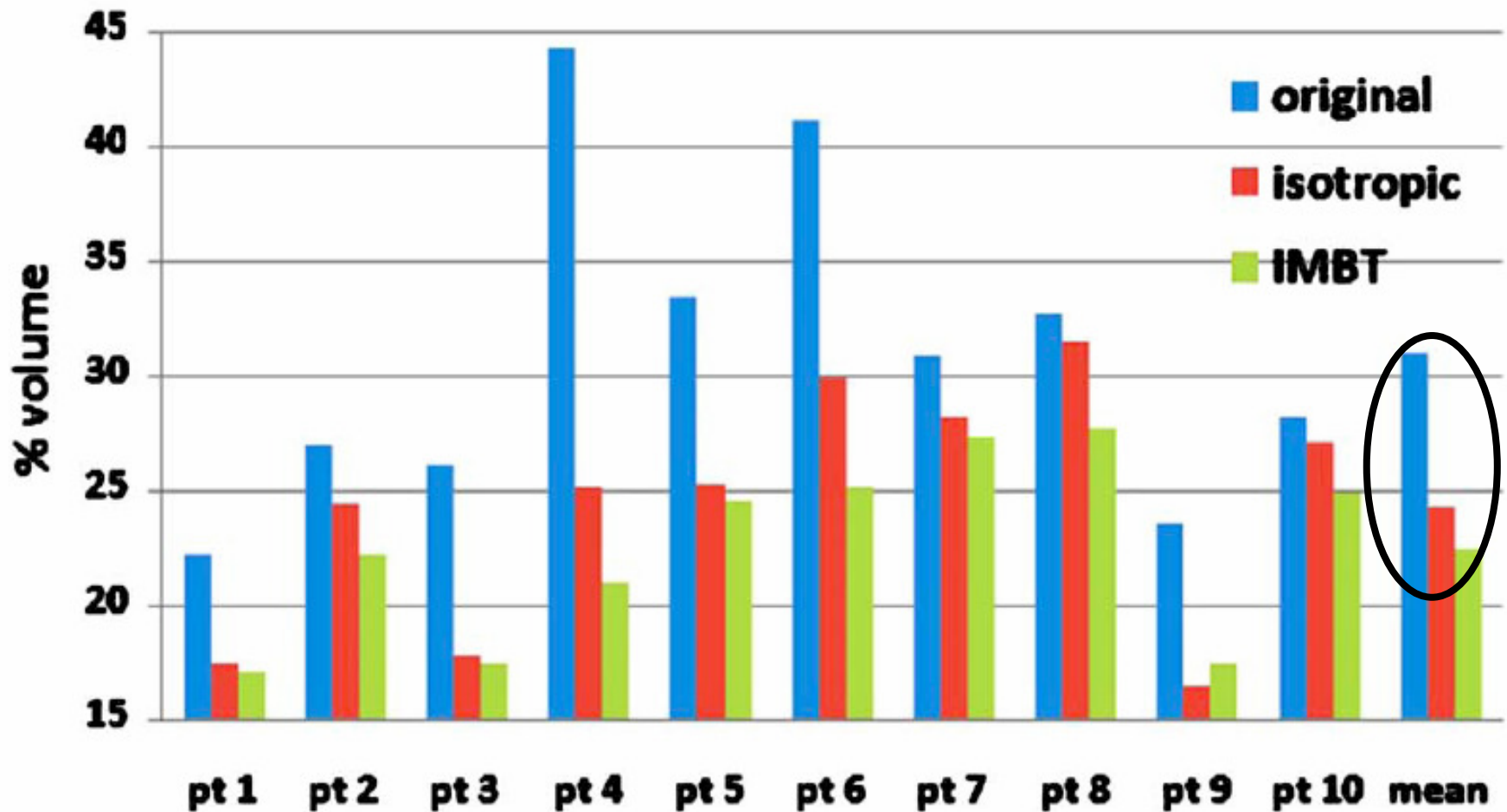
X-axis: % prescription dose

Results and Discussions
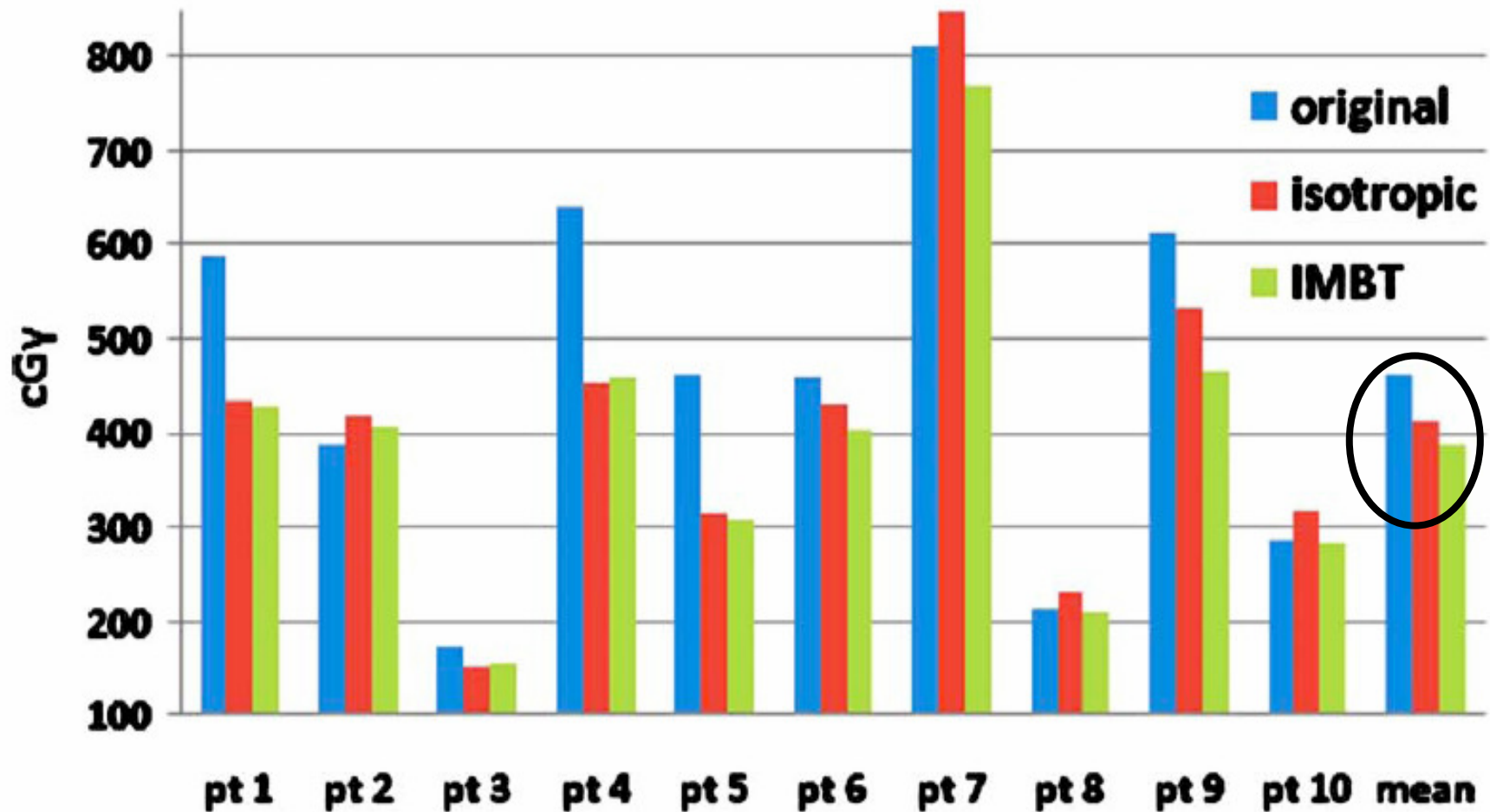

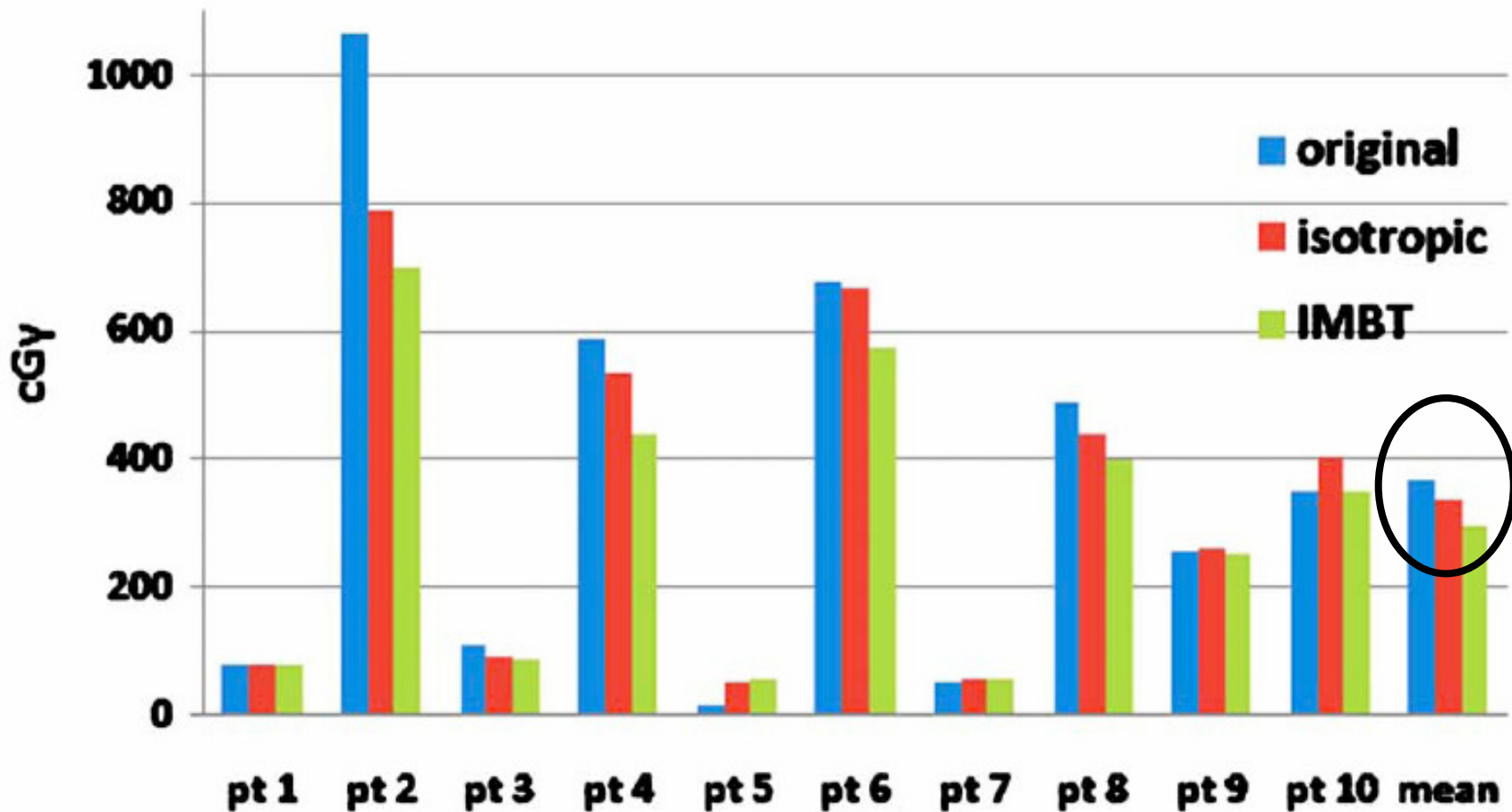(a) PTV V100

Results and Discussions

(b) PTV V200

Results and Discussions

(c) maximum dose to skin

Results and Discussions

(d) maximum dose to ribs

Conclusions

➢A dosimetry method has been proposed for IMBT and ten APBI cases were studied with IMBT

➢IMBT can further improve dose uniformity in the target and sparing to normal tissue as compared against the current clinical practice

➢However, the optimization and delivery time are prolonged

➢Delivery of IMBT plans depends on the further development of current technologies in source and applicator design

Future work
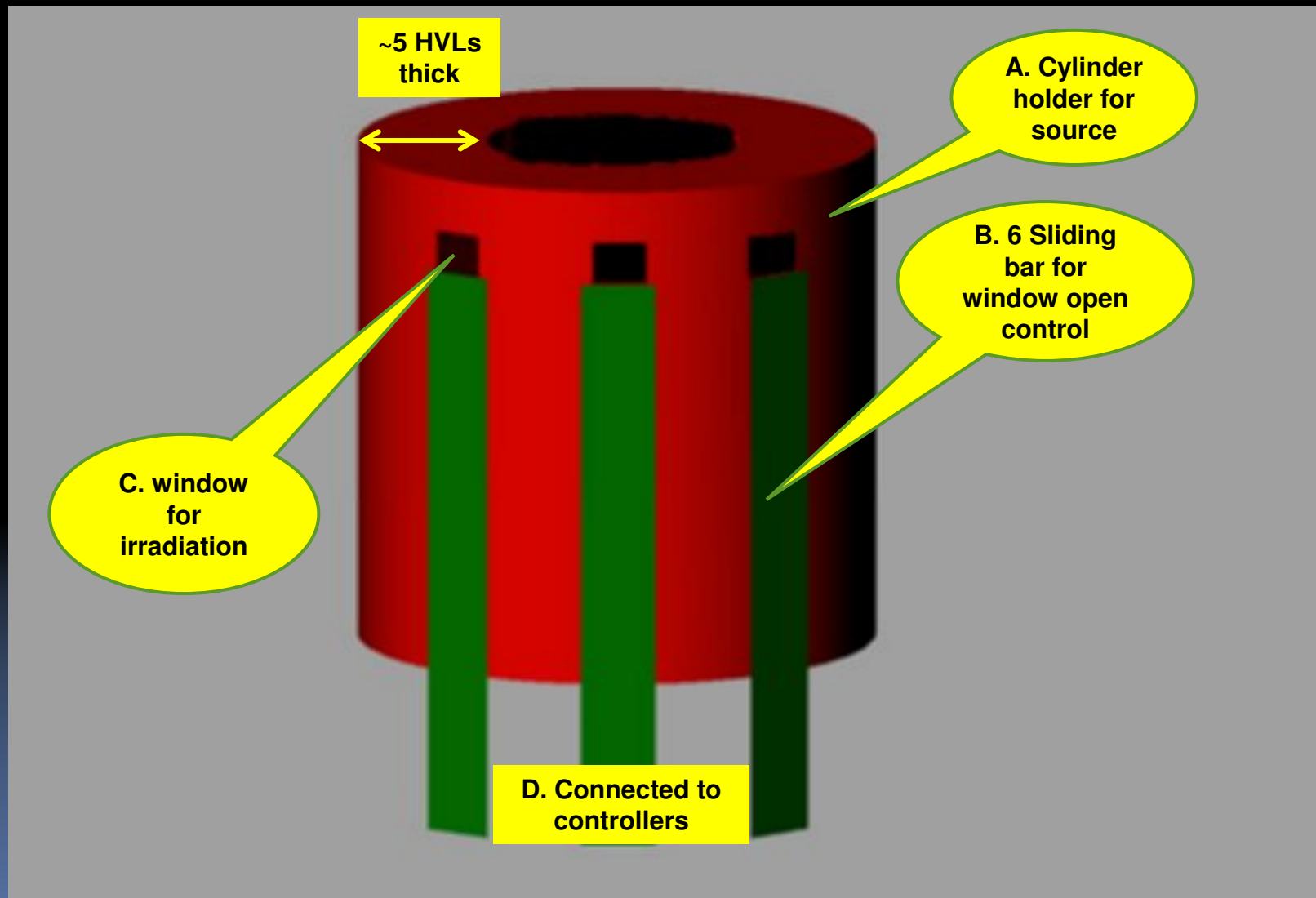
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References: Med. Phys. 37(7):3725-37 2010

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Thank You !