



Avaliação Dosimétrica de Múltiplas Metástases Encefálicas em Isocentro Único

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Especialista em Física da Radioterapia

METÁSTASES MÚLTIPLAS – TTO ISOCENTRICO

PHYSICS CONTRIBUTION

IJROBP
2010

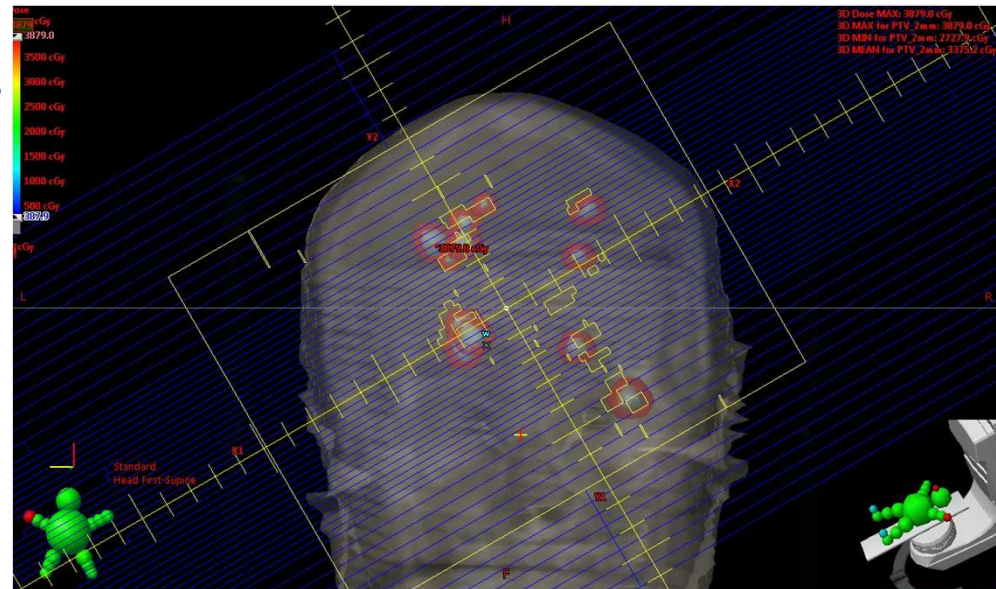
FEASIBILITY OF SINGLE-ISOCENTER VOLUMETRIC MODULATED ARC RADIOSURGERY FOR TREATMENT OF MULTIPLE BRAIN METASTASES

GRANT M. CLARK, M.D.,*[†] RICHARD A. POPPLE, PH.D.,* P. EDWARD YOUNG, M.S.,*
AND JOHN B. FIVEASH, M.D.*

*Department of Radiation Oncology, University of Alabama at Birmingham Comprehensive Cancer Center, Birmingham, AL; and

[†]West Virginia University School of Medicine, Morgantown, WV

- Tempo de tratamento encurtado (≈20min) independente das lesões
- Sistemas *frameless*
- Incorporação de imagens (ExacTrac, CBCT)
- Possibilidade técnica de tratamentos para mais de “3 lesões” (RTOG 9508)



Isocentrico vs. Muti isocentros

Frameless Image-Guided Radiosurgery for Multiple Brain Metastasis Using VMAT: A Review and an Institutional Experience

[Samir Abdallah Hanna](#),* [Anselmo Mancini](#), [Alisson Henrique Dal Col](#), [Rie Nadia Asso](#), and [Wellington Furtado Pimenta Neves-Junior](#)

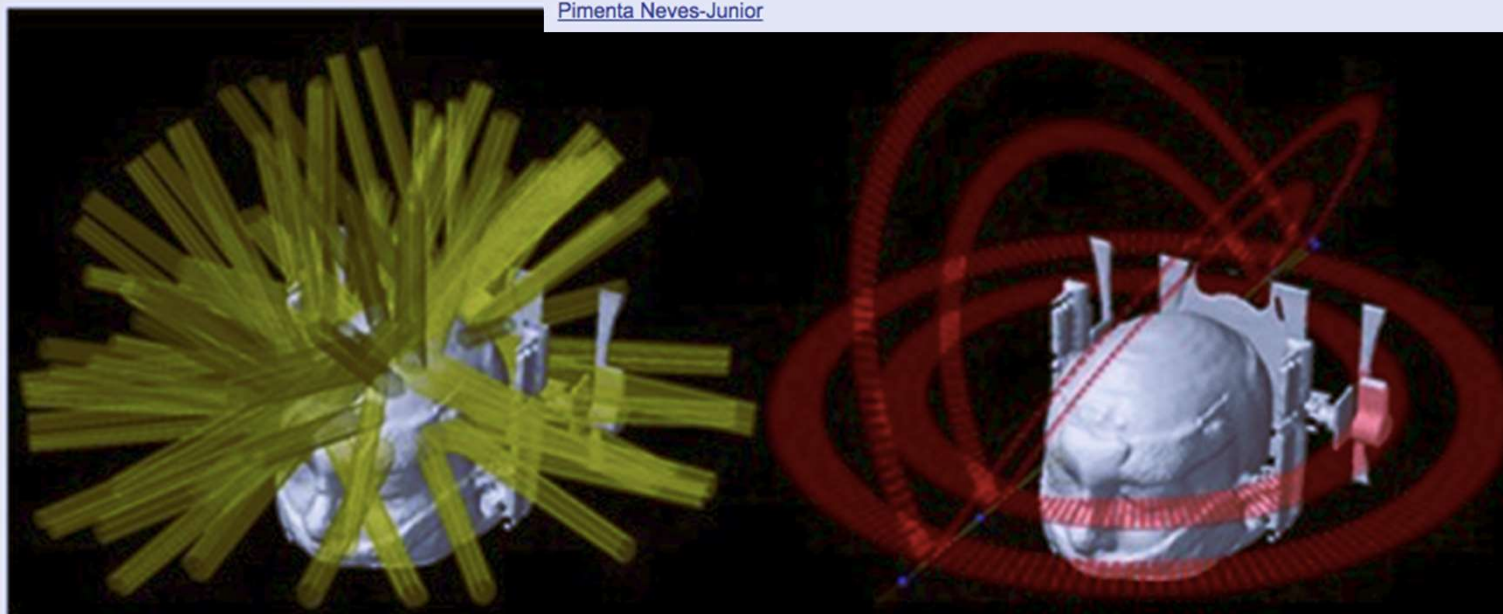


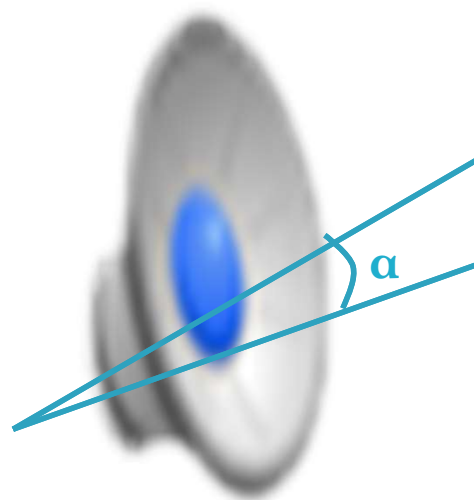
Figure 1

Field arrangements for two treatment techniques. (Left) 3D-CRT with 8 isocenters and 62 beams. (Right) VMAT with 1 isocenter and 6 arcs.

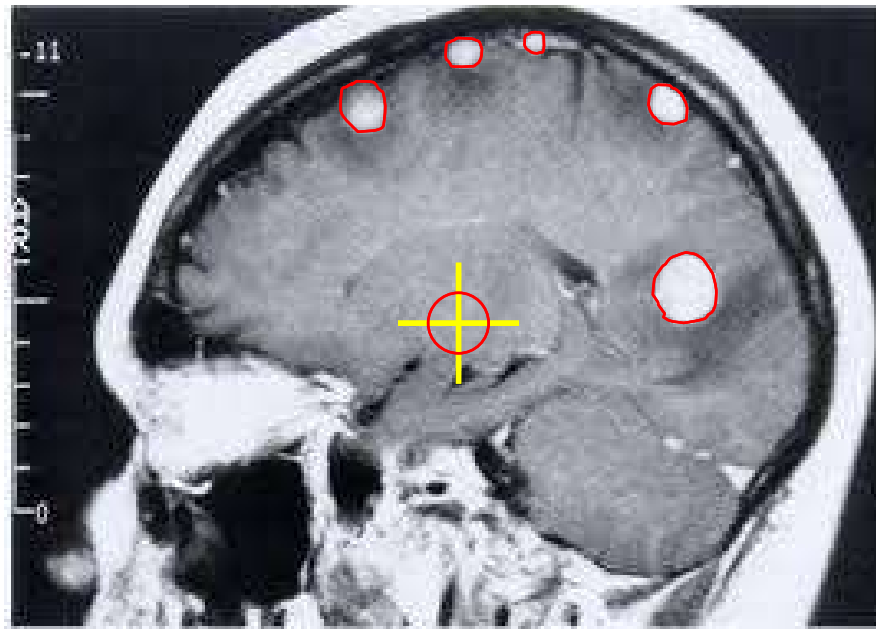
Hanna et al. Frameless Image-Guided Radiosurgery for Multiple Brain Metastasis Using VMAT: A Review and an Institutional Experience. Frontiers in oncology. 2019;9:703



O “RISCO ROTACIONAL”



Qual impacto dosimétrico?



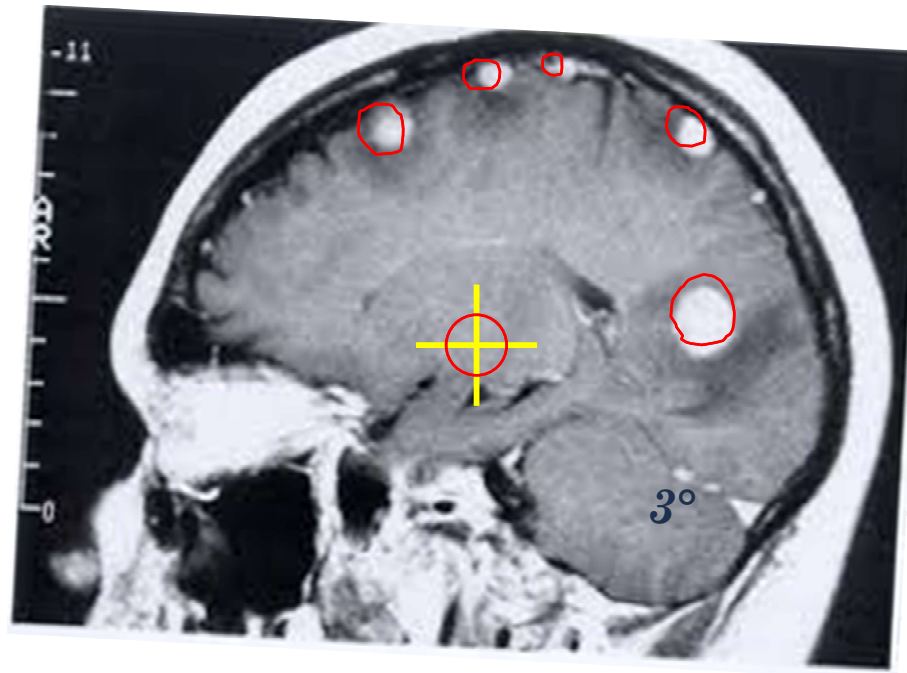
Qual impacto dosimétrico?

É linear?

Existe limite aceitável?

*Depende da
distância?*

*Existem
outros
fatores?*



*Depende da
posição do
isocentro?*

Perda de cobertura?

**Devemos fazer
Isocentricamente?**

Dose Média?



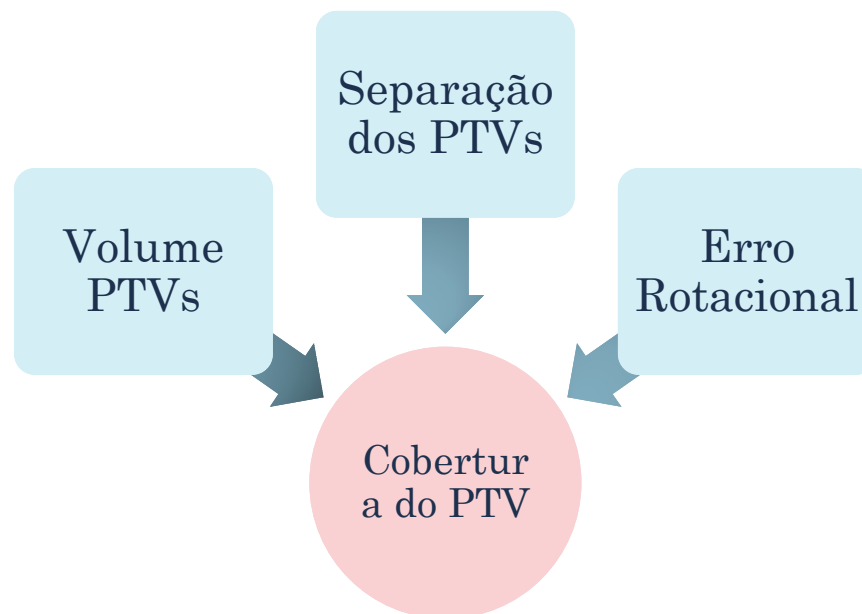
Qual impacto dosimétrico?

Single-Isocenter Multiple-Target SRS: Risk of Compromised Coverage

Justin Roper, PhD^{1,3}, Vorakarn Chanyavanich, PhD^{1,3}, Gregory Betzel, PhD^{1,3}, Jeffrey Switchenko, PhD^{2,3}, and Anees Dhabaan, PhD^{1,3}

Estudo retrospectivo:

- 50 casos, com **2 PTVs**
- 21Gy - VMAT
- Erros de 0,5°, 1,0° e 2,0°
- Análise de D_{95} e V_{95}

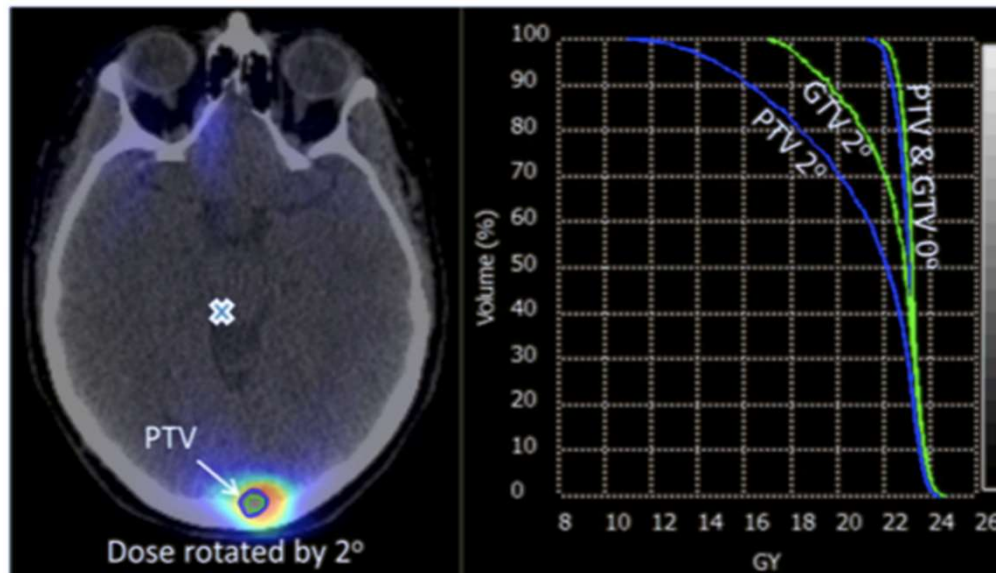


2 alvos e não utiliza margem de PTV



Single-Isocenter Multiple-Target SRS: Risk of Compromised Coverage

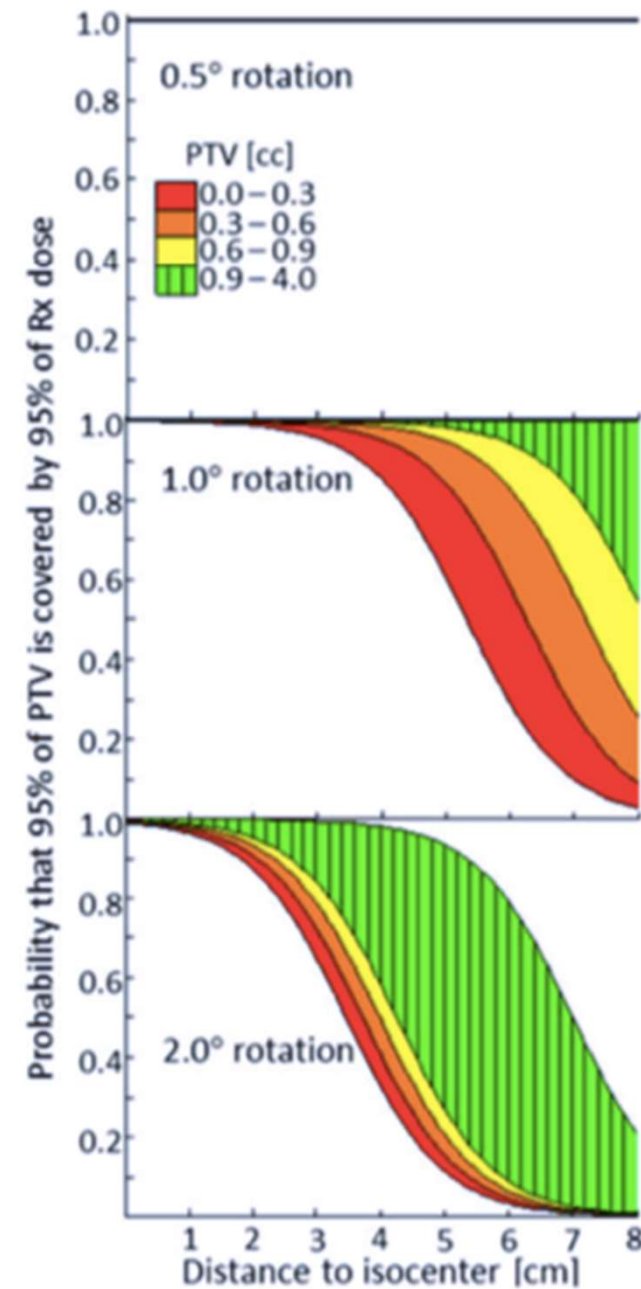
Justin Roper, PhD^{1,3}, Vorakarn Chanyavanich, PhD^{1,3}, Gregory Betzel, PhD^{1,3}, Jeffrey Switchenko, PhD^{2,3}, and Anees Dhabaan, PhD^{1,3}



Risco aumenta com:

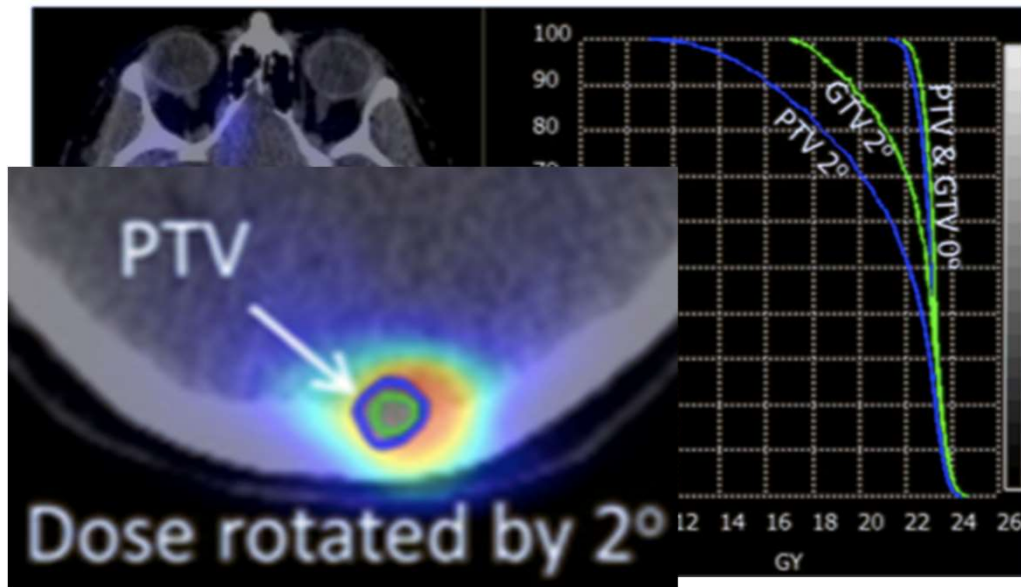
- ✧ Erro rotacional $>0,5^\circ$
- ✧ Distância do Isocentro
- ✧ Diminuição do volume

Int J Radiat Oncol Biol Phys. 2015 November 1; 93(3): 540–546



Single-Isocenter Multiple-Target SRS: Risk of Compromised Coverage

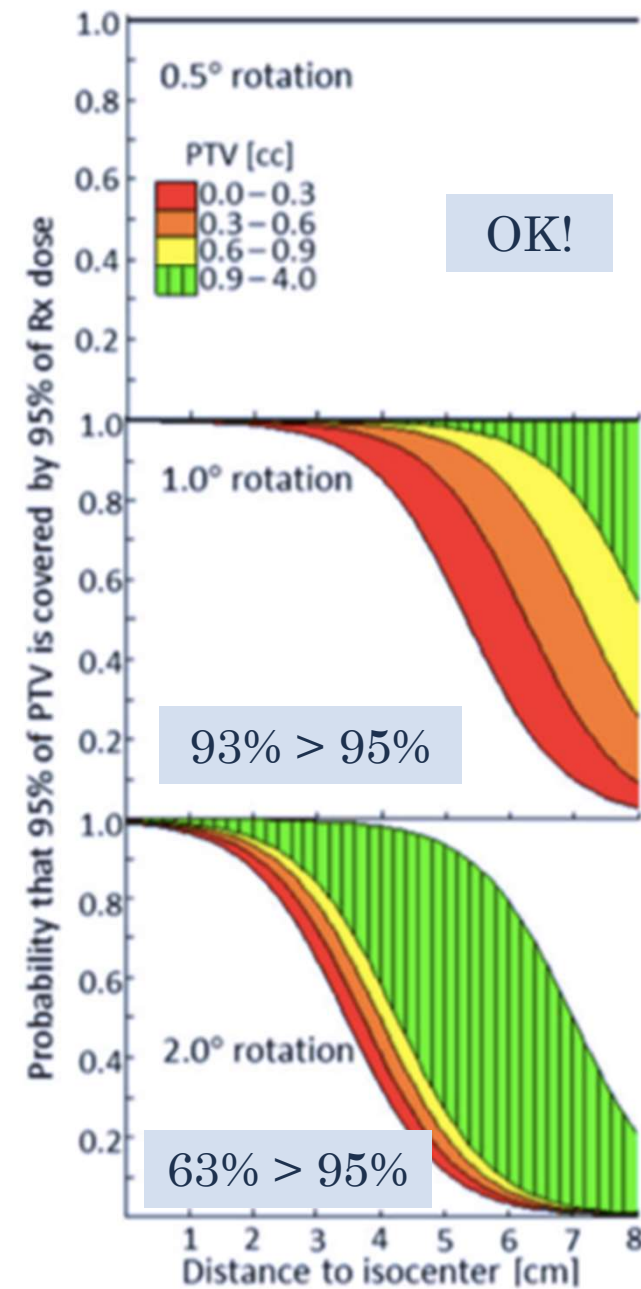
Justin Roper, PhD^{1,3}, Vorakarn Chanyavanich, PhD^{1,3}, Gregory Betzel, PhD^{1,3}, Jeffrey Switchenko, PhD^{2,3}, and Anees Dhabaan, PhD^{1,3}



Risco aumenta com:

- ✧ Erro rotacional >0,5°
- ✧ Distância do Isocentro
- ✧ Diminuição do volume

Int J Radiat Oncol Biol Phys. 2015 November 1; 93(3): 540–546



Qual impacto dosimétrico?

Dosimetric Effect of Rotational Setup Errors in Single-Isocenter Volumetric-Modulated Arc Therapy of Multiple Brain Metastases

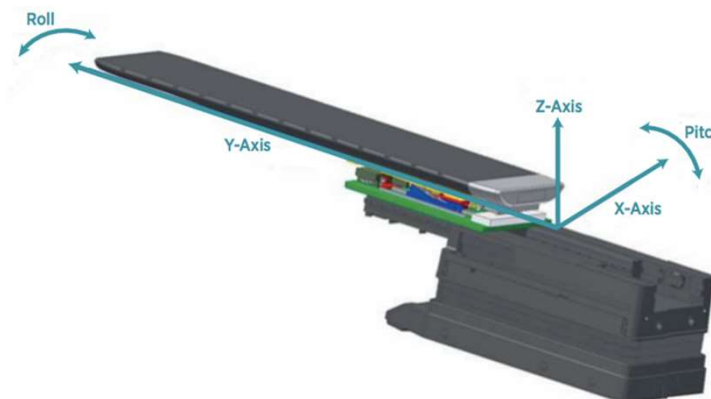
[Kasirajan Tamil Selvan](#),^{1,2} [Ganesan Padma](#),¹ [Murugesan Kesavan Revathy](#),¹ [N. Arunai Nambi Raj](#),³
[K. Senthilnathan](#),² and [P. Ramesh Babu](#)²

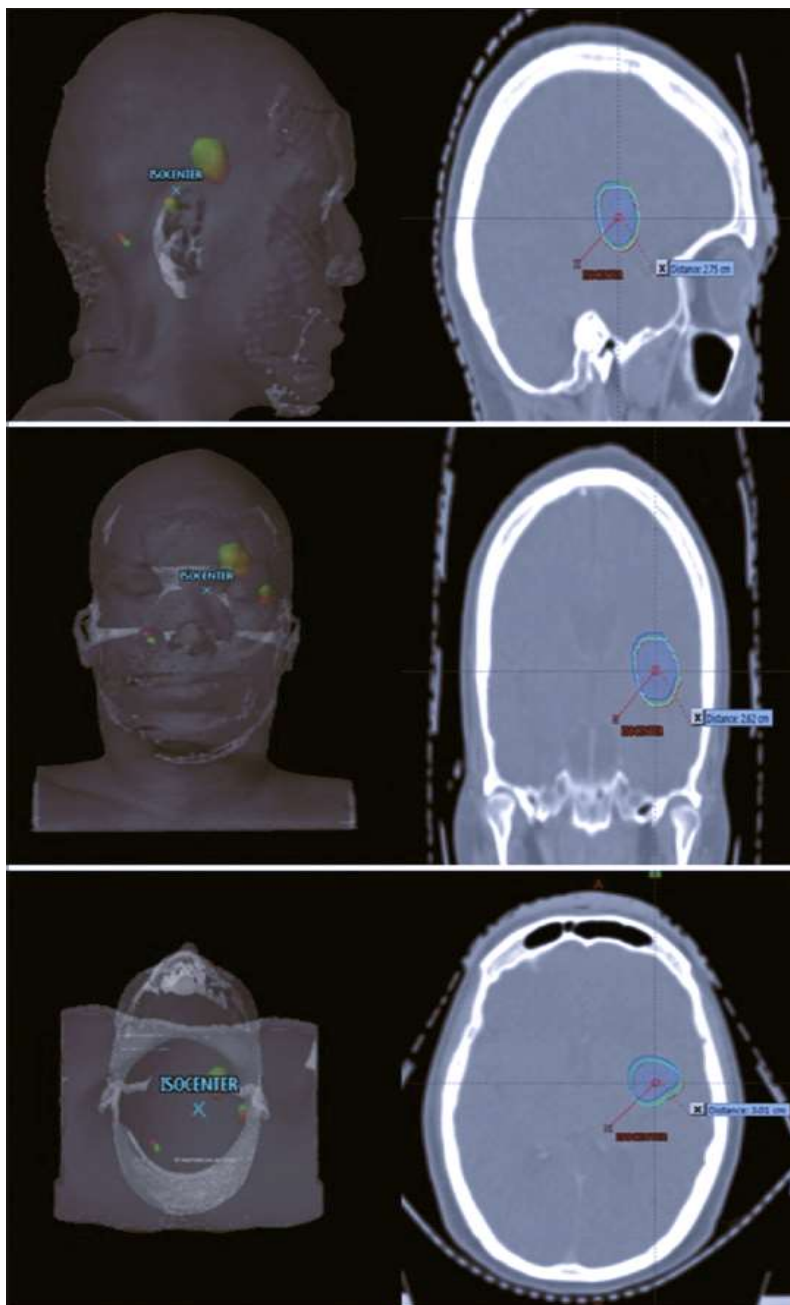
2019

Journal of Medical Physics

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- 10 Casos: 38 lesões
- 20Gy, SRS
- VMAT não-coplanar
- Isocentro no centro das lesões
- Pitch, Yaw e Roll - 1°, 3° e 5°
- V_{95} , D_{95} , D_{mean} e D_{min}

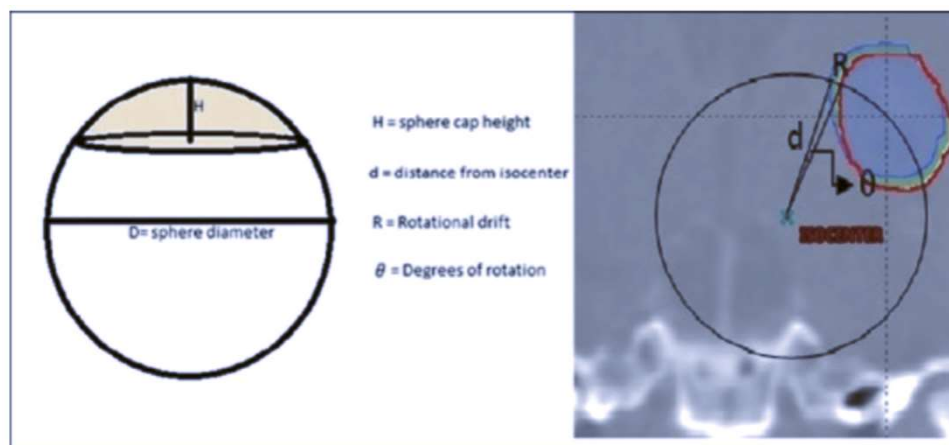




✓ Múltiplas Lesões (2-8)

✓ Análise para cada “eixo”

x Não utiliza PTV



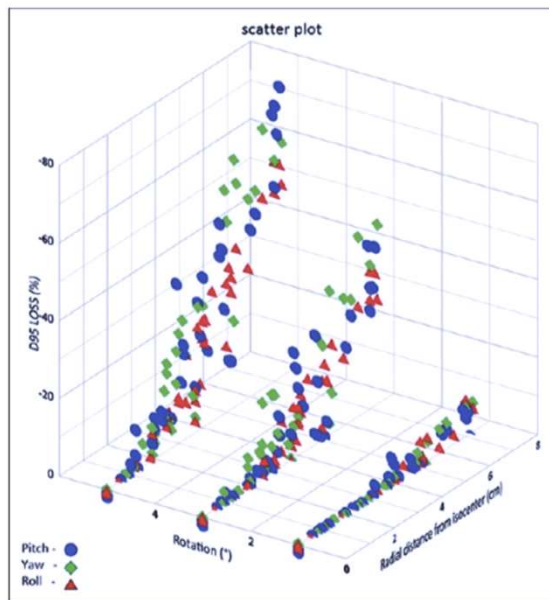
¹Experiência clínica:

- *Sistema frameless dedicado:*
Maior desvio de 4,1° e 90% < 2,5°

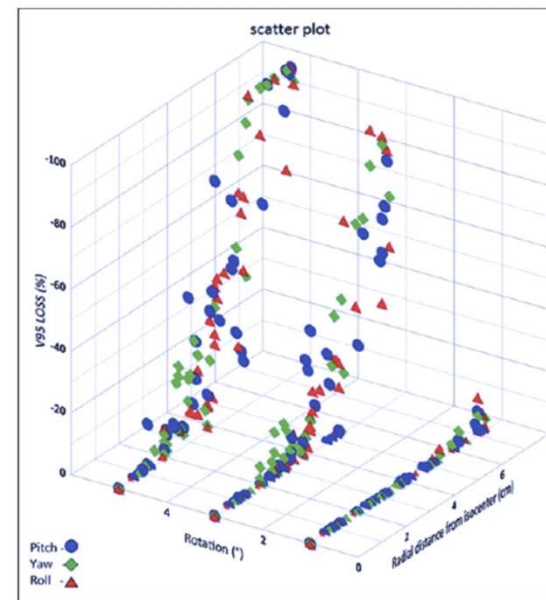
- *Sistema de 3 pontos:*
Maior desvio de 7° e 65% < 2,5°

Variações dosimétricas com a rotação e distância do isocentro:

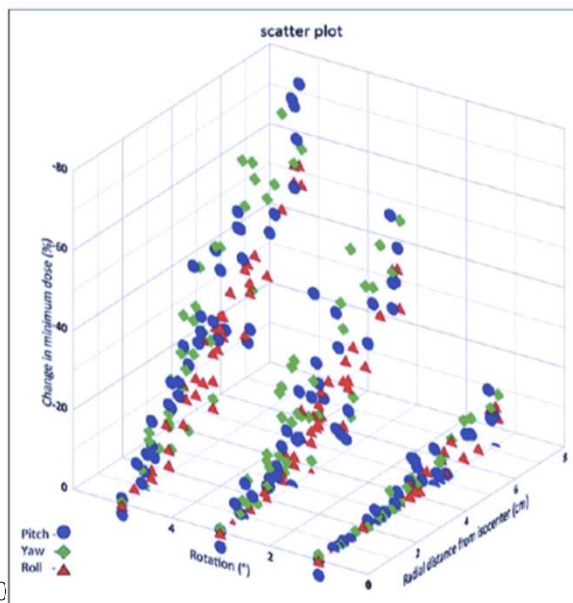
$D_{95\%}$



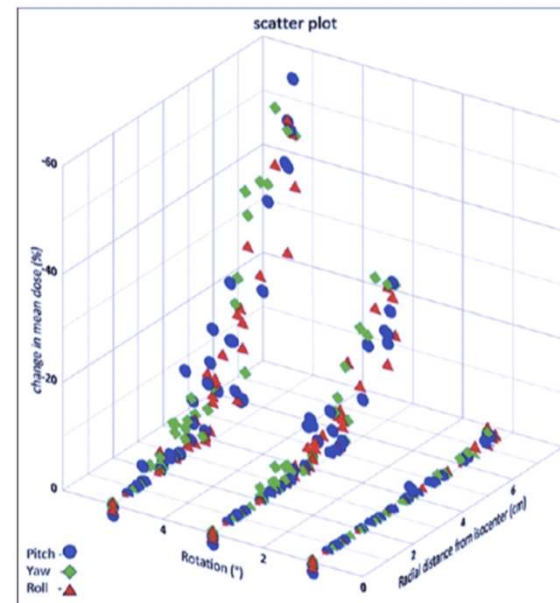
$V_{95\%}$



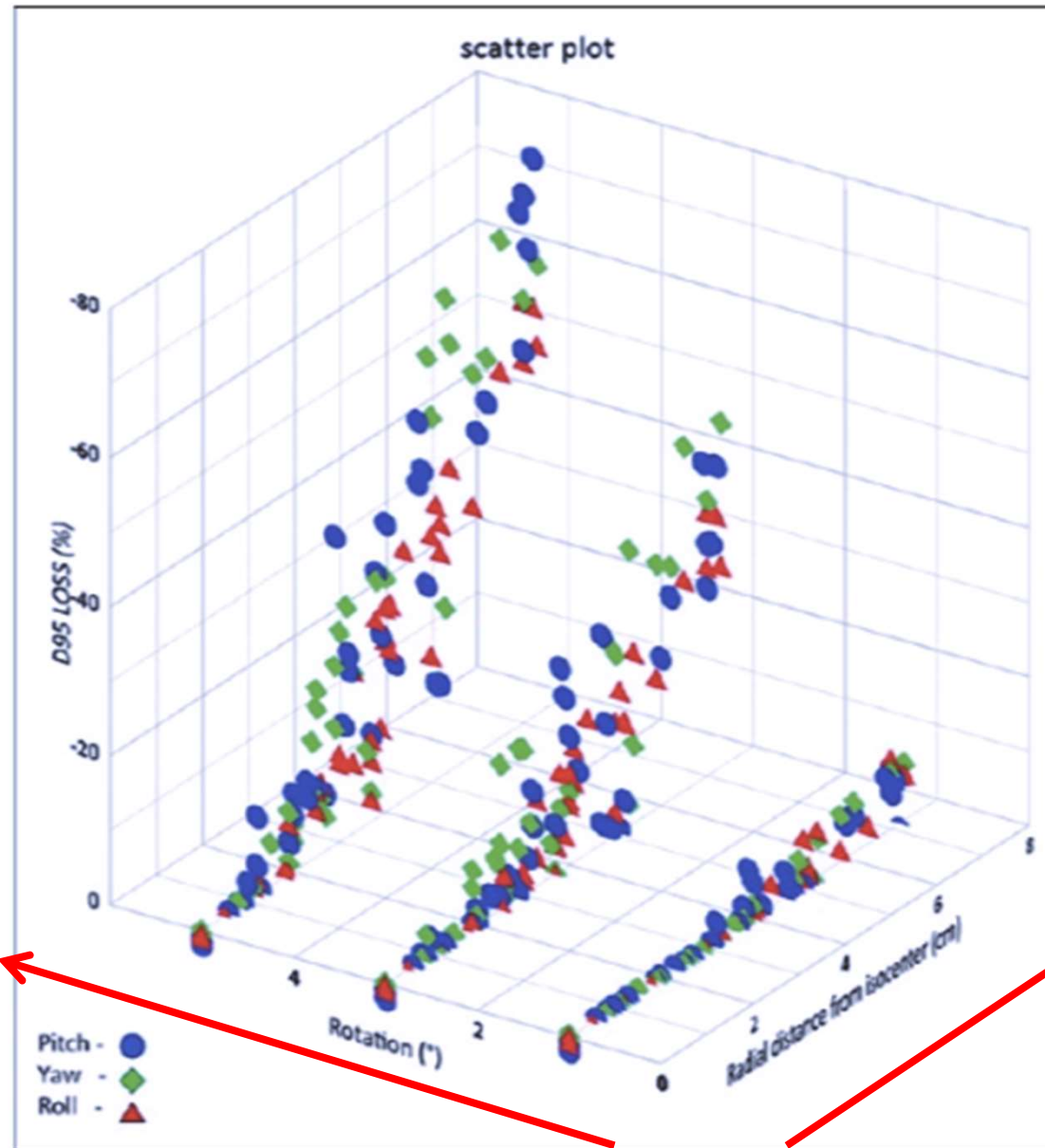
D_{min}



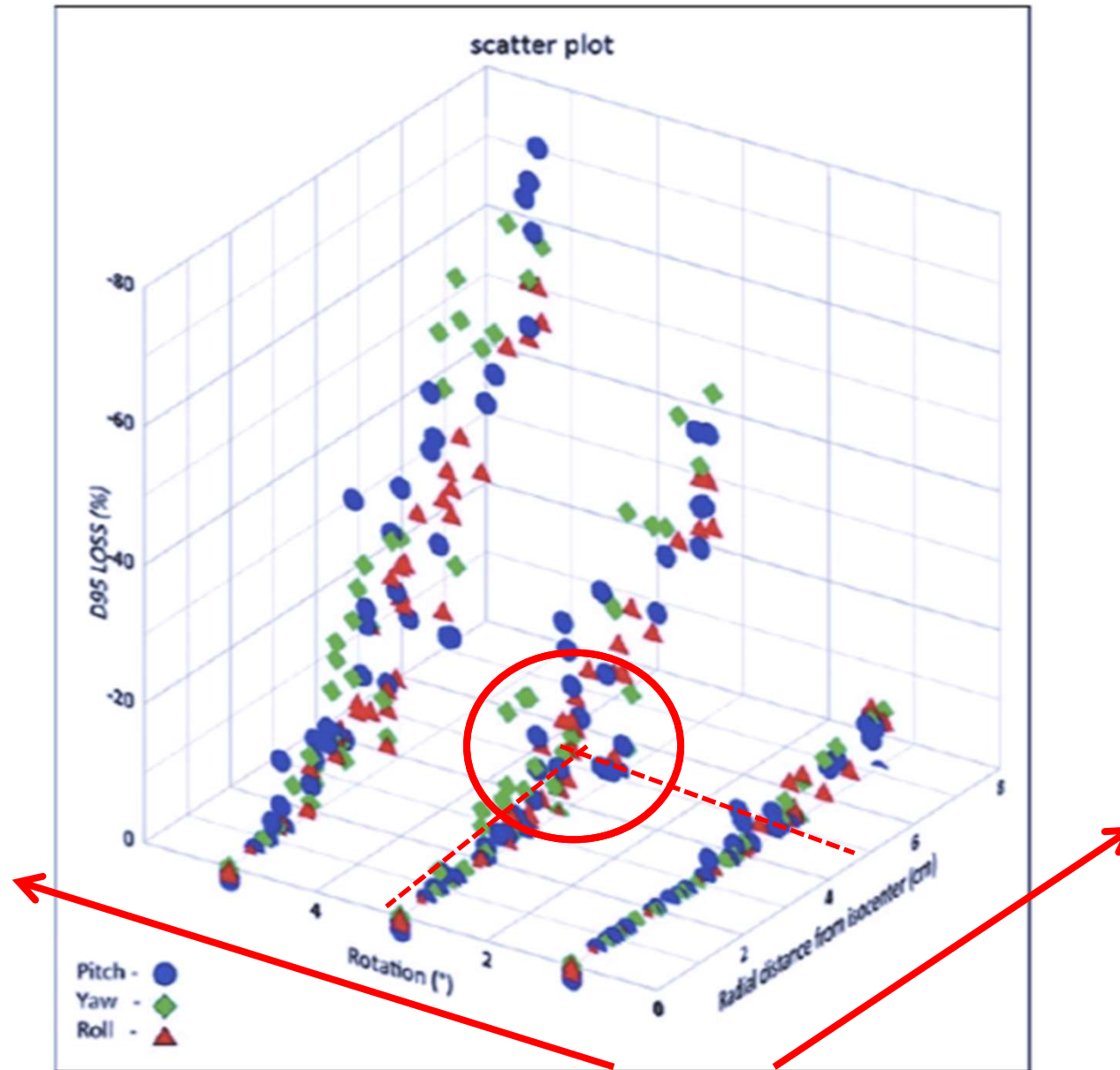
D_{mean}



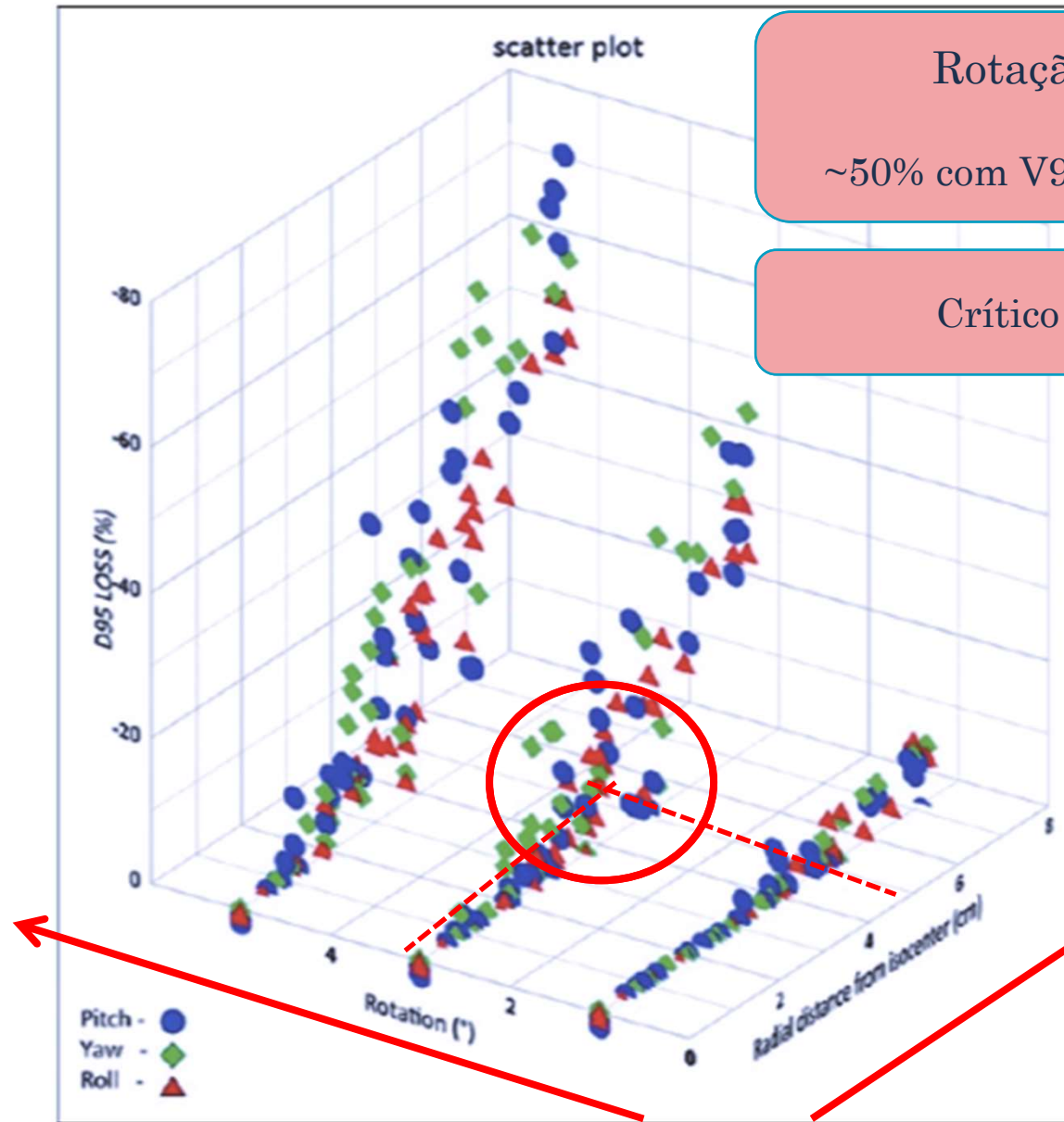
$D_{95\%}$



$D_{95\%}$



$D_{95\%}$



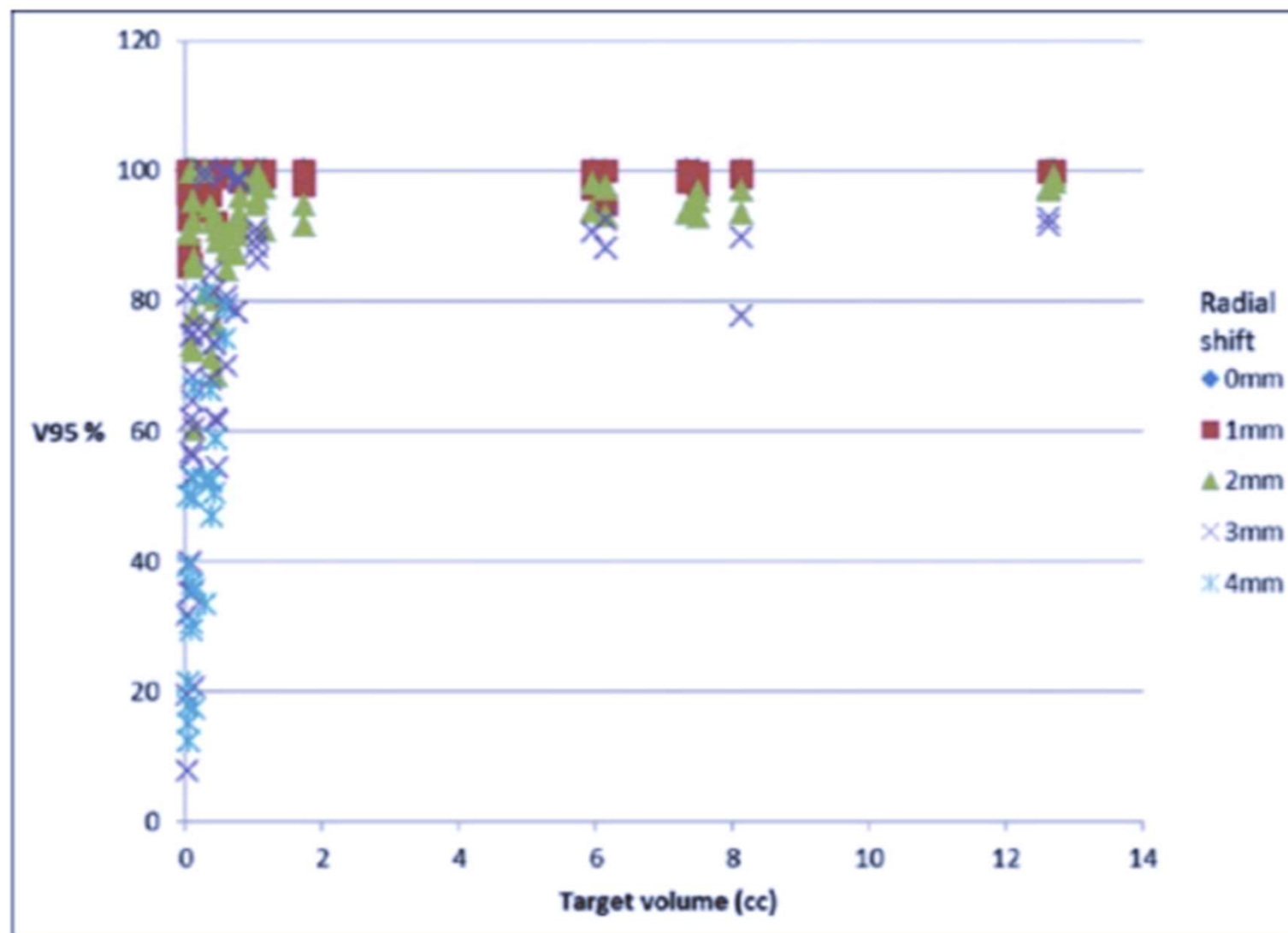
Rotação de 3°:

~50% com V95 e D95 < 95%

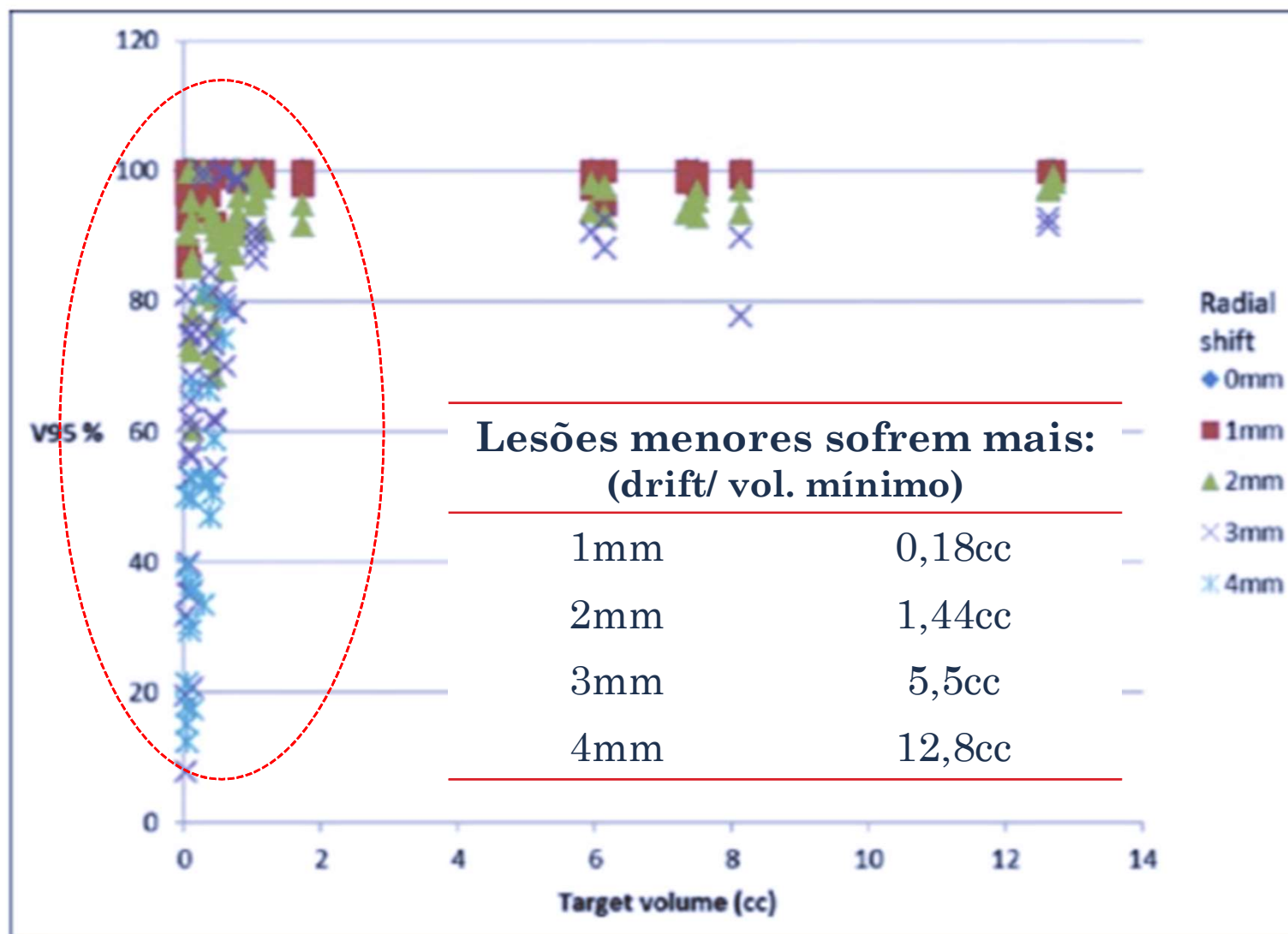
Crítico @4-5cm



$V_{95\%}$ vs. Volume



$V_{95\%}$ vs. Volume

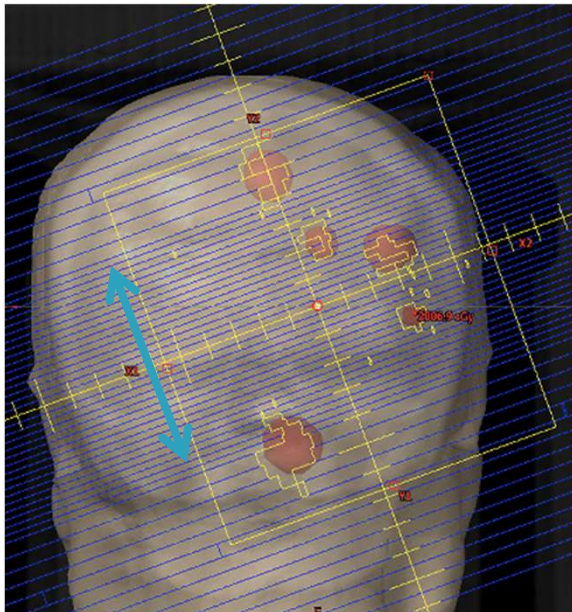


Existem outros
fatores relevantes?

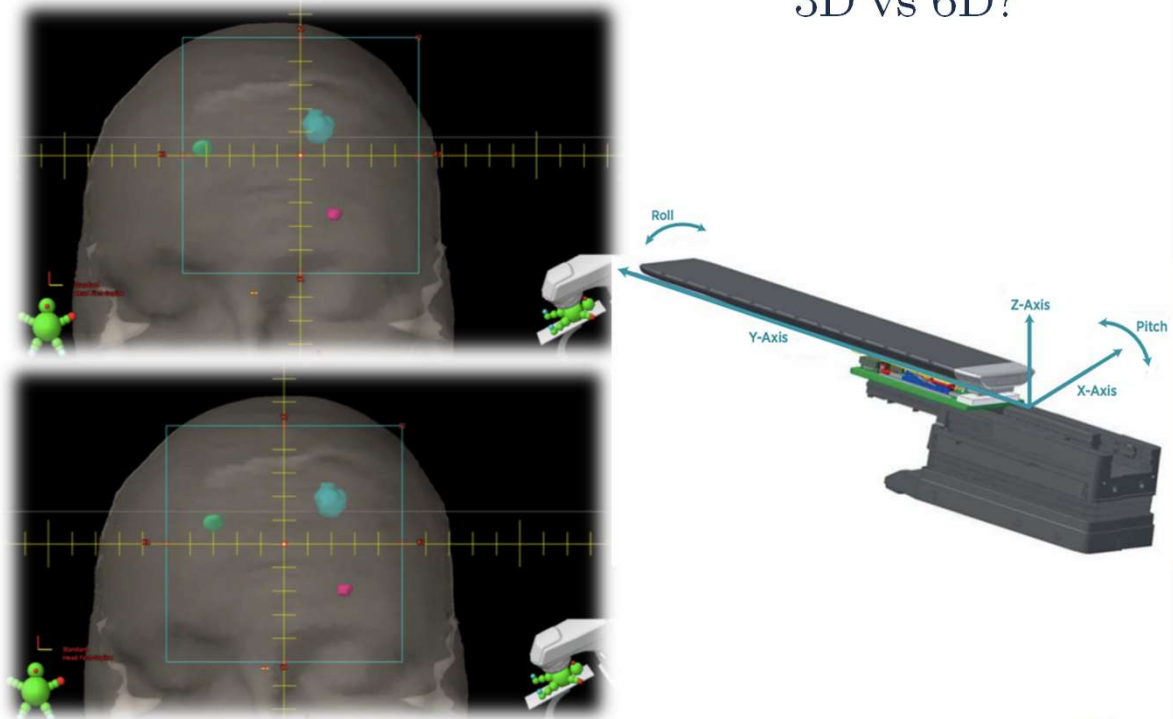
Physics considerations for single-isocenter, volumetric modulated arc radiosurgery for treatment of multiple intracranial targets

Carl Stanhope BS^a, Zheng Chang PhD^b, Zhiheng Wang PhD^b,
Fang-Fang Yin PhD^b, Grace Kim MD, PhD^b, Joseph K. Salama MD^b,
John Kirkpatrick MD, PhD^b, Justus Adamson PhD^{b,*}

MLC?



3D vs 6D?

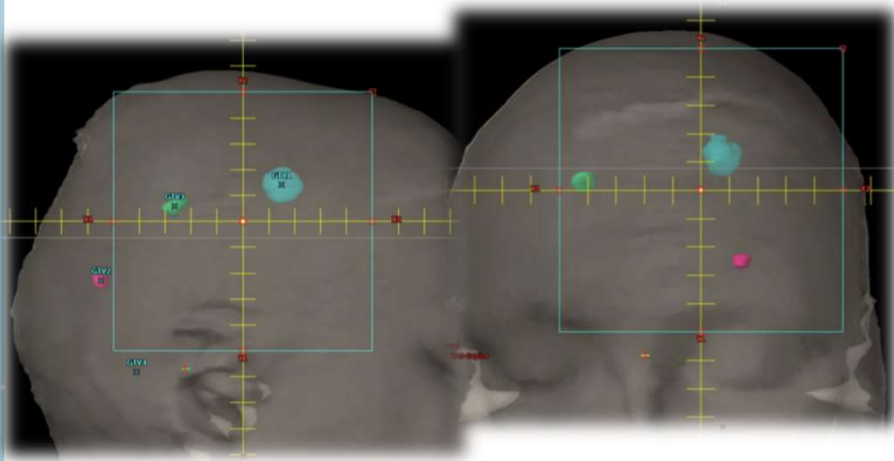


Isocentro?

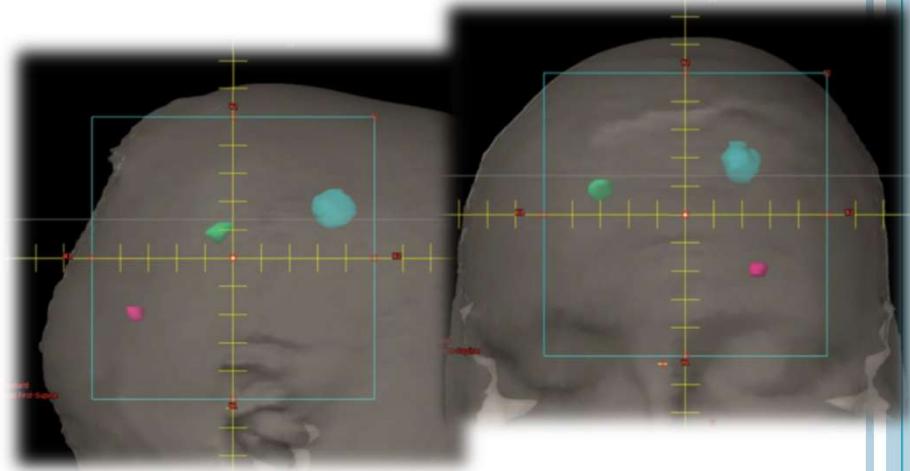


Colocação de isocentro: 4 estratégias

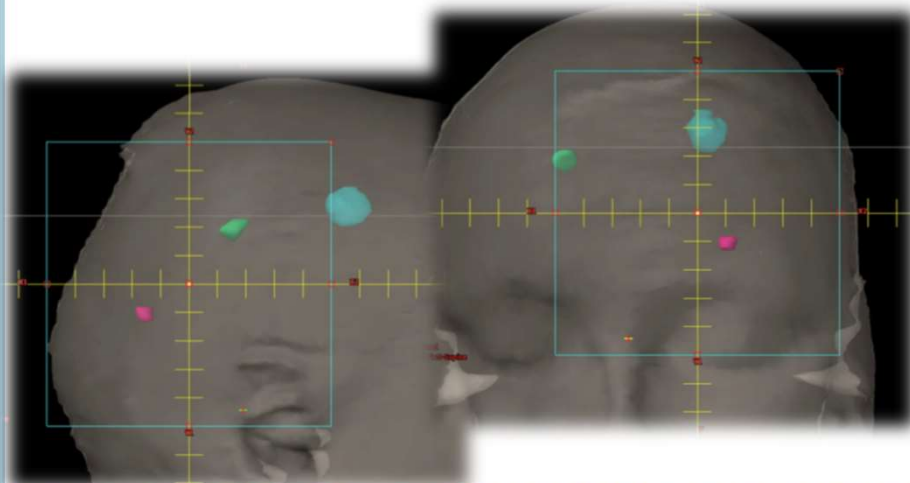
✓ Centróide Volume:
Centro de Massa das lesões



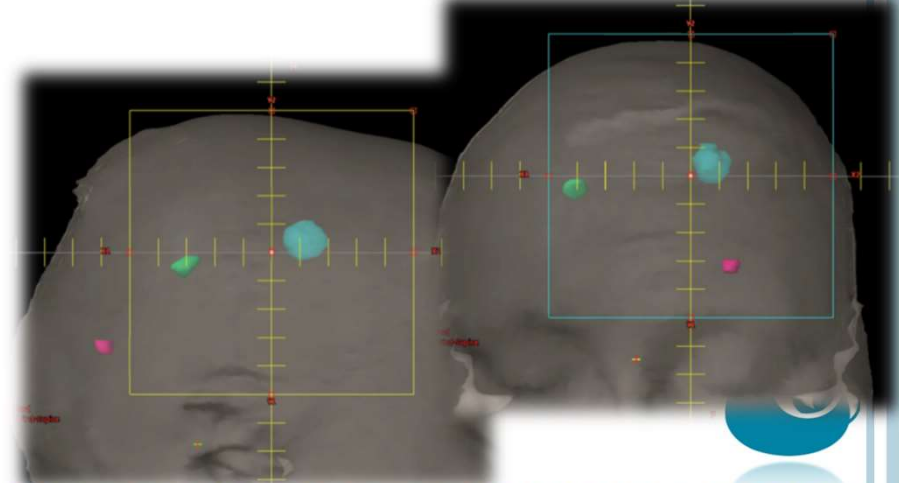
✓ Centróide Pontual:
Centro Geométrico das lesões



✓ Inverso do Volume:
Mais próximo das lesões de menor volume



✓ Algoritmo Eclipse™:
Algoritmo interno do software



Colocação de isocentro: 4 estratégias

✓ Centróide Volume:
Centro de Massa das lesões

- ✓ Benefício em alvos maiores
- ✓ Melhor $V_{50\%}^*$

✓ Centróide Pontual:
Centro Geométrico das lesões

- ✓ Benefício em alvos menores

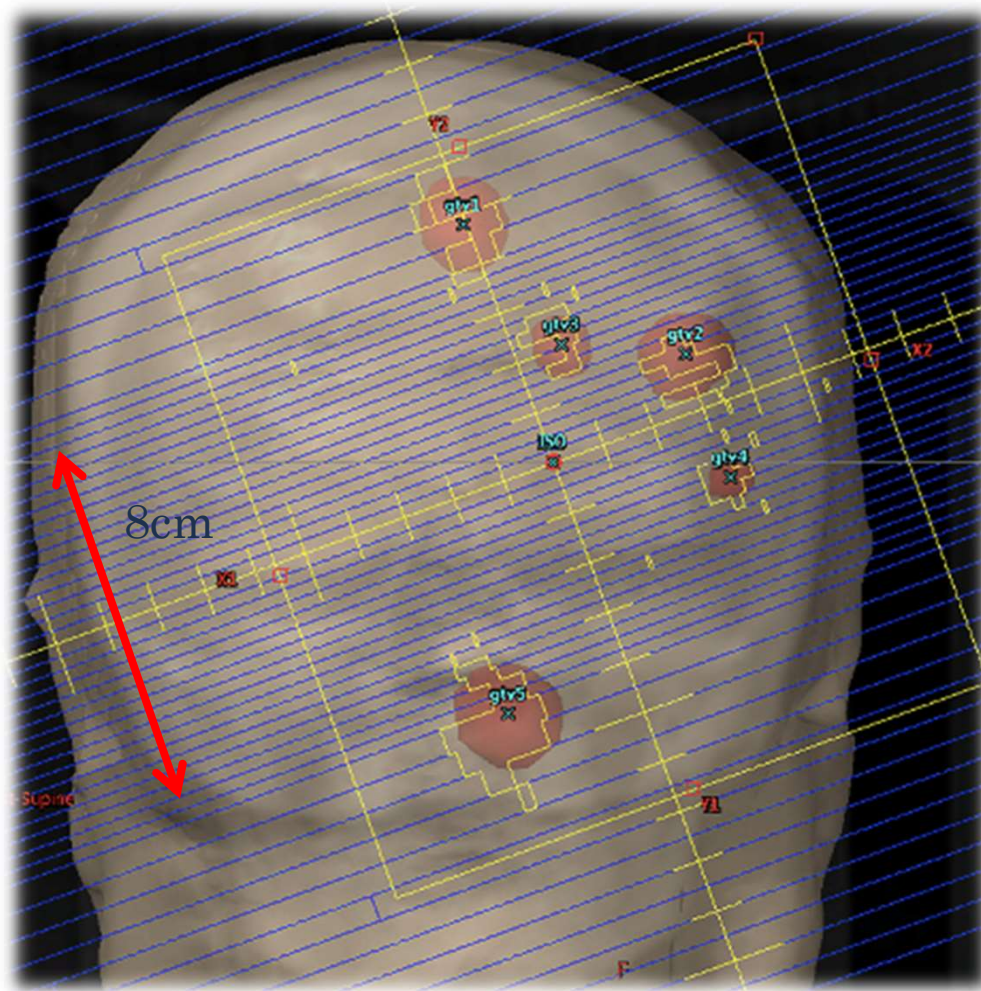
✓ Inverso do Volume:
Mais próximo das lesões de menor volume

- ✓ Benefício em alvos menores
- Perda de CI em alvos maiores

✓ Algoritmo Eclipse™:
Algoritmo interno do software

- Próximo ao Pontual
- Evita distâncias extremas ao iso

MLC: Lâminas, posição e colimador!



HD120™

Melhor resultado próximo ao isocentro:

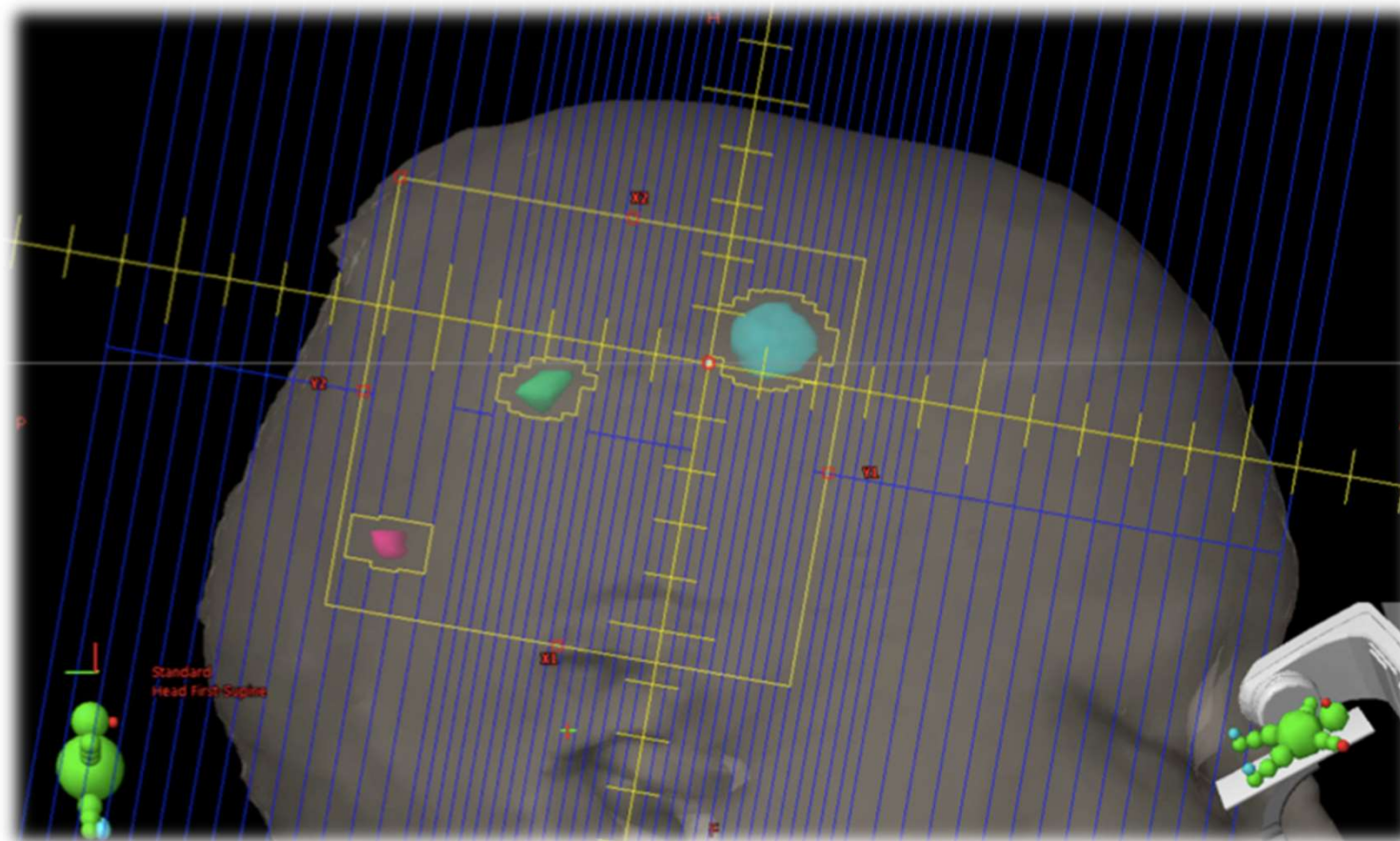
Erro rotacional ou MLC ???

- Lâminas de 2,5mm no centro
- Estratégia de dividir em 2 isos?

Dos 11 casos, dividindo
por 4 ou 5cm:
**9 ou 7 casos seriam
replanejados**



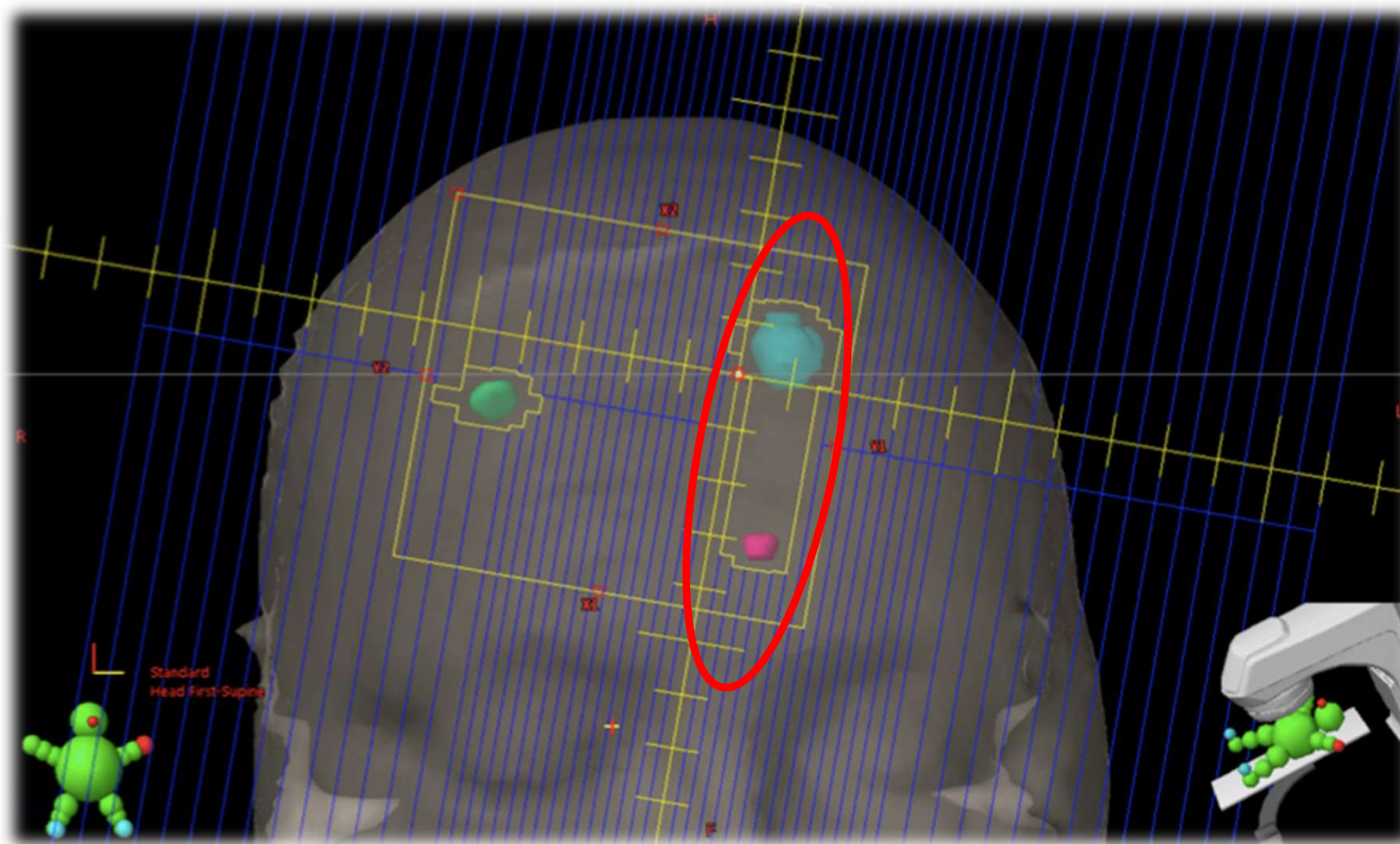
MLC: Lâminas, posição e rotação colimador!



Geometria de uma angulação não vale para o giro completo...



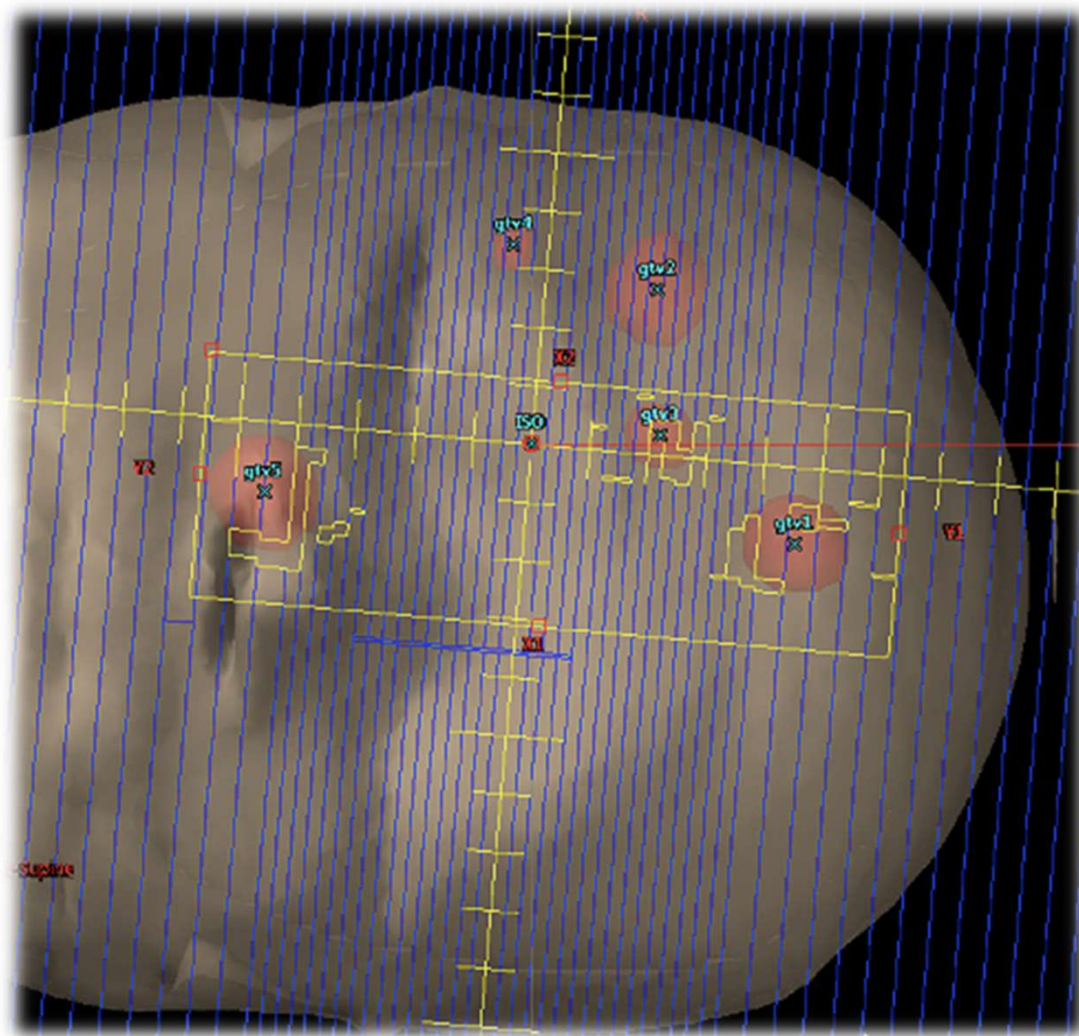
MLC: Lâminas, posição e rotação colimador!



Geometria de uma angulação não vale para o giro completo...
Cuidado com as ilhas!



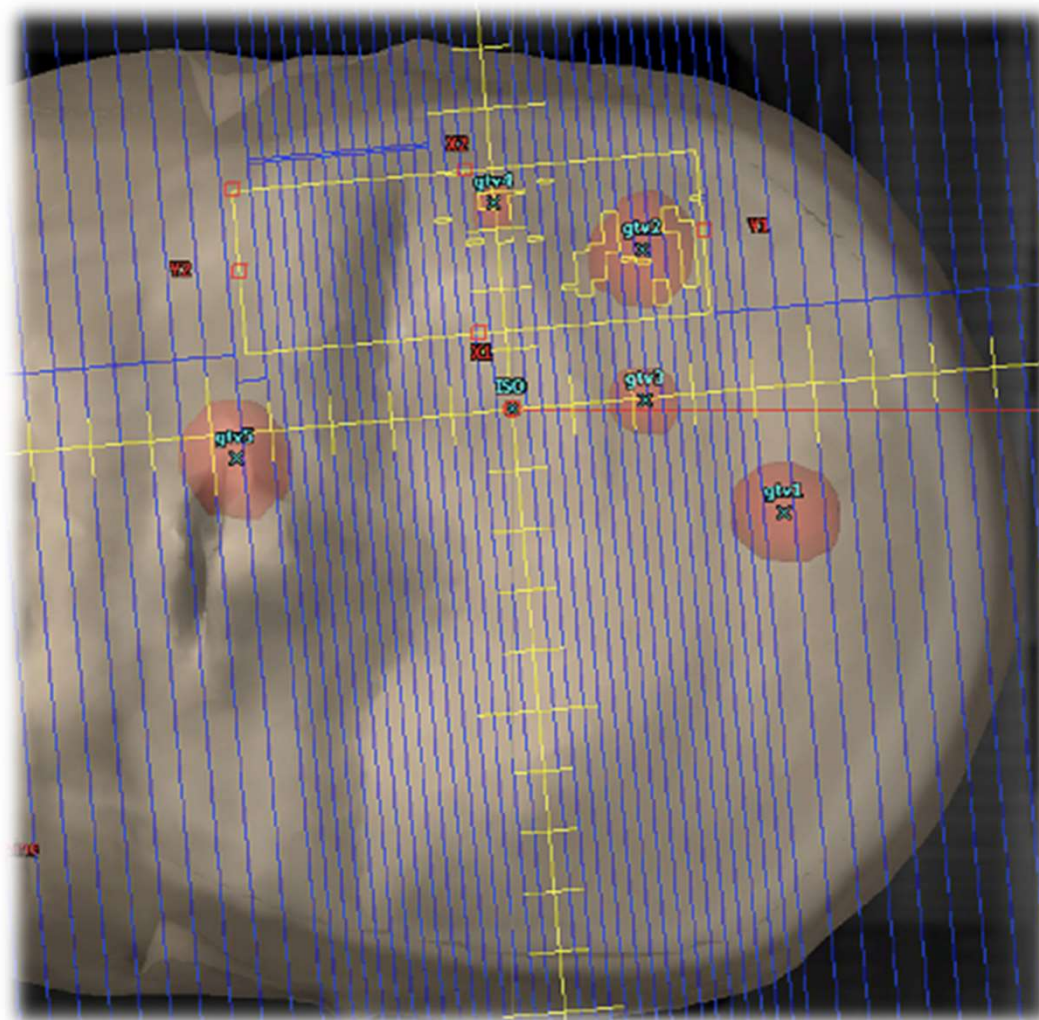
MLC: Lâminas, posição e rotação colimador!



“Escolha” de lesões por arcos



MLC: Lâminas, posição e rotação colimador!



“Escolha” de lesões por arcos



Erros



Incertezas



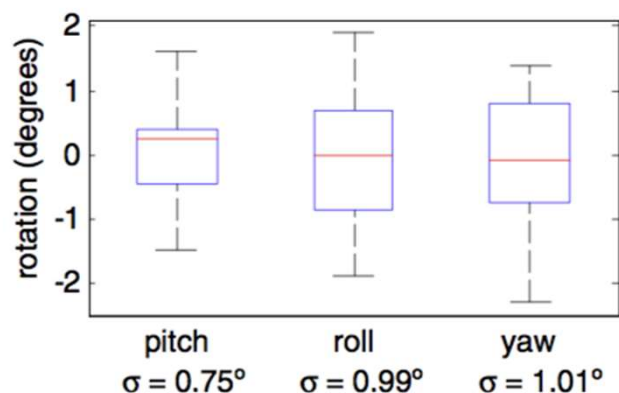
Cobertura dos GTVs...

PTV ???



Margens Rotacionais: Mesa Convencional vs. 6D

Ajuste pré tratamento



Ajuste pós tratamento

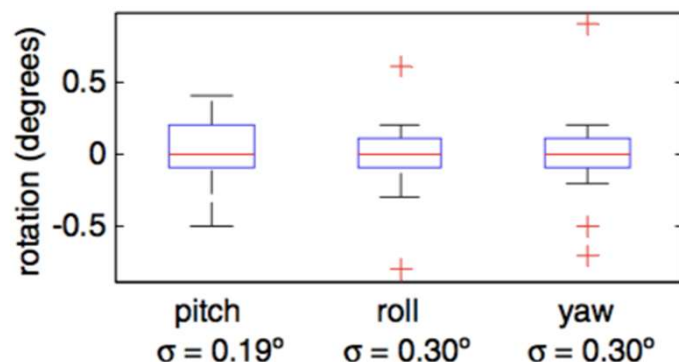


Table 2 Required margins calculated from Eq. (4) to account for initial (before 6D correction) and intraoperational rotational uncertainties

<i>P</i>	<i>d</i> (cm)	Margins for initial uncertainties (when no 6D correction is applied) (cm)			Margins for intraoperational uncertainties (cm)		
		Pitch	Roll	Yaw	Pitch	Roll	Yaw
.90	5.00	0.11	0.14	0.15	0.03	0.04	0.04
.95	5.00	0.13	0.17	0.17	0.03	0.05	0.05
.98	5.00	0.15	0.19	0.20	0.04	0.06	0.06
.90	10.00	0.21	0.28	0.29	0.06	0.09	0.09
.95	10.00	0.26	0.34	0.35	0.07	0.10	0.10
.98	10.00	0.29	0.39	0.40	0.08	0.12	0.12
.90	15.00	0.32	0.42	0.44	0.08	0.13	0.13
.95	15.00	0.38	0.51	0.52	0.10	0.16	0.15
.98	15.00	0.44	0.58	0.59	0.11	0.18	0.18

6D, 6 degrees of freedom. A 1-mm margin accounts for 95% of intraoperational uncertainties at 10 cm (values shown in bold).

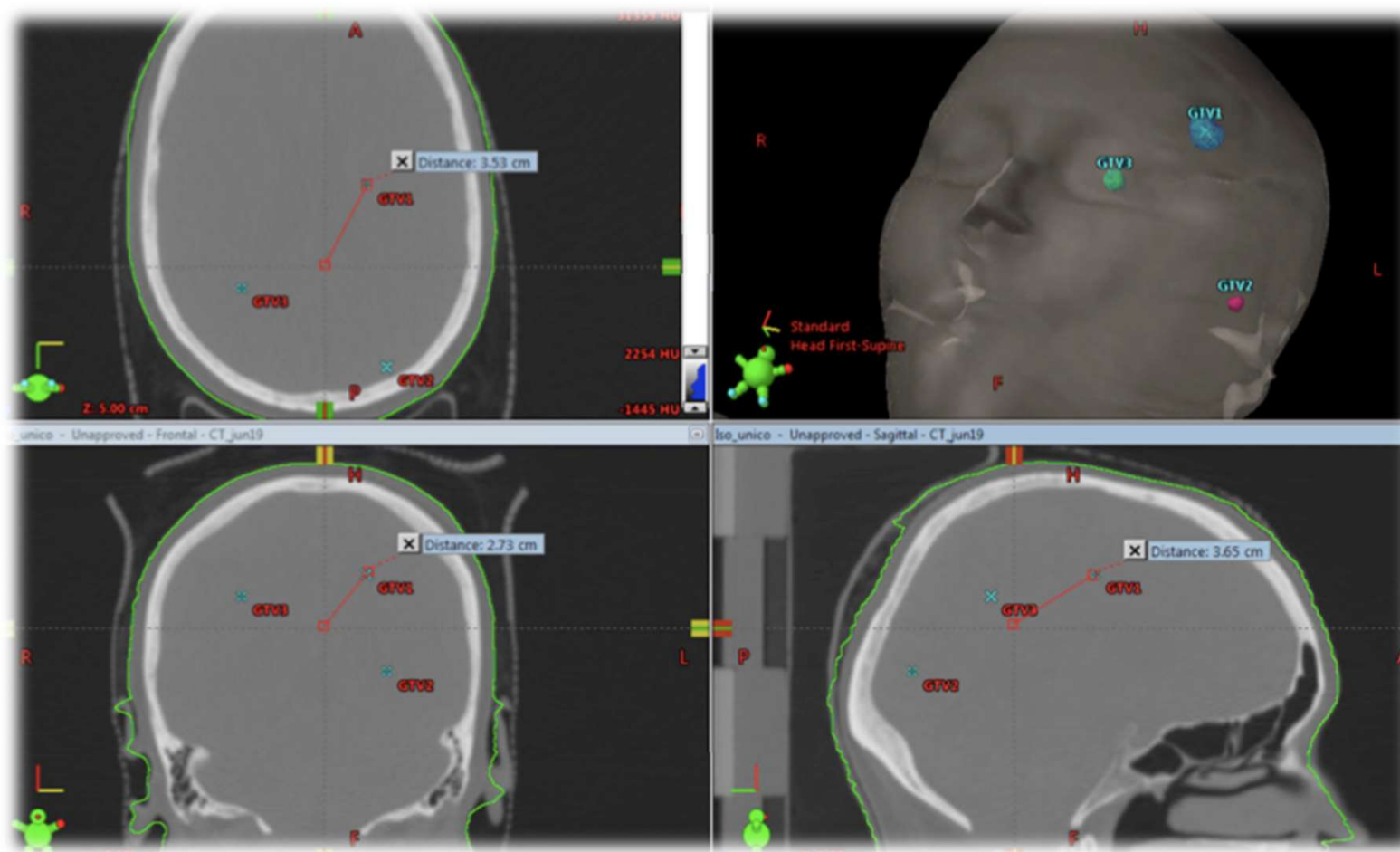
*Máscara BrainLab

Estratégia para adaptar margem!!!

0,35mm/cm do isocentro



Margens Rotacionais: Exemplo mesa convencional

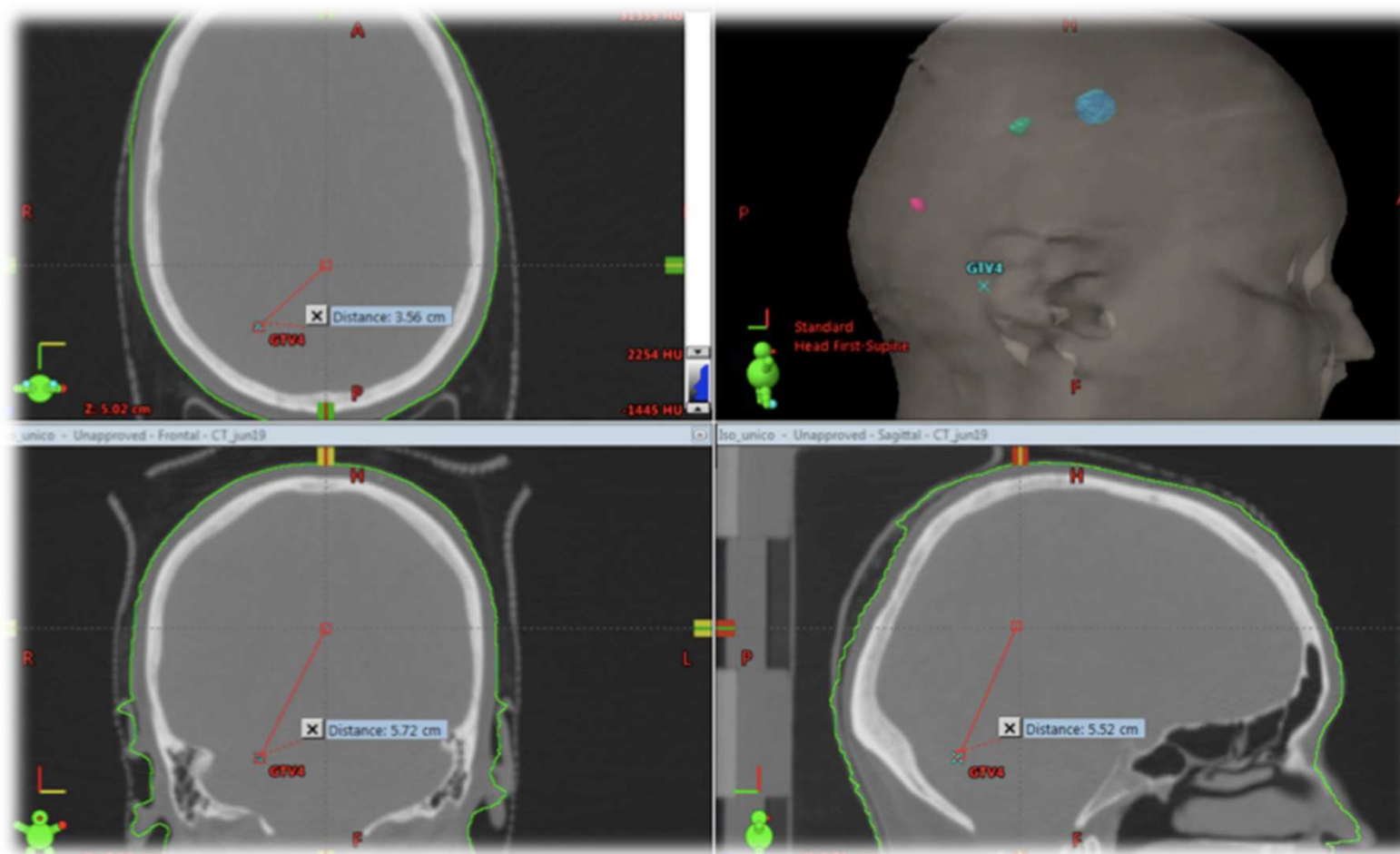


$$GTV_1 = \sqrt{[(3,6^2 + 2,7^2 + 3,5^2)]} = 5,7\text{cm}$$

$$\text{Margem}_{\text{PTV}} = 5,7\text{cm} \times 0,35\text{mm/cm} = 2\text{mm}$$



Margens Rotacionais: Exemplo mesa convencional

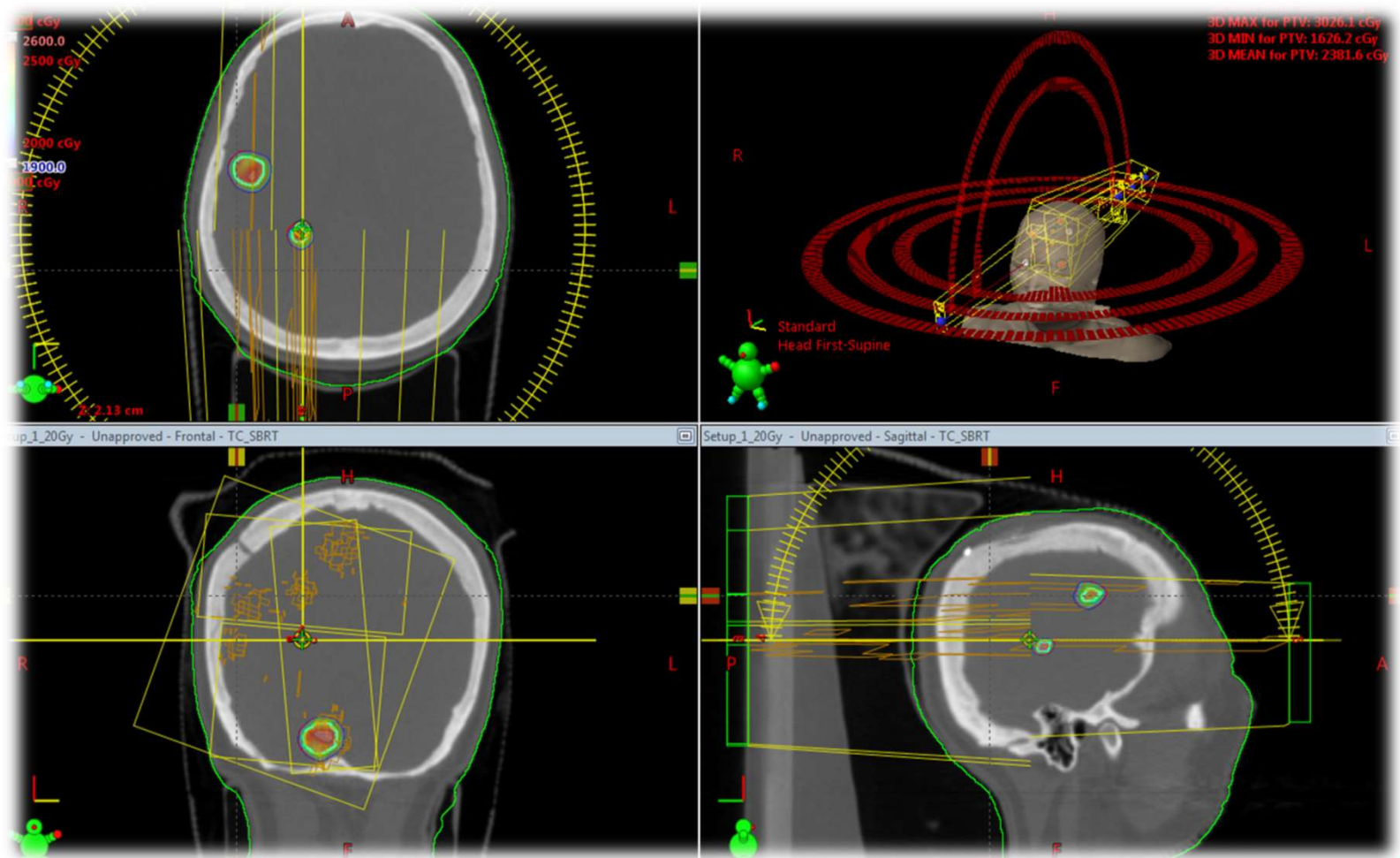


$$GTV_{\text{cerebelar}} = \sqrt{[(3,6^2 + 5,7^2 + 5,5^2)]} = 8,7\text{cm}$$

$$\text{Margem}_{\text{PTV}} = 8,7\text{cm} \times 0,35\text{mm/cm} = 3\text{mm}$$



Margens Rotacionais: Exemplo aplicado caso HMD



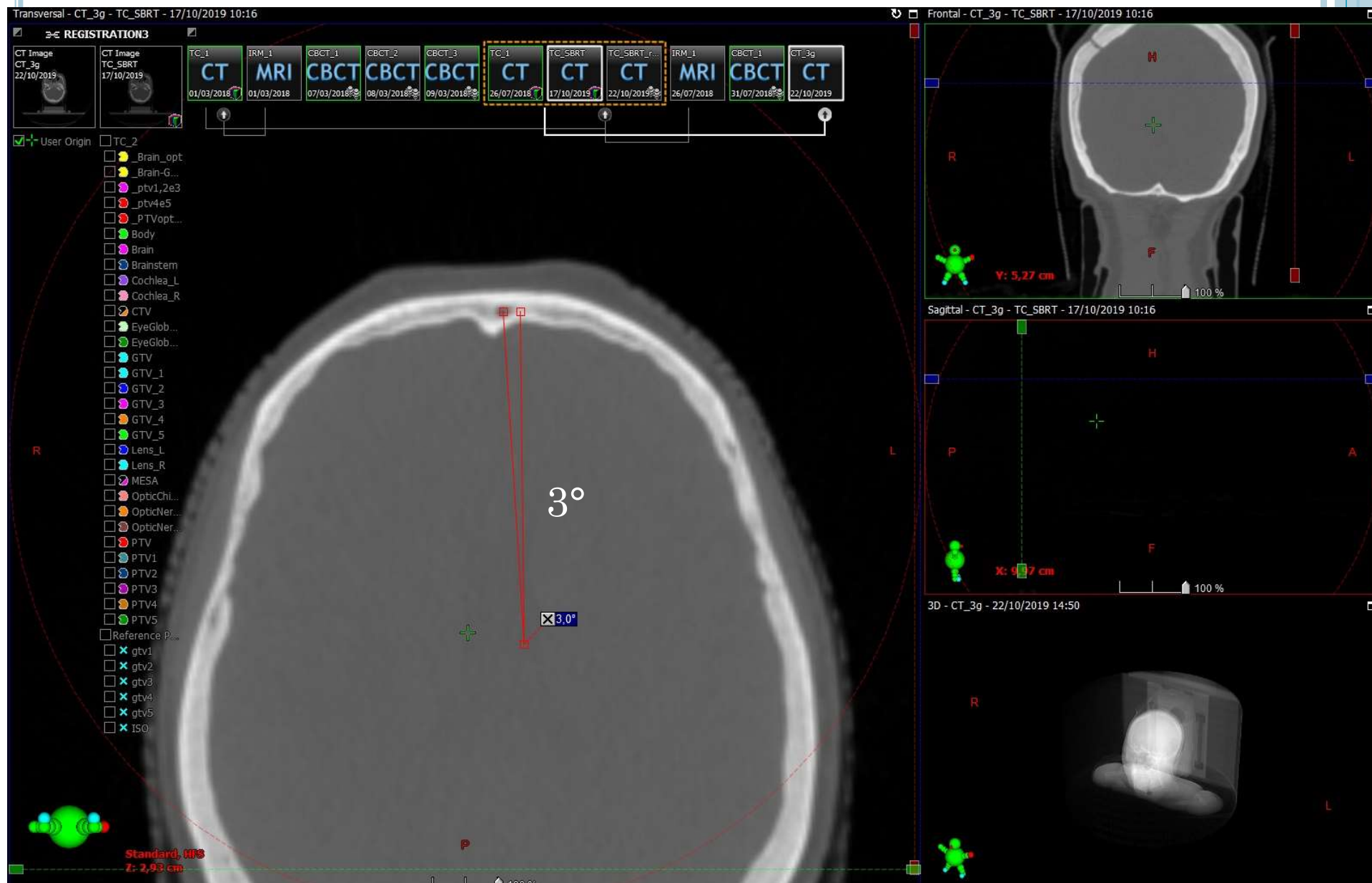
Planejamento realizado com margens baseadas em 0,35mm/cm



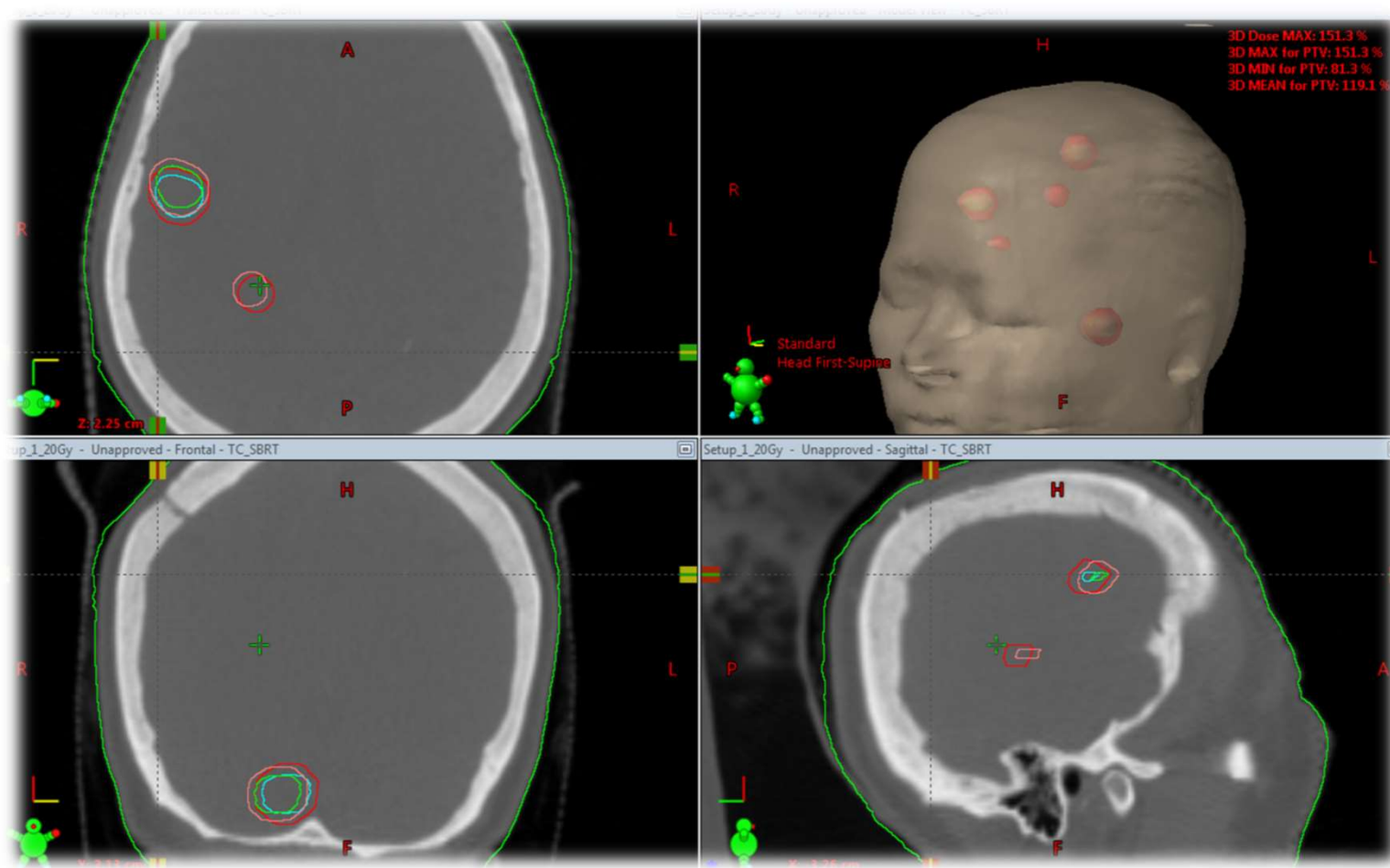
Margens Rotacionais: Exemplo caso HMD



Margens Rotacionais: Exemplo caso HMD



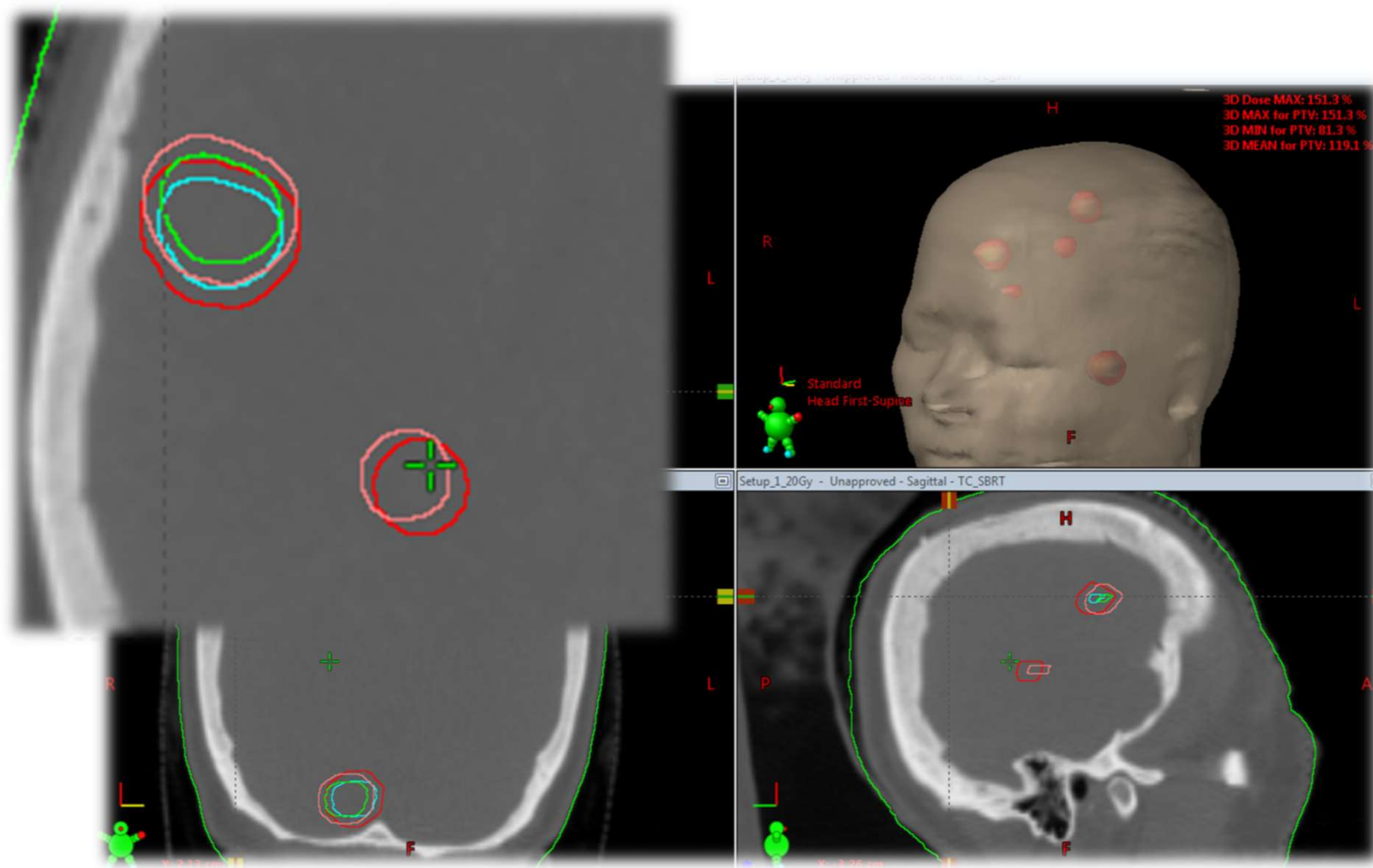
Margens Rotacionais: Exemplo caso HMD



Contornos rotacionados em 3°



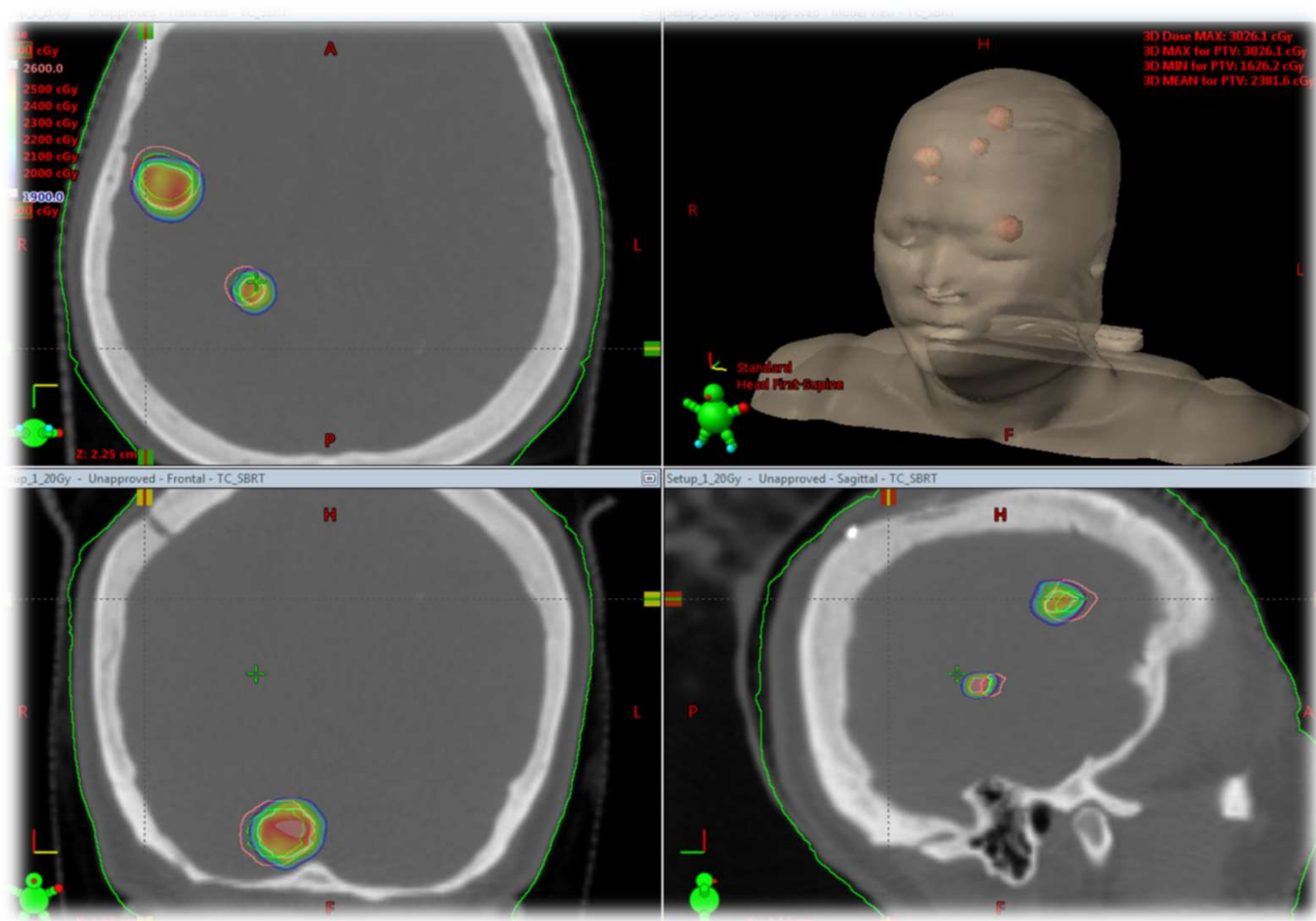
Margens Rotacionais: Exemplo caso HMD



Contornos rotacionados em 3°



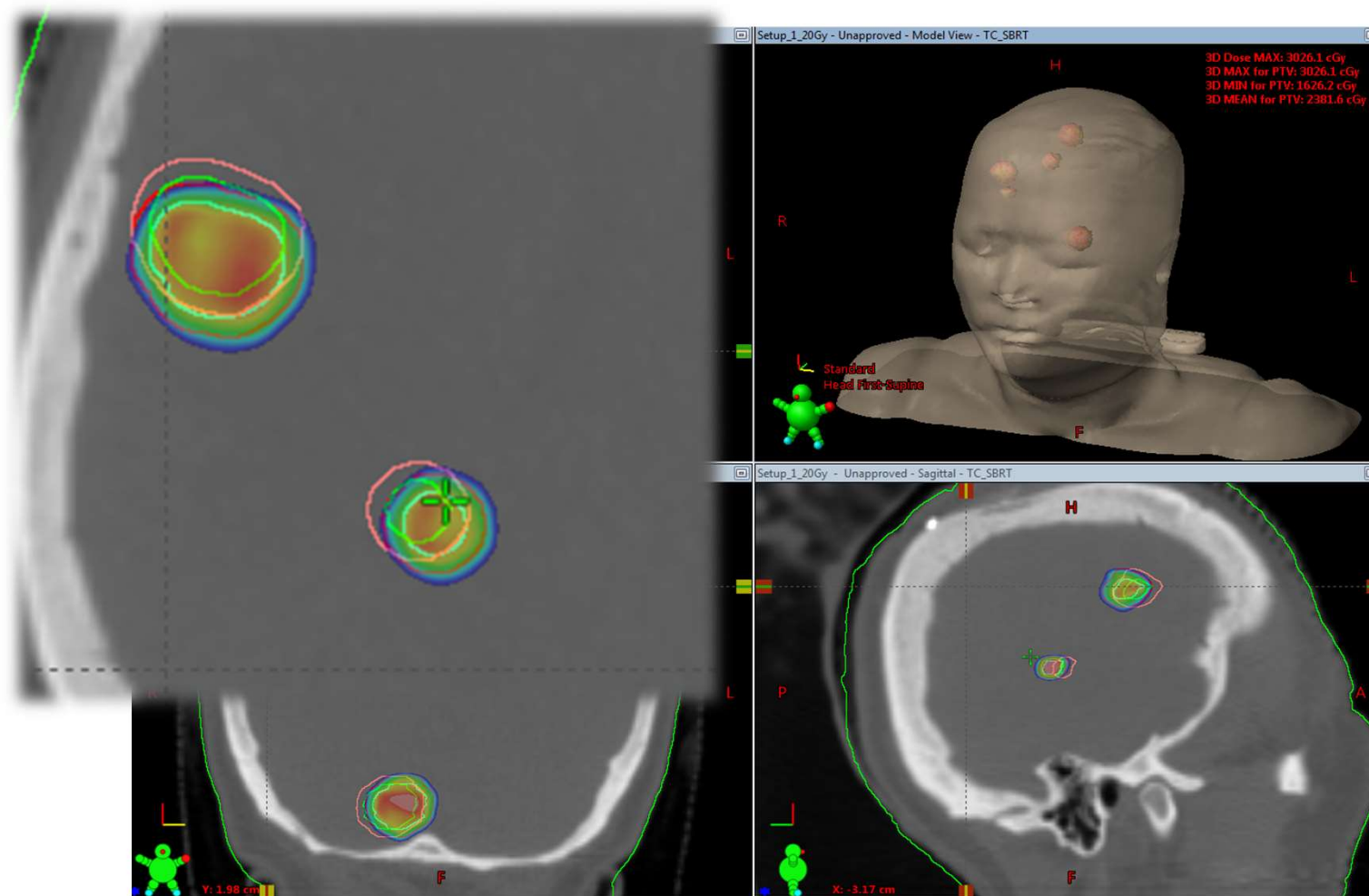
Margens Rotacionais: Exemplo caso HMD



Isodose “deslocada”



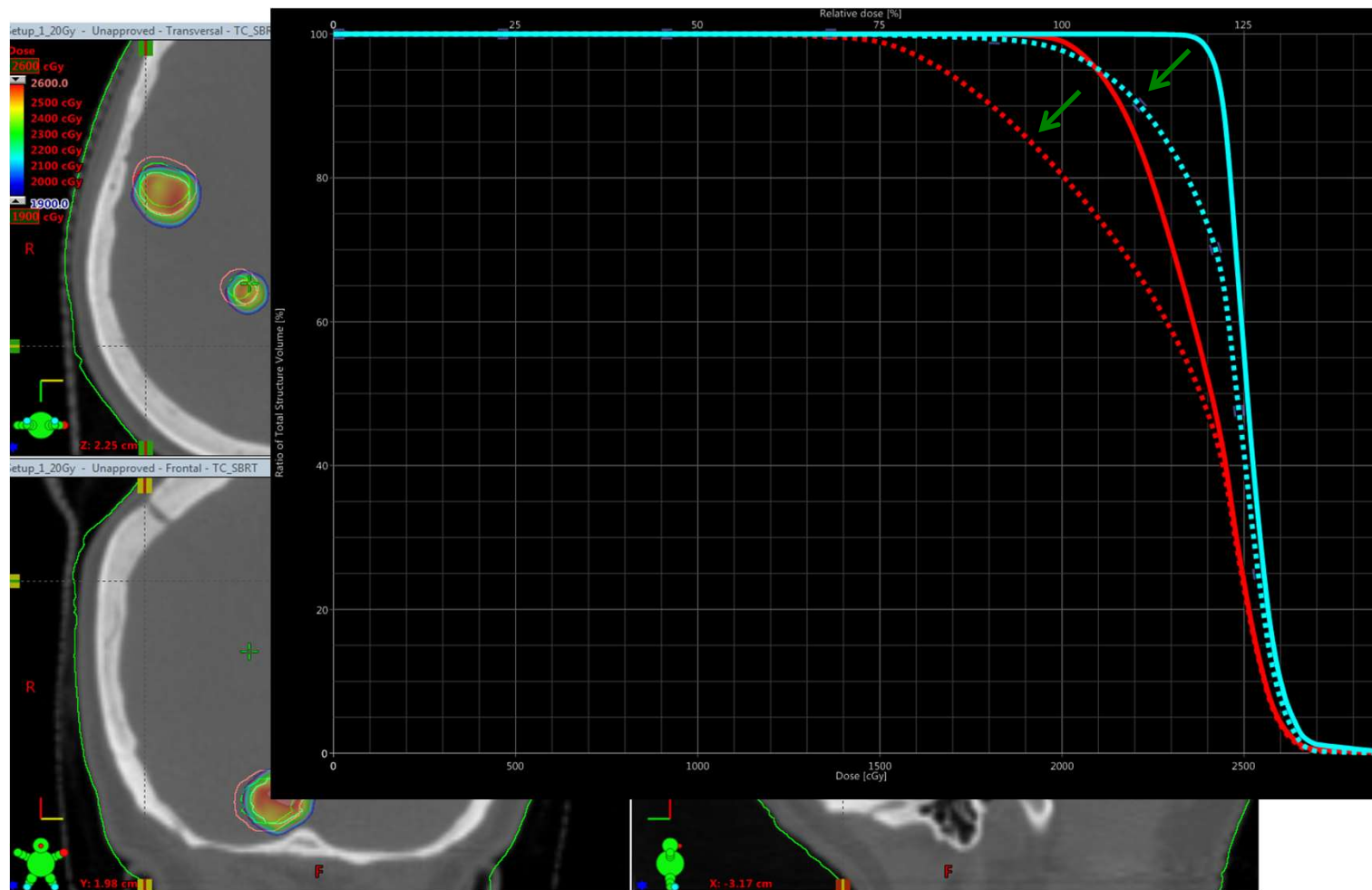
Margens Rotacionais: Exemplo caso HMD



Isodose “deslocada”



Margens Rotacionais: Exemplo caso HMD



- Análise de DVH: perda importante de D_{99} (100% → 77%)
- GTV ainda “coberto” – garantia da margem



Um olhar mais estatístico...

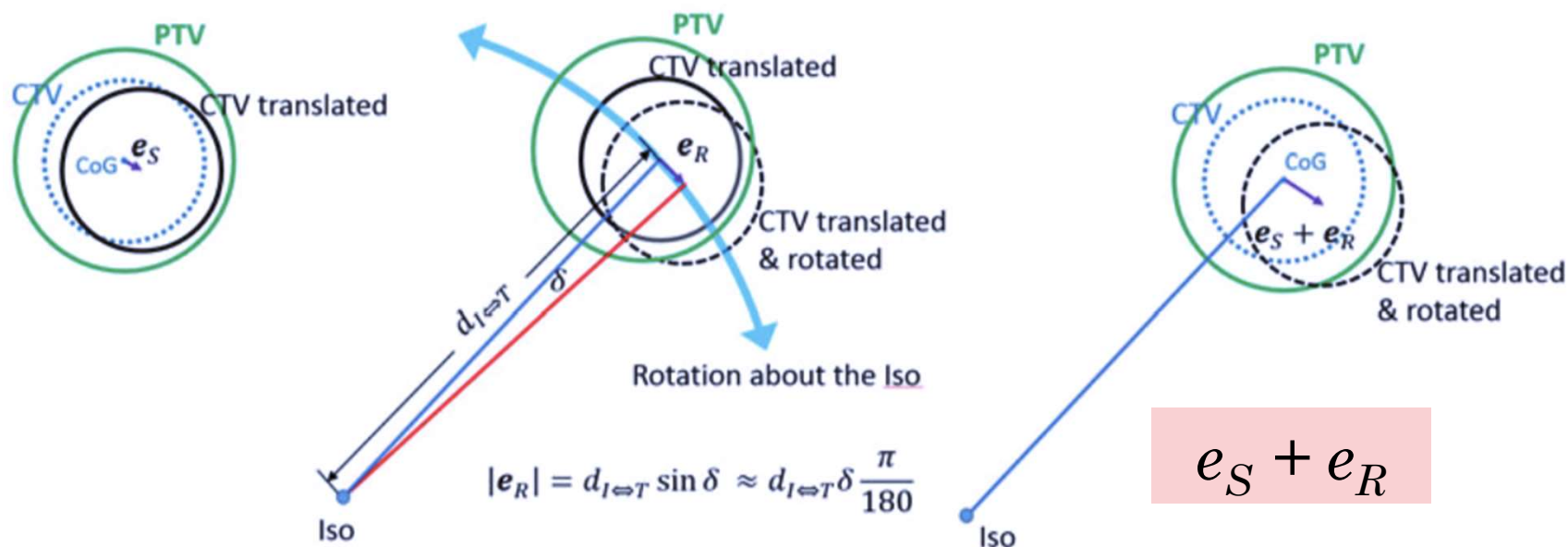
Med Phys. 2017 Jun;44(6):2115-2123. doi: 10.1002/mp.12262. Epub 2017 May 18.

A statistical model for analyzing the rotational error of single isocenter for multiple targets technique.

Chang J^{1,2}.



CTV coberto pela dose de prescrição 95% do tempo

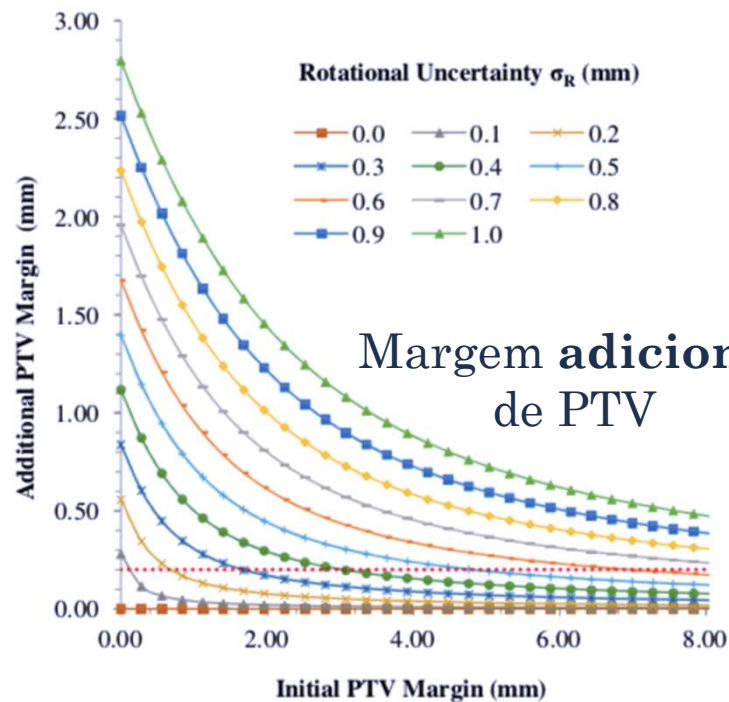


$$e_S + e_R$$

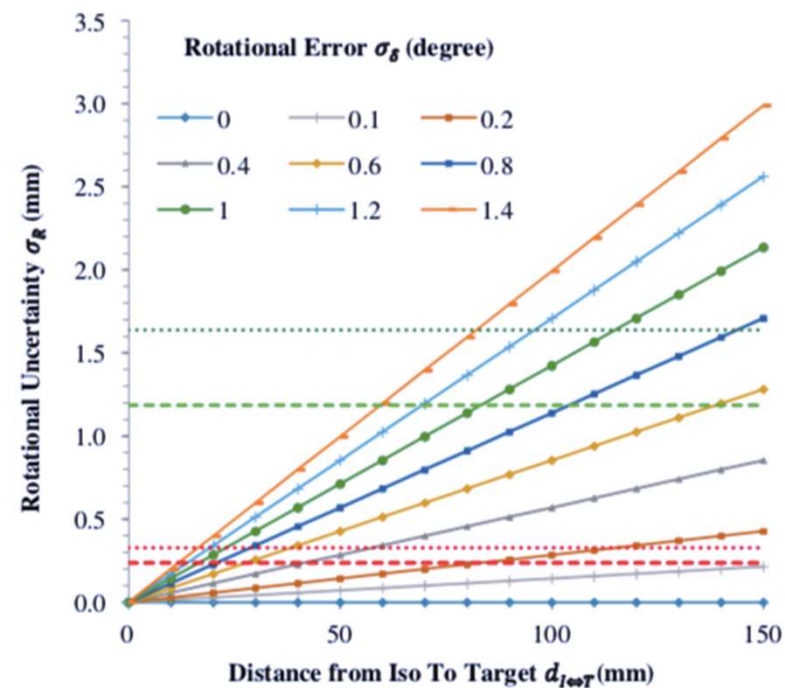
$$\sigma_R = \sigma_\delta \times d_{i \rightarrow T}$$

Med Phys. 2017 Jun;44(6):2115-2123



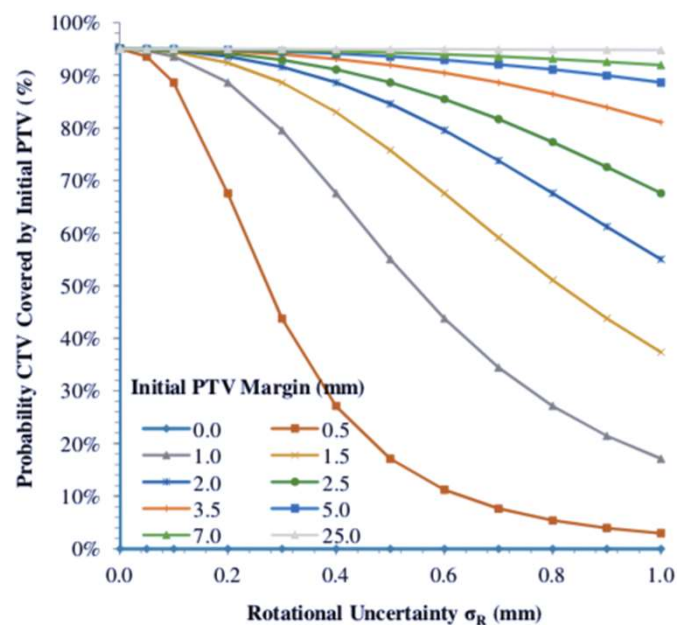


Margem adicional
de PTV



Incerteza com a
distância do Iso

% de cobertura
com a Incerteza
Rotacional



Um olhar estatístico (2)...

Incorporating the rotational setup uncertainty into the planning target volume margin expansion for the single isocenter for multiple targets technique

Jenghwa Chang PhD*

Natureza estatística:

- ✓ Relação não linear!
- ✓ Análise das incertezas rotacionais do sistema
- ✓ Distinção do PTV inicial (*setup*)

✓ σ_S

✓ $\sigma_R = 0,01424\sigma_d \times d_{I \leftrightarrow T}$

✓ Δ_M, M_E e M_S

Table 2 Values of σ_S (in mm) for selected M_S (planning target volume margin in mm for translational setup uncertainty) and clinical target volume coverage probabilities $(1 - \alpha) \times 100\%$

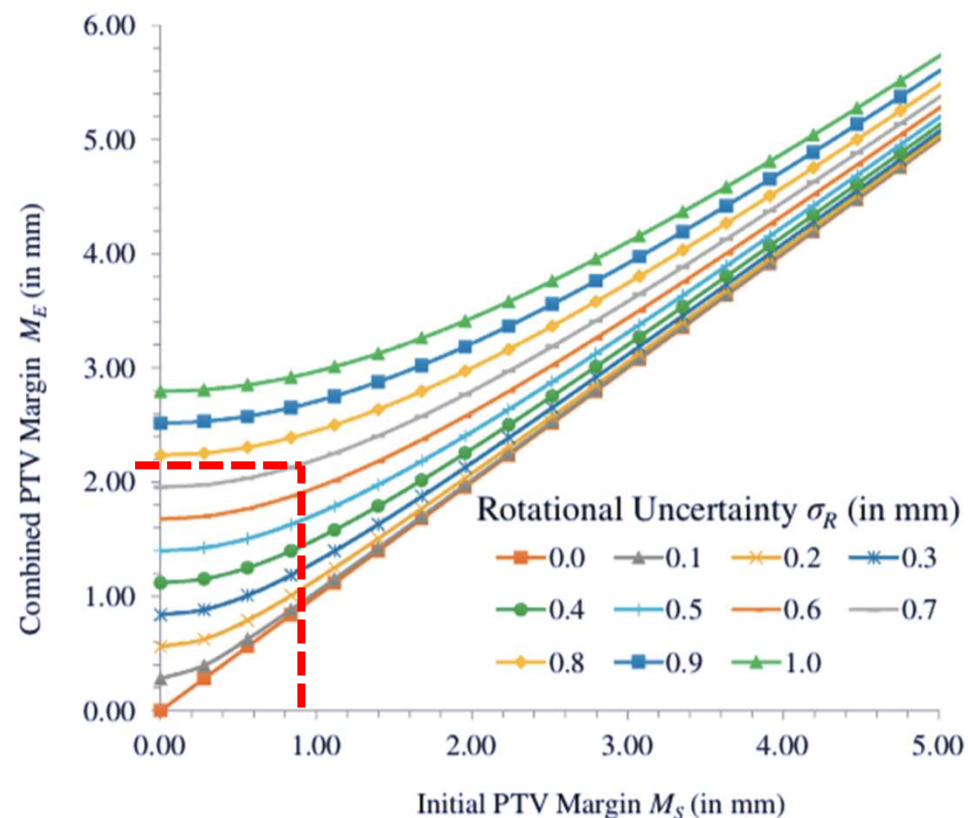
$(1 - \alpha) \times 100\%$	M_S (mm)		
	1.00	2.00	3.00
99%	0.30	0.59	0.89
95%	0.36	0.72	1.07
90%	0.40	0.80	1.20

Table 3 Calculated M_E (combined planning target volume margin in mm) for selected $d_{I \leftrightarrow T}$ (first row: distance from the isocenter to the clinical target volume in mm) and M_S (first column: initial planning target volume margin in mm due to translational uncertainty) after a rotational uncertainty of $\sigma_D = 0.35^\circ$ is introduced. The second row (σ_R in mm) is calculated as $\sigma_R = 0.01424d_{I \leftrightarrow T}\sigma_D$ and M_E is determined using the data from Figure 2

M_S	$d_{I \leftrightarrow T}$							
	0	20.0	40.0	60.0	80.0	100.0	120.0	160.0
	σ_R							
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.8
0.00	0.0	0.3	0.6	0.8	1.1	1.4	1.7	2.2
1.00	1.0	1.0	1.1	1.3	1.5	1.7	1.9	2.4
2.00	2.0	2.0	2.1	2.2	2.3	2.4	2.6	3.0
3.00	3.0	3.0	3.1	3.1	3.2	3.3	3.4	3.7

Exemplo clínico:

- Incerteza rotacional em graus:
 $\sigma_D = 0.5^\circ$ (*valor sugerido**)
- Distância do isocentro:
 $d_{I \leftrightarrow T} = 10\text{cm}$
- Incerteza Rotacional:
 $\sigma_R = 0.01424 \times 0,5 \times 100\text{mm} = 0,7\text{mm}$
- Margem inicial de PTV:
 $M_S = 1\text{mm}^{1,2}$



Margem Combinada:

$$M_E = 2,1\text{mm}$$

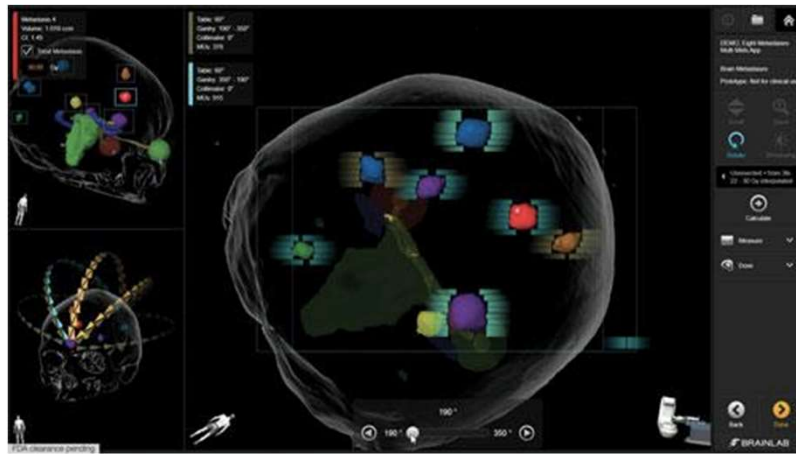
*Practical Radiation Oncology (2018) 8, 475-483

1. Int J Radiat Oncol Biol Phys. 2011 May 1;80(1):281-90
2. Int J Radiation Oncol Biol Phys, Vol. 91, No. 1, pp. 100e108, 2015



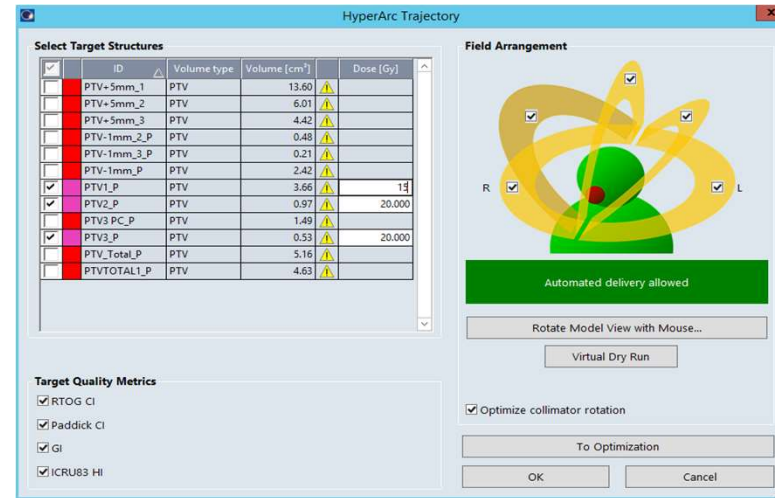
Sistemas automatizados comerciais

BrainLab Elements™



- ✓ Colocação automática
- ✓ Escolha de lesões por arco
- ✓ Velocidade de cálculo
- ✓ 3 Rotações de mesa
- ✓ Arcos dinâmicos (<MU)

Varian HyperArc™



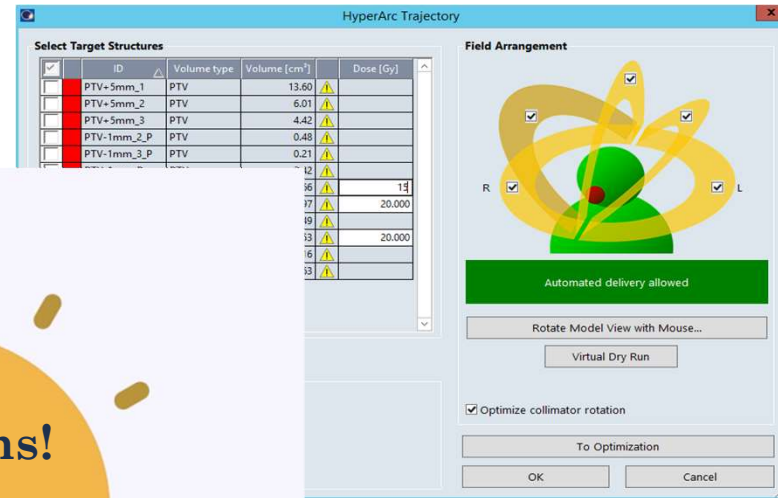
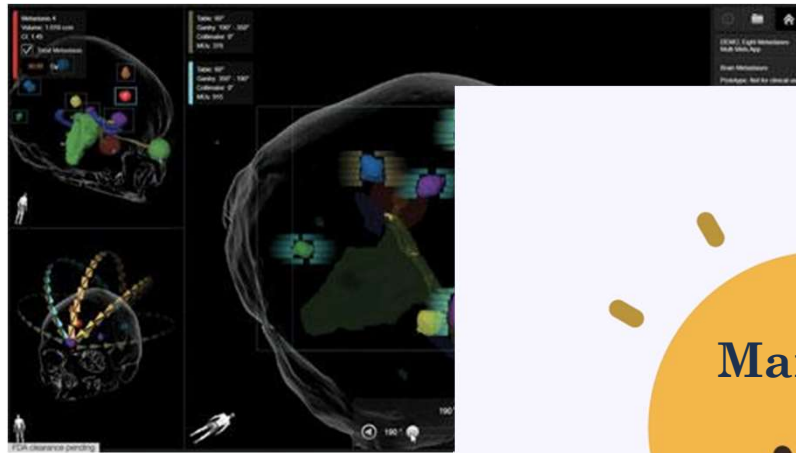
- ✓ Colocação automática
- ✓ Otimização colimadores
- ✓ NTO específico SRS
- ✓ Movimentação automática da mesa
- ✓ RapidArc™



Sistemas automatizados comerciais

Varian HyperArc™

BrainLab Elements™



- ✓ Colocação automática
- ✓ Escolha de lesões
- ✓ Velocidade de cá
- ✓ 3 Rotações de m
- ✓ Arcos dinâmicos (VMU)

automática

colimadores

efício SRS

ção automática da mesa

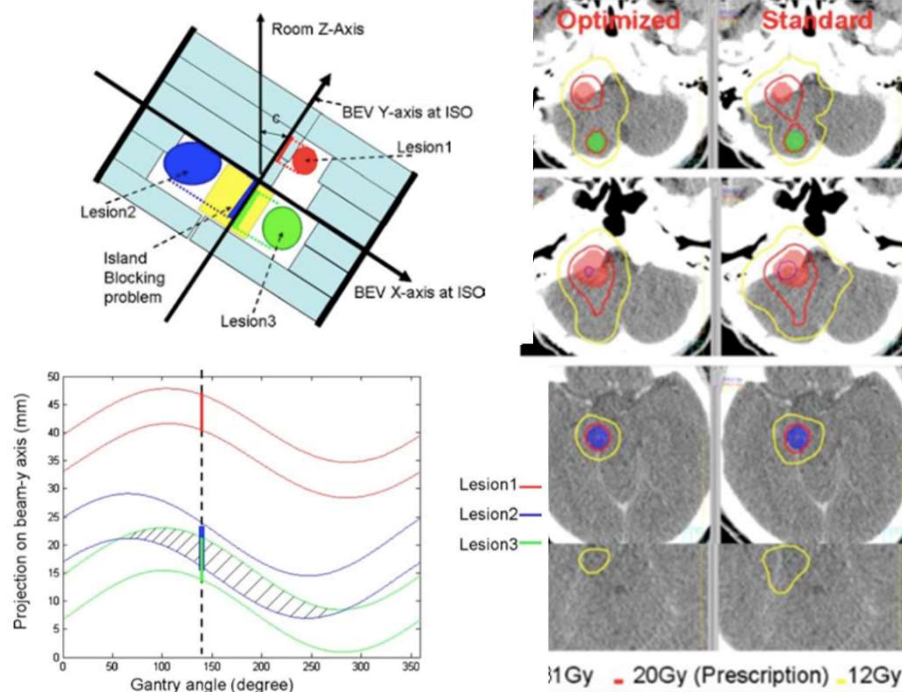


Ajustes de arcos e colimadores: *In-house Softwares*

A method for optimizing LINAC treatment geometry for volumetric modulated arc therapy of multiple brain metastases

Jun Kang,^{a)} Eric C. Ford, Koren Smith, John Wong, and Todd R. McNutt
Department of Radiation Oncology and Molecular Radiation Sciences, The Johns Hopkins University
School of Medicine, Baltimore, Maryland 21231

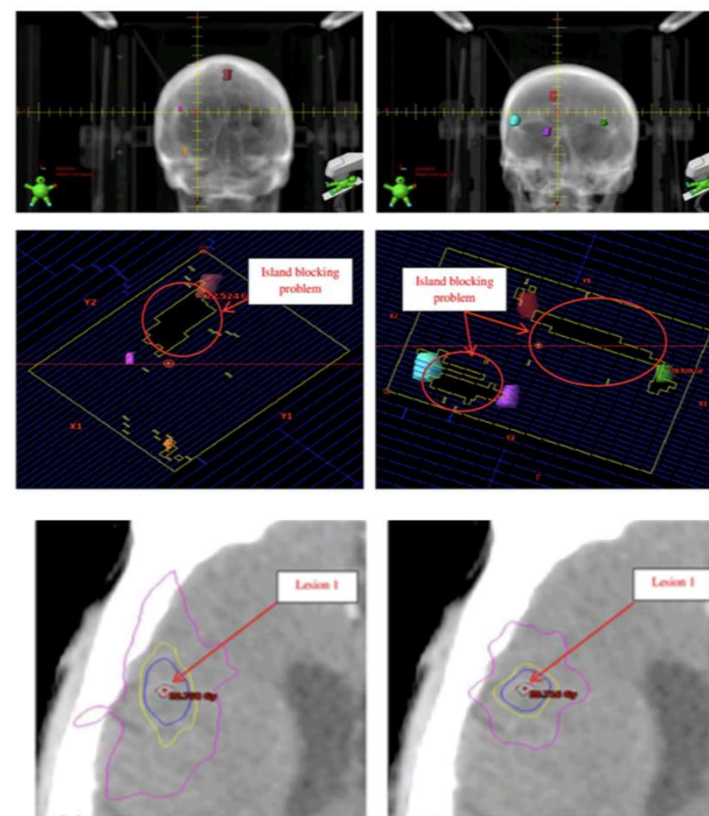
MedPhys 2010



Optimization of Treatment Geometry to Reduce Normal Brain Dose in Radiosurgery of Multiple Brain Metastases with Single-Isocenter Volumetric Modulated Arc Therapy

Nature 2016

Qixue Wu, Karen Chin Snyder, Chang Liu, Yimei Huang, Bo Zhao, Indrin J. Chetty & Ning Wen



Importância do planejamento (ainda!)

Evaluation of multiple factors affecting normal brain dose in single-isocenter multiple target radiosurgery

Yu Yuan, PhD¹, Evan M. Thomas, MD, PhD¹, Grant A. Clark, MD¹, James M. Markert, MD, MPH², John B. Fiveash, MD¹ and Richard A. Popple, PhD¹

Ajuste de colimadores:
Evitar ilhas

X

Uso de Jaw Tracking:
Evitar transmissão

X

Uso de Objetivo:
Forçar a função custo

?



Importância do planejamento (ainda!)

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Ajuste de colimadores:
Evitar ilhas

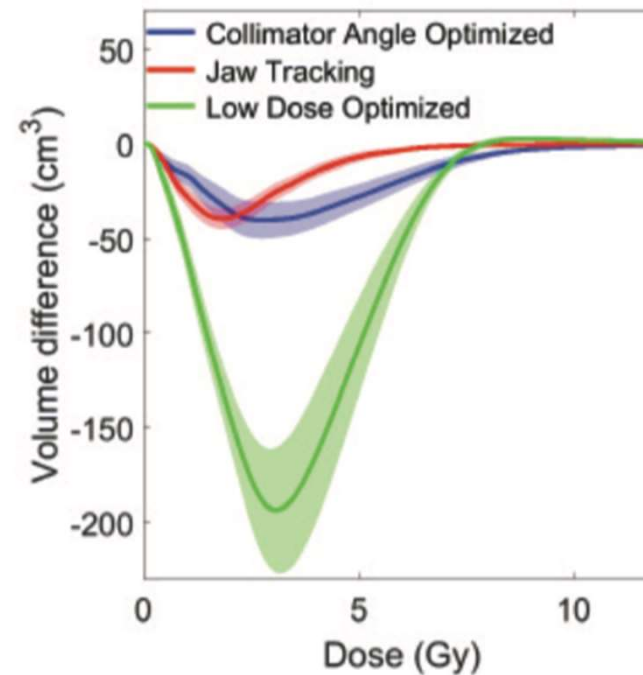
X

Uso de Jaw Tracking:
Evitar transmissão

X

Uso de Objetivo:
Forçar a função custo

→ Upper 1% < 1/6 Dose
→ Brain D_{mean} : 18% → 9%



ANÁLISE DE DVH - CONSTRAINTS

- ✓ Análise clássica de V_{10} ou V_{12} (<10cc) - mas para cada lesão!
- ✓ Difícil translação para múltiplas
- ✓ “Benchmarking”

Comparison of Plan Quality and Delivery Time between Volumetric Arc Therapy (RapidArc) and Gamma Knife Radiosurgery for Multiple Cranial Metastases

Evan M Thomas, M.S.¹, Richard A Popple, Ph.D.¹, Xingen Wu, Ph.D.¹, Grant M Clark, M.D.¹, James M Markert, M.D.², Barton L Guthrie, M.D.², Yu Yuan, Ph.D.¹, Michael C Dobelbower, M.D., Ph.D.¹, Sharon A Spencer, M.D.¹, and John B Fiveash, M.D.¹

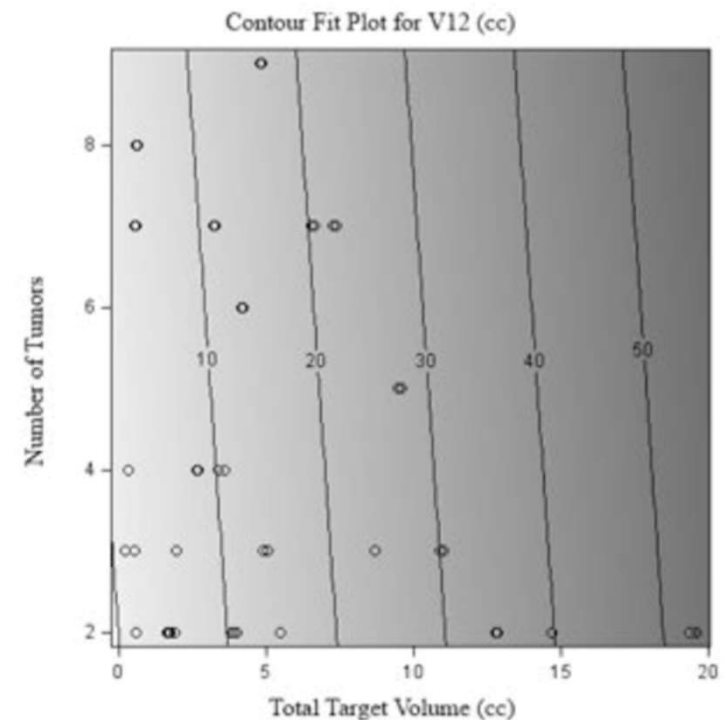


Gráfico de resultado esperado de V_{12} por número de lesões x volume

Neurosurgery. 2014 October ; 75(4): 409–418

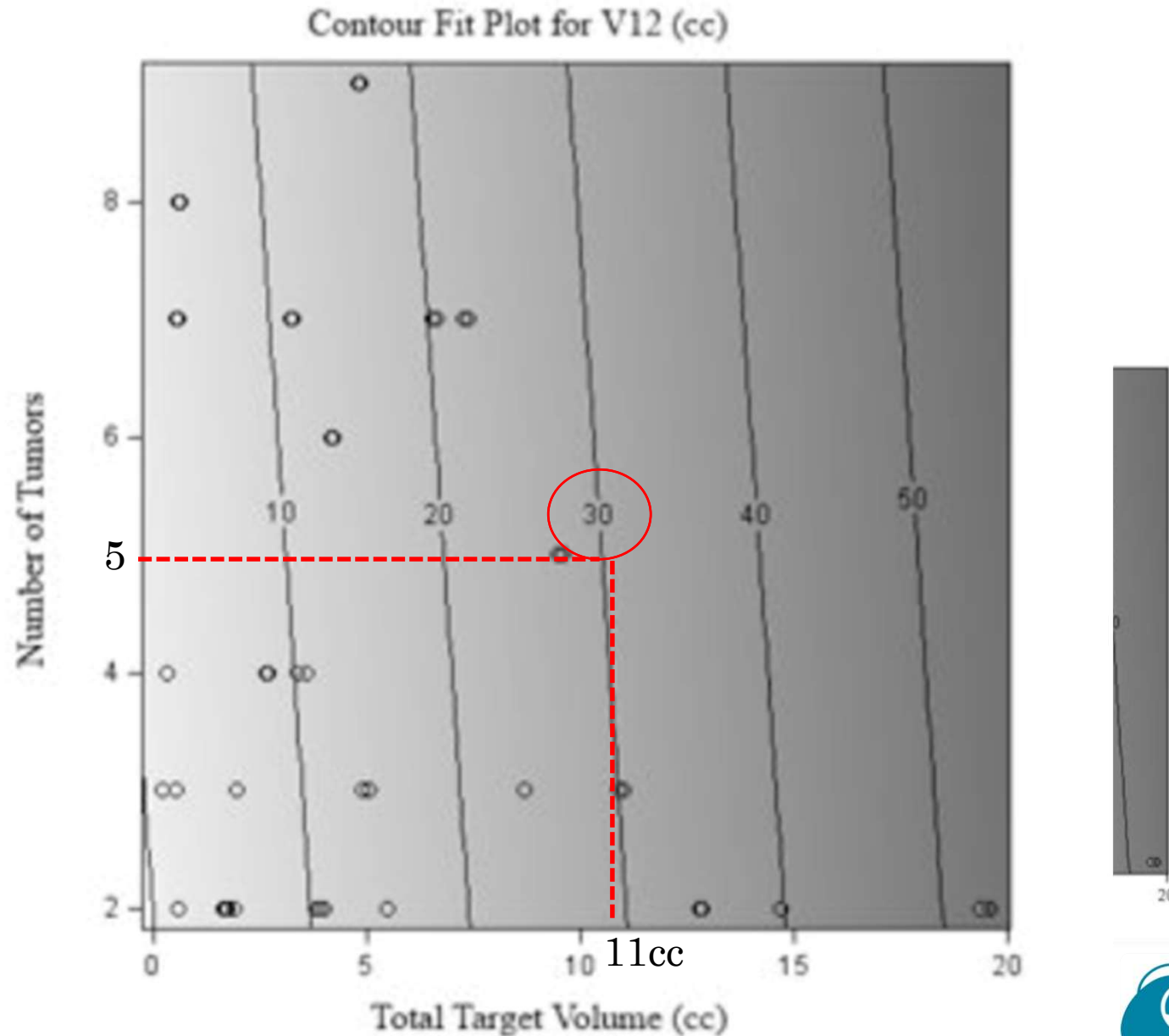


ANÁLISE

- ✓ Análise
- ✓ Dificil t
- ✓ “Bench

Comparison of Plan Volumetric Arc The Radiosurgery for M

Evan M Thomas, M.S.¹, Ric
James M Markert, M.D.², B
M.D., Ph.D.¹, Sharon A Spe



Gráfico

Neurosurgery. 2014 October ; 75(4): 409–418

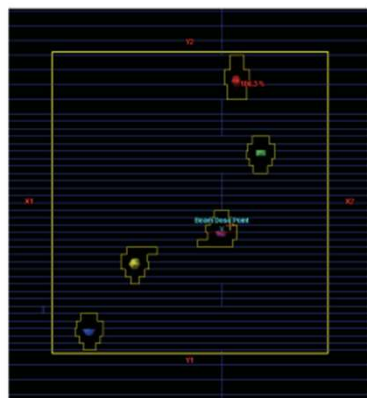


TESTES END-TO-END

Conheça e teste seu sistema - SEMPRE

Spatial variations of multiple off-axis targets for a single isocenter SRS treatment in Novalis Tx linac system

Sangroh Kim, PhD¹ Tzu-Chi Tseng, MS² and Andrew Morrow, MS³



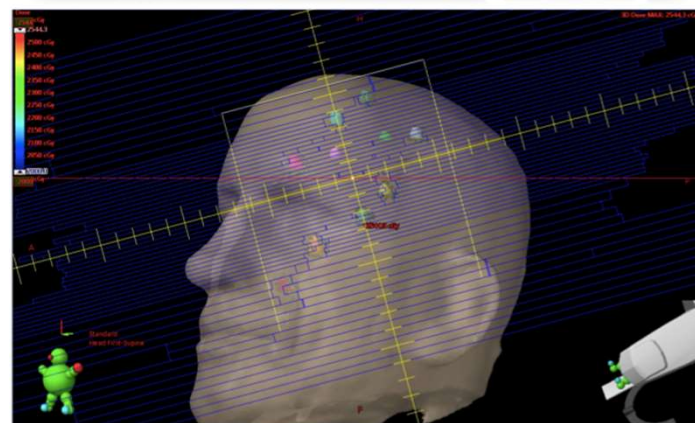
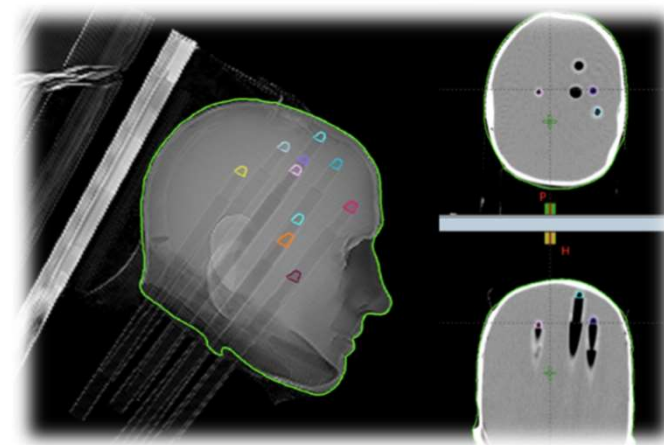
Avaliação Dosimétrica de Múltiplas Metástases

Validação end-to-end de tratamentos de múltiplas metástases encefálicas com radiocirurgia utilizando isocentro único e fantoma antropomórfico.

Thais Pires Flores

Orientador: Ademar Marques Caldeira Filho

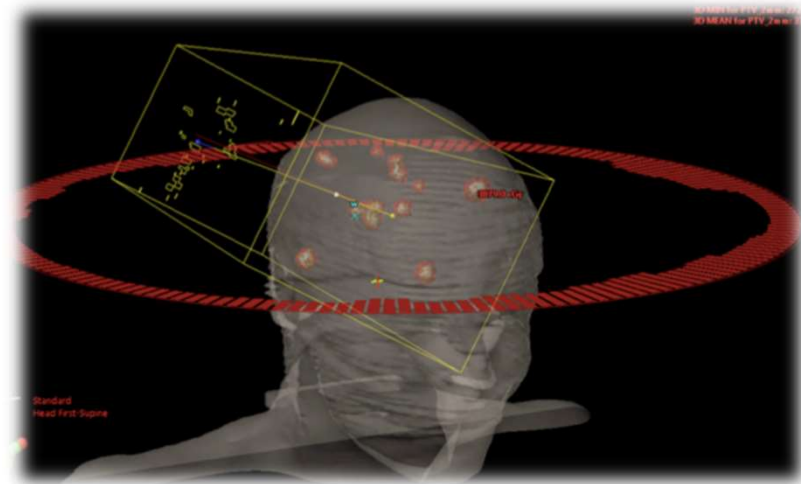
Faculdade de Física, Pontifícia Universidade Católica do Rio Grande do Sul



XXI Congresso SBRT – Rio de Janeiro

TAKE HOME MESSAGE

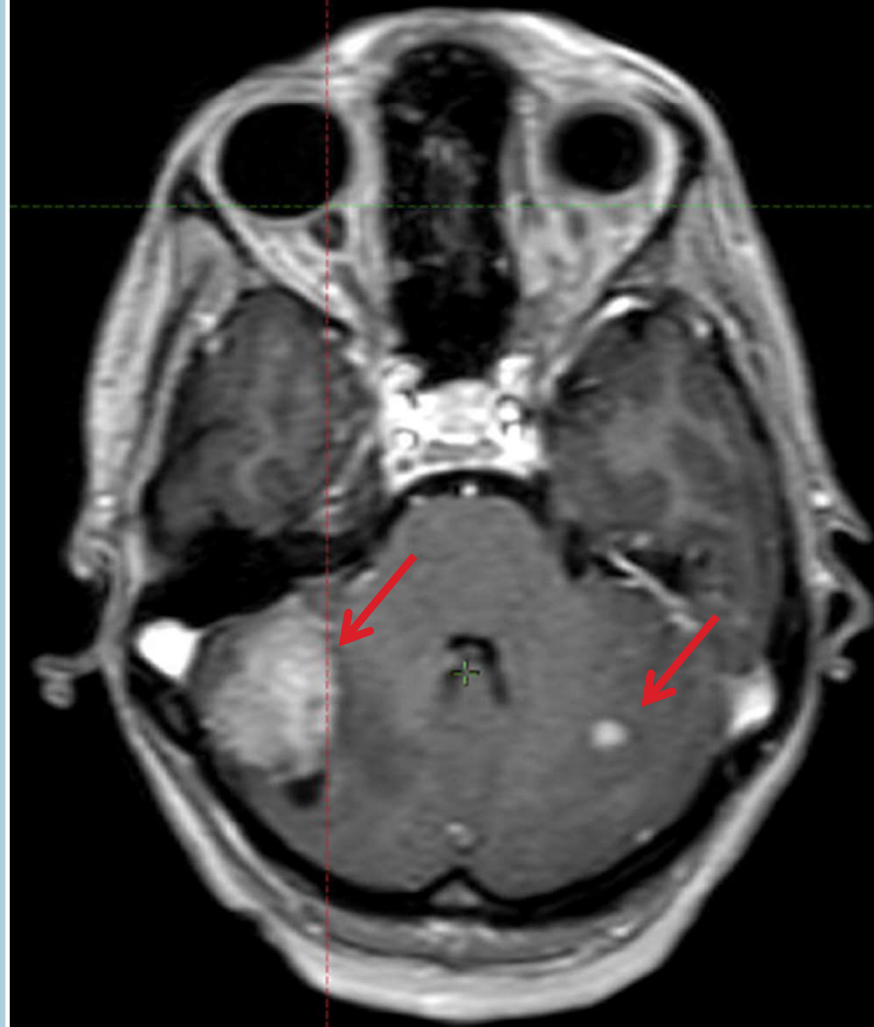
- ✓ Possível, mas requer cuidados na implementação e na rotina
- ✓ End-to-end
- ✓ Posição de isocentro, MLC, rotação de colimador
- ✓ Volume e distância do Isocentro
- ✓ Adequação das margens por lesão
- ✓ Constraints?



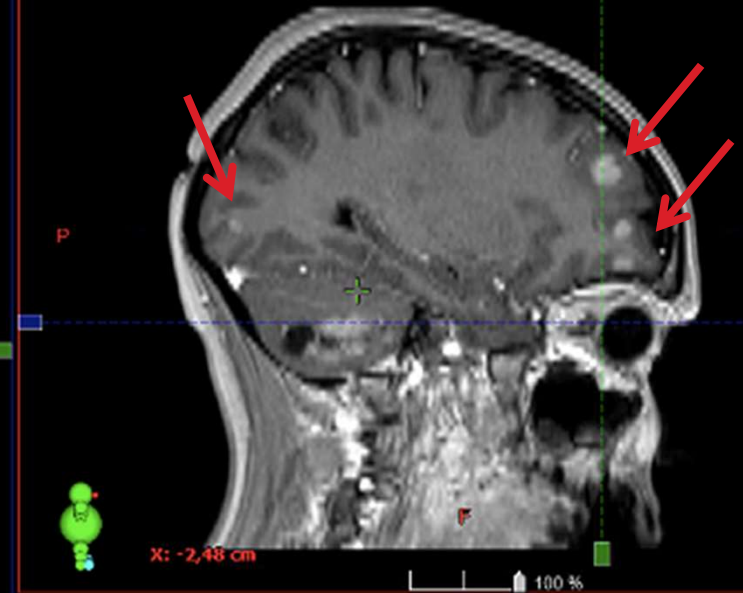
14 Lesões



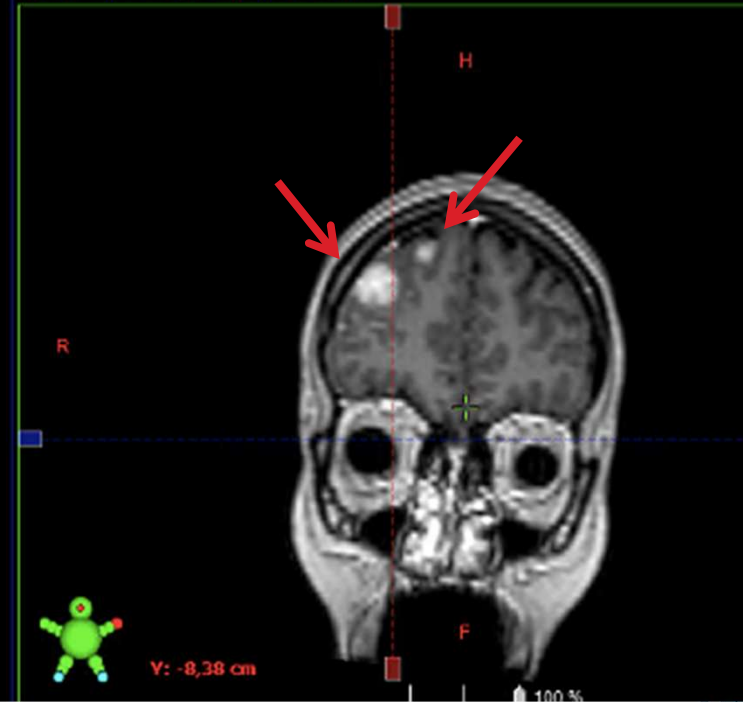
O que faz tudo ter sentido...



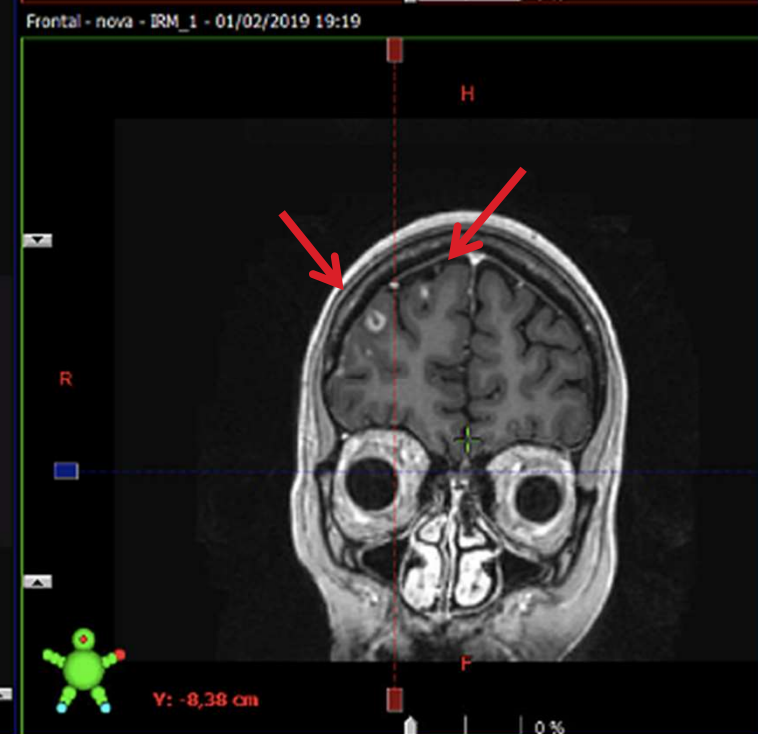
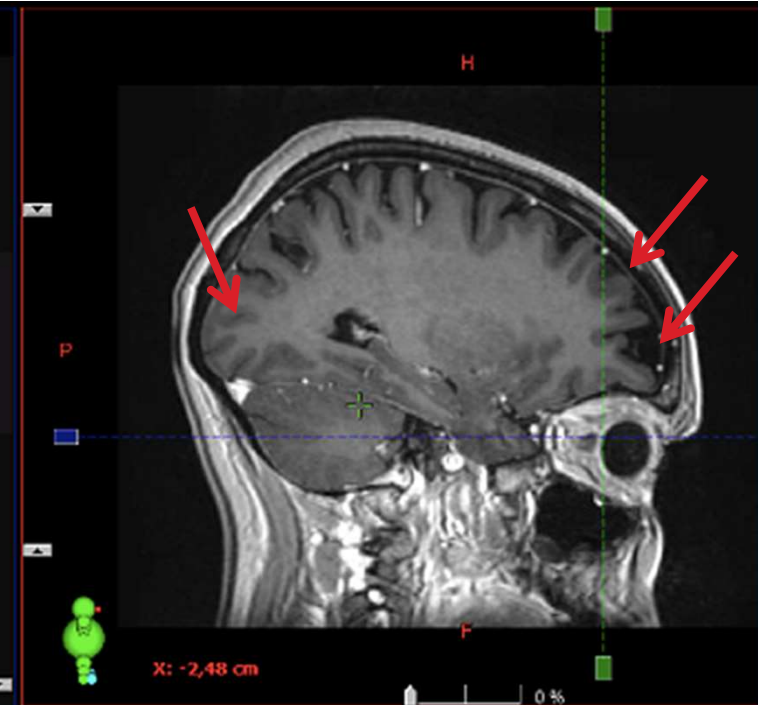
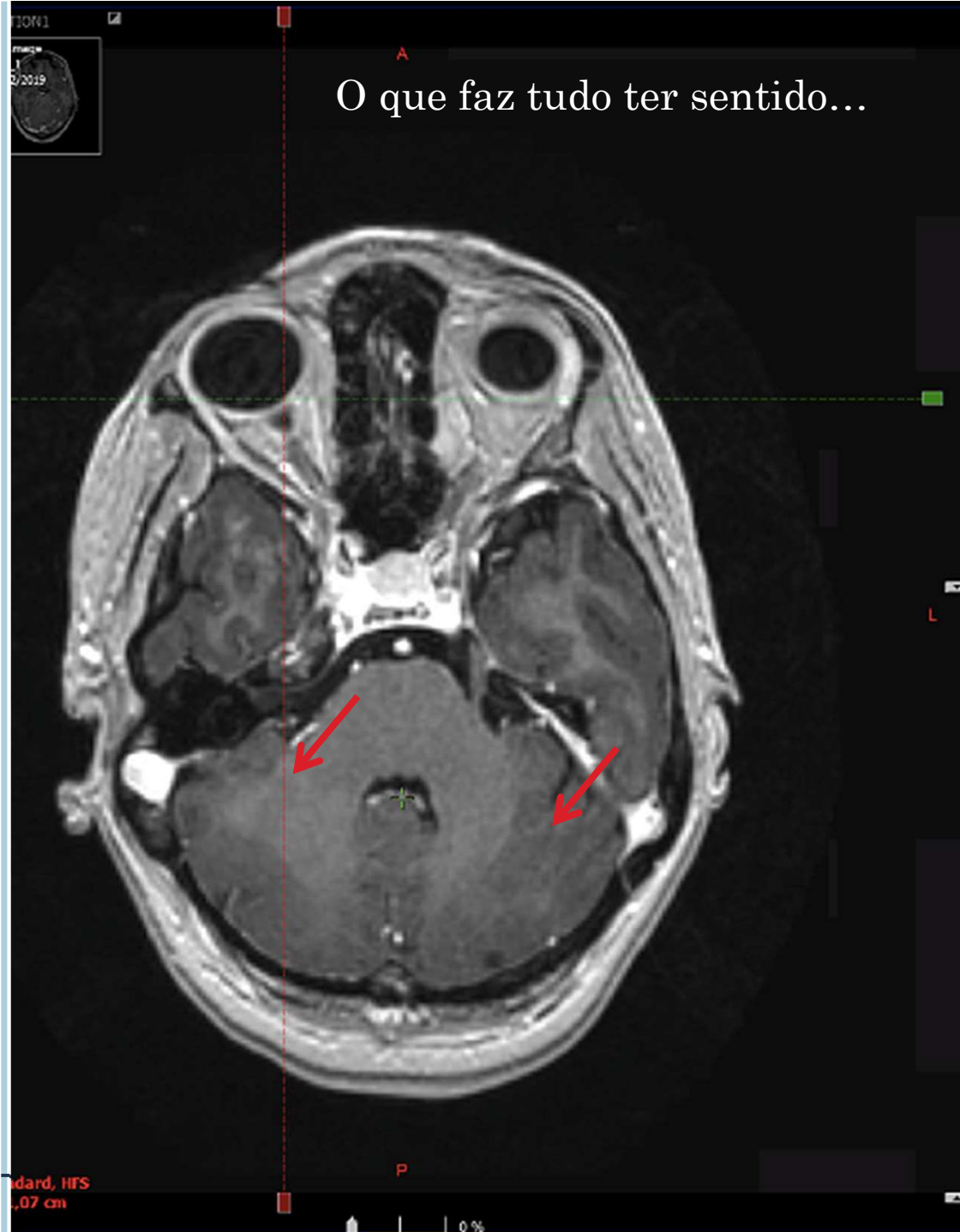
Standard, HFS
0,07 cm



Frontal - nova - IRM_1 - 01/02/2019 19:19



O que faz tudo ter sentido...





Hospital Mãe de Deus – Porto Alegre/RS

william.trinca@maededeus.com.br



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