Ambigüités de la prescription usuelle en radiothérapie stéréotaxique

T. Lacornerie, service de physique médicale

Plan

Prescription en radiothérapie stéréotaxique :

- % de couverture
- marge du PTV
- cas particulier du poumon

Conclusions et perspectives

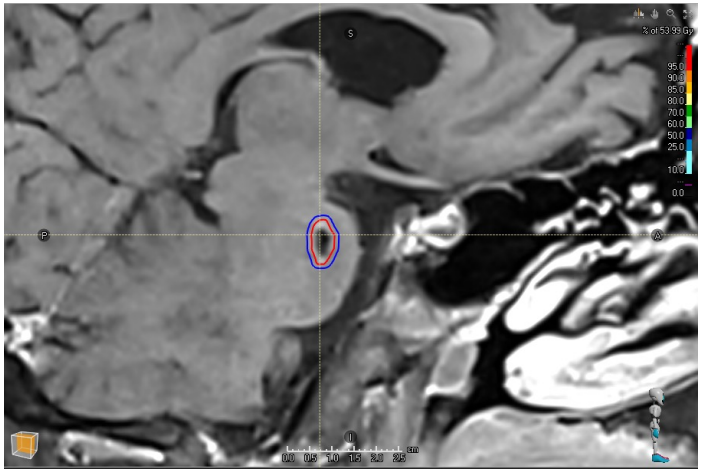
Radiothérapie stéréotaxique : prescription

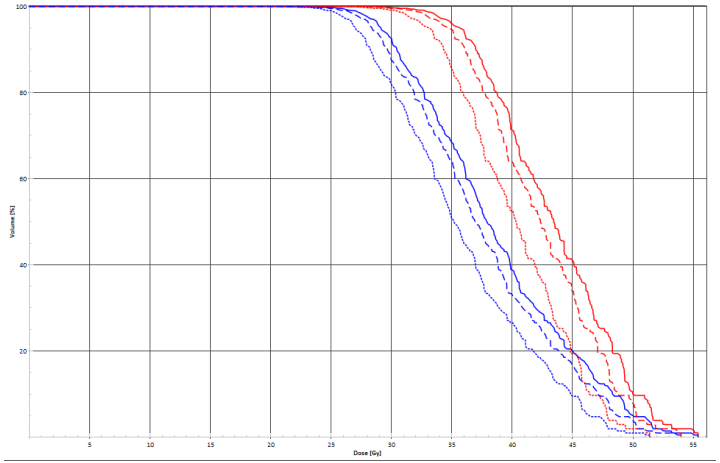
ICRU 91 (2017)

Absorbed dose is prescribed to the isodose surface D_V that covers an optimal percentage volume of the PTV (V) while optimally restricting dose to the PRV.

- Quelle surface d'isodose ? 50%, 70%, 80% du maximum ? Est-ce important ?
- Quel est le pourcentage optimal du PTV ? 100%, 99%, 98%, 95%
- Quelle marge pour le PTV ?

prescription SRT



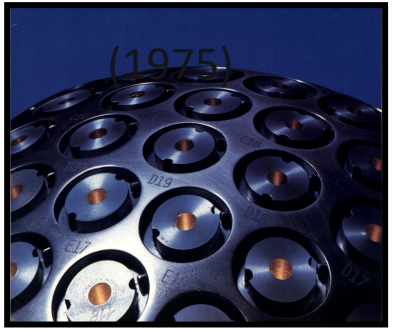


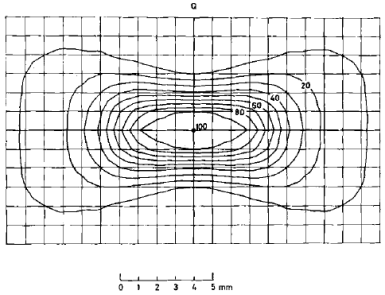
Prescription à D99%, D98%, D95% du PTV

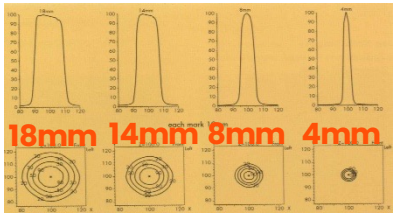
Pourquoi une prescription à une isodose périphérique ?

(1967)

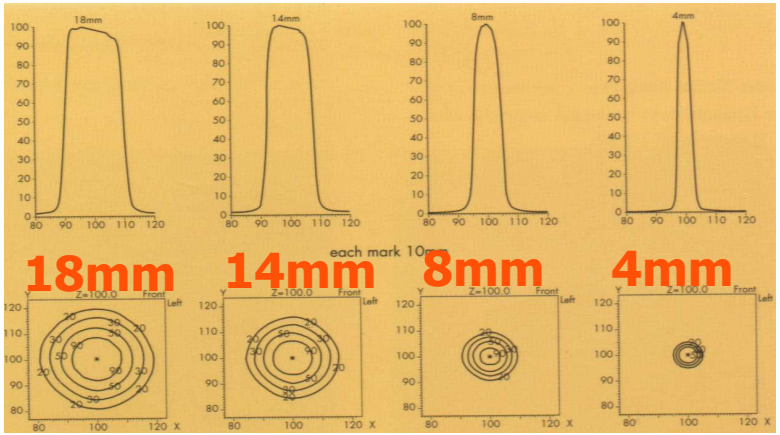
(1975)

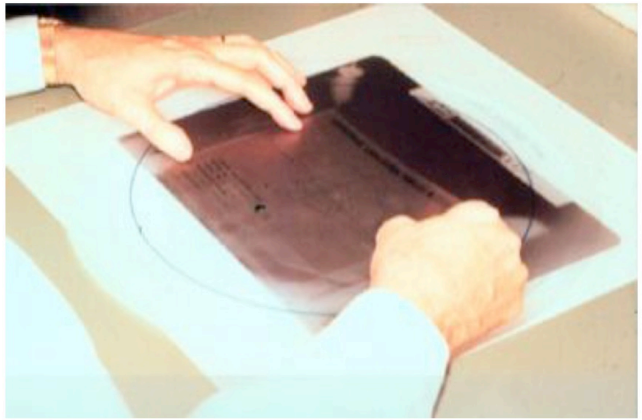






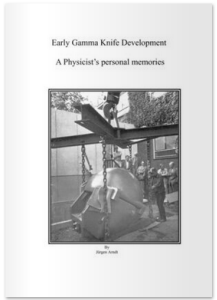
Pourquoi une prescription à une isodose périphérique ?





Gamma Knife : données de base

Pourquoi une prescription à une isodose périphérique ?



Early Gamma Knife Development A Physicist's personal memories

© by Jürgen Arndt

Early Gamma Knife Development A Physicist's personal memories By Jürgen Arndt

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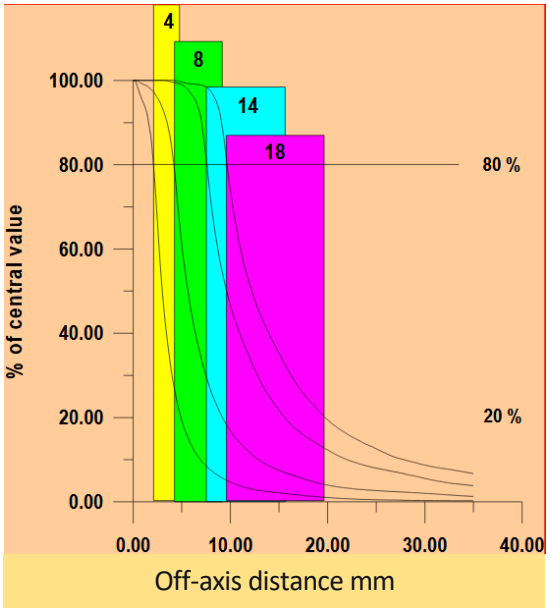
"Historically, dose prescription in SRS has been using the so-called "coverage isodose" to represent some form of minimum target dose, as it was related to techniques using fixed circular collimators."

Pourquoi une prescription à une isodose périphérique ?

Gamma Knife B

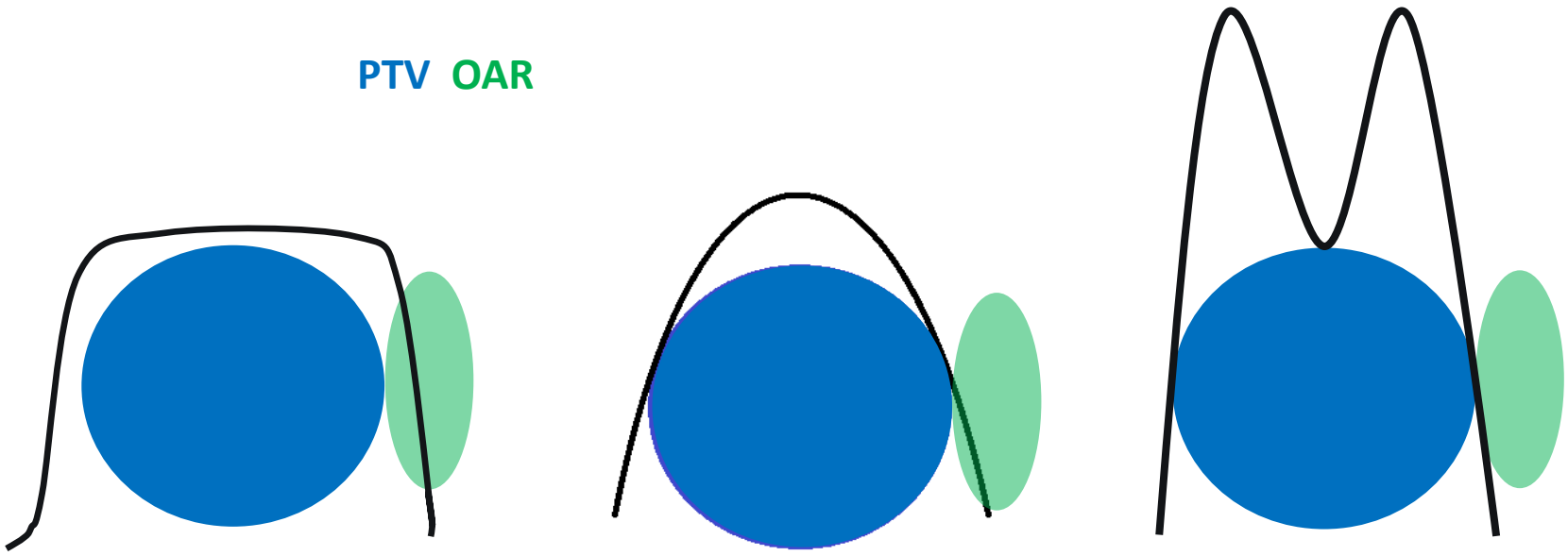


Pourquoi à 50% du maximum au Gamma Knife ?

📖J. Arndt AAPM 1999

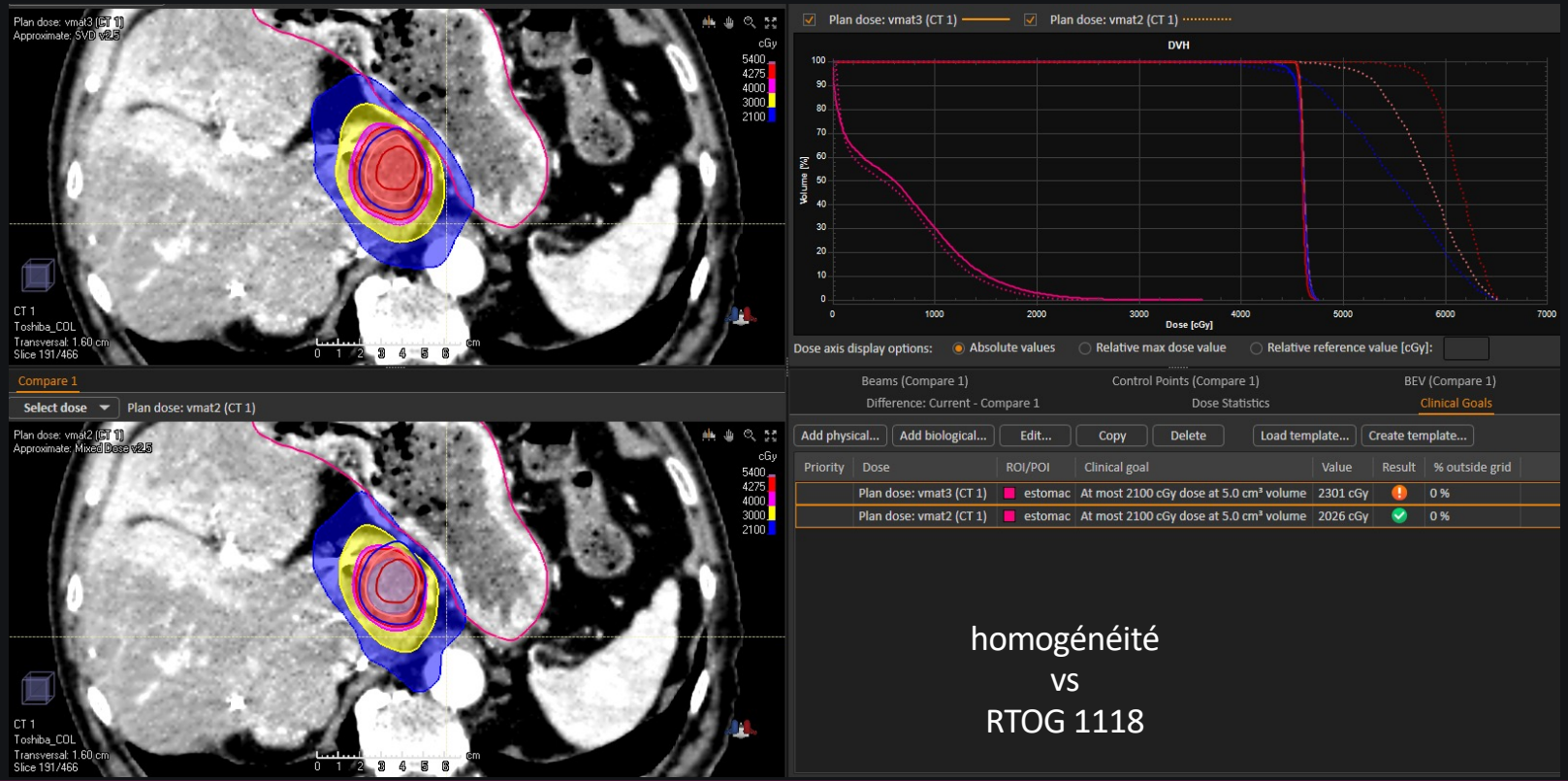
Isodose où le gradient est le plus fort
4 mm = 50 %
8 mm ≅ 60%
14 mm ≅ 70%
18 mm ≅ 80%

Hétérogénéité de dose dans le PTV



ICRU 83

Hétérogénéité de dose dans le PTV



homogénéité
vs
RTOG 1118

PTV

Définition du PTV : ICRU 91 : concept géométrique pour la planification et l'évaluation :

- englobe le GTV/**CTV** avec une marge pour s'assurer que le GTV/CTV reçoit avec une probabilité acceptable la dose de prescription
- mouvement internes, déformations des organes et positionnement
- propriétés mécaniques de la machine
- incertitudes de **contour : humaines** + imagerie (résolution, distorsion, recalage)

$\Rightarrow$ Compromis avec les OAR

PTV

$$PTV\ margin = \alpha\Sigma + \beta\sqrt{(\sigma^2 - \sigma_P{}^2)} - \beta\sigma_P$$

recette de Marcel van Herk

Σ : erreur systématique

σ : erreur aléatoire

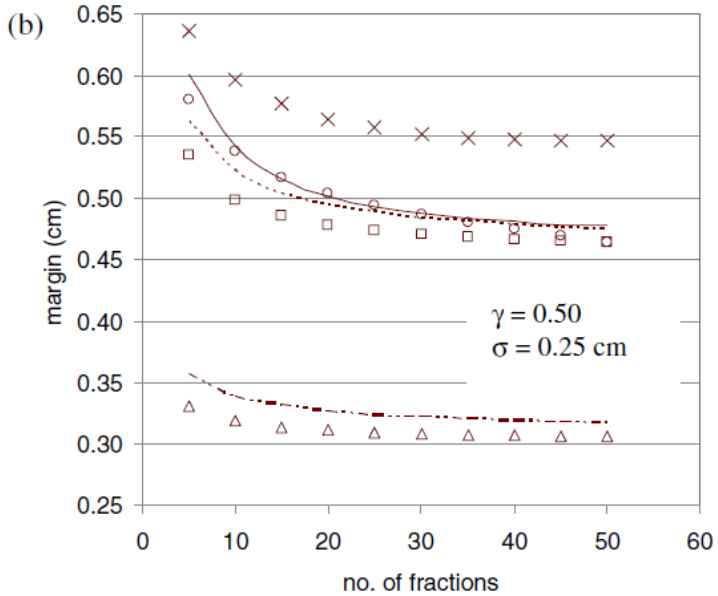
σ_p : pénombre

α : dépend de la probabilité de couverture souhaitée

β : dépend de l'isodose de prescription

PTV

📖Gordon, J. J., & Siebers, J. V. (2007). Convolution method and CTV-to-PTV margins for finite fractions and small systematic errors. *Physics in Medicine and Biology*



Moins il y a de séances plus il faut augmenter la marge …

PTV pour SRT

📖Grishchuk, D. *et al.* ISRS Technical Guidelines for Stereotactic Radiosurgery: Treatment of Small Brain Metastases (≤1 cm in Diameter). *Pract. Radiat. Oncol.* (2023).

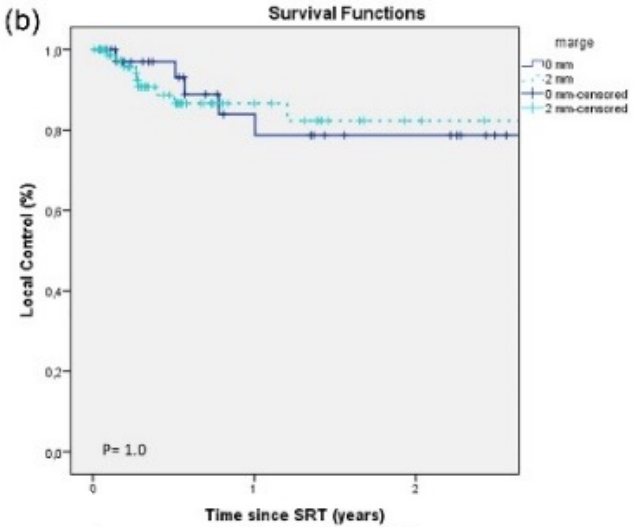
Q6. A PTV expansion be used in the treatment of small metastases (<1cm diameter)?

Strong consensus reached with 83% who agreed that PTV

Q7. The maximum margin that is acceptable to be applied to a small metastasis (<1 cm diameter) is:

Consensus not reached

PTV



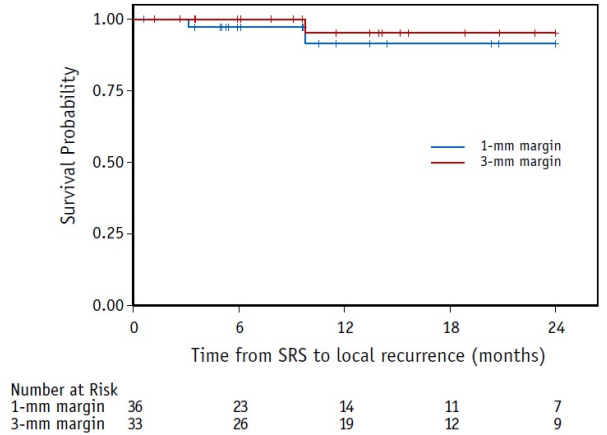


Fig. 2. Local control after stereotactic radiosurgery (SRS).

📖 Badloe, J. *et al.* Impact of PTV margin reduction (2 mm to 0 mm) on pseudoprogression in stereotactic radiotherapy of solitary brain metastases. *tipsRO* (2021).

📖 Kirkpatrick, J. P. *et al.* Defining the optimal planning target volume in image-guided stereotactic radiosurgery of brain metastases: Results of a randomized trial. *IJROBP* (2015).

SRT/SBRT : fortes doses

📖 ICRU 91

-effet sur l'ADN

-dommages vasculaires

-augmentation de l'immunité anti tumorale

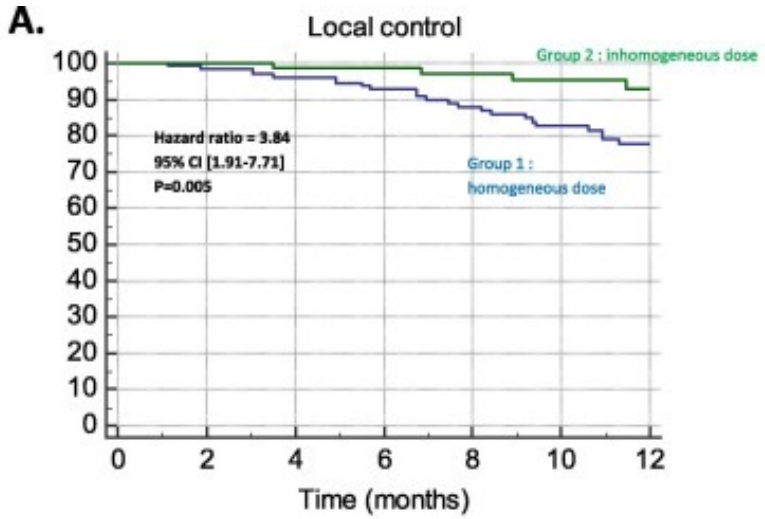
-cellules souches

-effet de voisinage

📖Song CW, et al. Biological Principles of Stereotactic Body Radiation Therapy (SBRT) and Stereotactic Radiation Surgery (SRS): Indirect Cell Death. IJROBP 2021

Est-ce la dose périphérique qui caractérise ces effets ?

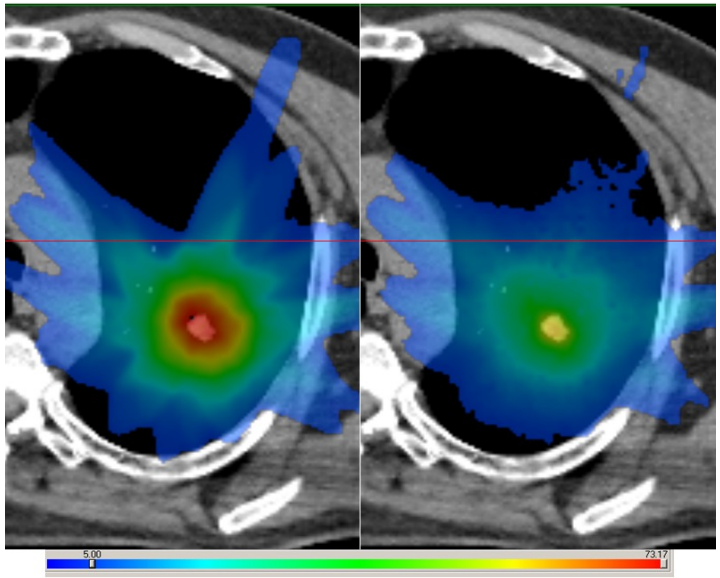
La dose périphérique ne prédit pas les résultats



Homogénéité:
(D2%-D98%)/D50% : 7.0% vs 34.2%

📖 F. Lucia *et al.*, “Inhomogeneous tumor dose distribution provides better local control than homogeneous distribution in stereotactic radiotherapy for brain metastases,” *Radiother. Oncol.*, 2019.

SBRT poumon: prescription



Algorithmes de calcul de dose

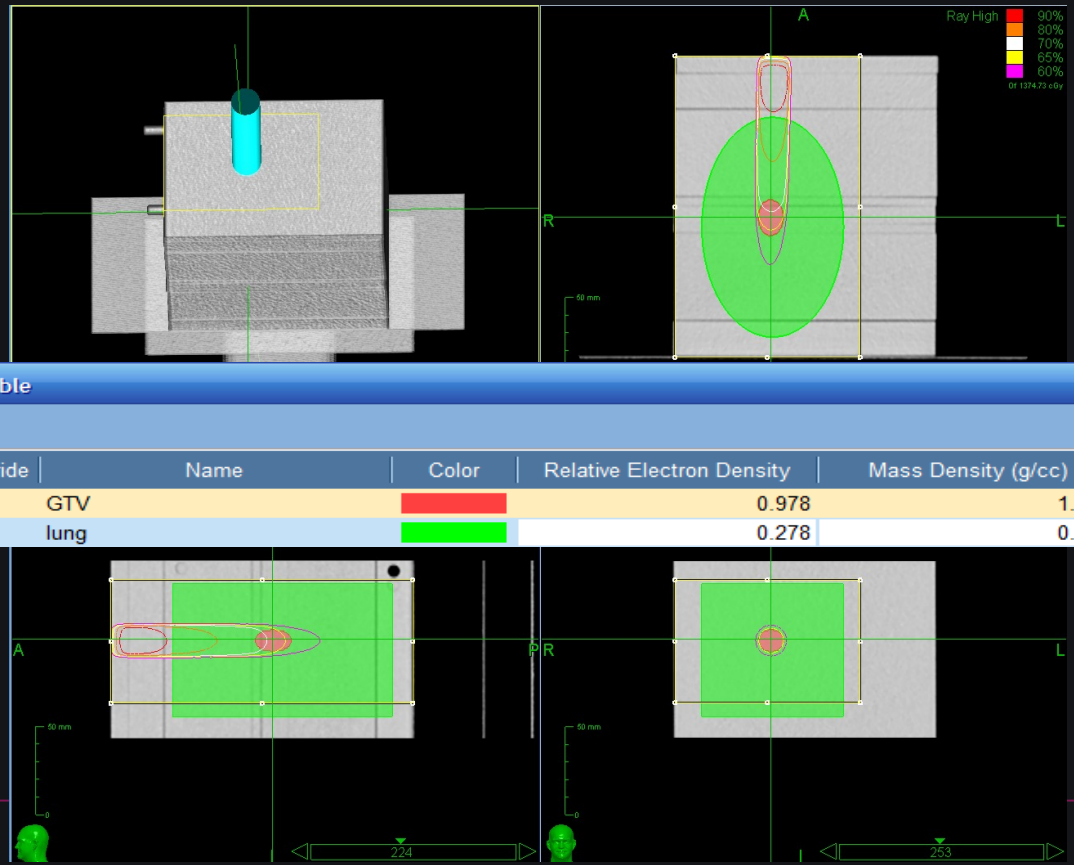
2 types :

- A : ne tiennent pas compte des **hétérogénéités** pour le parcours des **électrons** secondaires

- B et C : tiennent compte des …

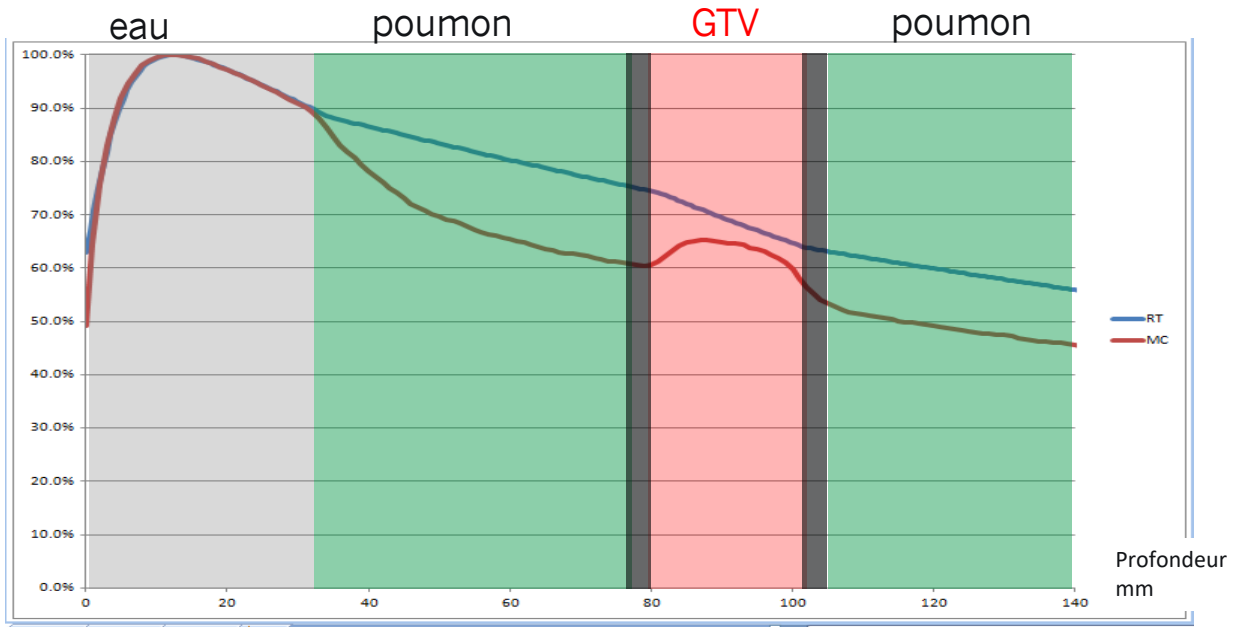
SBRT poumon

1 faisceau sur fantôme



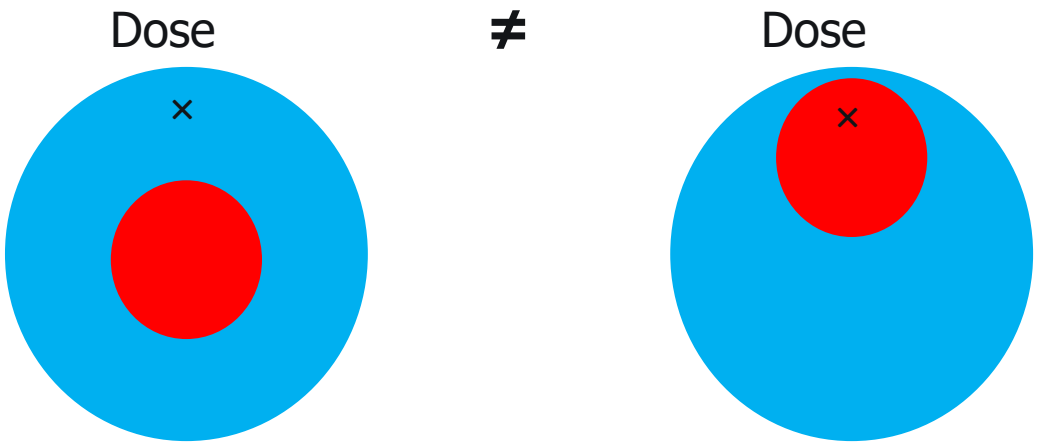
SBRT poumon

Dose sur l'axe du faisceau ∅30mm



SBRT poumon

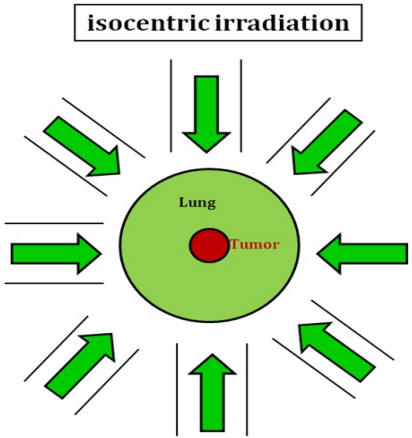
Le PTV volume fictif

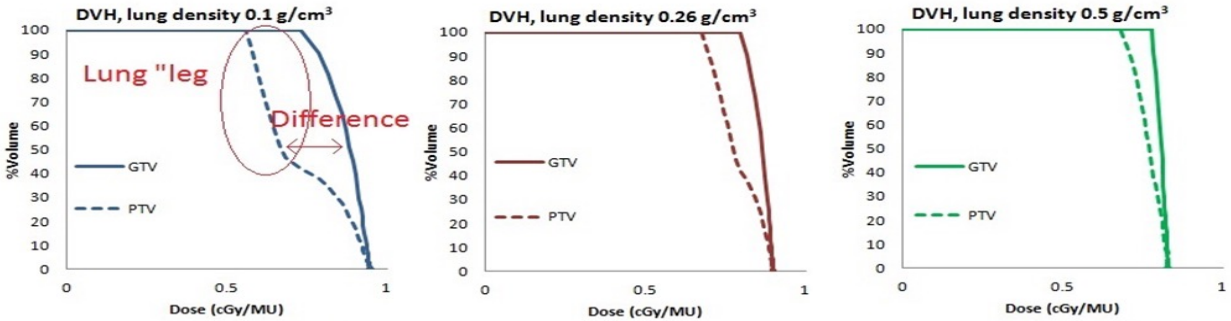


Le PTV n’est pas prédictif de la dose au GTV car il inclut des zones de faible densité

SBRT poumon

📖Lebredonchel et al.
About the non-consistency of PTV-based prescription in lung *Phys Med*





Lung density influence, for a GTV with 3 cm diameter, on DVH

Prescription : définition du PTV

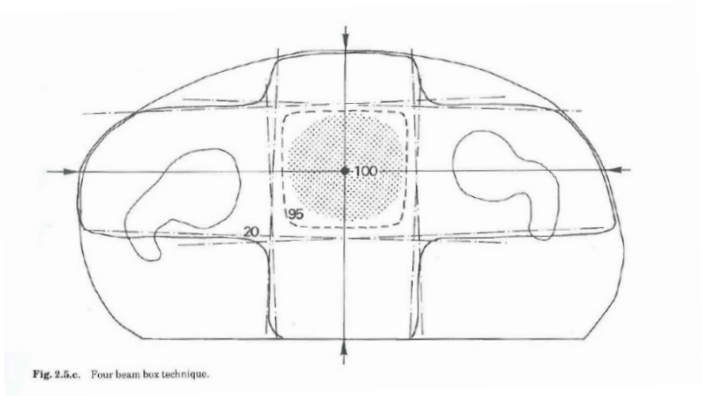
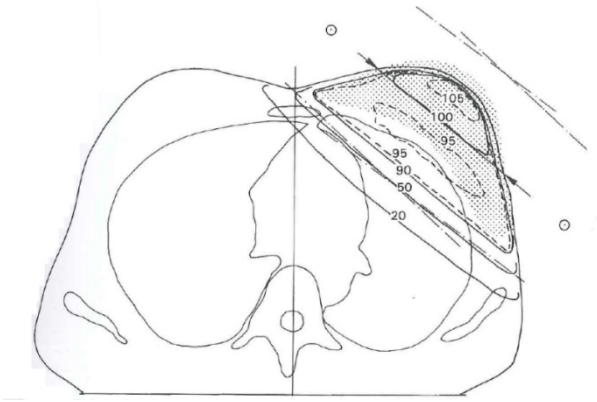


Fig. 2.5.c. Four beam box technique.

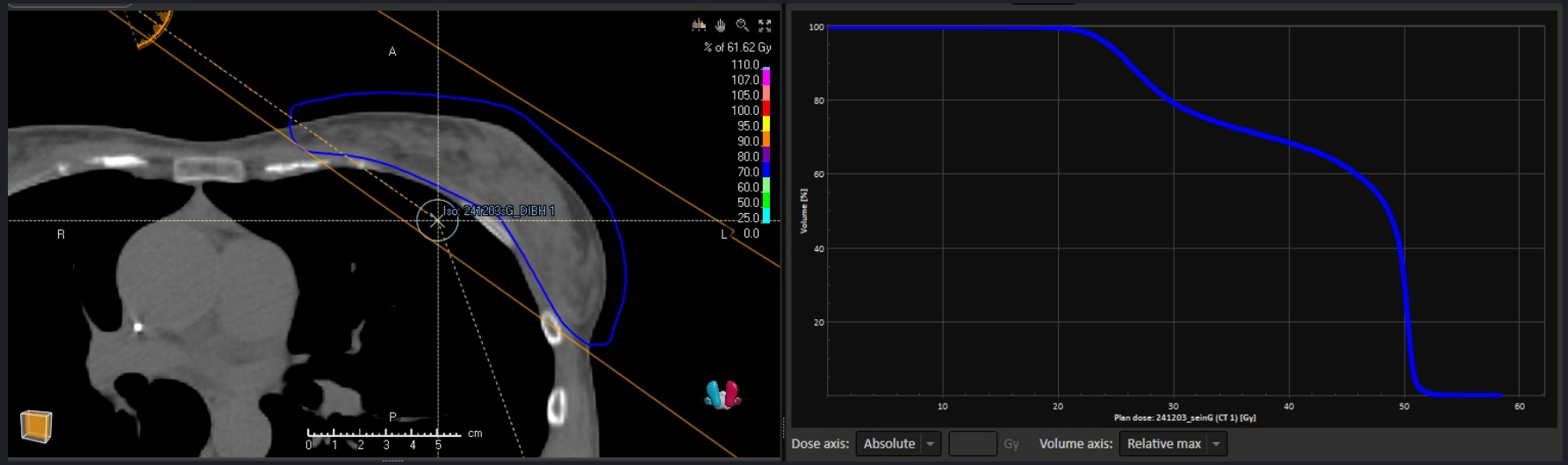


📖 ICRU report n°50 Prescribing, recording, and reporting photon beam therapy 1993

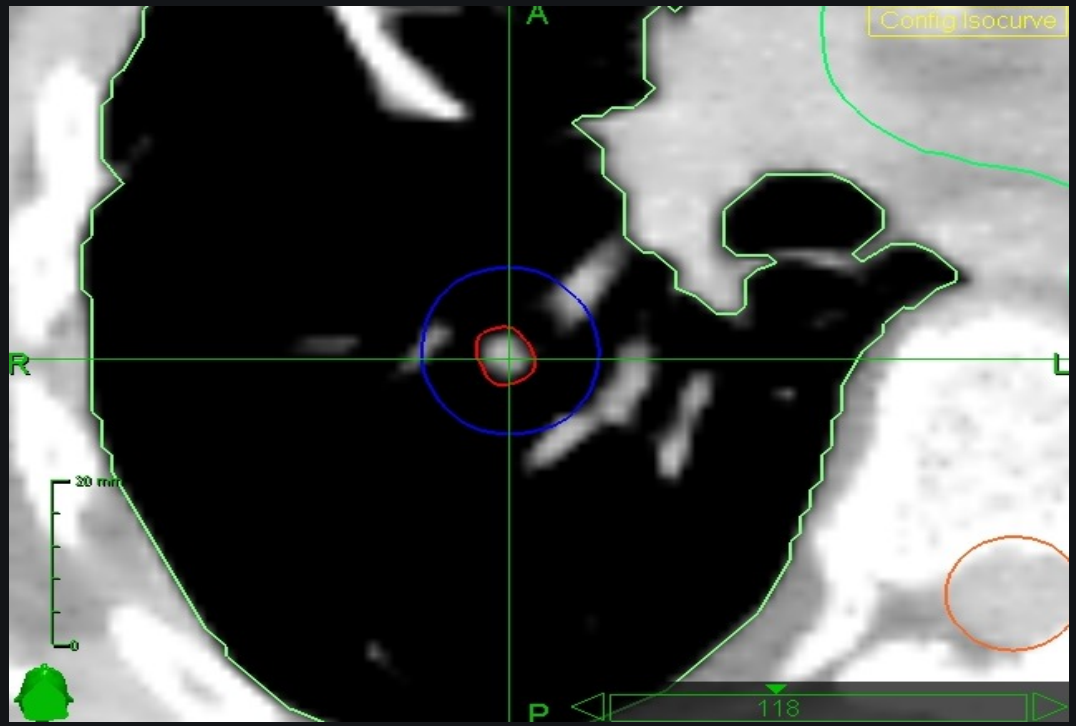
“The logical problem encountered when a PTV extends outside the skin should be answered”

📖 Jones D., book review ICRU n°50 Med. Phys. 1994

Prescririez-vous sur ce PTV ?



Pourquoi prescrire ou optimiser sur ce PTV ?



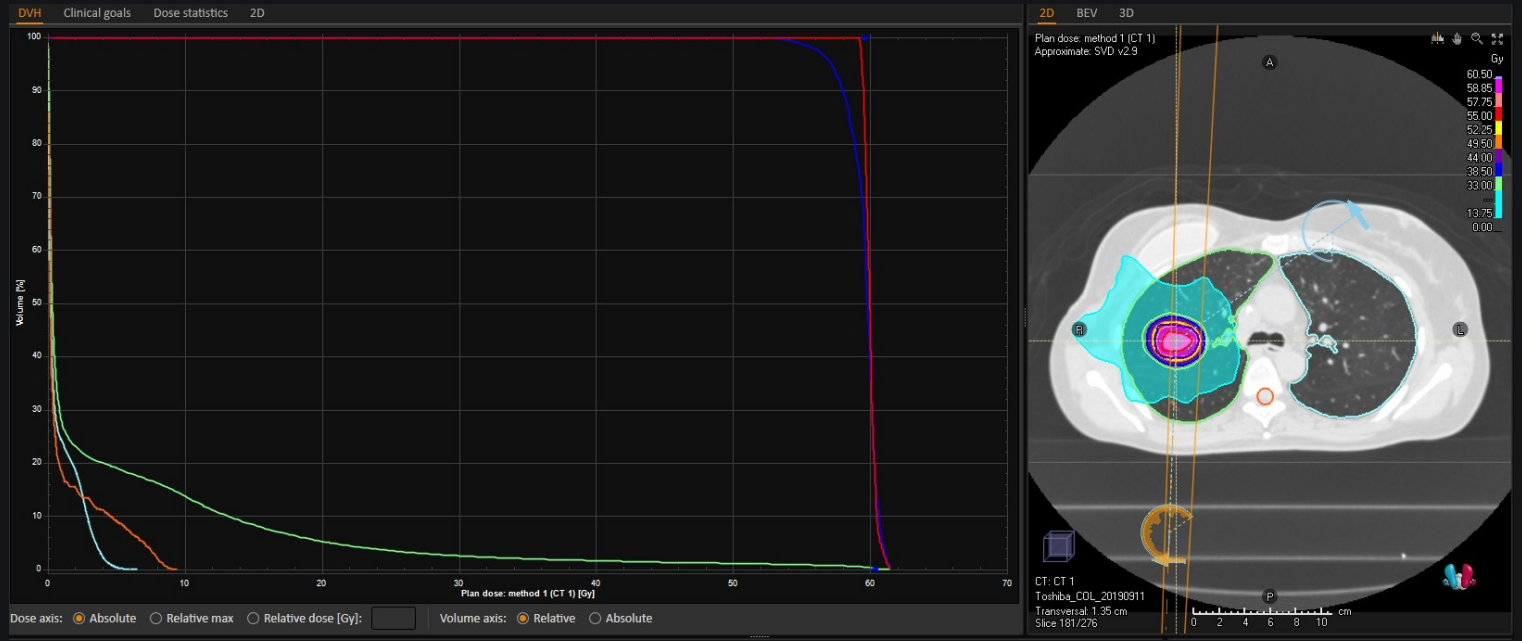
SBRT poumon

Méthode proposée :

- Cibler le PTV en optimisant avec un algorithme de type A
  → fluence de photon ~ homogène
- Recalculer avec type B→ dose correcte
- Prescrire avec type B sur le GTV
- Normalisation sur GTV D50% → représentative de la distribution de dose

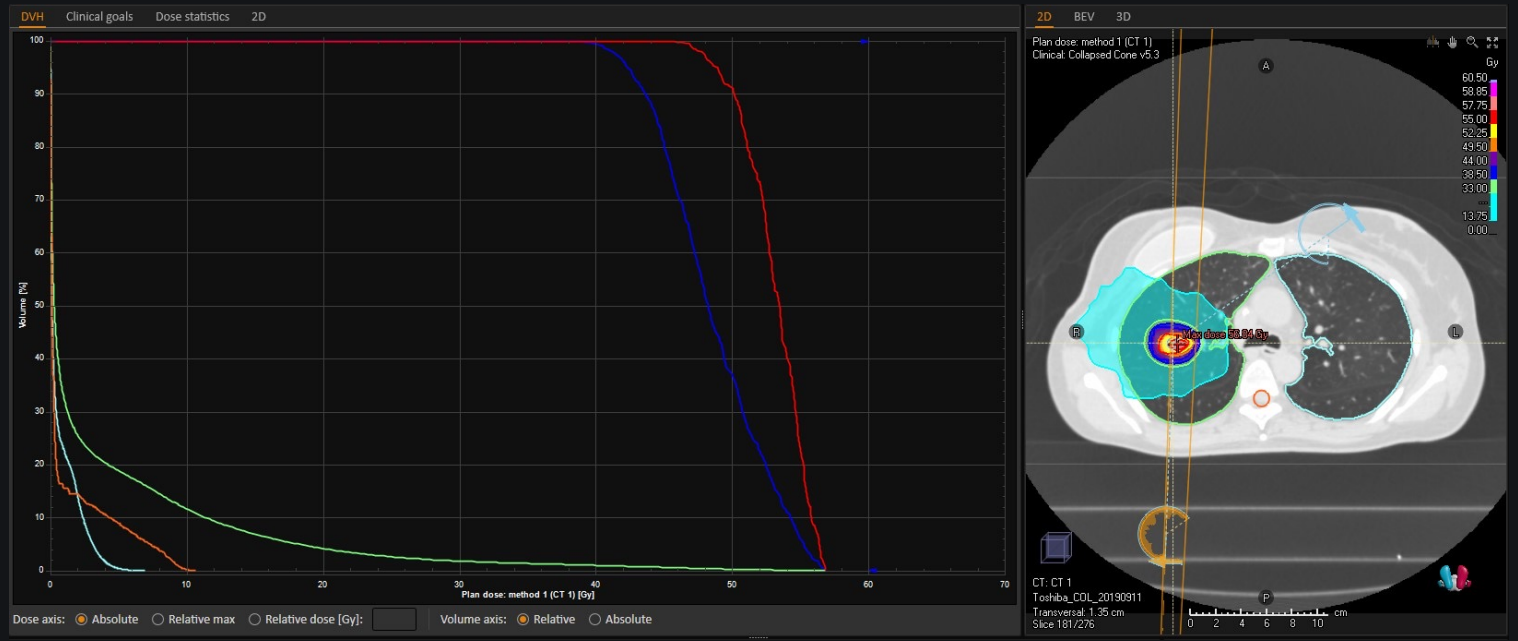
SBRT poumon

1ère méthode : optimisation de la fluence



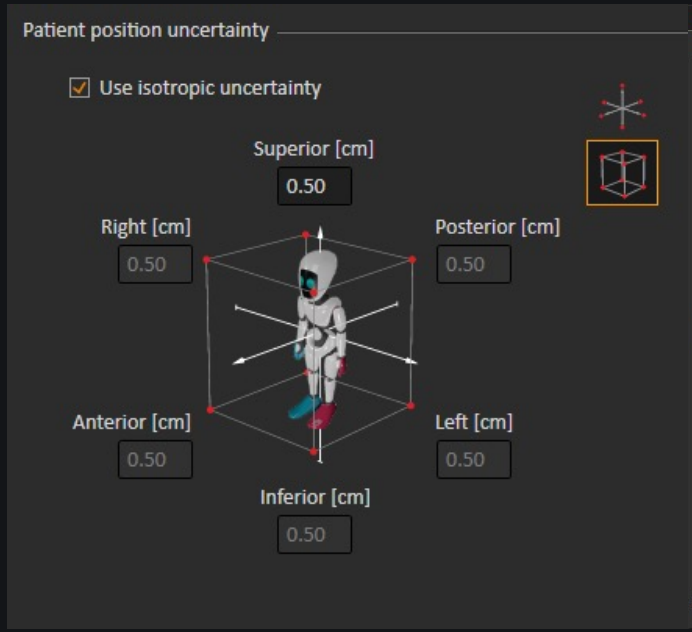
SBRT poumon

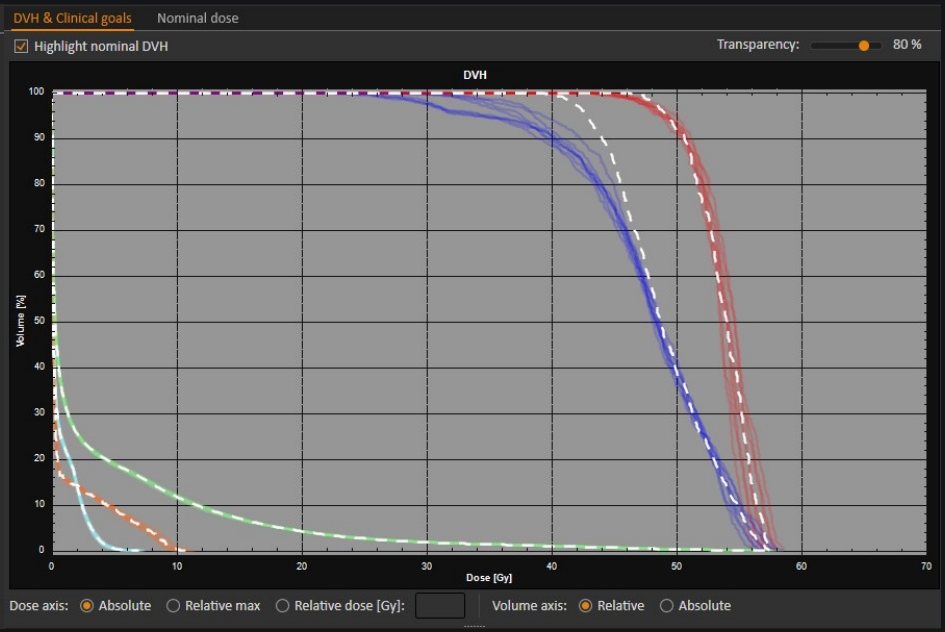
1ère méthode: optimisation de la fluence – calcul final avec algorithme type B



SBRT poumon

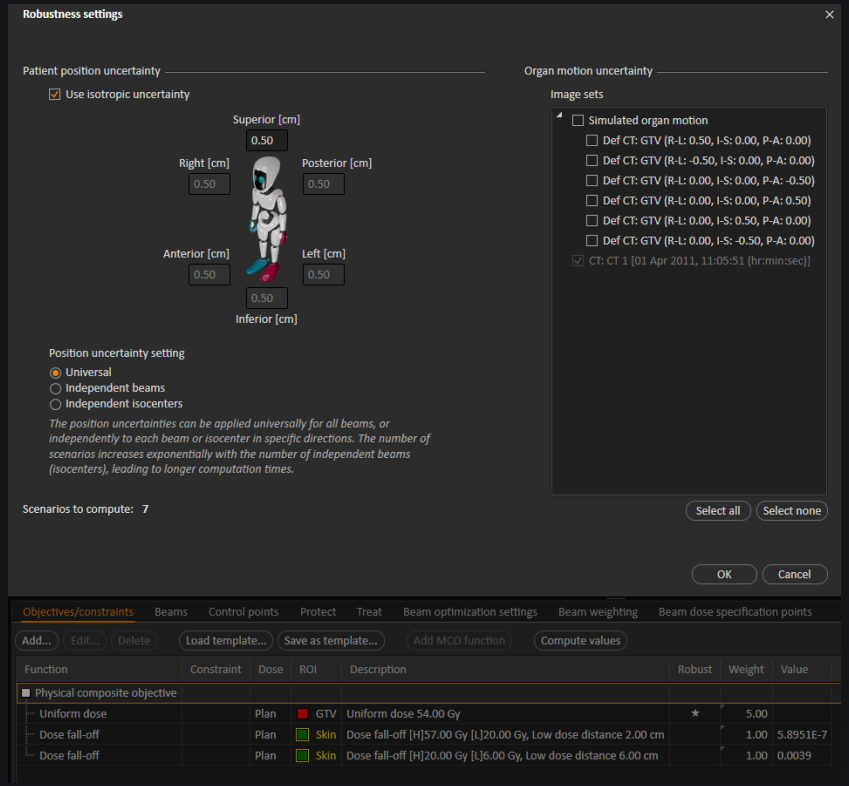
1ère méthode : optimisation fluence + calcul final type B – selon la position du patient





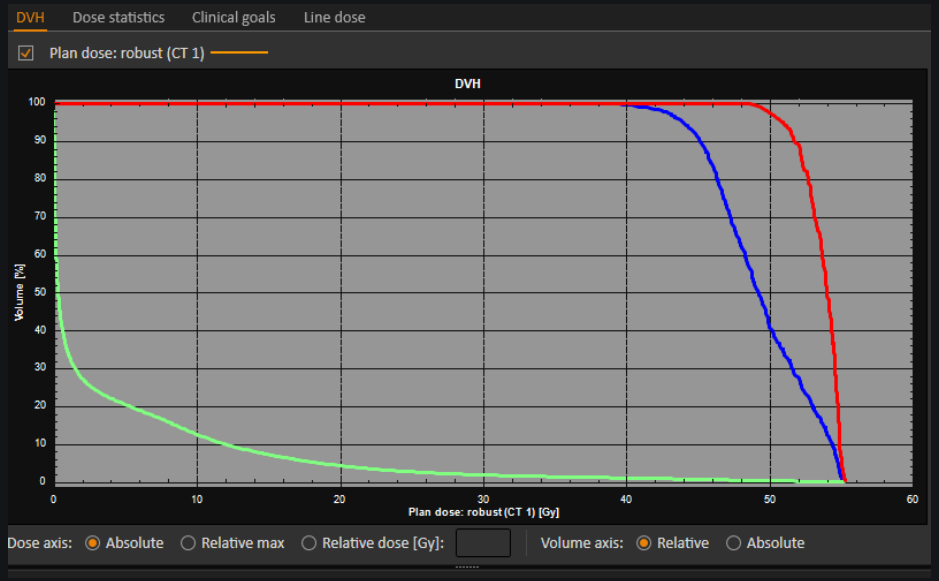
SBRT poumon

2ème méthode : optimisation robuste avec algorithme type B



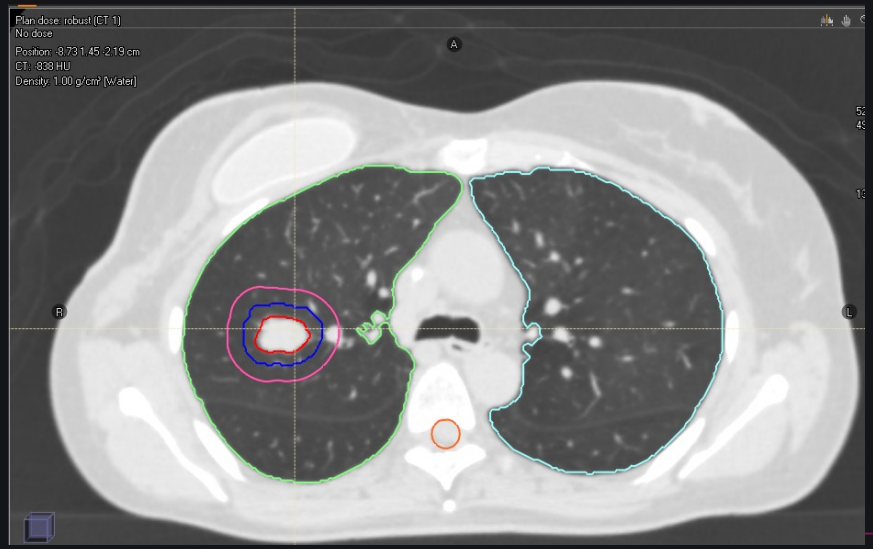
SBRT poumon

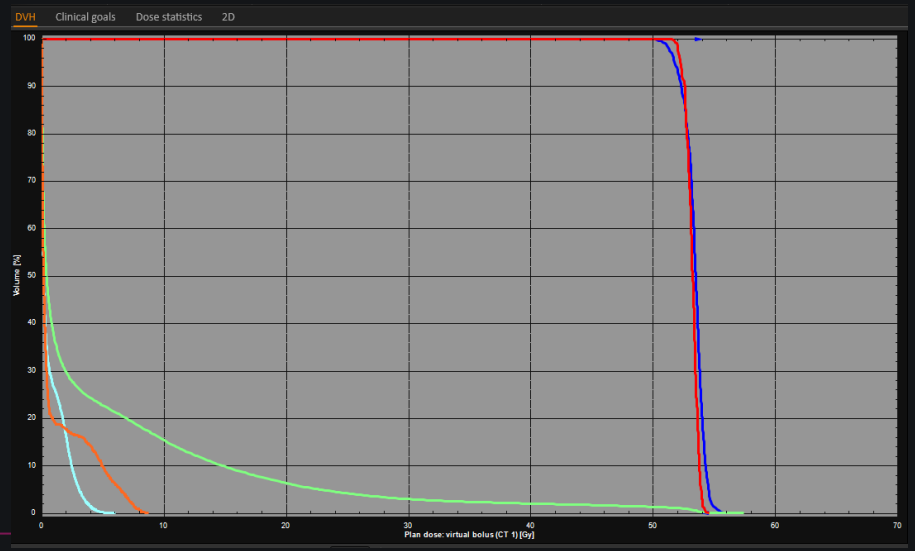
2ème méthode : optimisation robuste avec algorithme type B



SBRT poumon

3ème méthode : bolus virtuel avec algorithme type B : optimisation





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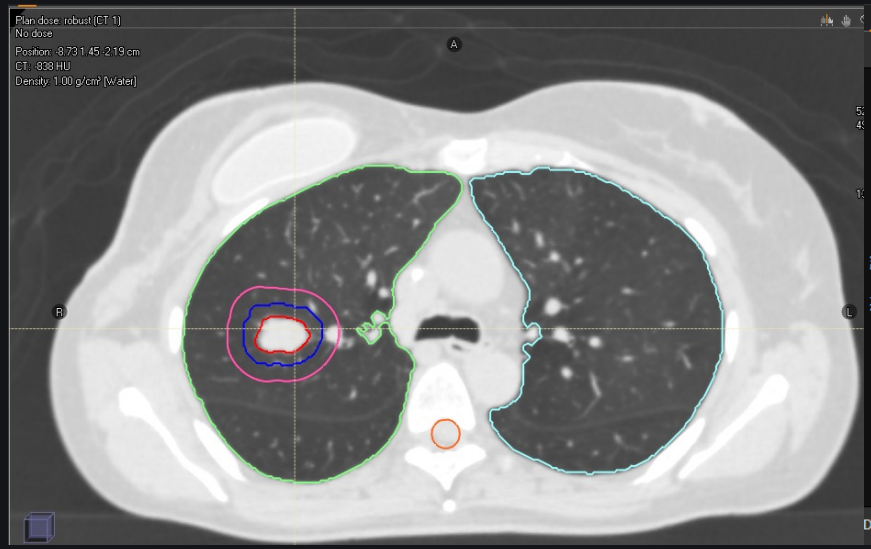
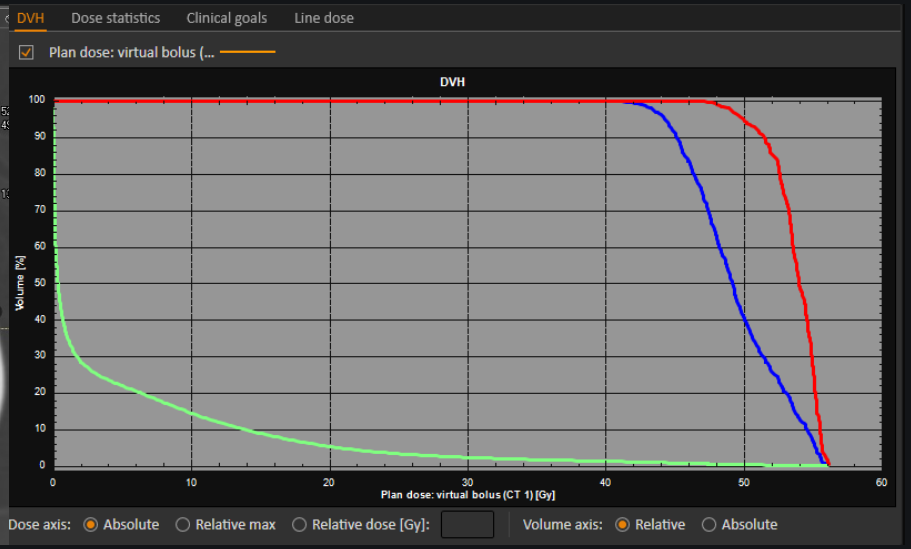
3ème méthode : bolus virtuel avec algorithme type B : calcul final sans bolus virtuel





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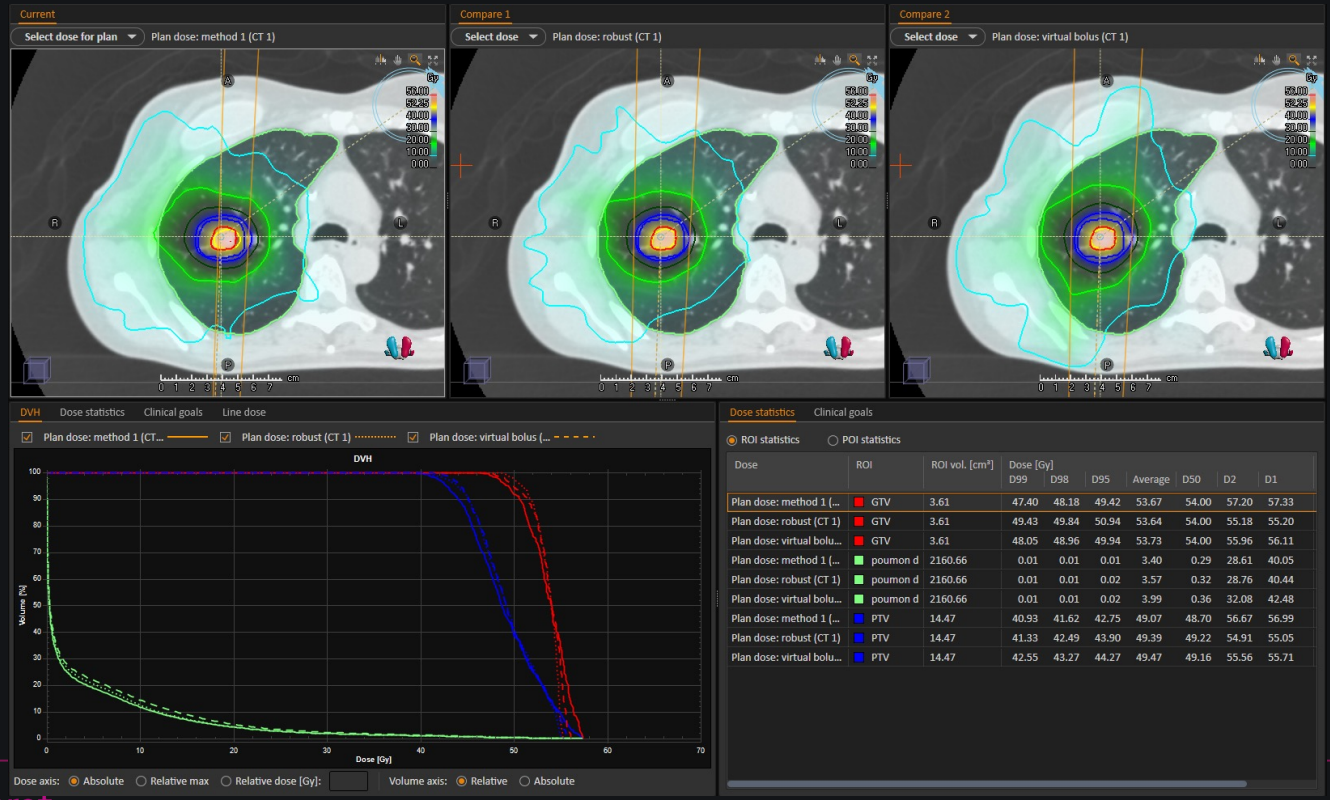
Optimisation : fluence robuste bolus virtuel



Dose	ROI	ROI vol. [cm³]	Dose [Gy] D99	D98	D95	Average	D50	D2	D1
Plan dose: method 1 (...	GTV	3.61	47.40	48.18	49.42	53.67	54.00	57.20	57.33
Plan dose: robust (CT 1)	GTV	3.61	49.43	49.84	50.94	53.64	54.00	55.18	55.20
Plan dose: virtual bolu...	GTV	3.61	48.05	48.96	49.94	53.73	54.00	55.96	56.11
Plan dose: method 1 (...	poumon d	2160.66	0.01	0.01	0.01	3.40	0.29	28.61	40.05
Plan dose: robust (CT 1)	poumon d	2160.66	0.01	0.01	0.02	3.57	0.32	28.76	40.44
Plan dose: virtual bolu...	poumon d	2160.66	0.01	0.01	0.02	3.99	0.36	32.08	42.48
Plan dose: method 1 (...	PTV	14.47	40.93	41.62	42.75	49.07	48.70	56.67	56.99
Plan dose: robust (CT 1)	PTV	14.47	41.33	42.49	43.90	49.39	49.22	54.91	55.05
Plan dose: virtual bolu...	PTV	14.47	42.55	43.27	44.27	49.47	49.16	55.56	55.71

SBRT poumon

L’optimisation pour prendre en compte le PTV mais en prescrivant au calcul final sur le GTV peut se faire par 3 méthodes qui donnent le même résultat :

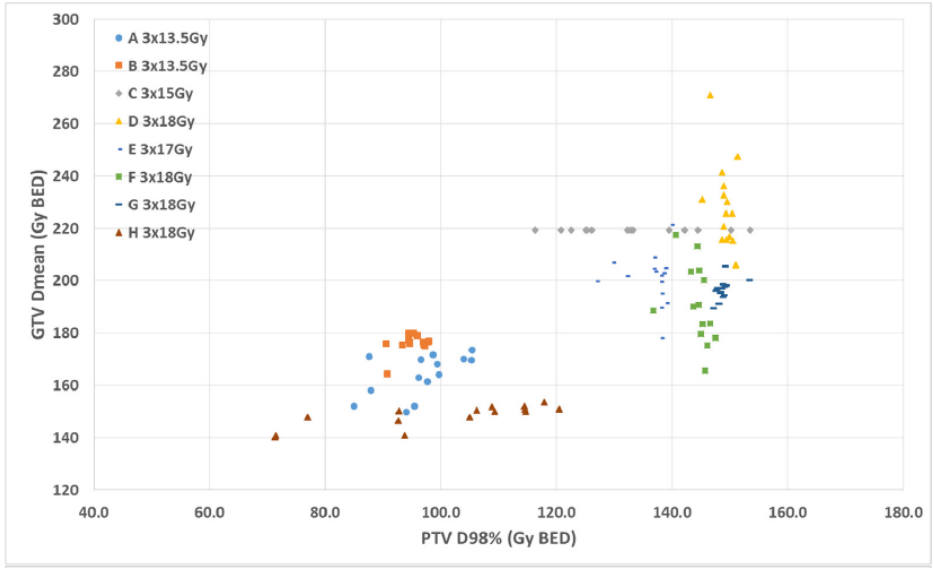
- fluence (= optimisation avec algorithme type A)
- robuste
- bolus virtuel

Comme pour le sein et tous les cas où il n’y a pas d’équilibre électronique dans une partie du PTV

SBRT poumon

📖 de Jong, E. E. C., et al. (2020). Variation in current prescription practice of stereotactic body radiotherapy for peripherally located early stage non-small cell lung cancer: Recommendations for prescribing and recording according to the ACROP guideline and ICRU report 91. *Radiotherapy and Oncology*

A



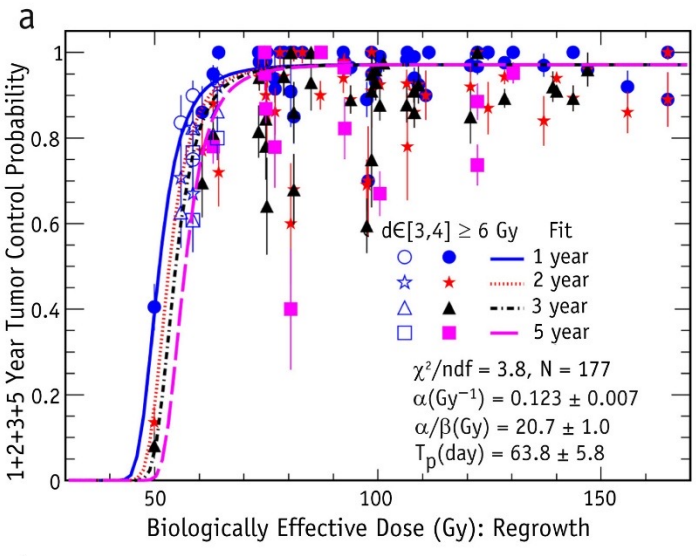
SBRT poumon

📖 de Jong, E. E. C., et al. (2020). Variation in current prescription practice of stereotactic body radiotherapy for peripherally located early stage non-small cell lung cancer: Recommendations for prescribing and recording according to the ACROP guideline and ICRU report 91. *Radiotherapy and Oncology*

- To prescribe 3 fractions of 15 Gy such that a minimum PTV D98% of 100 Gy BED_{10Gy} and minimum GTV/ITVmean dose of 150 Gy BED_{10Gy} is achieved.
- To report the dose and other items like planning details according to ICRU-91.
- To report explicitly both PTV and GTV/ITV D98%, D2% and Dmedian (wherever the GTV is in the PTV envelop, the median dose remains more stable than the mean dose).

SBRT poumon : prescription sur le GTV ou PTV, est-ce important ?

📖 Eriguchi, T. et al. Relationship between Dose Prescription Methods and Local Control Rate in SBRT for Early Stage NSCLC: Systematic Review and Meta-Analysis. *Cancers* (2022)



SBRT poumon : prescription sur le GTV ou PTV, est-ce important ?

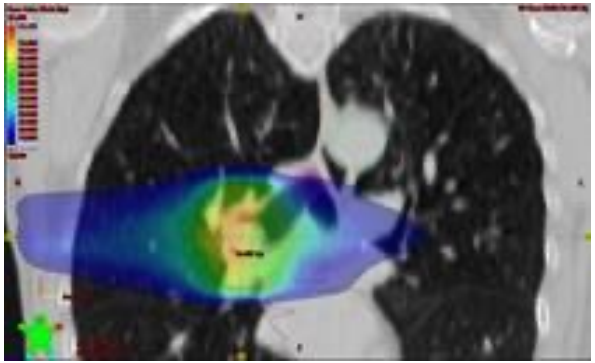
📖 Lindberg, K.,et al (2021). The HILUS-Trial—a Prospective Nordic Multicenter Phase 2 Study of Ultracentral Lung Tumors Treated With Stereotactic Body Radiotherapy. *Journal of Thoracic Oncology*

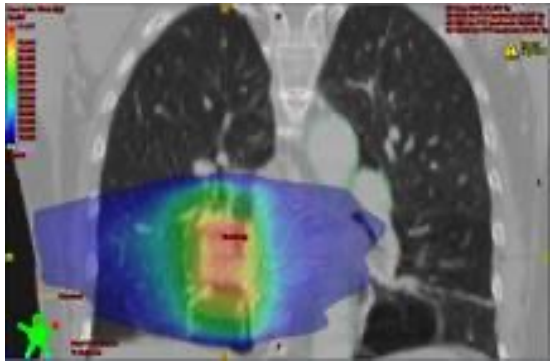
"The dose (7 Gy × 8 to all centrally located targets) was prescribed to approximately the 67% isodose line (in relation to the maximum dose [D_{max}]) as closely as possible encompassing the PTV"

PTV, cc median[d]	43.1	(9.8–180.0)	40.3	(9.8–167.0)	45.5	(12.8–180.0)

SBRT poumon : prescription sur le GTV ou PTV, est-ce important ?

📖 Lindberg, K.,et al (2021). The HILUS-Trial—a Prospective Nordic Multicenter Phase 2 Study of Ultracentral Lung Tumors Treated With Stereotactic Body Radiotherapy. *Journal of Thoracic Oncology*





Exemples de grade 5 (30 patients/230)

prescription SBRT poumon : conclusion

- Nécessité d’utiliser les algorithmes les plus précis (type B ou +)

- La dose au PTV ne prédit pas la dose au GTV
- L’optimisation des plans peut se faire comme le sein :
  - optimisation de la fluence
  - optimisation robuste
  - bolus virtuel
- Nécessité de rapporter la distribution de dose avec plus d’éléments que la seule dose périphérique (GTV D50%, cf ICRU n°91)

Conclusions générales

Ce qu'on peut encore lire aujourd'hui :

Les cibles ont été traitées avec des marges de 3 à 6 mm, des doses de 45 à 60 Gy, en 3 ou 5 séances, prescrites à une isodose marginale de 60 à 80% du maximum couvrant entre 90 et 99% du volume

Conclusions générales

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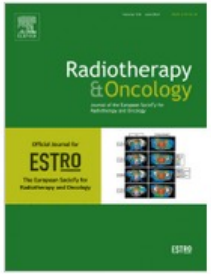
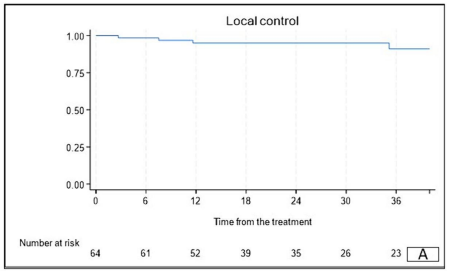
Definitive results of a prospective non-randomized phase 2 study on stereotactic body radiation therapy (sbrt) for medically inoperable lung and liver oligometastases from breast cancer



A mimimum biological effective dose (BED) ≥ 100 Gy, considering α/β of 10 for tumor, was required. Lung metastases were treated with 60 Gy in 3 or 8 fractions, 48 Gy in 4 fractions, 50 Gy in 5 fractions. For liver metastases, different schedules in 3 or 6 fractions were employed. Most commonly prescribed doses were 45, 54, 61.89 and 75 Gy in 3 fractions, 54, 60 and 63 Gy in 6 fractions."

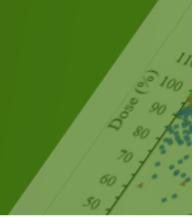


Conclusions générales

Dose prescription and reporting in stereotactic body radiotherapy: A multi-institutional study

Indra J. Das • Poonam Yadav • Aaron D. Andersen • Zhe Jay Chen • Long Huang • Mark P. Langer • Choonik Lee • Lin Li • Richard A. Popple • Roger K. Rice • Peter B. Schiff • Timothy C. Zhu • Mohamed E. Abazeed • Show less

Published: February 21, 2023 • DOI: https://doi.org/10.1016/j.radonc.2023.109571 • Check for updates



Highlights

- Dose prescription, recording, and reporting in SBRT is highly variable.
- Adherence to the International Codes, ICRU-83 and ICRU-91 is not uniform.
- Dosimetric variability across institutions is significant.
- Variable dosimetry makes federated comparison of clinical data difficult.
- Informed guidelines for SBRT is urgently needed.

Conclusions générales

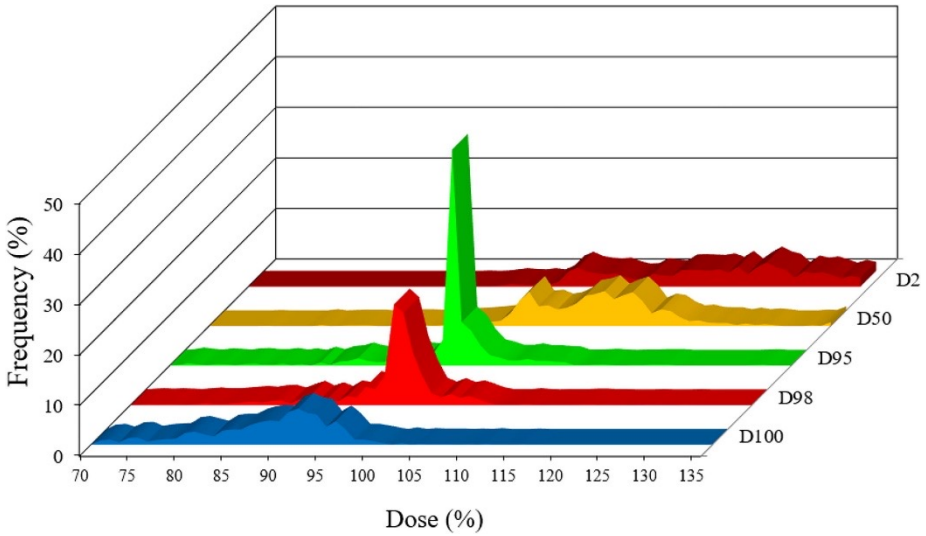


Fig. 2. Frequency distribution of the pattern of dose prescription parameters used in 9 academic institutions. The dose parameters, D95 and D98 are the preferred choices
indicated by the peak. The ICRU-83 adapted D50 in PTV was not considered by the majority of the institutions

DGMP/DEGRO WG SRT

"(…) this Delphi process achieved absolute consensus on the requirement of additional dosimetric goals beside the prescription isodose and PTV coverage, e.g., for the gross target volume (GTV)."

"(…) insights can be derived from the outcomes of existing studies, particularly those emphasizing the median dose to the GTV as pivotal for local control and the harmonization of treatment protocols."

Prescription multiparamétrique

📖 Moustakis, C. *et al.* Planning Benchmark Study for Stereotactic Body Radiation Therapy of Liver Metastases: Results of the DEGRO/DGMP WG on Stereotactic Radiation Therapy and Radiosurgery. *IJROBP* (2022).

📖 Moustakis, C. *et al.* Planning Benchmark Study for Stereotactic Body Radiation Therapy of Pancreas Carcinomas with Simultaneously Integrated Boost and Protection: Results of the DEGRO/DGMP Working Group on Stereotactic Radiation Therapy and Radiosurgery. *IJROBP*(2024)
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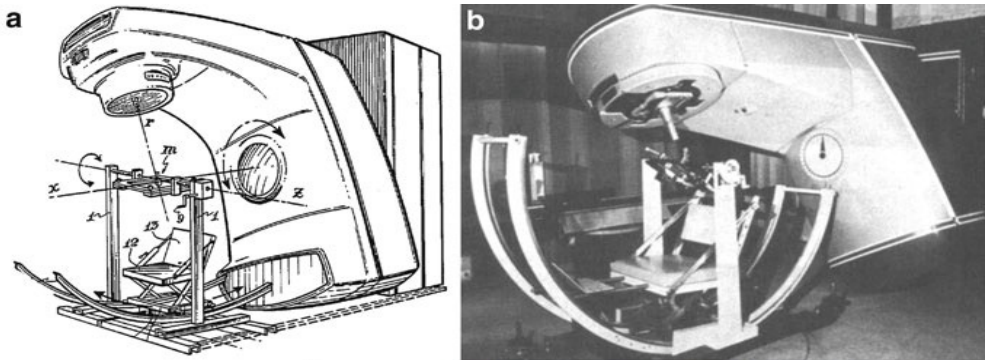
"Multiparametric specification of target dose (GTV & PTV)"

"This study shows the feasibility of harmonizing liver SBRT treatment plans across different TPSs and delivery techniques when a sufficient set of clinical goals is given.

"The method of GTV D50% prescription can be performed in all systems, improving overall consistency"

Conclusion

- L’effet des fortes doses dans le GTV rend le calcul usuel du PTV inopérant
- La dose périphérique au PTV est insuffisante pour caractériser le traitement
  (et encore moins pour les lésions pulmonaires)
- Nécessité de rapporter les grandeurs ICRU pour tous les volumes (PTV, CTV, GTV)
- La prescription multiparamétrique (PTV, GTV) est sans doute l’avenir pour harmoniser les pratiques



Merci de votre attention