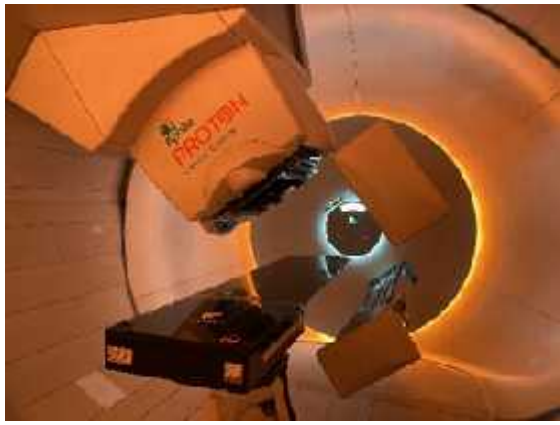
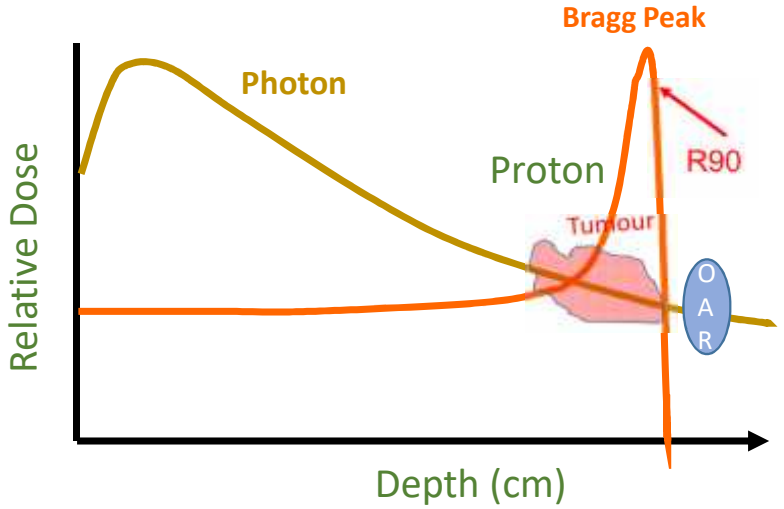


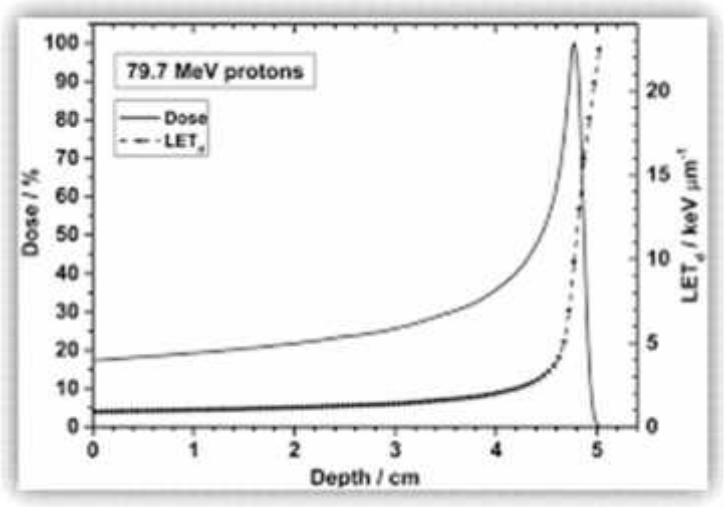
Proton plan evaluation:
How to ‘Bragg’ about a perfect plan

Dayananda S Shamurailatpam, **PhD, Dip R P, MCMPI**
Head Department of Medical Physics

Rational for proton beam therapy

- Physical depth dose characteristics
  - Proton have finite range (e.g R90)
  - Proton can be stopped
  - No exit dose

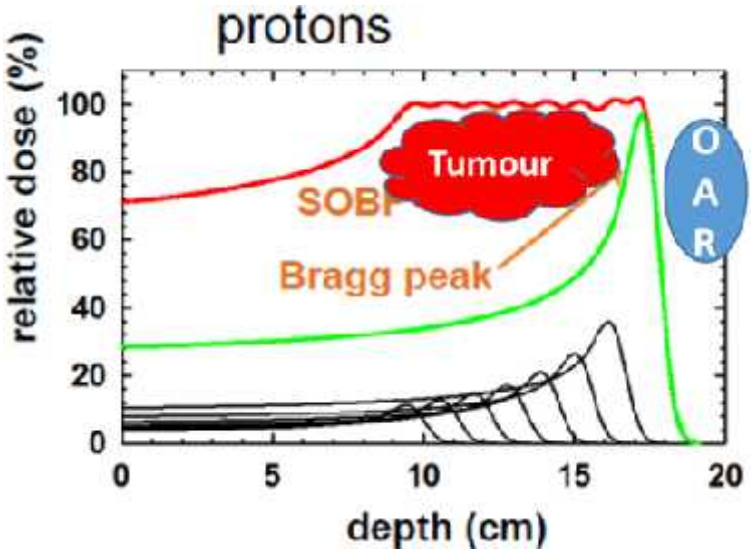




- Radiobiology
  - LET of charged particles increases as the particles slow down near the end of their range
  - The greater the LET, the greater is the RBE.
  - RBE of charged particles is greatest in the region of their Bragg peak.
  - RBE : 0.7 – 1.5; Universal RBE of proton =1.1

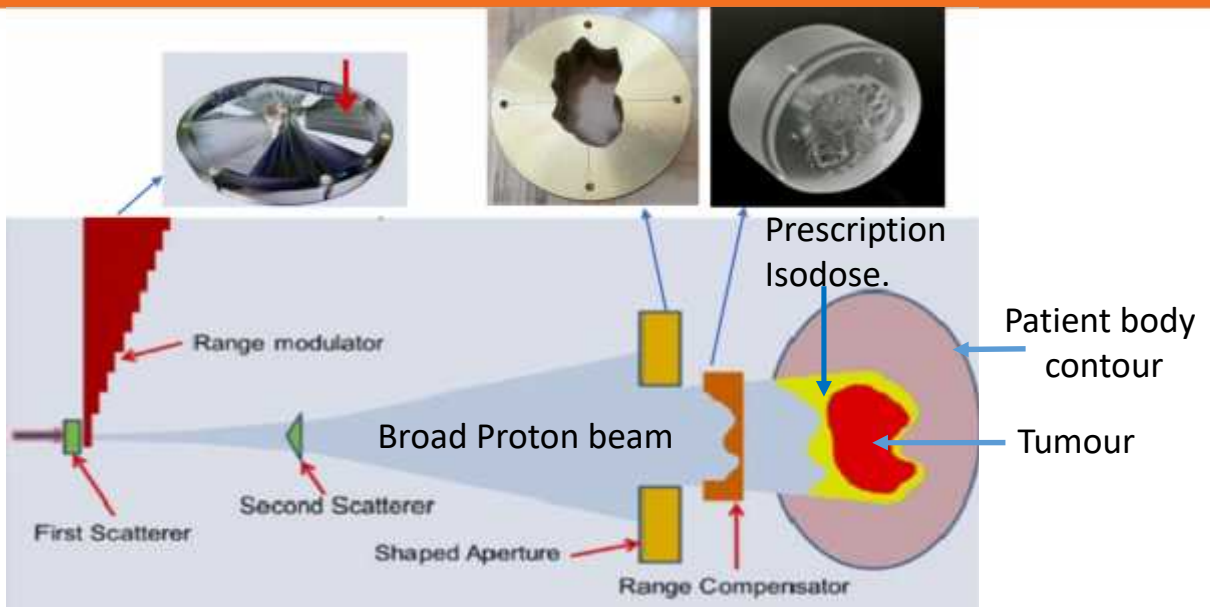
Spread Out Bragg Peak (SOBP)

- Narrow width of the pristine Bragg peak is broaden out along the beam direction to cover the tumour extent
- SOBP can be achieve by super positioning multiple pristine Bragg peak of different proton energies
- Thus a treatment field comprises of multiple proton energies



Treatment Planning & delivery technique in Proton Therapy

- Passive Scattering Technique
- Active scanning Technique

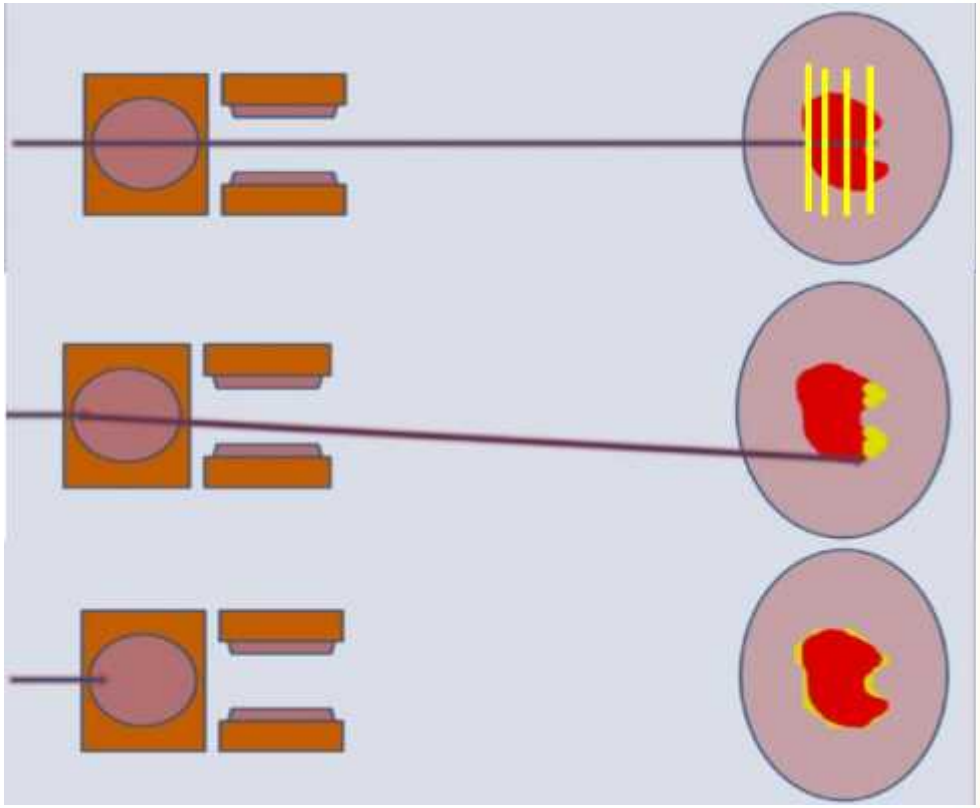


Passive scattering technique

- Use broad proton beam
- Use range modulator to spread out the Bragg peak
- Require Patient & Field specific hardwires
  - Apertures & Range compensators
- Labour intensive & time consuming
- Less conformal, Spillage of prescription isodose towards the proximal side of the beam
- Neutron contamination, Radiation safety issue, neutron dose to patient
- Treatment planning & delivery is very robust

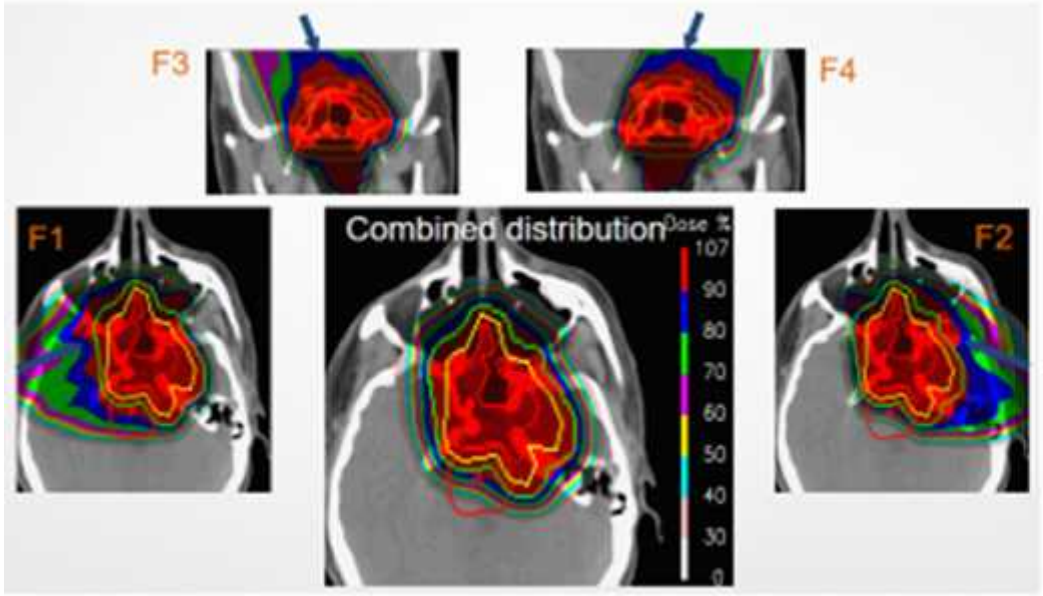
Active scanning technique
Pencil beam scanning technique (PBS)

- Use magnetically stirred narrow proton pencil beam of different energies
- Tumour is treated layer by layer and voxel by voxel
- Distal layer is treated with a larger proton energy
- Proton energy gradually decrease towards the proximal end of the tumour
- Produce highly conformal dose distribution
- Allows Intensity modulated proton therapy (IMPT)
- No patient & Field specific hardwires
- Sensitive to uncertainty



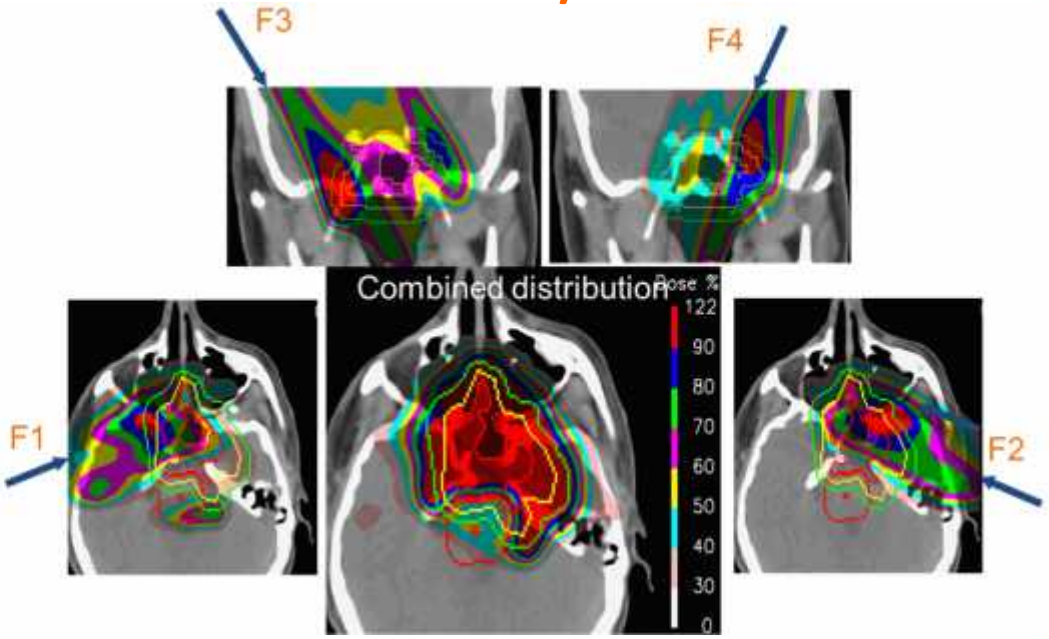
PBS treatment planning technique (IMPT)

SFO/SFUD



Each field is optimize to deliver uniform dose to tumour

MFO/MFUD



Optimize to deliver a resultant uniform dose to tumour from non-uniform dose contribution from individual fields

Lomax 1999, PMB 44: 185-205

Robust optimization

Optimization approach/Planning technique → SFO → MFO/IMPT → Hybrid → Robust optimization

Minimax optimization for handling range and setup uncertainties in proton therapy

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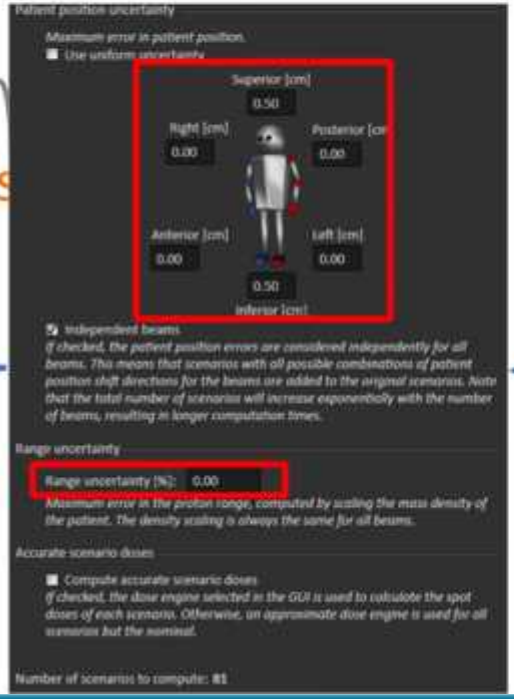
PTV / bs



Create multiple scenario

Optimize on covering all scenarios

CTV

Incorporate set-up, organ or target motion and range uncertainty in to treatment planning process

Treatment Plan evaluation of Passive Scattering Technique

Plan parameters

1. Selection of correct CT-dataset (Multiple binned image set in case of 4DCT)
2. Correctness of multi-modality image fusion & contour propagation
3. **Selection of correct CT-calibration curve**
4. Contour review & creation of Physics planning contours
5. **Mitigation of possible changes in CT No/ RSP / CT-artefact**

1. No of beams, beam direction, bsPTV approach/PTV approach/Hybrid
2. Lateral, Distal & proximal safety margin for aperture & range compensator
3. Beam patching, overlap margin & Range Smearing & smearing radius
4. Dose (RBE) & fraction prescription
5. Proton energy, Modulation width, field weight
6. Physical & Radiobiological optimization parameters

Plan Outcome

1. Plan evaluation for assessment of clinical goal fulfilment and dose reporting
2. Qualitatively using dose distribution in all axial, sagittal & coronel images
3. Quantitatively using DVH & DV indices for target coverage, target conformity, dose homogeneity, Maximum dose and dose volume to OARs
4. Evaluation using Radiobiological model
4. **Robust evaluation for set-up error, range uncertainty and internal target motion**

Treatment Plan evaluation for PBS Technique

Plan parameters

1. Selection of correct CT-dataset (Multiple binned image set in case of 4DCT)
2. Correctness of multi-modality image fusion & contour propagation
3. **Selection of correct CT-calibration curve**
4. Contour review & creation of Physics planning contours
5. **Mitigation of possible changes in CT No/ RSP / CT-artefact**

1. No of beams, beam direction,
2. bsPTV approach/PTV approach/CTV approach/ Hybrid
3. Planning technique: SFO, MFO, Hybrid, Robust Optimization
4. Optimization parameters: Spot spacing, spot distribution pattern and energy layer separation
5. Dose (RBE) & fraction prescription
6. Physical & Radiobiological optimization parameters

Plan Outcome

1. Plan evaluation for assessment of clinical goal fulfilment and dose reporting
2. Qualitative evaluation using dose distribution in all axial, sagittal & coronel images
3. Quantitatively evaluation using DVH & DV indices for target coverage, target conformity, dose homogeneity, Maximum dose and dose volume to OARs
4. Evaluation using Radiobiological model
5. **Robust evaluation for set-up error, range uncertainty and internal target motion**

Dosimetric benefit of PBT in CSI

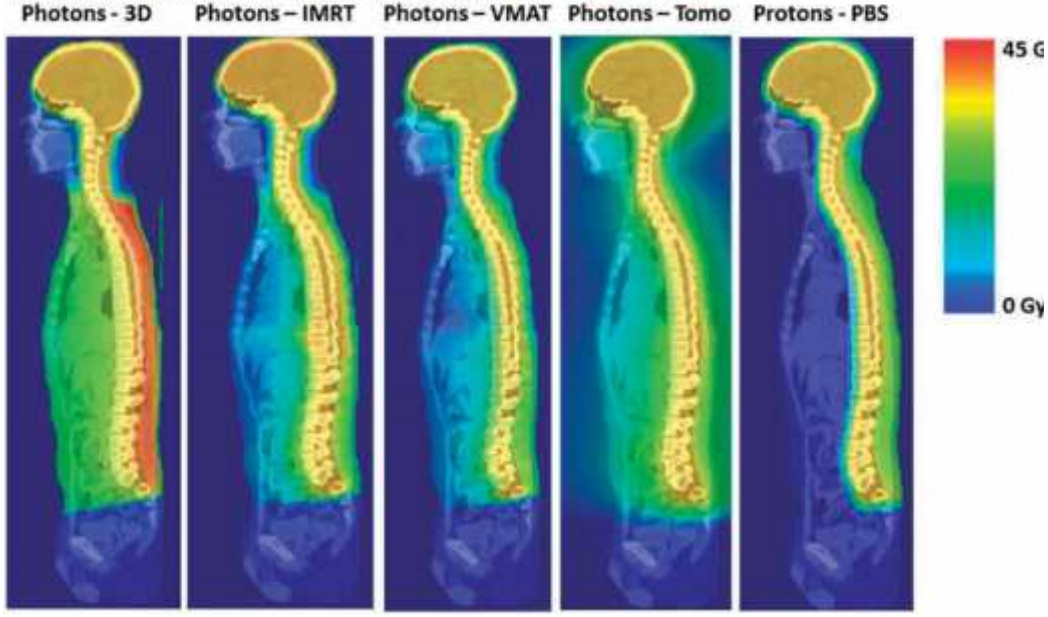
ACTA ONCOLOGICA
https://doi.org/10.1080/0284186X.2018.1465588

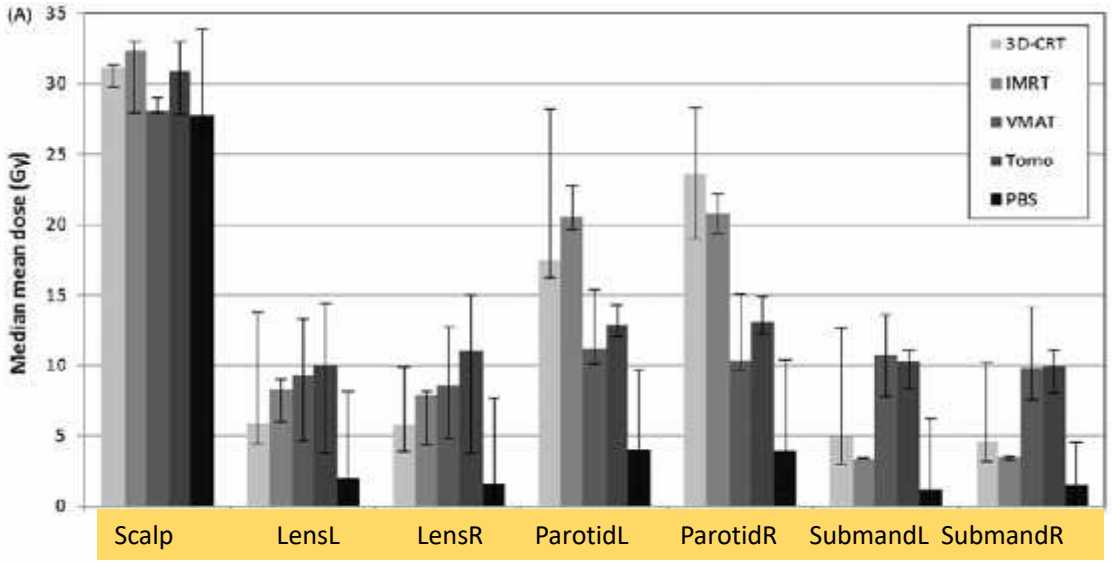
ORIGINAL ARTICLE

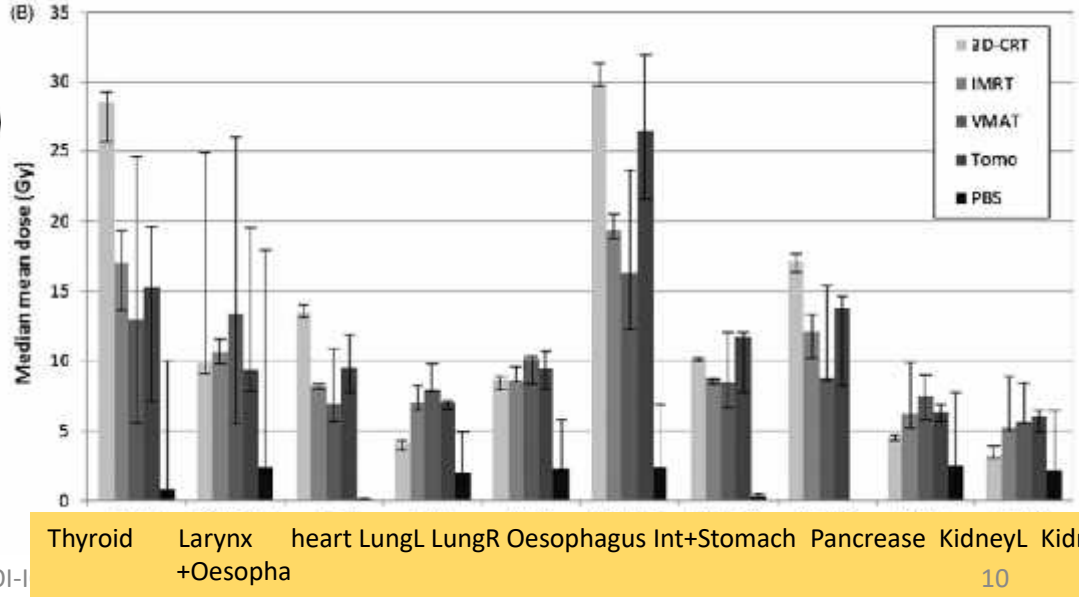
OPEN ACCESS

Dosimetric comparison of five different techniques for craniospinal irradiation across 15 European centers: analysis on behalf of the SIOP-E-BTG (radiotherapy working group)

Enrica Seravalli[a], Mirjam Bosman[a], Yasmin Lassen-Ramshad[b], Anne Vestergaard[b], Foppe Oldenburger[c], Jorrit Visser[c], Efi Koutsouveli[d], Chryssa Paraskevopoulou[d], Gail Horan[e], Thankamma Ajithkumar[e], Beate Timmermann[f], Carolina-Sofia Fuentes[f], Gillian Whitfield[g], Thomas Marchant[h], Laetitia Padovani[i], Eloise Garnier[i], Lorenza Gandola[j], Silvia Meroni[j], Bianca A. W. Hoeben[k], Martijn Kusters[k], Claire Alapetite[l], Sandra Losa[l], Farid Goudjil[l], Henriette Magelssen[m], Morten Egeberg Evensen[m], Frank Saran[n], Gregory Smyth[o], Barbara Rombi[p], Roberto Righetto[p], Rolf-Dieter Kortmann[q] and Geert O. Janssens[a]







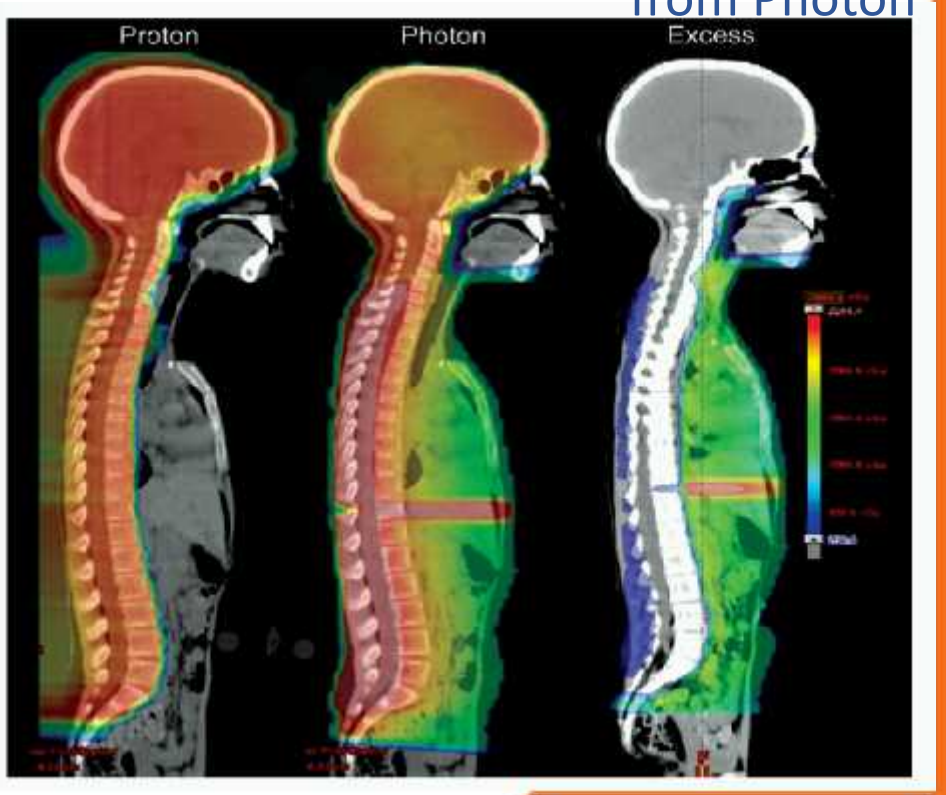
15 European centres
3 centres per technique
36Gy/1.8Gy

Dosimetric benefit of PBT in CSI

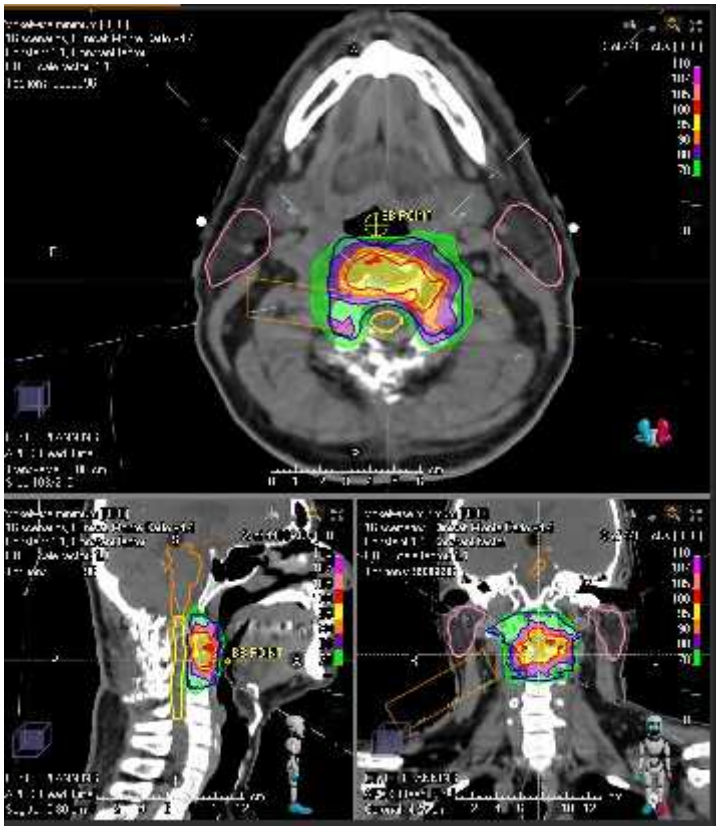
Reduction of OARs Dose

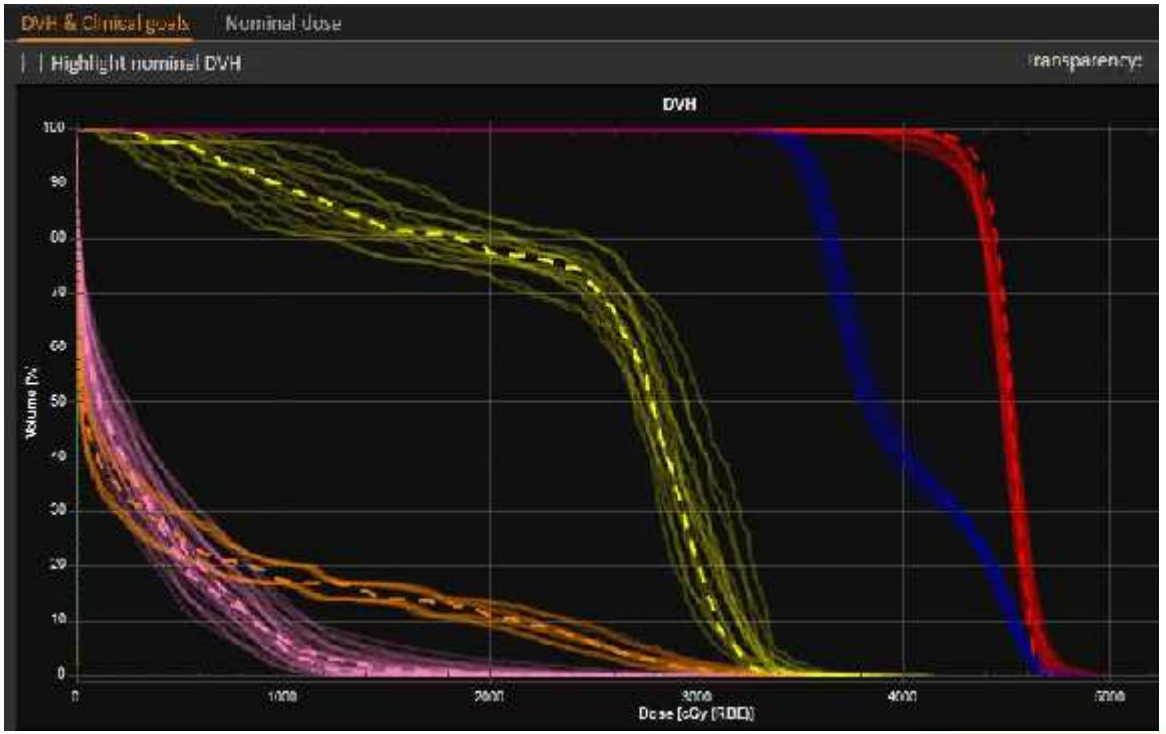
- In CSI, mandible, parotid gland, thyroid gland, lung, kidney, heart, ovary, uterine, and other non-target intracranial structures (St Clair 2004 IJROBP, Lee 2005 IJROBP, Howell 2012 IJROBP)
- Models predict lower risk of second cancer, lower rate of pneumonitis, cardiac failure, xerostomia, blindness, hypothyroidism, and ototoxicity (Mirabell 2002 IJROBP, Newhauser 2009 PMB, Thaddei 2010 PMB, Brodin 2011, Acta Oncol, Zhang 2013 PMB).

Proton Photon Excess Dose from Photon

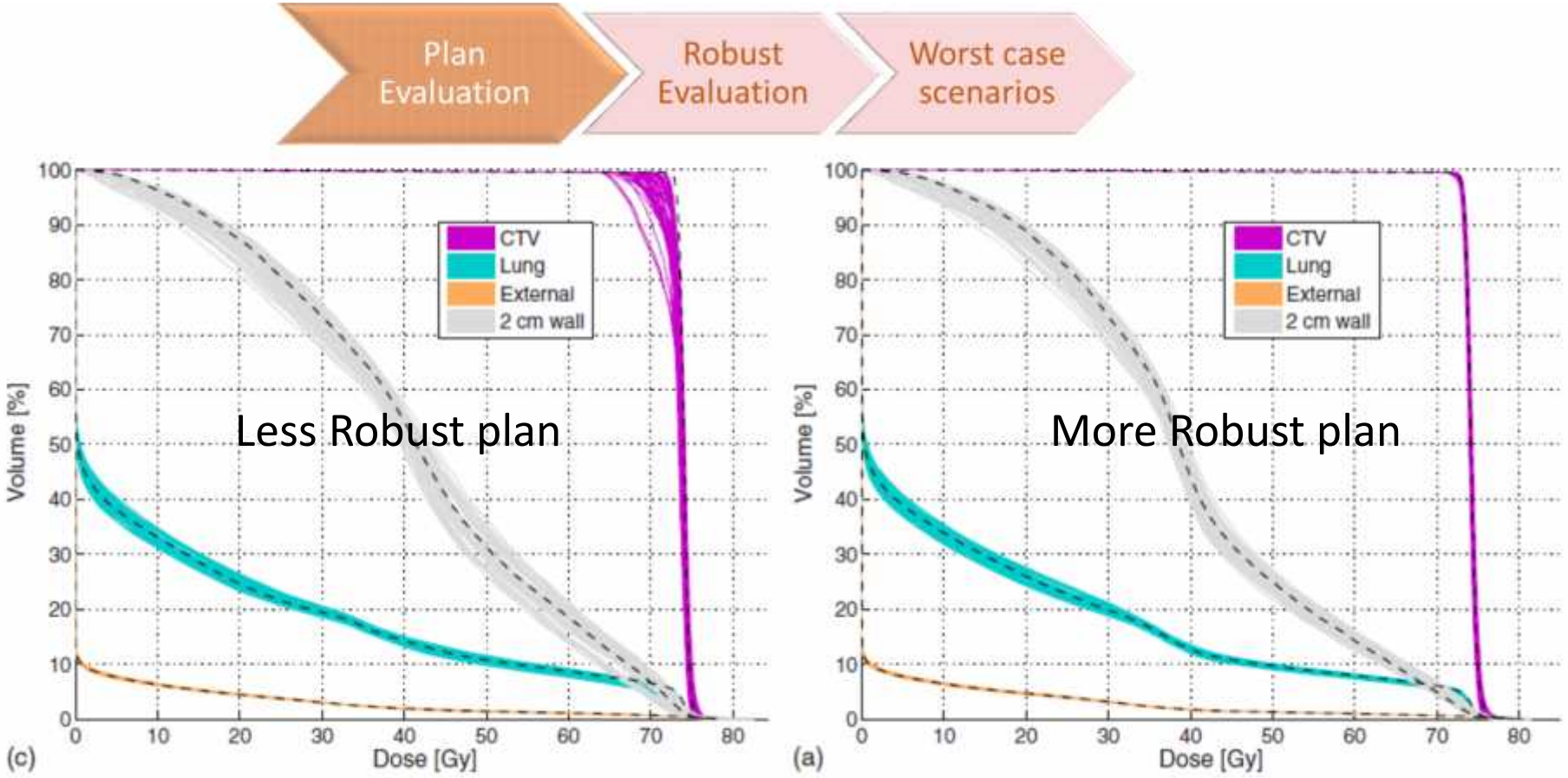


Plan evaluation for Robustly optimized MFO-IMPT of Chordoma

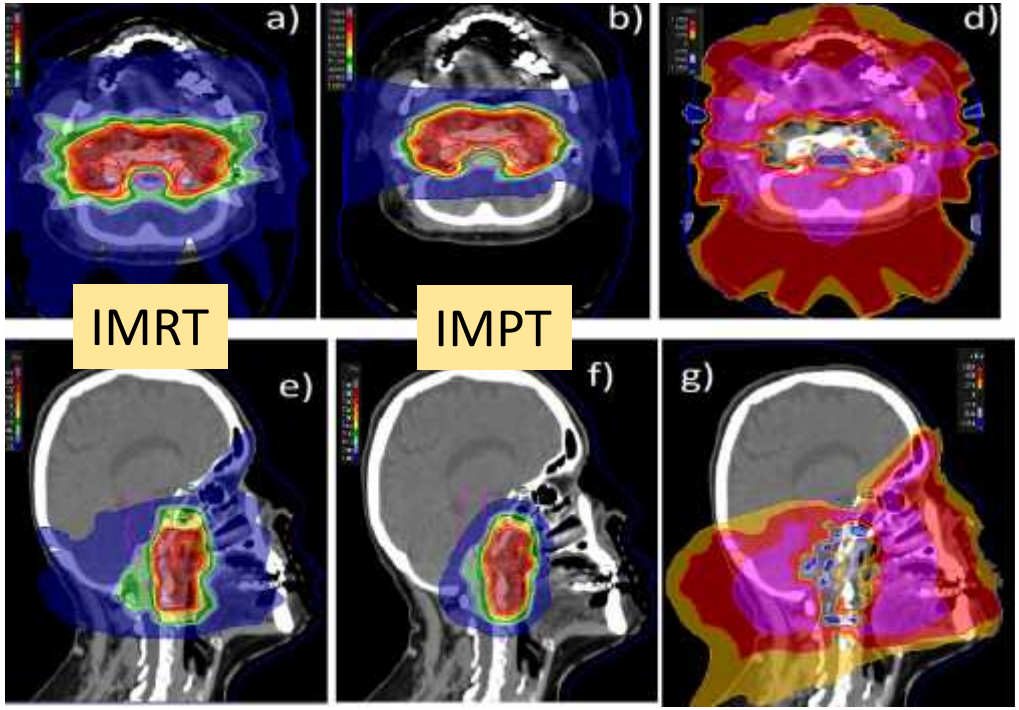


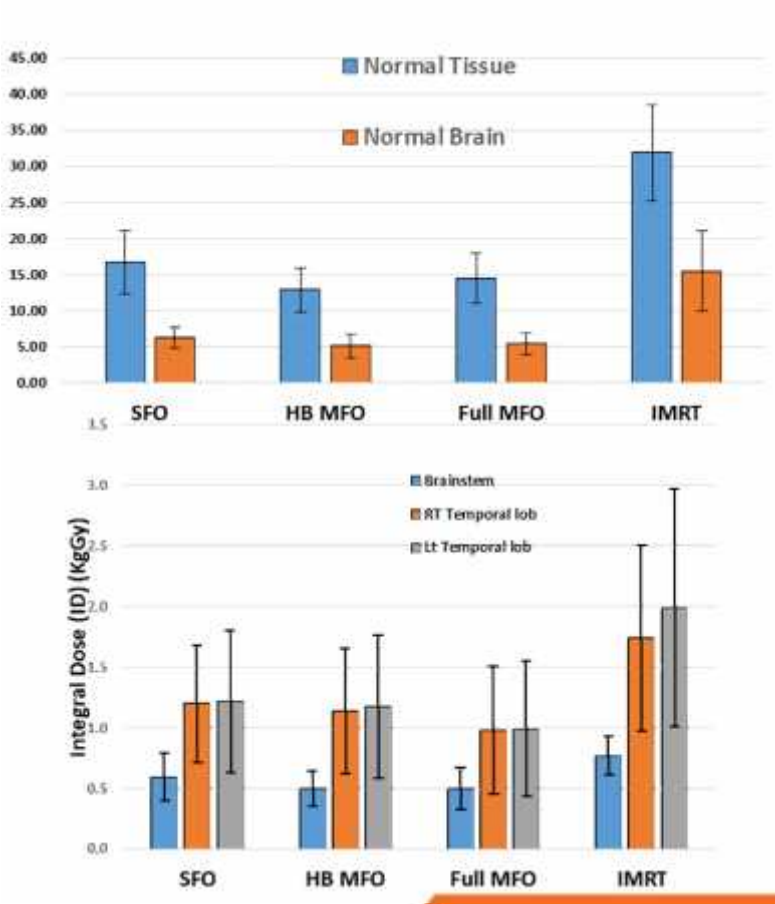


Robust evaluation

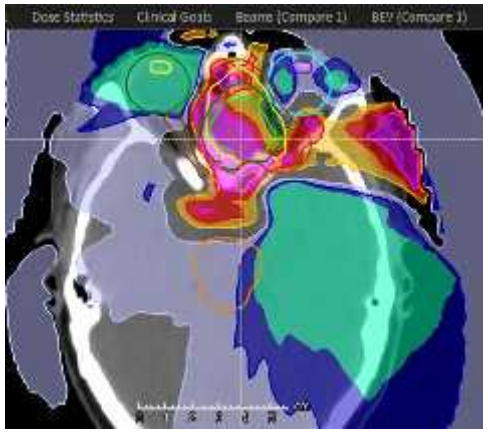


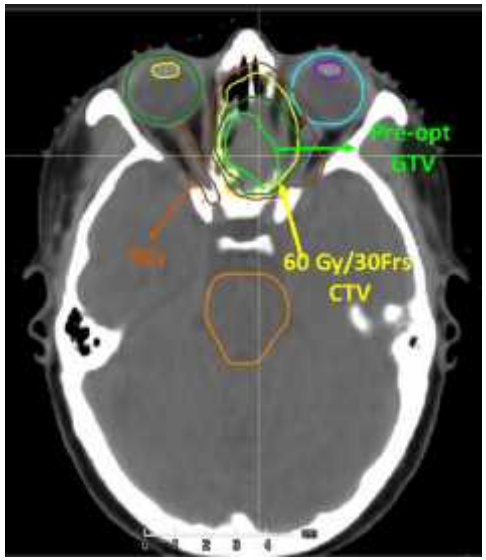
MFO-IMPT vs IMRT for chordoma

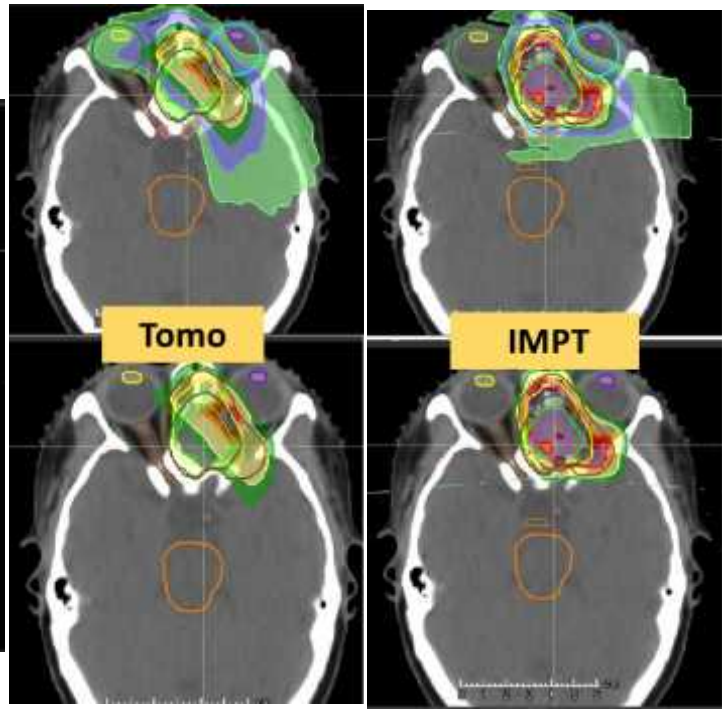




IMPT vs Helical Tomotherapy for Recurrent esthesioneuroblastoma of Nasal Cavity



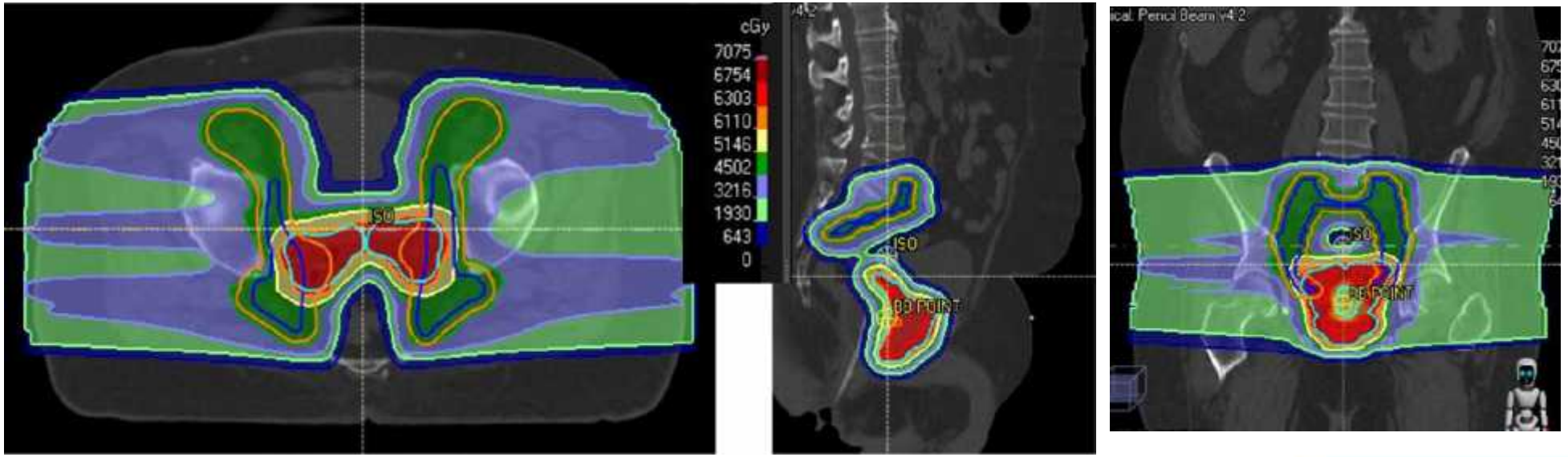




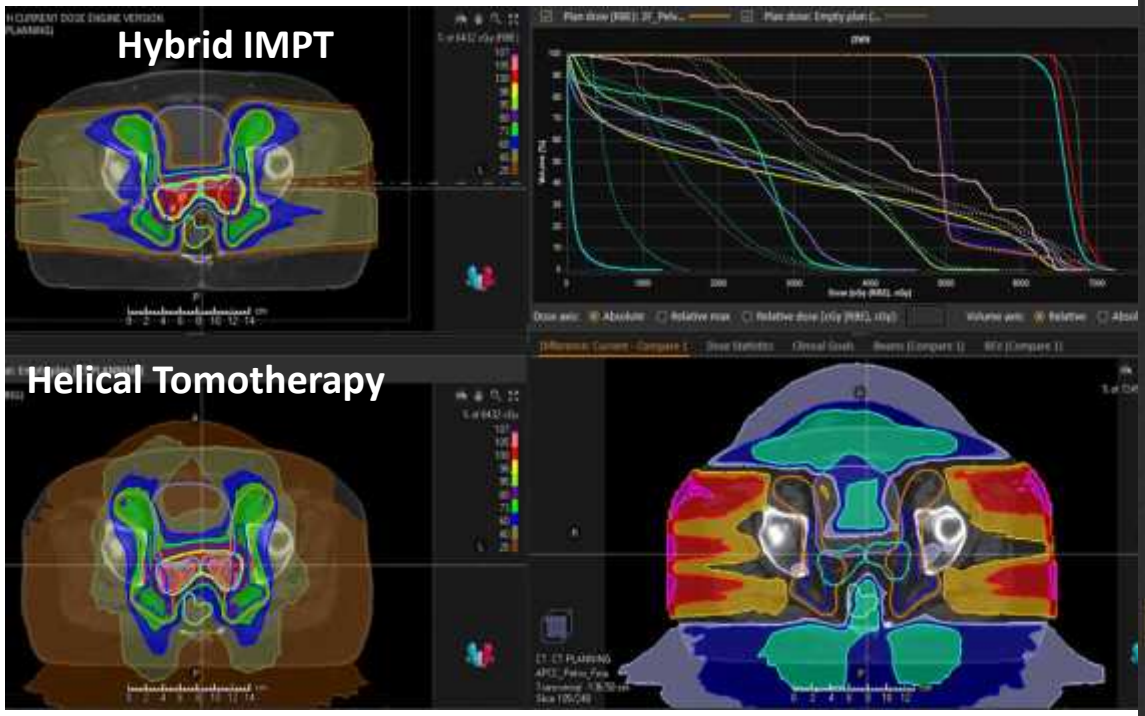
Dose	ROI	ROI vol. [cm³]	Dose [cGy] D99	D98	D95	Average	D50	D2	D1	%
Plan dose: 4F_MFO-Fi...	BRAINSTEM	23.93	0	0	0	48	7	515	711	0 %
Plan dose: Empty plan...	BRAINSTEM	23.92	81	91	120	1132	1027	2839	3105	0 %
Plan dose: 4F_MFO-Fi...	CTV RATIONAL	37.39	4609	5328	5700	6113	6172	6462	6498	0 %
Plan dose: Empty plan...	CTV RATIONAL	37.38	2427	2869	3837	5433	5556	6222	6263	0 %
Plan dose: 4F_MFO-Fi...	PREOP GTV	4.84	5632	5680	5745	6110	6132	6508	6535	0 %
Plan dose: Empty plan...	PREOP GTV	4.78	2324	2583	3037	5080	5357	6302	6347	0 %
Plan dose: 4F_MFO-Fi...	OPTIC_NERVE_RT	0.6	179	216	264	509	483	892	926	0 %
Plan dose: Empty plan...	OPTIC_NERVE_RT	0.58	665	699	719	994	960	1427	1486	0 %
Plan dose: 4F_MFO-Fi...	OPTIC_NERVE_LT	0.42	4855	5008	5215	5762	5803	6172	6200	0 %
Plan dose: Empty plan...	OPTIC_NERVE_LT	0.39	3380	3659	4318	5280	5405	5860	5879	0 %
Plan dose: 4F_MFO-Fi...	PTV high risk	11.67	4267	4875	5675	6063	6129	6460	6510	0 %
Plan dose: Empty plan...	PTV high risk	11.67	1852	2063	2536	5145	5623	6286	6309	0 %
Plan dose: 4F_MFO-Fi...	PTV low risk	63.08	3426	4090	4937	5944	6085	6438	6481	0 %
Plan dose: Empty plan...	PTV low risk	63.04	2077	2518	3560	5337	5526	6181	6234	0 %
Plan dose: 4F_MFO-Fi...	LENS_LEFT	0.19	154	154	156	400	377	694	802	0 %
Plan dose: Empty plan...	LENS_LEFT	0.19	700	707	748	999	949	1459	1548	0 %
Plan dose: 4F_MFO-Fi...	LENS_RIGHT	0.17	49	50	55	156	145	354	409	0 %
Plan dose: Empty plan...	LENS_RIGHT	0.18	2119	2136	2189	2469	2476	2832	2854	0 %

Hybrid IMPT for Ca. Prostate

- 64.32 GyRBE/24Frs to primary prostate
- 48 GyRBE/24Frs to nodes



Hybrid IMPT vs Helical Tomotherapy for Ca. Prostate

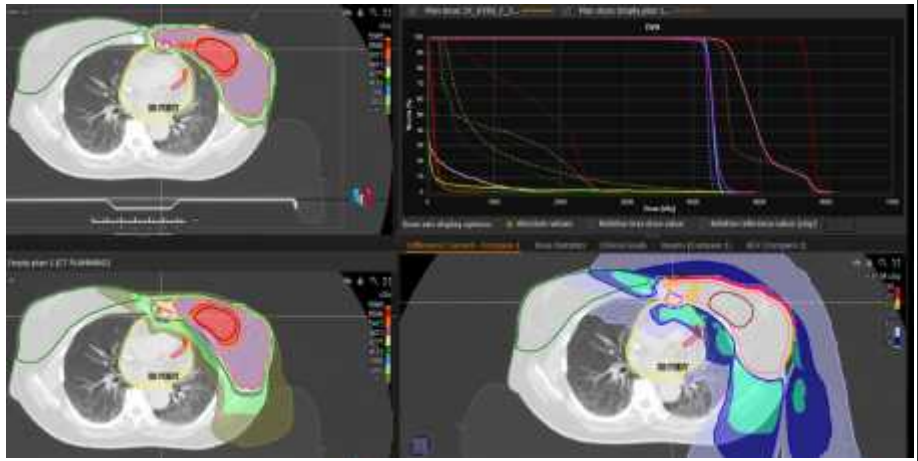


Dose	ROI	ROI vol. [cm³]	Dose [cGy (RBE), cGy] D99	D98	D95	Average	D50	D2	D1
Plan dose (RBE): 2F_P...	Anal canal	12.61	1	2	4	87	43	484	691
Plan dose: Empty plan...	Anal canal	12.58	314	321	337	618	526	1410	1477
Plan dose (RBE): 2F_P...	BLADDER	324.01	0	3	12	2718	2455	6531	6570
Plan dose: Empty plan...	BLADDER	323.99	1591	1617	1698	3915	3634	6810	6826
Plan dose (RBE): 2F_P...	CTV N	374.40	4790	4811	4843	5120	4971	6613	6673
Plan dose: Empty plan...	CTV N	374.13	4934	4951	4979	5217	5096	6792	6852
Plan dose (RBE): 2F_P...	CTV P	66.93	6424	6436	6457	6676	6650	7072	7127
Plan dose: Empty plan...	CTV P	66.89	6627	6649	6685	6771	6776	6846	6859
Plan dose (RBE): 2F_P...	Femoral Head L	183.40	7	12	27	2183	2603	3395	3543
Plan dose: Empty plan...	Femoral Head L	183.43	188	201	235	1554	1457	3271	3428
Plan dose (RBE): 2F_P...	Femoral Head R	175.13	19	24	38	1964	2327	3691	3860
Plan dose: Empty plan...	Femoral Head R	175.18	195	206	233	1410	1306	3105	3262
Plan dose (RBE): 2F_P...	PENILE BULB	5.91	415	632	1058	4291	4508	6445	6453
Plan dose: Empty plan...	PENILE BULB	5.88	759	787	868	3346	3022	6841	6879
Plan dose (RBE): 2F_P...	PTV_50/25	844.19	4640	4709	4775	5076	4947	6649	6717
Plan dose: Empty plan...	PTV_50/25	846.15	4809	4868	4934	5200	5091	6796	6833
Plan dose (RBE): 2F_P...	PTV_67/25	206.94	6088	6151	6259	6570	6568	6982	7041
Plan dose: Empty plan...	PTV_67/25	206.73	6410	6449	6516	6743	6773	6887	6909
Plan dose (RBE): 2F_P...	Rectum	146.68	34	46	70	2674	2015	6388	6438
Plan dose: Empty plan...	Rectum	146.70	1515	1729	2026	4059	3668	6590	6613
Plan dose (RBE): 2F_P...	Sigmoid	82.61	93	114	155	2605	2914	4850	4914
Plan dose: Empty plan...	Sigmoid	82.21	1839	1867	1955	3422	3323	5048	5223

Proton in Lt Breast

- Ca Lt Breast pT1nN0sn Mx
- CTVs (57, 45, 42 GyRBE/20Frs)

SFUD-IMPT vs Tomotherapy in Lt sided Breast



Dose	ROI	ROI vol. [cm³]	Dose [cGy] D99	D98	D95	Average	D50	D2	D1
Plan dose: 2F_GTR3_F...	CONTRALATERAL BREAST	1119.43	0	0	0	48	7	419	724
Plan dose: Empty plan...	CONTRALATERAL BREAST	1119.44	173	188	211	677	377	2533	2740
Plan dose: 2F_GTR3_F...	CTV 42	104.52	3883	4073	4177	4305	4303	4541	4592
Plan dose: Empty plan...	CTV 42	104.55	4129	4148	4167	4236	4229	4382	4408
Plan dose: 2F_GTR3_F...	CTV 45	1125.43	4367	4426	4512	4972	4895	5848	5885
Plan dose: Empty plan...	CTV 45	1125.38	4288	4341	4401	4747	4534	5789	5815
Plan dose: 2F_GTR3_F...	CTV 57	98.18	5604	5635	5671	5789	5787	5960	5983
Plan dose: Empty plan...	CTV 57	98.13	5614	5630	5651	5732	5725	5868	5888
Plan dose: 2F_GTR3_F...	CTV SCF	75.34	4161	4174	4196	4295	4294	4422	4437
Plan dose: Empty plan...	CTV SCF	75.28	4148	4157	4171	4224	4223	4306	4321
Plan dose: 2F_GTR3_F...	HEART	688.69	0	0	0	113	8	1727	3190
Plan dose: Empty plan...	HEART	688.65	243	253	275	949	556	3926	4188
Plan dose: 2F_GTR3_F...	LAD	2.59	11	17	21	95	82	308	347
Plan dose: Empty plan...	LAD	2.5	434	443	470	1663	1845	2573	2650
Plan dose: 2F_GTR3_F...	SPINAL CORD	24.31	0	0	0	154	0	1374	1542
Plan dose: Empty plan...	SPINAL CORD	24.44	160	169	179	993	422	2556	2612