Evaluation of Beam Arrangements for Anal Canal Treatment Using Proton Pencil Beam Scanning

Ariel Hoang, R.T.(R), Josie Ruzek, B.S., Mahsa Dehghanpour, EdD, MS, CMD, Jamie Baker, PhD, MEd, CMD, Rachael Martin Paulpeter, PhD, Joshua Niedzielski, PhD, Sam Beddar, PhD, Gabriel Sawakuchi, PhD, Emma B. Holliday, PhD, MD, Luis Perles, PhD

University of Texas MD Anderson Cancer Center, School of Health Professions

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PURPOSE

This research is a retrospective study on the dosimetric impact of varying beam arrangements for pelvic intensity modulated proton therapy (IMPT) when treating patients with anal canal cancers with lymph node involvement. Protons are known for their Bragg Peak which creates a steep dose fall-off, allowing for greater sparing of OAR. The impact of beam arrangement in IMPT to the physical dose of pelvic OAR and PTV is investigated to find if there is a most optimal arrangement.

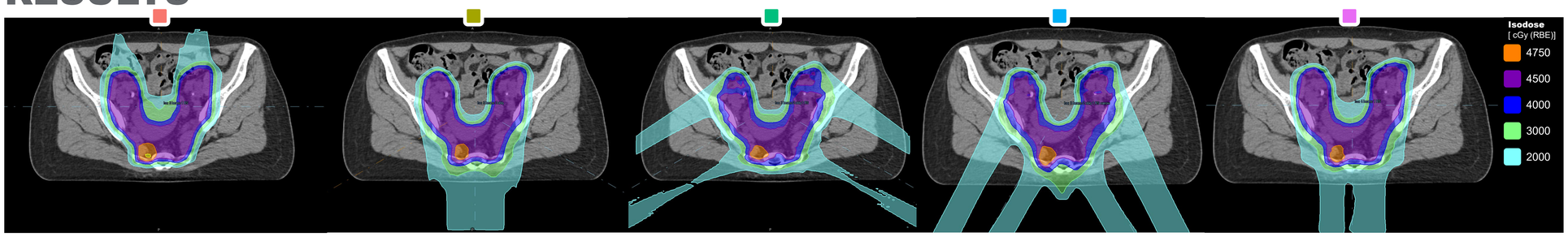
Plan Name	Beam Count	Beam 1	Beam 2	Beam 3	Beam 4
3 beams 1 RS	3	0° RS*	90°	270°	-
3 beams 2 oblq	3	180°	120°	240°	-
3 beams 2 oblq 1 RS	3	0° RS*	120°	240°	-
3 beams 2 oblq 1 RS narrow	3	0° RS*	150°	210°	-
4 beams 1 RS	4	0°RS*	90°	180°	270°

METHODS

This study involves 22 patients who were treated for anal canal cancer with lymph node involvement. Each patient data set was planned with five different beam arrangements. In some cases, a range shifter was used anteriorly. Plans were optimized with guideline optimizer settings and planning structures, and additional optimization objectives were used as needed. A planning structure including the bowel bag, bladder, and genitalia with a 1 cm margin subtracted from the PTV's was used. OAR sparing was prioritized while achieving reasonable coverage to the various targets. 13 patients received two-level prescriptions while the remaining 9 received three-level prescriptions. A Wilcoxon statistical data analysis and a Bonferroni correction was completed to evaluate coverage to the PTVs and OARs. The PTVs were normalized, and $p<0.00236$ is considered significant. For OARs, $p<0.0125$ were significant.

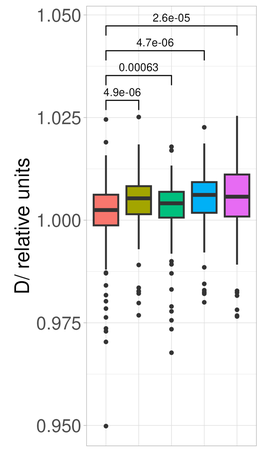
Primary Tumor Size	PTV1	PTV2
>2 cm	43Gy in 25 fractions	50 Gy in 25 fractions
2 to 5 cm	45Gy in 27 fractions	54 Gy in 27 fractions
>5 cm	47Gy in 29 fractions	47Gy in 29 fractions
Nodal Size	**PTV3**	
>2 cm	50Gy in 25 fractions	
2 to 5 cm	54Gy in 27 fractions	

RESULTS



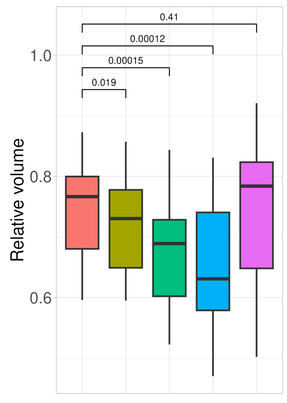
Legend
- 3 beams 1 RS
- 3 beams 2 oblq
- 3 beams 2 oblq 1 RS
- 3 beams 2 oblq 1 RS narrow
- 4 beams 1 RS

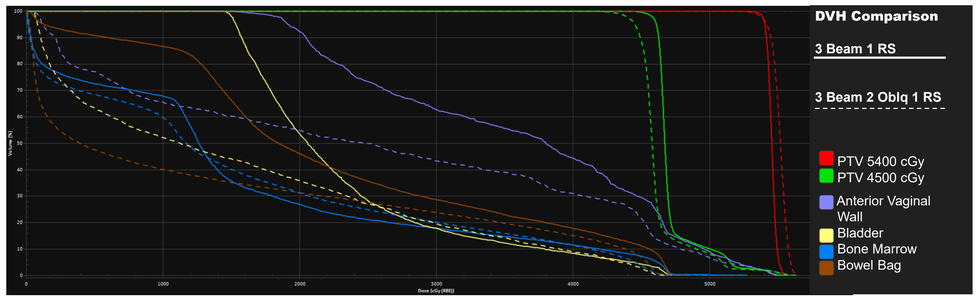
Relative PTVs

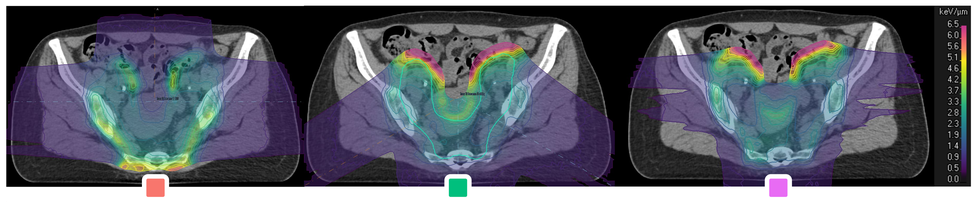


Bone Marrow

Dose at Absolute Volume

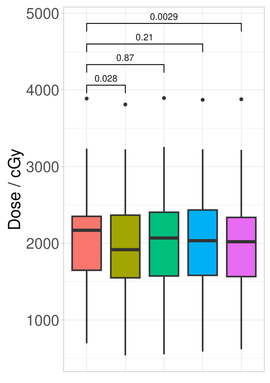






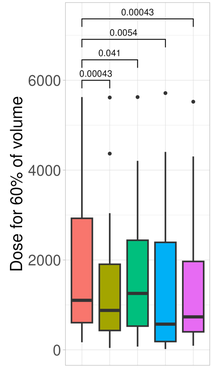
Bladder

Mean Dose



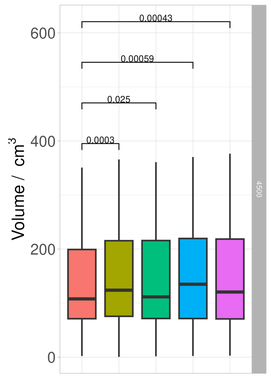
Anterior Vaginal Wall

Dose at Volume



Bowel Bag

Volume at 45Gy



Volume	Constraint	Optimization Objective	Priority
PTV High	D95% > 100% Rx	D100% >102% Rx Dmax < 103% Rx	100 100
PTV Medium	D95% > 100% Rx	D100% >102% Rx Dmax < 103% Rx Dose fall-off High to Med, 0.5cm Target EUD Rx, Alpha 1	100 100 80 80
PTV Low	D95% > 100% Rx	D100% >102% Rx Dmax < 103% Rx Dose fall-off Med to Low, 1 cm	100 100 80
CTV	D98% > 100% Rx	D100% > 100% Rx Dmax < 110% Rx	100 100
Bowel Bag	D150cc < 35Gy D200cc < 30Gy Dmax < 54Gy	D22% < 35Gy D30% < 30 Gy Dmax < 5250 Gy	Constraint
Bladder	D35% < 40Gy D50% < 30Gy		Varied
Bone Marrow	D90% < 10Gy		
Genitalia	D20% < 30Gy D67% < 20Gy		

DISCUSSION

All beam arrangements were able to achieve clinically acceptable coverage on PTVs while significantly decreasing physical dose to nearby structures, further emphasizing the benefit of altering beam angulation in achieving all clinical goals. For sparing the OAR, there was not a conclusive “best” arrangement as one OAR may be prioritized over another within the same arrangement, see below:

- **PTV** coverage overall increased for all beam arrangements except in "3 beams 2 Oblq"
- **Bone Marrow’s** volume at dose was significantly reduced in all oblique beam arrangements
- **Bowel bag**
  - Volume receiving 45Gy significantly increased for all beam arrangements except "3 beams 2 Oblq"
  - Volume receiving low dose of 20Gy significantly decreased for all beam arrangements except "3 beams 2 Oblq 1 RS"
  - Dmax decreased significantly in "4 beams 1 RS"
- **Bladder**
  - Mean dose significantly decreased for "4 beams 1 RS"
  - Overall, no statistical significance, but for volume receiving 45 GY, it is higher in "3 beams 2 Oblq 1 RS Narrow"
- **Anterior Vaginal Wall** mean dose reduced for "3 beams 2 Oblq 1 RS Narrow" and “4 beams 1 RS"

CONCLUSIONS

Appropriate beam arrangements in IMPT plan design can be considered to achieve selective OAR sparing. Further research is necessary to continue developing optimal proton planning, and the potential use of LET optimization can be considered when using different beam arrangements.

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CONTACT

1) Ariel Hoang, amhoang@mdanderson.org
2) Josie Ruzek, jsruzek@mdanderson.org
3) Dr. Luis Perles, laperles@mdanderson.org
4) Dr. Jamie Baker, jabaker@mdanderson.org