MR-Linac collimator size limitation and impact on the treatment of GYN patients

Richard Corbett III B.S.,* Mark Mergler B.S.,* Alberto Avila,* Jamie Baker Ph.D, M.Ed., C.M.D.,* Pam Castillo B.S., C.M.D.,† Belinda Lee B.S., C.M.D.,† Angela Sobremonte B.S., C.M.D.,† and Sastry Vedam Ph.D ‡

*School of Health Professions, The University of Texas MD Anderson Cancer Center, Houston, TX 77030, USA
† Departments of Radiation Dosimetry, The University of Texas MD Anderson Cancer Center, Houston, TX 77030, USA
‡ Departments of Radiation Physics, The University of Texas MD Anderson Cancer Center, Houston, TX 77030, USA

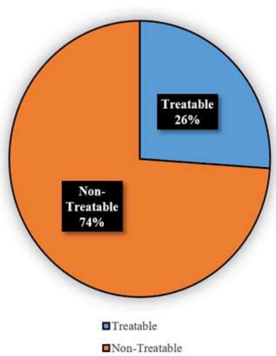
THE UNIVERSITY OF TEXAS MD Anderson Cancer Center

Introduction

Previously, both imaging and treatment machines were separate and unique to one another. Today, healthcare providers can perform both tasks on a single machine as Swedish company, Elekta, has pioneered the technology of integrating MRI imaging – instead of kV-imaging – with a linear accelerator, called the MR-Linac (MRL). Elekta commissioned a 1.5T split-coil MRI to ensure quality imaging with a modern 7MV linac; however, the magnet strength in the MRL is lessened where the linac sits. Furthermore, the TPS is established on Elekta's Monaco program, which utilizes the Monte Carlo Algorithm to calculate dose more precisely.

Usage of MRI in radiotherapy treatment planning (RTP) has been established for various tumor sites, while proven to have a superior advantage over its traditional counterparts. However, clinical use of MRI for RTP is constrained primarily based upon geometric distortion and the absence of electron density information. In order to diminish distortion, engineers and physicists used modified sequence parameters and distortion correction algorithms. Moreover, the absence of electron density information is resolved by co-registering MR images to CT images. Nonetheless, there are inherent collimator size limitations and only in/out shifts that can be accomplished on a MRL.

With focus on GYN cases, the purpose of this research is: to determine which GYN patients/cases can be treated with the MRL; to discuss how the MRL treats tumors; to describe possible solutions to MRL treatment planning and treatment challenges; and to compare MRL to current irradiation techniques and machinery.



Methods & Materials

Treatability

A set of 46 randomly selected GYN patients, who were previously treated with external beam radiation at MD Anderson Cancer Center (MDACC), was generated to evaluate treatability on the MRL. Three-dimensional (3D) data was collected from the original treatments planned on Pinnacle (Philips, Andover, MA) TPS. The data included Gross Tumor Volumes (GTVs), max GTV dimensions (X, Y, and Z), Planning Target Volumes (PTVs), max PTV dimensions (X, Y, and Z), and max patient circumferences within or around the treatment region. In determining treatability of GYN cases, the inherent physical limitations of the MRL were applied during assessment, with Y-dimension constraints the most significant limiting factors. Ultimately, patients were deemed treatable if PTV dimensions fit within the inherent constraints of the MRL.

Statistical Analysis

135 calculations were completed to give statistical values for both treatable and non-treatable results.

MRL Planning Comparisons

To visualize the difference in treatment planning and systems, five of the treatable cases were re-planned using the Monaco TPS for MRL and was compared to VMAT Pinnacle TPS re-plans for Varian Linacs. Dose Volume Histogram (DVH), isodose line distribution, calculation speed, optimization outcomes, and the overall treatment was contrasted for the comparison.

Results

GYN Patient Dimensional Data Collection

# of Pat	GTV volume - no margin (cc)	Max GTV: x dimension (cm)	Max GTV: y dimension (cm)	Max GTV: z dimension (cm)	PTV volume - with margin (cc)	Max PTV: x dimension (cm)	Max PTV: y dimension (cm)	Max PTV: z dimension (cm)	Max patient circumference (axial) (cm)	Treatable ?
1	303.5	8.7	8.3	9.7	1246	14	24	13	69.2	No
2	56.1	5.4	4.2	5.6	2015	22.6	21.4	11.3	71.8	No
3	98.2	6.2	7.1	5.3	515.5	10.1	11.2	7.7	119.1	Yes
4	61.3	5	6.2	4.5	1254.3	16.4	22.9	12.8	137.6	No
5	120.1	6.2	7.2	6.2	529.1	11	10.7	6.2	117.8	Yes
6	34.3	4.6	4.7	2.8	298.7	7.8	15.3	5.5	117.8	Yes
7	249.2	12	8.3	5.6	1408.3	116.3	23	13.8	129.5	No
8	30.7	5.5	6	3.8	1761.02	16	31.7	15.3	139.5	No
9	65.3	6.6	4.8	6	1182.9	20.5	23.6	10.8	120	No
10	22.5	3.5	3.2	4.8	48.4	4	4.5	5.5	158	Yes
11	6.5	2.5	3.5	2.3	1253.8	14.5	15.2	13.8	126.3	Yes
12	15	3.8	2.5	3.8	1152.2	15	21	12.2	117.8	No
13	23.2	11.4	8.2	5.5	1280.4	15.2	37.7	11.7	149.9	No
14	3	13.9	17	6.3	1673.7	16.9	32	15.3	134.5	No
15	110.2	7.6	6.3	8.1	215.3	25.1	21.7	14.6	110.3	No
16	56.6	4.2	5.9	4.3	696.8	20.6	14.3	13.8	120.6	Yes
17	20.2	19	5.2	4	944.3	29.4	23.8	19.5	138.5	No
18	182.4	6.2	9.2	7.3	1961.5	23.1	23.4	15.4	108.7	No
19	142.7	8	7	5.5	1684.1	14.5	31.5	14.5	125.7	No
20	222.5	8	7	10.5	448.5	9.5	8.5	12.5	125.7	Yes
21	60.4	4.7	5.3	6.7	258.3	15.4	10	10.4	135.4	Yes
22	56.5	1	1.3	2.3	981.2	14.5	30	12	142	No
23	307.9	10.6	7.9	8.2	1337.1	18.5	20.5	13.5	137.5	No
24	22	7	4	3	1529.6	16.5	22.5	14	136.5	No
25	2.8	6.5	11	3	1312	16.5	35	12	164.5	No
26	173.07	8	9	8	340.9	9.2	10.3	9.5	104.5	Yes
27	30.4	7	4	5.5	1434.6	18	30.5	15	145	No
28	5.5	3.5	9	3	233.6	7.5	16.5	5.5	127	No
29					1110.1	17	18	15.5	139.5	Yes
30	79.2	6.1	6	4.1	2056	21	23.5	18.5	129.5	No
31	13.3	3	6	3	1687.9	20	31	16	122	No
32	288.3	8.5	11	10.5	288.3	8.5	11	10.3	109.5	Yes
33	61.9	4.8	5.1	4.5	120.2	14.7	23.8	10.3	162.7	No
34	37.9	4.7	4.8	3.2	1954.6	19.7	17	15.1	124.7	No
35	7.7	12.5	13.9	4	297.8	18.9	16.3	10.9	150.5	No
36	21.4	11	18.1	6.5	1740	14.2	30.4	14.1	171.5	No
37	418.6	12.1	17.5	11.5	1478.2	16.4	29.8	14.8	172.2	No
38					977.7	15.5	15.3	9.5	127.5	Yes
39	43.3	4.2	3.7	5	1636.1	16.6	22.4	22.6	121.6	No
40	8.6	2.7	2.1	2.7	1761.2	14.3	21	15	121	No
41	61.5	5.4	4.5	4.7	1942	17.9	19.5	14.4	189.4	No
42	3.6	1.4	2.2	1.4	701.4	8.9	29.1	10.1	133.8	No
43	11.4	7.4	6.6	5	396.3	10.8	16.6	13.2	137.6	No
44	10	2.2	7.2	2.1	1373	17.6	20.9	13.5	165.9	No
45	18.6	3.5	8.7	5.9	2168.6	15.9	29.4	14.9	117.5	No
46	791.8	14	14.2	14.3	3462.3	25.7	38.5	18.1	165.2	No

TABLE 1. Analytical Statistics of Treatable GYN Patients

	*GTV Volume Avg (cc)	*Max GTV x dimension Avg (cm)	*Max GTV y dimension Avg (cm)	*Max GTV z dimension Avg (cm)	PTV Volume Avg (cc)	Max PTV x dimension Avg (cm)	Max PTV y dimension Avg (cm)	Max PTV z dimension Avg (cm)	Max patient circumference – axial Avg (cm)
Mean x̄	106.3	5.6	6.4	6.1	563.8	11.8	12	10	125.1
Sample Standard Deviation	94.6	2.1	2.4	2.9	373.6	4.6	3.7	3.4	14.3
Z score	0.168	-1.027	-0.607	0.757	-3.033	-1.397	-4.293	-2.88	-1.107
p Value	0.865	0.303	0.542	0.447	0.002	0.162	< 0.00001	0.004	0.267
p<0.05 Significance	N	N	N	N	Y	N	Y	Y	N
95% Confidence Interval	106.3 ± 58.633	5.6 ± 1.302	6.4 ± 1.488	6.1 ± 1.797	563.8 ± 211.38	11.8 ± 2.603	12 ± 2.09	10 ± 1.92	125.1 ± 8.091

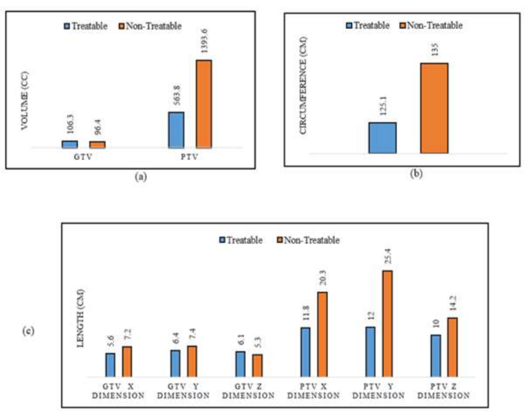
* Data for GTV measurements used 10 of the 12 patients due to a lack of GTV contours on two of the treatable cases.

TABLE 2. Analytical Statistics of Non-Treatable GYN Patients

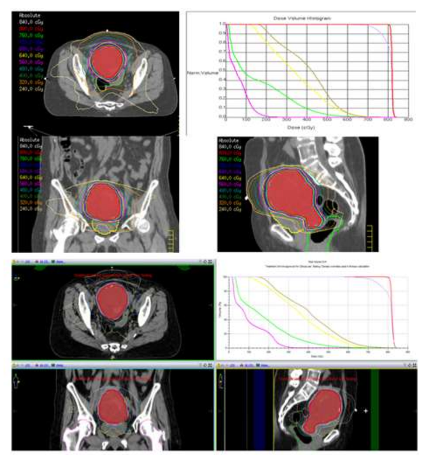
	GTV Volume Avg (cc)	Max GTV x dimension Avg (cm)	Max GTV y dimension Avg (cm)	Max GTV z dimension Avg (cm)	PTV Volume Avg (cc)	Max PTV x dimension Avg (cm)	Max PTV y dimension Avg (cm)	Max PTV z dimension Avg (cm)	Max patient circumference – axial Avg (cm)
Mean x̄	96.4	7.2	7.4	5.3	1393.6	20.3	25.4	14.2	135
Sample Standard Deviation	159.3	4.1	4.4	2.7	672.8	17.5	6	2.9	25.3
Z score	-0.089	0.589	0.359	-0.334	1.801	0.848	2.581	2.136	0.65
p Value	0.928	0.555	0.719	0.741	0.072	0.395	0.0099	0.032	0.516
p<0.05 Significance	N	N	N	N	Y	N	Y	Y	N
95% Confidence Interval	96.4 ± 53.546	7.2 ± 1.378	7.4 ± 1.479	5.3 ± 0.908	1393.6 ± 226.149	20.3 ± 5.588	25.4 ± 2.0.17	14.2 ± 0.975	135 ± 8.5

TABLE 3. Comparison of 3-Dimensional Delineations of Treatable v. Non-Treatable GYN Patients Using an Independent Samples Confidence Interval

	GTV Volume Avg (cc)	Max GTV x dimension Avg (cm)	Max GTV y dimension Avg (cm)	Max GTV z dimension Avg (cm)	PTV Volume Avg (cc)	Max PTV x dimension Avg (cm)	Max PTV y dimension Avg (cm)	Max PTV z dimension Avg (cm)	Max patient circumference – axial Avg (cm)
90% Confidence Interval	9.9 ± 89.452	1.6 ± 2.276	1 ± 2.454	0.8 ± 1.66	829.8 ± 345.207	8.5 ± 8.648	13.4 ± 3.112	4.2 ± 1.711	9.9 ± 13.003
95% Confidence Interval	9.9 ± 107.328	1.6 ± 2.731	1 ± 2.944	0.8 ± 1.992	829.8 ± 414.061	8.5 ± 10.373	13.4 ± 3.733	4.2 ± 2.052	9.9 ± 15.597
99% Confidence Interval	9.9 ± 143.492	1.6 ± 3.651	1 ± 4.936	0.8 ± 2.663	829.8 ± 553.134	8.5 ± 13.847	13.4 ± 4.986	4.2 ± 2.742	9.9 ± 20.835



Graphs: (a) Average Treatable GTV & PTV Volumes v. Average Non-Treatable GTV & PTV Volumes; (b) Comparison of Treatable v. Non-Treatable Max Average Patient Axial Circumference; (c) Comparison of Treatable v. Non-Treatable Average 3-Dimensional Delineations



Smallest Planning Difference. Patient 32 – Replanned case with smallest planning comparison variances: (a) transverse, coronal, and sagittal viewing planes of planned dose distribution, along with the plan DVH, utilizing Pinnacle TPS; (b) transverse, coronal, and sagittal viewing planes of planned dose distribution, along with the plan DVH, utilizing Monaco TPS.

Conclusions

Due to MRL's Y-dimension Field Size (FS) limitations ($Y_1 \leq 11$cm; $Y_2 \leq 11$cm; $Y_{Total} \leq 22$cm), 74% of the GYN cases did not meet the standard treatment constraints of the MRL. Statistical analysis determined PTV volume and PTV 3D measurements determined treatability, with Y-dimension size the major source. The 34 non-treatable patient PTV Y-dimensions delineated a standard mean of 25.4±2.017cm at 95% confidence compared to the 12 treatable patient PTV Y-dimensions delineating at 12±2.09cm. Analytics also confirmed maximum patient circumference is a determining factor of treatability: as circumference increases, treatability, on average, decreases. Moreover, the comparison revealed qualitative equivalence of treatment plans generated in Monaco for MRL treatment and in Pinnacle for conventional linac treatment. MRL planning is equally conformal to VMAT.

The ideal GYN candidate to be treated on the MRL should fall within the following estimated constraints, with approximately 95% confidence of treatability: GTV volume ≤ 165 cc; GTV X-dimension ≤ 7 cm; GTV Y-dimension ≤ 8 cm; GTV Z-dimension ≤ 8 cm; PTV volume ≤ 775 cc; PTV X-dimension ≤ 15 cm; PTV Y-dimension ≤ 14 cm and (Y_1 and Y_2 ≤ 10 cm); PTV Z-dimension ≤ 12 cm; axial-circumference ≤ 135 cm, and no periaortic lymph node involvement.

In conclusion, the MRL showcases assurance in not only maintaining quality of treatment but also revolutionizing radiation therapy.

References

1. Schultz, C. (2016). SP-0485: MRL: Clinical introduction. Radiotherapy and Oncology, 119, p.S232. doi:10.1016/S0167-8140(16)31734-0.
2. Zagoudis, J. (2016). The promise of MRI-guided radiation therapy.
3. Rai, R., Kumar, S., Batumalai, V., Elwadia, D., Ohanessian, L., Juresic, E., Liney, G. P. (2017). The integration of MRI in radiation therapy: Collaboration of radiographers and radiation therapists. Journal of Medical Radiation Sciences, 64(1), 61-68. doi:10.1002/jmrs.225.
4. Mowry, C. D., Pimentel, A. S., Sparks, E. S., & Hanlon, B. P. (2013). Materials characterization activities for "take our sons & daughters to work day" 2013.
5. Elekta. (2016, April 27). Transformative potential of Elekta's high-field MR-guided linear accelerator highlighted in seven abstracts at ESTRO 35.
6. Borman, P. T., Tijssen, R. H., Bos, C., Moonen, C. T., Raaymakers, B. W., & Glitzner, M. (2018). Characterization of imaging latency for real-time MRI-guided radiotherapy. Physics in Medicine & Biology,63(15), 155023. doi:10.1088/1361-6560/aad2b7.
7. Chuter, R., Whitehurst, P., Choudhury, A., van Herk, M. and McWilliam, A. (2017). Technical Note: Investigating the impact of field size on patient selection for the 1.5T MRL. Medical Physics, 44(11), 5667-5671.
8. Jäkel, O. (2018). SP-0546: MRL technological advances and potential usability in clinical setting. Radiotherapy and Oncology, 127, S290-S291.
9. Cree, A., Barraclough, J., Dubec, M., Hambrock, T., Van Herk, M., Choudhury, A., & McWilliam, A. (2018). 152 poster MRI-guided treatment planning for cervical cancer patients treated with a combination of external beam radiotherapy and PDR-brachytherapy. Radiotherapy and Oncology,71. doi:10.1016/s0167-8140(04)80203-2.
10. Kishan, A. U., & Lee, P. (2016). MRI-guided radiotherapy: Opening our eyes to the future. Integrative Cancer Science and Therapeutics,3(2), 420-427. doi:10.15761/icst.1000181
11. F. Khan and J. Gibbons, *Khan's The Physics Of Radiation Therapy*, 5th ed. (Wolters Kluwer, Philadelphia, 2016), pp. 414-429.
12. Elekta, Elekta AB.