Robustness of Chest Wall Plans and Setup Uncertainties

Christian Seua, M.S., B.S.; Kanza Shahid; Sankalp Dwivedi, B.S.; Jamie Baker, Ph.D., M.Ed., B.S., C.M.D; Kent Gifford, B.S., Ph.D.; Melissa Mitchell, M.D., Ph.D.; Tony Bonetati, B.S., C.M.D

University of Texas at MD Anderson Cancer Center, Houston, TX 77030

THE UNIVERSITY OF TEXAS
MD Anderson Cancer Center

Abstract

Iso-centric shifts that may occur during chest wall irradiation can change the robustness of a plan. The current method for planning chest-wall cases is Volumetric Modulated Arc Therapy (VMAT) and 3D conformal radiation therapy. VMAT utilizes a combination of intense modulation with inverse planning of arc therapy. 3D planning utilizes static photon fields and Internal Mammary Chain (IMC) electron fields to treat the chest wall region. A planning target volume (PTV) expansion of the target is utilized to reduce the chance of a geometric miss. In cases where the chest wall does not have enough tissue to create these margins, it is unclear how treatment plans could change due to isocenter shifts. The goal of this study is to determine what effect an iso-centric shift has on thin chest wall plans. In this study, we looked at 3D conformal radiation therapy and VMAT plans with chest walls <5mm and applied 5mm and 7mm shifts right-left, and anterior-posterior using the perturbed dose feature in RayStation. The perturbed dose function allows us to simulate specific shifts and apply them to clinical dose. A comparison was made between the original and new plans to determine if the proposed shift would have a significant impact on organs at risk (OARs), targets, and overall robustness of the plan. The original and shifted plans were evaluated using the clinical goals along with a dose volume histogram (DVH) comparison. The data showed that the clinical target volume (CTV) for the chest wall, supraclavicular region, and internal mammary nodes were all affected by the shifts. The differences caused by these shifts resulted in critical target coverage not meeting the acceptable values. By determining the effects shifts have on chest-wall plans, we aim to standardize and fortify the need for adaptive planning or lack thereof in this clinical situation.

Introduction

Two commonly used methods to plan chest wall cases are 3D and VMAT (Volumetric Modulated Arc Therapy) techniques. VMAT chest wall planning utilizes a combination of intense modulation with inverse planning of arc therapy to deliver the dose. 3D chest wall planning utilizes tangent photon fields, supraclavicular photon fields, and IMC (Internal Mammary Chain) electron fields to treat the chest wall region. Because of the complexity of planning these cases, setup variations along with anatomical changes can cause the plan to change throughout the course of the treatment. One common inconsistency that can occur throughout the course of treatment are isocenter shifts.[1,2] To account for these uncertainties, a PTV (Planning Target Volume) expansion is utilized to reduce the chance of a geometric miss.[3] In cases where the patient has a thin chest wall, there may not be enough tissue to create these margins. Overlooking the effect of organ motion when planning may also result in unsatisfactory dose deliverance to the target.[4,5] Thin chest wall patients are particularly sensitive to both uncertainties. A tool that can help assess the robustness of chest wall plans is the perturbed dose function in RayStation. The perturbed dose function allows the planner to simulate the current plan with hypothetical shifts. Adding hypothetical shifts in various directions using the perturbed dose tool in RayStation can help account for uncertainties that could result in the need for adaptive planning, saving time for our patients and oncology team. Evaluating the isodose lines, dose-volume histogram, targets, and organs at risk, between clinical plans and plans with incorporated shifts will help identify how well the clinical plans can withstand the shifts. Our research will focus on evaluating the effects a 5mm and 7mm shift in the anterior-posterior and left-right direction can have on thin chest-wall plans using the perturbed dose function for both 3D planning and VMAT treatment.

Materials and Methods

All patients were planned and treated at the University of Texas MD Anderson Cancer Center. The data set consisted of 9 patients with a chest wall <5mm planned using 3D and VMAT techniques. Five cases were planned using VMAT techniques in RayStation and four cases were planned using 3D techniques in Pinnacle. The four cases planned in Pinnacle were imported into RayStation in order to use the perturbed dose function. Use of multicentric fields, including electrons to treat the medial chest wall and internal mammary nodes, lateral tangents, and a superior supraclavicular field were standard for the 3D plans. Since the IMC electron fields were not able to be accurately imported into RayStation, the IMC fields were recreated and monitor units (MUs) from Pinnacle were entered. Multiple beam sets were created for the 3D plans due to the utilization of a mix of photon and electron fields. Using the compute perturbed dose tool in RayStation, a change in patient setup was simulated. All patient plans were shifted 5mm right, left, anteriorly, and posteriorly for each beam set in the plan. Once the 5mm shifts were added to each beam set, the sum dose tool in RayStation was used to create a plan with the total dose. To evaluate the original plan against the shifted plan, the summed dose plan with all the beam sets that incorporated the same directional 5mm shifts were exported and then reimported to produce a new separate plan with the total dose. The process was then repeated for a 7mm shift right, left, anteriorly, and posteriorly. Dose Volume Histograms and the clinical goals of the altered 3D plans were compared to the original plans based on Table 1. The comparison of the VMAT plans were compared based on Table 2. The difference in coverage for the CTV chest wall, CTV internal mammary nodes (IMN), CTV Axilla, and CTV supraclavicular nodes (SCV) were recorded. The change in the dose to the OARs such as the lungs, and the heart, were recorded and evaluated against the original plan and organ dose constraints. A comparison between the CTV coverage of the altered VMAT and 3D plans was made to evaluate the magnitude of change between the treatment techniques.

Target	Name	ConvFx (50Gy/25Fx)	OAR	50Gy/25Fx	
				Metric	Accept
Primary	Chest Wall	Dmin = 90%			
	Axilla_Ipsi		Heart	Mean	≤5Gy
	SCV_Ipsi		Lt Ventricle	V5Gy	≤25%
	IMN_Ipsi		Lung_Ipsi	V20Gy	≤35%

Table 1. Target and OAR Constraints for 3D Chest wall plans

Target	Name	ConvFx (50Gy/25Fx)	OAR	50Gy/25Fx	
				Metric	Accept
Primary	Chest Wall	Dmin = 98%			
	Axilla_Ipsi		Heart	Mean	≤5Gy
	SCV_Ipsi		Lt Ventricle	V5Gy	≤25%
	IMN_Ipsi		Lung_Ipsi	V20Gy	≤33%
			LAD	Max	≤25Gy
			Brachial Plexus_Ipsi	Max	≤52Gy
			Lung_Contra	V2Gy	≤8%
			Spinal Cord	Max	≤20Gy

Table 2. Target and OAR Constraints for VMAT Chest wall plans

Results

The original VMAT plans, and the average of the incorporated shifts were compared in Table 3-8 for all primary targets and OARs. The 5mm and 7mm shifts from plan 3 and plan 7 resulted in coverage of the chest wall and SCV to fall below the 98% target constraint while the coverage of the axilla and IMN were largely unaffected by both shifts. On average, the OARs for plan 3 with the 5mm and 7mm shifts were all still within the target constraints. The only OARs for plan 7 that didn't meet the dose constraint were the spinal cord and the heart. The 7mm shifts decreased the coverage of the targets more than the 5mm shifts in all directions for plan 11. The OARs for plan 11 were all below the dose constraints except for the brachial plexus and the spinal cord. Plan 2 and plan 10 were both bilateral chest wall cases. Both the 5mm and the 7mm shifts resulted in the chest wall coverage for both plans falling below the target dose constraint. The average coverage to the axilla for both plans minimally decreased with the 5mm and 7mm shifts. The maximum dose to the spinal cord increased above the dose constraint for both plans when a 5mm and 7mm shift was incorporated. Based on Table 9, shifts in the anterior-posterior direction will more likely require a re-plan as opposed to a shift in the lateral direction.

The original 3D plans, and the average of the 5mm and 7mm shifts were compared in Table 9-13. plan 1 demonstrated that on average, the 5mm shifts showed a minimal decrease in chest wall and Internal mammary node (IMN) coverage but a considerable decrease in dose to the SCV, and axilla minimum dose. The 7mm shifts produced similar results with target coverage. For plan 4, the average 5mm and 7mm shifts met the target coverage for the chest wall but saw a decrease in dose to the SCV and the axilla, however the IMN minimum dose saw a slight increase. The average results from plan 12 showed that both 5mm and 7mm shifts decreased the coverage of the chest wall with 7mm shifts having a bigger effect. Both shifts minimally decreased the dose to the axilla, and IMN. Plan 13 failed to meet target coverage in the original 3D plan for the chest wall and the average 5mm and 7mm shifts showed a decrease in all the targets except for the IMN minimum dose. For all 3D plans, the OARs were largely unaffected by both the 5mm and 7mm shifts. Based on Table 14, shifts in the posterior or right direction will more likely require a re-planning of the case as opposed to a shift in the anterior or left direction.

Discussion

Based on the results obtained, target coverage for the VMAT plans were more affected by an anterior-posterior shift as opposed to a lateral shift. In figure 1, there is a decrease observed in the chest wall coverage when an anterior 5mm shift was simulated. Due to the amount of coverage being lost from an anterior 5mm shift, this plan would have to be re-planned. A 7mm shift anterior-posterior further decreased the coverage of the targets. Due to the contour of a thin chest wall, there is more room for error laterally as opposed to anterior or posteriorly. The VMAT plans also had more difficulty with overdosing the OARs when shifts were incorporated. For the bilateral VMAT case, due to the large chest wall target needing to get adequate coverage, a 5mm posterior decreased the chest wall coverage below 90% as seen in figure 2. When a 7mm shift was incorporated into the VMAT plans, coverage of the chest wall dropped further causing more cases having to be re-planned. Overall, a replanning of a VMAT case would be required for a 5mm shift in the anterior-posterior and a 7mm shift in any direction would require a re-plan. 3D plans showed robustness in the chest wall coverage except for when a posterior or right shift is incorporated. A right shift incorporated in the 3D plans displayed a drop in the minimum dose to the SCV causing a re-planning of the case. In Figure 3, the left sided chest wall case had a drop in the SCV coverage when there was a 5mm shift to the right.

The drop in coverage to the SCV is possibly due to the margin that is created between the SCV target and the medial border of the SCV field losing coverage. The loss in SCV coverage laterally largely depended on what side was being treated. Shifts in all directions for the 3D plans minimally affected the OAR doses. A 7mm shift was still not enough to cause a drastic change in the OAR doses.

Conclusion

Our research focused on evaluating the effects of 5mm and 7mm shifts in the anterior-posterior and left-right direction can have on thin chest-wall plans using the perturbed dose function. Our research also concluded that for the VMAT plans, a 5mm shift in the anterior-posterior direction will decrease the coverage more than a shift in the lateral direction causing a re-plan of the chest wall case. VMAT plans are more robust for lateral shifts. A 7mm shift for VMAT plans in any direction would result in a re-plan of the case. Based on our data, the 3D plans would require a re-plan of the case for 5mm and 7mm shifts in the posterior or right direction. The 3D plans are more robust for anterior shifts. In conclusion, a shift that is greater than 5mm in any direction for 3D and VMAT thin chest wall plans will have to be re-planned. Iso-center shifts during chest wall radiation therapy can have a significant impact on treatment outcomes. By considering possible iso-shifts in a plan evaluation, a more robust plan can be achieved.

References

1. Liao, X., Wu, F., Wu, J., Peng, Q., Yao, X., Kang, S., Zhao, Y., & Orlandini, L. C. (2020). Impact of positioning errors in the dosimetry of VMAT left-sided post mastectomy irradiation. *Radiation oncology (London, England)*, *15*(1), 103. https://doi.org/10.1186/s13014-020-01556-w
2. Stroom, J., Vieira, S., Mateus, D., Greco, C., Fogliata, A., Nicolini, G., Clivio, A., Vanetti, E., & Cozzi, L. (2014). On the robustness of VMAT-SABR treatment plans against isocentre positioning uncertainties. *Radiation oncology (London, England)*, *9*, 196. https://doi.org/10.1186/1748-717X-9-196
3. Fredriksson A. (2012). A characterization of robust radiation therapy treatment planning methods-from expected value to worst case optimization. *Medical physics*, *39*(8), 5169–5181. https://doi.org/10.1118/1.4737113
4. Dunlop, A., Colgan, R., Kirby, A., Ranger, A., & Blasiak-Wal, I. (2019). Evaluation of organ motion-based robust optimisation for VMAT planning for breast and internal mammary chain radiotherapy. *Clinical and translational radiation oncology*, *16*, 60–66. https://doi.org/10.1016/j.ctro.2019.04.004
5. Van der Veen, G. J., Janssen, T., Duijn, A., van Kranen, S., de Graaf, R. J., Wortel, G., Wiersma, T. G., & Damen, E. (2019). A robust volumetric arc therapy planning approach for breast cancer involving the axillary nodes. *Medical dosimetry: official journal of the American Association of Medical Dosimetrists*, *44*(2), 183–189. https://doi.org/10.1016/j.meddos.2018.06.001

Contact

Christian Seua
MD Anderson Cancer Center
Email: cseua@mdanderson.org