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Dosimetric Evaluation of Left-Sided Chest Wall VMAT Treatment with and Without Jaw Tracking; Dose Comparison of Left Anterior Descending Artery versus Heart Mean Dose

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Research Outline

. Abstract

I. Introduction

1. Research question
2. Review statistics of women diagnosed with left-side breast cancer who receive mastectomy
    1. Survival rates for group
    2. Growling Trends
    3. A look at long-term side effects to assess long-term toxicities (ie cardiac related toxicity)
3. Define VMAT and jaw-tracking technique
    1. Discuss the difference between IMRT and VMAT
    2. Advantages and disadvantages of the jaw-tracking technique
4. Purpose of the study summary and why is it important

. Literature Review

1. Jaw-tracking technique used in IMRT research for left-side post-mastectomy chest wall treatments
2. Max dose to mean heart and LAD when performing IMRT with jaw-tracking utilized

. Methods

1. Research Design
    1. Equipment
        1. Linear Accelerator type from hospital A and hospital B

            2. MLC type for each machine
        2. Treatment planning System
        3. Plan Discuss patient treatment original design – energy selection IMN, supraclavicular node included or not, bolus use
        4. Contouring Methods
    2. Patient selection
        1. Demographics of patients
        2. Inclusion and Exclusion criteria

IV. Research Design

V. Results

1. Analysis of Data

VI. Discussion

VII. Conclusion

VIII. Appendix

IX. References

Abstract

Radiation therapy has significantly improved breast cancer survival rates; however, it can still lead to long-term side effects, particularly affecting the heart. Left-side breast cancer patients face higher risks due to the proximity of the heart to the treatment area. To mitigate cardiac toxicity, various strategies, including jaw tracking and Volumetric Modulated Arc Therapy (VMAT), have been proposed. This study investigates the dosimetric impact of VMAT plans with and without jaw tracking on the left anterior descending artery (LAD) dose and heart mean dose in post-mastectomy breast cancer patients. Ten patients previously treated with VMAT were evaluated, and the results were analyzed using paired samples t-test. The study found that the presence of jaw tracking did not have a significant effect on the LAD or heart dose. Although there was a reduction in LAD dose for 70% of patients with jaw tracking, the clinical relevance of the 100cGy difference requires further investigation. Considering the lack of statistical significance and potential trade-offs in other critical structures, the study suggests that patients need not seek treatment at a different location solely due to the absence of jaw tracking on a specific machine. Further research and clinical studies are necessary to comprehend the clinical implications of small dose differences on critical structures in breast cancer radiotherapy planning. The data analysis did not yield a significant t-value, indicating that the choice of a specific machine for treatment should not unduly inconvenience the patient. Balancing lower lung dose versus LAD dose is crucial due to the numerous variables and critical structures involved. Although jaw-tracking plans exhibited lower average maximum and mean doses, the difference was not statistically significant compared to plans without jaw-tracking. In conclusion, while the use of jaw tracking should be considered if available, this research indicates that it may not be the sole determining factor for plan quality.

Introduction and Background

According to the American Cancer Society, there is a 13% or a 1 in 8 chance that a woman will be diagnosed with breast cancer. Of those diagnosed, the survival rate has only improved over the last few decades. Death due to a breast cancer diagnosis has dropped by 43% since 1989 (American Cancer Society, 2020). Unfortunately, patients who undergo radiation therapy for the treatment of breast cancer will still experience a range of side effects despite the improved survival rates. Short-term effects may include changes in breast and skin both in appearance and feel, lymphedema, and fatigue. But what is of major concern are the long-term effects of radiation treatment. This can consist of lung and bone issues, and more significantly, long-term side effects on the heart (Ewertz & Jensen, 2011). This problem is more significant particularly for women with left-side treatments because of the proximity of the heart to the breast treatment area. Extended life expectancy has prompted a focused emphasis on improving the quality of life for these women post-treatment. It has been found that women with left-sided radiotherapy treatment experience higher levels of cardiac morbidity compared to women who receive adjuvant radiotherapy for right-side breast cancer (Garg & Kumar, 2022). Cardiac toxicity or damage to the heart can cause heart failure, myocardial fibrosis, arrhythmias, and coronary artery disease so special care is taken to reduce the dose to this particular critical structure (Hufnagle et al., 2020).

Several strategies can be used to minimize toxicity to the heart including, breath hold treatment, Intensity Modulated Radiation Therapy (IMRT), or Volumetric Modulated Arc Therapy (VMAT). The dose delivered to the heart during left-side breast irradiation has been of increasing concern as to what techniques can be best used to minimize the effects. Manipulating the position of the post-mastectomy chest wall (PMCW) during treatment with breathing techniques to allow for more distance between the PMCW and the heart is one way of limiting the dose to the heart structure. VMAT and IMRT can also be used as a way to reduce the dose to the heart.

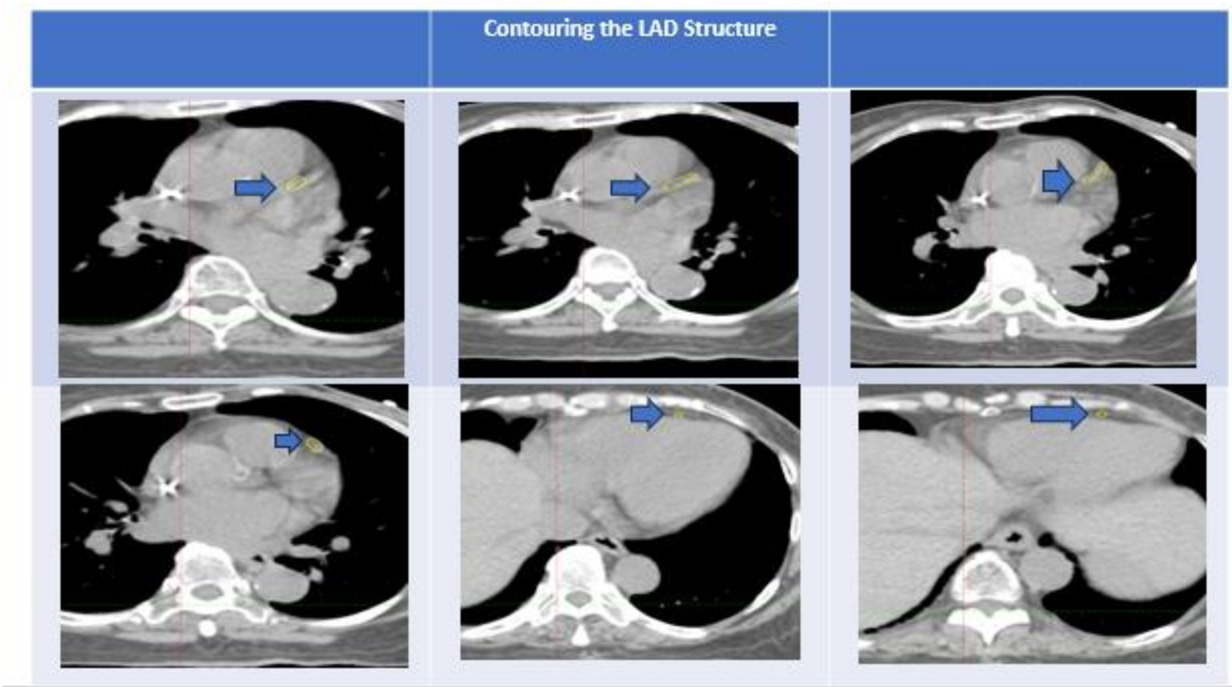
VMAT describes how the linear accelerator is used in radiation therapy and how the dose is delivered. Traditionally a group of static fields delivering treatment was the standard and is known as intensity-modulated radiation therapy. In contrast, a field that rotates continuously around the patient with a close to constant delivery of dose to the treatment site is referred to as a VMAT treatment. During a jaw-tracking delivery, the jaws of the field are moving along with the MLC aperture to minimize leakage radiation that occurs between the MLC leaves (Yao et al., 2019). In radiation oncology departments, the goal is to always keep the dose as low as reasonably achievable (ALARA), so although it may seem insignificant, the use of jaw-tracking may decrease the possibilities of cardiac toxicity for this population. Furthermore, there have been recent questions regarding the effects of radiation dose contribution not just to the heart mean dose but more specifically the dose to the left anterior descending artery (LAD) structure (Hoppe et al., 2020). Patients being seen in the radiation department are increasingly younger and long-term heart conditions post-radiation treatment is a growing concern. (Nieder et al., 2007) The current standard practice is to evaluate heart mean dose alone when evaluating the quality of a radiation treatment plan. This concept, however, is changing.

The idea that the LAD dose is a better predictor for cardiac events post-radiation treatment is leading to more emphasis on the dose restrictions to this structure. Monitoring the LAD and how this could play a role in the outcome of this critical structure and long-term toxicity to the heart is becoming more widespread and evaluated. It will not be in the scope of this research to define whether the mean heart dose or the dose to the LAD structure is more critical, however, it will be an evaluation of that LAD dose and comparing the mean dose to the heart overall while also looking at the LAD dose as a separate structure and assessing whether the use of jaw tracking or not has a large enough impact on the planning quality to warrant a re-evaluation of treatment options for patients undergoing left-sided post-mastectomy chest wall (PMCW) treatment.

For patients being treated for left-sided PMCWl, the dose to the heart is critical and small modifications in the planning treatment process can make a substantial difference in the mean heart dose overall. This study aims to investigate the dosimetric impact on the LAD with and without jaw tracking for post-mastectomy breast cancer patients being treated with a VMAT technique. There is an oncology institution located in the Western United States area with two centers providing radiation therapy treatments. Patients previously treated at the institution will be identified as to whether jaw tracking was or was not used for treatment. An alternative plan with or without jaw tracking will be generated, and the dose to heart and LAD will be compared.

Figure1.1

Axial slice views of the Left Anterior Descending artery (LAD) contour from the superior to the inferior aspect of the structure.



Literature Review

A study comparing 3Dimensional Conformal Radiation Therapy (3D CRT) compared to IMRT found that the mean dose to the heart and the LAD was significantly higher on the IMRT deliveries, which is to be expected. However, what was interesting was the differences found between the individual structures proved to be significant.   In the IMRT treatment, the mean heart dose shows a dose delivery of 17.70Gy whereas the LAD dose was 31.53Gy. The dramatic difference in dose concluded that more attention needs to be given to the LAD as opposed to the mean dose alone. This is done to ensure proper evaluation is conducted due to the severity of the side effects. The article also noted that these patients will undergo multiple follow-up imaging procedures and that the continued dose to the heart structure will be ongoing. (Garg & Kumar, 2022)

In the review of the literature, it was also found that jaw-tracking treatments versus non-jaw-tracking techniques have been evaluated primarily for intensity-modulated radiation therapy (IMRT) for various treatment sites for example, lung, esophagus, and even PMCW. With that said, there is a dose distribution difference when comparing IMRT treatments to VMAT radiation delivery. In the clinic where research will be conducted, IMRT static beam delivery is not utilized. All non-3-D conformal treatments are done using volumetric modulated arc therapy delivery. To the best of my knowledge, there have been no papers describing the impact of jaw tracking on LAD dose in regards to post-mastectomy left-sided chest wall patients during the use of VMAT treatment delivery, and whether there is a significant difference for dosing compared to non-jaw-tracking.

A study comparing the use of jaw-tracking with IMRT delivery did find significant dose differences in OARs for patients with and without reconstruction surgery at the time of treatment. Also, the mean heart dose was found to be lower but the subject of the heart dose, in particular, was not elaborated on. (Jung et al., 2022) Also noted was the benefit of jaw-tracking usage when it relates to dose-sparing for critical structures. The plan comparisons were similar, but the difference was predominantly seen in the OARs. The V20 lung dose saw a 0.6% decrease, the spinal cord was lower by 0.7% and the heart showed a 0.4% dose drop when jaw-tracking was used. (Feng et al., 2015).

<u>Research Design</u>

Upon approval from the hospital IRB department and the University IRB, this project will be a retrospective dosimetric analysis of patients previously treated for left chest wall irradiation. Ten patients will be evaluated to determine the dosimetric impact of VMAT plans with and without jaw tracking on the LAD dose and the heart mean dose. Data will be collected from the previously treated patients at this institution. The patients treated with a VMAT technique and left-sided breast diagnosis post-mastectomy >18 years of age will be included in the study. Those with a diagnosis of right-sided breast cancer and treated with a technique other than VMAT will be excluded. In the treatment planning system Eclipse^{TM} (Varian Medical System, Palo Alto) the plan will be copied, and the LAD contoured on the datasets (*Figure 1.1*). Contours will be reviewed by two investigators. Plans will then be re-optimized either with jaw-tracking enabled or optimized with jaw-tracking disabled depending on how it was planned initially.

The machines used at the two locations are a Varian Trilogy^{TM} IX with a standard multi-leaf collimator (MLC) without jaw-tracking capabilities and a Varian Truebeam^{TM} with high-definition leaves with jaw-tracking capabilities. A Varian Edge^{TM} machine with micro leaves was also used and jaw-tracking is available on this linear accelerator. To avoid any inaccuracies in the data, patients treated on the Varian Edge with jaw-tracking will be re-planned without jaw-tracking on the Varian Edge due to the difference in the leaf properties. VMAT planning techniques will be utilized with two to four partial arcs. The dose calculation algorithm used is the AAA. The heart mean dose, the LAD mean, and the LAD max dose will be analyzed for all plans. The calculated Dmax dose on the plans will also be compared. Dose volume histograms for each plan will be utilized for the evaluation of the plan quality. Data will be examined using paired samples t-test.

<u>Methods</u>

All patients were simulated on a Phillips Big Bore CT (**Philips** Healthcare, Cleveland, **Ohio**, USA). Participants were simulated in the supine position, with a wing board, arms up, hands holding the wing board posts, an upper vac-lock immobilization device, and a knee bolster. The treatment planning system used was Eclipse version 15.6 (Varian Medical System, Palo Alto, CA) Optimization model used was PO 15605 and the calculation model was AAA. For all patients, the clinically treated planning CT and structures were used for the planning study. The target PTV included the site of mastectomy and regional lymph nodes per institutional guidelines. The contoured organs at risk consisted of the right and left lungs, heart, spinal cord, and left anterior descending artery (LAD). For all patients, the dose prescription used was 45Gy in 25 fractions. Organs at risk consisted of the spinal canal, spinal canal with a 5mm additional margin, heart, and left lung. Targets consisted of supraclavicular nodes and the post-mastectomy chest wall with and without expanders in place.

Patient plans at this institution were archived in computer drive folders filed by patient name, treatment site, technique, and total dose. The anonymization process, the dose algorithms, and the patient origin were deleted so those settings would be entered back into the calculation models tab in Eclipse and compared for accuracy. Next, the monitor units were also verified using the dose calculation option in the planning tab, and the calculated volume with preset values was selected to view exact monitor units and the max dose was verified. To verify the patient user origin, we went into the properties of the registered images on the encrypted and unencrypted plan to ensure they matched. Lastly, in the original participants' eclipse plans there is usually an approved C1_tx site course as well as a C1_Planning course. The C1_Planning course would need to be set from Completed to Active in the course properties. The approved plan linked to the physician's prescription in the C1_tx site course was copied and pasted into the C1_Planning so the Optimization window became available. To ensure plan consistency with the clinically used plans, the dose objectives were reproduced for each patient in the corresponding new plan. Each encrypted plan was then pulled into the contouring window and a new structure for the left anterior descending artery was added and contoured. Once the new structure were contoured, plans were recalculated to retrieve dose statistics for the LAD structure. The ten encrypted plans were copied again and the optimization objectives used for the original plan were applied and the jaw tracking option was either enabled or disabled depending on how it was originally planned. The optimizer was allowed to run the plan calculated and the LAD statistics analyzed. For those plans that were planned on the Trilogy machine, since jaw tracking was not an option on this linac, the machine had to be changed to the Truebeam machine. For the other plans treated on the Edge and Truebeam, the jaw tracking setting was disabled for analysis. The optimizer was then allowed to run through the four MR levels and the calculation process was performed.

Various data points were used to make comparisons between the plans with jaw tracking versus the same plan without jaw tracking. They included the total plan max dose, heart mean and max dose, LAD max and mean dose, and PTV D95 coverage. A paired-sample t-test was used to compare the dose to the target and organs at risk with significance set to detect significant differences at $p < 0.05$. *Figure* 1.3 shows an example of a plan with and without jaw tracking.

Results

Paired T-test was used for statistical analysis of the collected data. The PTV target coverage was maintained as closely as possible without making alterations between the initial and subsequent plans to allow for a valid comparison. The PTV D95% average difference between the two sets of plans was 1.32% ($p = 0.78$). The plans that were run with jaw tracking enabled showed a lower global max dose difference although the differences were not statistically significant $p = 0.31$). The spinal canal max dose difference of 282.45cGy between plan averages seemed to be the metric that benefited the most from using the jaw-tracking enabled technique. The spinal canal maximum dose exhibited a lower dose with the jaw-tracking enable overall (p = 0.4789)(Figure 1.2).

When reviewing the data specifically for the mean and maximum dose to the LAD when using the jaw tracking technique, it did not show any significant difference in LAD dose. The t-value was 0.93 for the maximum LAD dose and 0.3 for the mean dose. The average difference between jaw tracking enabled versus disabled was a lower max dose with jaw tracking enabled by 99.04cGy. The mean dose for the LAD, when jaw tracking was enabled, displayed an even smaller average difference of 19.62cGy. Furthermore, the heart mean dose was slightly higher with the jaw tracking enabled. The left lung mean, V10, and V20 all showed slightly higher averages with the jaw tracking enabled technique. The difference in the plan averages of 1.45% dose was also lower for the jaw tracking disabled technique.

Data Summary

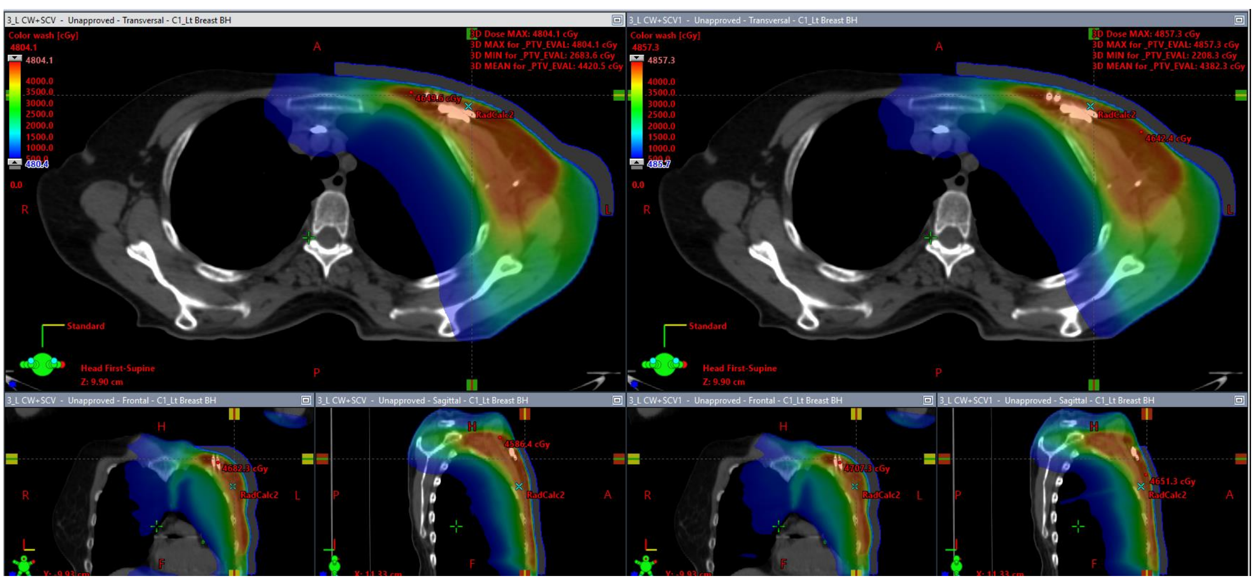
Figure 1.2

Dosimetric summary showing the average dose to OARS and PTV for plans with and without jaw tracking enabled.

	Jaw Tracking On	Jaw Tracking Off	Average Difference	P Value (.05 or Less=Significance)
LAD Max Dose (Gy)	29.80	30.70	0.90	0.3790
LAD Mean (Gy)	12.10	12.30	0.20	0.7744
Heart Mean (Gy)	6.31	6.29	0.02	0.9684
Global Max %	115.48	117.37	1.89	0.3159
D95% PTV	93.33	93.16	0.17	0.7876
Lt Lung V10%	49.50	49.40	0.10	0.9460
Lt Lung V20%	26.40	25.00	1.40	0.5818
Lt Lung Mean (Gy)	15.00	14.50	0.50	0.5654
Spinal Canal Max (Gy)	21.20	24.00	2.80	0.4789

Figure 1.3

Dosimetric plan evaluation comparison of a plan with jaw tracking enabled versus a plan with jaw tracking disabled.



With Jaw Tracking Enabled	Jaw Tracking Disabled

Discussion

"Between VMAT plans with and without jaw tracking for post-mastectomy chest wall patients, despite a lower max and mean dose to the LAD, the result were not statistically significant. The statistical analysis of the data using paired T-test showed no significant difference in the planning target volume (PTV) coverage between plans with and without jaw tracking (average difference of 1.32%, p = 0.78). Plans with jaw tracking enabled exhibited a slightly lower global maximum dose, but the differences were not statistically significant (p = 0.31). The mean and maximum doses to the left anterior descending artery (LAD) did not show significant differences, with average dose reductions of 19.62cGy and 99.04cGy, respectively, when jaw tracking was enabled. However, the heart mean dose was slightly higher with jaw tracking enabled, and other organs at risk also showed slightly higher average doses with this technique. The overall difference in plan averages was 1.45% for doses, which was also lower for the jaw tracking disabled technique.

There were a few variables that could affect the data collection that could be addressed and researched further for increased accuracy of the project as a whole. The largest variable that could have played a factor in the data outcome is the number of available plans used in the research. There was a lack of available patient plans to utilize for the research project. This is a relatively new technique for this clinic and is not typically the standard when treating left PMCW breast cancer patients. Normally, this is delivered using a 3-dimensional technique as opposed to using VMAT. Given more dedicated time, a planner could plan more PMCW patients using VMAT to allow for a larger patient population to evaluate. Another area that could be improved on is using the same planner to replan the non-jaw tracking enabled and the enabled technique. There will be an inherent difference between how planners push on certain oars and optimization techniques, and how they evaluate plans before physician review. Another variable that could be eliminated in a future research project is also having the same radiation oncologists review all the plans to ensure similar plan quality for comparison. In this study, the investigator used the dose of PTV and OARs achieved in the clinical plan, as a dosimetric reference for the new plan. Ideally, the same machine model and MLC models would be used for comparison. The initial question, however, was if the patient should be transferred to the neighboring clinic for treatment so it seems appropriate to make this comparison between the different machines in this case. Lastly, contouring the LAD structure takes time accuracy, and practice. Some of the plans used contrast for the initial simulation which made it much more efficient to contour this structure whereas the plans without contrast showed to be much more difficult. It is not a common contour required by dosimetrists and would take some practice in identifying the tract that the structure follows.

Seven of the ten plans did show a decrease in mean and maximum dose to the LAD the difference wasn't enough to show a superior plan technique. The difference in cGy even 100 is a big deal dosimetically to those working within the field of radiation oncology but insignificant in planning for post-mastectomy chest wall from a statistical standpoint. Even though the results were not significant, we found that 70% of the patients, showed a nice reduction in dose to the LAD structure. However, However, what is the impact of 100cGy to the LAD? Whether a difference of 100cGy has a clinical impact can be answered in additional clinical studies in the future.

Given the low significance found in the two different techniques, it is not warranted to have a patient travel further out of their way to be treated at a different location due to the lack of jaw tracking technique on the Trilogy machine. Due to the subsequent higher maximum doses seen in other critical structures, it is a trade-off and balance to get to a quality plan with minimal dose to the normal structures while still maintaining PTV coverage.

Conclusion

In conclusion, radiation therapy has significantly improved breast cancer survival rates, but long-term side effects, especially on the heart, remain a concern. Left-side breast cancer patients are at higher risk due to the proximity of the heart to the treatment area. This study investigated the dosimetric impact of VMAT plans with and without jaw tracking on the left anterior descending artery (LAD) dose and heart mean dose for post-mastectomy breast cancer patients. The results showed that while there was a reduction in LAD dose for some patients with jaw tracking, the difference was not statistically significant. The study suggests that the use of jaw tracking may not be a decisive factor for plan quality alone, and further research is needed to understand the clinical implications of small dose differences on critical structures in breast cancer radiotherapy planning. It also emphasizes the importance of monitoring both the mean heart dose and the dose to the LAD to assess the quality of radiation treatment plans for these patients. Patients need not travel to a different location solely due to the absence of jaw tracking on a specific machine, as the trade-offs in other critical structures should be carefully considered in treatment planning. Future clinical studies can help determine the clinical impact of small dose differences and improve the quality of radiation treatment for left-sided post-mastectomy breast cancer patients. For left-sided post-mastectomy chest wall patients receiving VMAT treatment, plans with jaw tracking did not show a significant difference to LAD dose. While the dose did suggest a lower dose to this organ, future research into the dosimetric thresholds for LAD dose can better inform the significance of this research.

Appendix

Raw Data

Each individual patient and specific metric taken from treatment planning system.

ID	Jaw Tracking LAD Max Dose	Jaw Tracking Disabled LAD Max Dose	Jaw Tracking LAD Mean Dose	Jaw Tracking Disabled LAD Mean Dose	Jaw Tracking Mean Heart Dose	Jaw Tracking Disabled Mean Heart Dose	Jaw Tracking Global Max Dose	Jaw Tracking Disabled Global Max Dose	Jaw Tracking PTV Coverage D95%
P-001	3691.5	3694	1653.8	1519.9	857.1	776.5	113.50%	114.20%	78.1656
P-002	4544.1	4116	2359.2	1912.8	961.9	768.6	111.8	111.4	97.0187
P-003	592.6	683.3	278	334.1	168.8	219.9	112.9	114.1	98.9672
P-004	4104.6	4166.5	1898.2	1800	858.1	743.7	115.7	117.8	95.7804
P-005	1781.8	1689.6	862.4	917.4	448.3	533.3	112.7	113.1	96.1046
P-006	4842.2	4943.4	1398.6	1401.2	866.1	786.6	115.7	112.7	96.1756
P-007	3465.7	3393.1	1191.6	1339.3	799.9	883.2	114.6	110.9	99.3193
P-008	4219.7	4548.5	885.7	1147.4	514	466.4	133.6	137.4	89.9115
P-009	1440.3	2329.1	907.4	1172.3	448.7	653.4	112.9	114.1	90.8436
P-010	1101.5	1210.9	649.8	736.5	390.9	466.7	111.4	128	91

ID	Jaw Tracking Disabled PTV Coverage D95%	Jaw Tracking Lt Lung V10	Jaw Tracking Disabled Lt Lung V10	Jaw Tracking Lt Lung V20%	Jaw Tracking Disabled Lt Lung V20%	Jaw Tracking Lt Lung MeancGy	Jaw Tracking Disabled Lt Lung MeancGy	Jaw Tracking Spinal Canal Max	Jaw Tracking Disabled Spinal Canal
P-001	78.9736	75.8	78.60%	34.2	37.70%	1860	1909.6	2685.5	2358.7
P-002	94.5906	80.2	68.8	59.7	37	2486	1857.2	2307.4	2757.7
P-003	97.2395	22.7	23.9	6	6.9	671	729.4	1145.1	1286
P-004	96.1499	56.8	47.1	31.1	26.5	1741.1	1549.6	2867	2864
P-005	95.5889	56.6	64.2	31.4	33.6	1652.5	1777.4	2515.1	2528.6
P-006	95.9932	43.6	43.6	21.5	20.6	1341.1	1341.3	2456.1	2095.1
P-007	98.8053	56.7	66.1	34.3	40	1959.8	2106.9	3444.8	3181.6
P-008	94.4583	38.8	30.4	18.4	16	1230.3	1059.5	1649.8	1606.2
P-009	88.7568	31.4	34.3	12.4	14.5	990.4	1060.7	2966.3	2611.6
P-010	91	32.7	36.7	15.2	16.9	1025.7	1122.1	2631.5	2758.8

Data Collection Average

Combined patient average for each dose constrain metric evaluated.

Jaw Tracking LAD Max Dose cGy	Jaw Tracking Disabled LAD Max Dose cGy	Jaw Tracking LAD Mean cGy	Jaw Tracking Disabled LAD Mean Dose cGy	Jaw Tracking Mean Heart Dose cGy	Jaw Tracking Disabled Mean Heart Dose cGy	Jaw Tracking Global Max Dose	Jaw Tracking Disabled Global Max Dose	Jaw Tracking PTV Coverage D95%	Jaw Tracking Disabled PTV Coverage D95%
2978.4	3077.44	1208.47	1228.09	631.38	629.83	115.48%	11737.00%	93.33%	93.16%

Jaw Tracking Lt Lung V10%	Jaw Tracking Disabled Lt Lung V10%	Jaw Tracking Lt Lung V20%	Jaw Tracking Disabled Lt Lung V20%	Jaw Tracking Lt Lung Mean cGy	Jaw Tracking Disabled Lt Lung Mean cGy	Jaw Tracking Spinal Canal Max cGy	Jaw Tracking Disabled Spinal Canal cGy
49.53	49.37%	26.42%	24.97%	1495.79	1451.37	2122.38	2404.83

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