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Breast radiotherapy

Quantifying radiation dose delivered to individual shoulder muscles during breast radiotherapy

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ABSTRACT

Background and purpose: Radiotherapy is an effective treatment for managing breast cancer, but patients may experience shoulder morbidity after completing radiotherapy. There is a knowledge gap regarding how the inclusion of the regional lymphatics in radiation treatment regimens influence the radiation dose delivered to the underlying shoulder musculature.

Material and methods: Five standardized radiation treatment regimens were developed from the computed tomography (CT) scans of 11 patients: tangent fields only (T), high tangent fields (HT), T + supraclavicular fossa and axillary apex with an anterior oblique beam (SCV), T + SCV + axillary nodes with an anterior oblique beam (SCV + AX), and T + SCV + AX with the nodal regions treated with a directly opposed beam configuration (DO). The muscle volumes for nine shoulder muscles anatomically located with the treatment regimens were segmented from the same CT scans. The effect of the nine muscles and five treatment regimens on the percentage of each muscle receiving at least 48 Gy (V48 Gy) was analyzed with two-way and one-way repeated measures ANOVAs.

Results: A statistically significant interaction existed between the nine shoulder muscles and five treatment regimens ($p < 0.001$) on the V48 Gy dose. Subsequent one-way analyses found statistically significant main effects of treatment plan on the V48 Gy dose for each muscle ($p < 0.001$). The pectoralis major and minor had the greatest V48 doses across the five treatments regimens. The HT, SCV + AX and DO treatment regimens produced statistically significant increases in the V48 dose of the latissimus dorsi and teres major. The infraspinatus, subscapularis, supraspinatus, teres minor, and trapezius only observed statistically significant V48 doses when treated with a DO plan.

Conclusions: These findings highlight the muscles (pectoralis major, pectoralis minor, latissimus dorsi, and teres major) that may exhibit future morbidity after radiation, and indicate that nodal RT delivered with a DO beam arrangement delivers the highest muscle dose.

Nearly 70% of women diagnosed with early-stage breast cancer are treated with breast-conserving surgery and radiotherapy (RT) [1]. RT is effective in managing breast cancer, reducing the recurrence of breast cancer and increasing long-term survival [2]. External beam radiation is the most widely used form of RT, often in the supine position with two coplanar tangential photon beams encompassing the entire breast [3]. The standard tangential beam arrangement can be expanded to include a portion of the axillary nodes within the treatment volume [4], otherwise known as a "high-tangent" field. Alternatively, the treatment volume can be expanded to include the supraclavicular and/or axillary nodes by adding a third beam oriented in an anterior oblique direction [5]. The use of this third beam to treat node-positive breast cancer patients is expected to increase in the coming years. The AMAROS trial recently found in a subset of clinically node negative but pathologically node positive patients that RT to the axillary nodes is as effective at regional control as an axillary lymph node dissection, but with a reduced risk of lymphedema [6].

It is important to address the long-term sequelae of axillary RT treatments as they become more frequent in future years. The increased treatment volume to encompass regional nodes may increase the dose to shoulder muscles and could explain the greater rate of shoulder morbidity in patients treated with nodal RT [7]. In support of the effect of RT on shoulder morbidity, the AMAROS trial found that axillary RT yielded impairment in upper extremity range of motion and quality of life that was equivalent to the axillary dissection arm [6]. Furthermore, axillary RT trended toward greater restriction in arm mobility when compared to axillary dissection. Similarly, RT has been identified as a significant

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source of arm and shoulder morbidity across a variety of patient-reported outcome surveys and biomechanical assessments [7–12].

The current study addresses how different beam configurations utilized in breast cancer RT influence the radiation dose delivered to individual shoulder muscles. The dose delivered to the shoulder musculature within the treatment volume is not routinely measured in clinical practice and has only been reported for the entire shoulder musculature [13]. The radiation delivered to individual shoulder muscles that are anatomically located within the planned treated fields for breast cancer patients has yet to be measured. Identifying the individual muscles most impacted by various beam configurations is important for elucidating the underlying causes of shoulder morbidity after RT and optimizing future RT protocols. Therefore, the objective of this study was to describe how different RT beam arrangements influence the radiation dose incidentally delivered to a various shoulder muscles that reside within the treatment volume.

Materials and methods

A retrospective review of patient CT treatment simulations was approved by the Institutional Board Review of Northwestern University. Eleven consecutive patients with unilateral breast cancer treated with breast-conserving surgery and sentinel-node biopsy followed by chemotherapy and RT to the breast and axilla were identified. An *a priori* sample size calculation was performed after the first five patients were analyzed (partial eta squared = 0.861). Using a repeated measures ANOVA, a statistically significant within-subjects interaction (alpha = 0.05 level) could be detected with 80% power with ten patients. The female patients had a mean age of 52 years (range: 36–70 years), 3 patients were treated on the right side and 8 patients were treated on the left side, and breast cancer staging was IIA for 3 patients, IIB for 4 patients, IIIA for 1 patient, and IIIC for 3 patients. CT simulation scans were acquired previously for clinical care (Phillips Healthcare, Andover, MA; Brilliance Big Bore Oncology scanner, 85 cm bore size, 60 cm scan field of view). In all scans, the patient's arms were fully abducted with the patient's elbow flexed and hands placed behind the head. The selection of patients that underwent axillary RT insured that the CT scans included the entire shoulder musculature within the image volume. Treatment regimens were created with the Pinnacle treatment planning system (Phillips Radiation Oncology Systems, Fitchburg, WI). Five treatment regimens were created for each patient (Table 1) to simulate how the variations in treatment regimens affect the radiation dose delivered to individual muscles.

A treatment regimen of 50 Gy in 2 Gy fractions was prescribed for all treatment regimens. A field-in-field technique was used in the tangent fields to optimize homogeneity and keep the breast to within ±7% of the prescription dose. In brief, the five beam arrangements were designed as follows:

- Tangent (T): tangents fields included the entire breast without intentional coverage of the adjacent lymph nodes.
- High Tangent (HT): the standard tangent fields were modified to also include the entire level 1 axillary nodes.
- Supraclavicular field (SCV): an anterior obliqued nodal field was added to the standard tangent fields using a mono-isocentric technique. This was designed to encompass the supraclavicular fossa and level III of the axilla. The lateral boundary was placed at the medial aspect of the humeral head. The prescription point was selected to limit the hot spot to <110% of the rx dose and to cover the nodal contours with at least 90% of the rx dose.
- Supraclavicular + axilla field (SCV + AX): A nodal field was added to the standard tangent fields. This was designed to encompass the supraclavicular fossa and levels I–III of the axilla. The lateral boundary was placed past the lateral aspect of the humeral head. The prescription point was selected to limit the hot spot to <110% of the rx dose and to cover the nodal contours with at least 90% of the rx dose.
- Directly opposed fields (DO): The anterior obliqued nodal field used in SCV + AX was directly opposed with an identical field. The prescription point was set at midplane. The beams were weighted in a 60/40 ratio favoring the anterior obliqued field. This represents a historical beam arrangement still used at a handful of centers.

The boundaries for nine shoulder muscles that are anatomically located within the planned treatment fields described above were segmented on each axial slice of the CT simulation. The segmented muscles were the infraspinatus, latissimus dorsi, pectoralis major, pectoralis minor, subscapularis, supraspinatus, teres major, teres minor, and trapezius. The latissimus dorsi was not fully visible within the CT scan's field of view, so segmentation was limited to the portion of the muscle superior of the T7 thoracic vertebrae. The radiodensity window was adjusted to distinguish between the individual muscles and their respective borders with adjacent muscles. Segmentation was initially performed by a specialist in human anatomy and imaging (DBL), and was further reviewed by an attending radiation oncologist (JBS). Radiation dose to the individual muscles was measured within the Pinnacle software for each treatment plan. Representative CT scans are shown in Fig. 1 along with the radiation isodose curves and individual muscle segmentations.

The outcome measurements for this study were the mean radiation dose in Gy delivered to each muscle and the percentage volume of the individual muscles that receive a radiation dose of at least 30 Gy (V30 Gy) or 48 Gy (V48 Gy). The V30 Gy measurement signifies individual muscles that received a moderate dose of radiation with a standardized 50 Gy treatment regimen. The V48 Gy measurement signifies individual muscles that received a near maximal dose for patients treated with a standardized 50 Gy treatment regimen. Statistical analyses were performed in SPSS (v24, IBM Corp., Armonk, NY). A two-way repeated measures ANOVA was used to test the V48 Gy measurement for a significant interaction between the five treatment regimens and nine individual muscles. Both muscle and treatment plan were treated as within-subject factors. One-way repeated measure ANOVAs were individ-

Table 1
Treatment plans used to simulate radiation dose delivered to individual muscles.

Abbreviation	Scan information	Total dose (Gy)
T	Tangent beams inclusive of the whole breast volume	50
HT	High tangent beams inclusive of the whole breast volume and level I axillary nodes	50
T + SCV	Tangent beams inclusive of the whole breast volume and anterior oblique beam inclusive of level III axillary nodes	50
T + SCV + AX	Tangent beams inclusive of the whole breast volume and anterior oblique beam inclusive of level I-III axillary nodes	50
T + SCV + AX (DO)	Tangent beams inclusive of the whole breast volume and directly opposed anterior-posterior oblique beams inclusive of level I-III axillary nodes	50