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ORIGINAL ARTICLE

An imaging evaluation of the simultaneously integrated boost breast radiotherapy technique

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Abstract

Introduction: To evaluate in-field megavoltage (MV) imaging of simultaneously integrated boost (SIB) breast fields to determine its feasibility in treatment verification for the SIB breast radiotherapy technique, and to assess whether the current-imaging protocol and treatment margins are sufficient. **Methods:** For nine patients undergoing SIB breast radiotherapy, in-field MV images of the SIB fields were acquired on days that regular treatment verification imaging was performed. The in-field images were matched offline according to the scar wire on digitally reconstructed radiographs. The offline image correction results were then applied to a margin recipe formula to calculate safe margins that account for random and systematic uncertainties in the position of the boost volume when an offline correction protocol has been applied. **Results:** After offline assessment of the acquired images, 96% were within the tolerance set in the current department-imaging protocol. Retrospectively performing the maximum position deviations on the Eclipse™ treatment planning system demonstrated that the clinical target volume (CTV) boost received a minimum dose difference of 0.4% and a maximum dose difference of 1.4% less than planned. Furthermore, applying our results to the Van Herk margin formula to ensure that 90% of patients receive 95% of the prescribed dose, the calculated CTV margins were comparable to the current departmental procedure used. **Conclusion:** Based on the in-field boost images acquired and the feasible application of these results to the margin formula the current CTV-planning target volume margins used are appropriate for the accurate treatment of the SIB boost volume without additional imaging.

Introduction

In 2011, we introduced the simultaneous integrated boost (SIB) technique to our department in the treatment of breast radiotherapy for early stage post-operative breast conserving surgery patients. This was introduced as studies have shown that the use of a three-dimensional conformal simultaneous boost technique (3D-CRT-SIB) as part of breast conserving therapy results in excellent local control and survival, without any increased normal tissue complications.[1–3] The SIB technique uses photon fields to deliver the boost treatment to the surgical cavity simultaneous with the breast tangential fields.[1–3] This hypofractionated technique enables the treatment course to be completed in 28 fractions, with an escalated dose delivered to the tumour bed.[4–6]

Due to the greater conformity of this technique in comparison to traditional electron or mini-tangent photon boosts the dose distribution may be more susceptible to setup errors and therefore care should be taken in ensuring adequate margins and treatment verification imaging (TVI) is applied to ensure accurate treatment delivery.[4,7] The current departmental treatment verification method is based on the one comparative to Harris et al. extended no action level (eNAL) protocol where the mean setup error is calculated from a fixed number of fractions with additional imaging at regular intervals.[6–9] Imaging of the medial tangential beam is currently used for position verification on fractions 1–3 and weekly thereafter, with an action level threshold of 1.1 cm deviation from planned lung volume. Some studies suggest that additional treatment verification

should be performed when treating non-tangential beams such as those used in the SIB technique to ensure adequate coverage of the boost target volume.[5,6] Such studies have investigated the use of an additional anterior–posterior (AP) verification film, cone beam computed tomography matching (CBCT) and surgical clip matching using kilovoltage (kV) imaging.[4–11] As kV imaging is not available on all linear accelerators in our department, it is necessary to verify breast cancer treatments with megavoltage (MV) imaging. The purpose of this study was to determine whether our current imaging protocol and the treatment margins used are sufficient in ensuring the accurate treatment delivery of the SIB breast technique or whether MV in-field imaging of SIB fields are required for treatment verification purposes.

Methods

Patients and planning

Ethics approval was obtained from the hospital Ethics Review Committee to undertake the study and to retrospectively access the electronic data required. All patients receiving the SIB breast technique were considered for inclusion in the study during the period June 2011 to June 2013. Sixty-one patients were simulated during this time frame in the supine position on an inclined breast board with both arms abducted above their head. Patients were excluded from the study if: the primary breast scar location did not correlate to the location of clinical target volume (CTV) boost volume as visualised on the planning CT; the scar wire was not placed on the patient during CT simulation or at time of treatment image acquisition; less than five images were acquired during the course of treatment; if the wire was not visible on the in-field image. This method of non-probability convenience sampling allows for a fast accrual of data for assessment. Of the nine patients included in the study, four received left-sided treatment and five received right-sided treatment. A 0.3-cm reconstructed slice-free breathing CT scan was acquired for planning purposes. Radiopaque wire was placed on the primary breast scar for visualisation on the CT scan in the Eclipse™ planning system (Version 10; Varian, Palo Alto, CA, USA). The CTV boost volume was delineated by the treating radiation oncologist as 1 cm around microscopic disease based upon the pre-operative imaging reports, surgical and histopathology reports, and the planning CT scan. A margin from the CTV to planning target volume (PTV) of 0.5 cm was applied to create the SIB boost volume. The patient characteristics including CTV and PTV are presented in Table 1.

Table 1. Patient characteristics.

Characteristic	Average	Range
Age (years)	57	48–74
Tumour size (cm)	2.43	0.4–4.5
CTV volume (cm^3)	23.14	3.6–62.01
PTV volume (cm^3)	56.8	13.69–124.25
Chest wall separation (cm)	20.8	18.4–24.5

CTV, clinical target volume; PTV, planning target volume.

Patients were prescribed 50.4 Gy in 28 fractions to the whole breast using medial and lateral tangential fields and 64.4 Gy in 28 fractions to the SIB boost delivered via an appropriate two field only technique, most commonly a wedged pair (see Fig. 1). All fields were treated at the same isocentre. The radiopaque scar wire was contoured in the treatment planning system for offline matching to digitally reconstructed radiographs (DRR).

Treatment verification imaging and retrospective analysis

Patients included in the study received TVI according to the current-imaging protocol using the electronic portal image device (EPID). This involves MV electronic portal images (EPIs) of the medial tangent for the first three fractions and weekly thereafter. Where there is a deviation from the action threshold of 1.1 cm from the planned lung volume the patient would be re-setup and repeat imaging would be performed. In-field MV images of the SIB fields were also acquired during treatment delivery using the EPID on imaging fractions (i.e. fractions 1, 2, 3, 8, 13, 18, and 23) with no added dose to the patient. As this study was assessing our current imaging protocol for SIB breast technique we chose not to increase imaging dose received by the patient nor the duration of treatment delivery time by taking additional orthogonal images. Radiopaque wire was placed on the patients primary breast scar when taking these in-field images only. The in-field images were assessed retrospectively offline and were manually registered to the DRR as created from the planning CT (see Fig. 2).

For each of the nine patients, between five and seven pairs of EPI were analysed to determine the displacement of the boost region based upon the matching of the scar wire. Images from a total of 53 sessions were acquired (106 images). Displacements were recorded in the vertical, longitudinal and lateral directions. The mean and standard deviation of the displacements was calculated for each individual patient and from this the overall mean and standard deviation for the whole patient group was calculated.

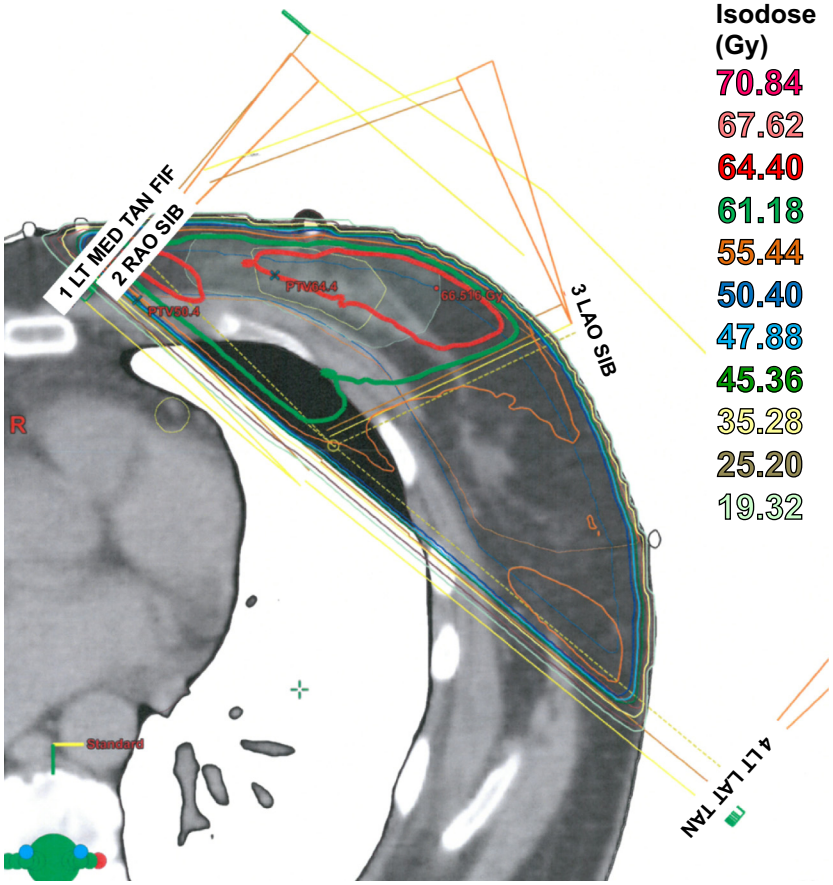


Figure 1. An example of an simultaneously integrated boost plan depicting the planning target volume (PTV) breast (shown in blue) and PTV boost (shown in light green) volumes, field arrangement and dose distribution.

Margins

A margin formula was used to assess treatment accuracy based on the images acquired. Van Herk et al. used a dose-probability-based approach to derive simple algorithms for choosing treatment margins. The Van Herk margin formula ($\alpha\Sigma + \beta\sigma'$) describes the margin required to ensure that for a set percentage of patients, the CTV receives a set percentage of the prescribed dose.[12] This formula has been used in previous breast studies for margin calculation.[8,10,11] The α coefficient was selected to be 2.5 to ensure 95% of patients receive the prescribed dose with the assumption of 3D errors. The β value of 0.73 is selected for the boost volume to receive 77% of the 14 Gy boost dose in order to receive 95% of the total prescribed 64.4 Gy. This assumes the whole breast has already received 50.4 Gy from the tangential fields. A penumbra value of 0.32 cm is selected for σ_p which assumes no multi-leaf collimator (MLC) shielding, which results in more generous margin values than assuming MLCs are used. Therefore, the full formula we used to calculate the safe margins that account for the random and systematic uncertainties in position of the boost volume when an offline correction protocol has been applied is $m_{ptv} = 2.5\Sigma + 0.73(\sigma - 0.32\ \text{cm})$.

Results

After offline assessment of the 106 images acquired, 96% were within the acceptable tolerance of the current department-imaging protocol (<1.1 cm). The measured translational displacement averages of the SIB in-fields are represented in Table 2. The largest setup inaccuracies can be seen in the longitudinal direction. Retrospectively performing the position deviations on the Eclipse™ treatment planning system demonstrated the effect of setup error on the dose distribution for each plan (see Fig. 3).

In this study, the maximum translational error in the longitudinal direction of 1.1 cm for one particular patient and on one image occasion resulted in a minimum dose variance of 0.4% and a maximum dose variance of 1.4%

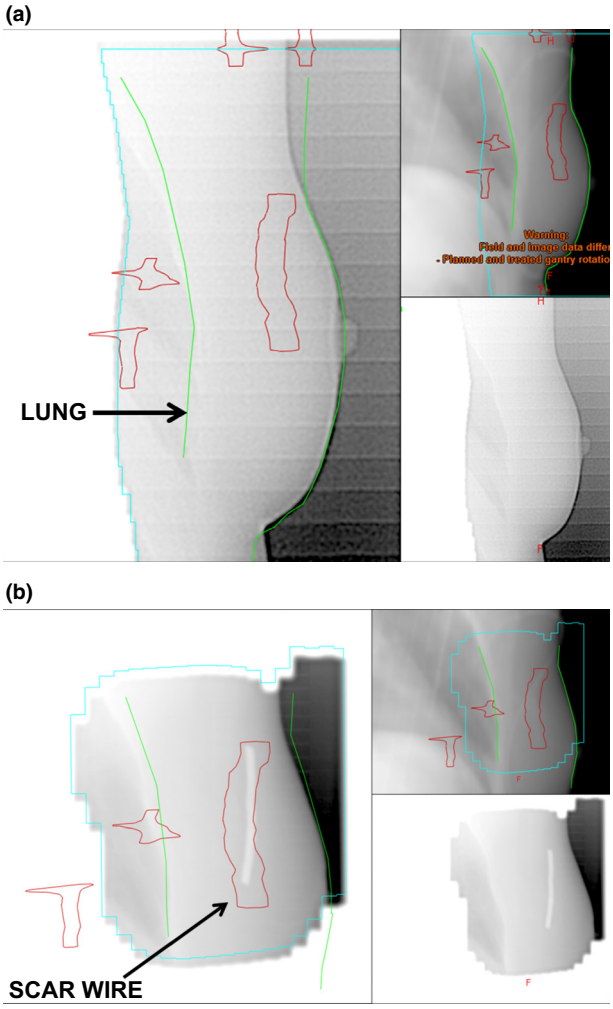


Figure 2. An example of offline digitally reconstructed radiographs registration of patient 3. (A) Medial tangent field demonstrating lung volume matching and (B) of the simultaneously integrated boost in-field demonstrating scar wire matching).

being delivered to the CTV boost when compared the original plan. This plan comparison also assumes that the patient was treated for the whole course of treatment at this maximum translational error which was not the case as seen in further imaging. Furthermore, applying our results to the margin formula $(2.5\Sigma + 0.73\sigma')$ to ensure that 90% of patients receive 95% of the prescribed dose, the calculated CTV margins required were comparable to the CTV-PTV margins currently used as per the department procedure (see Table 3).

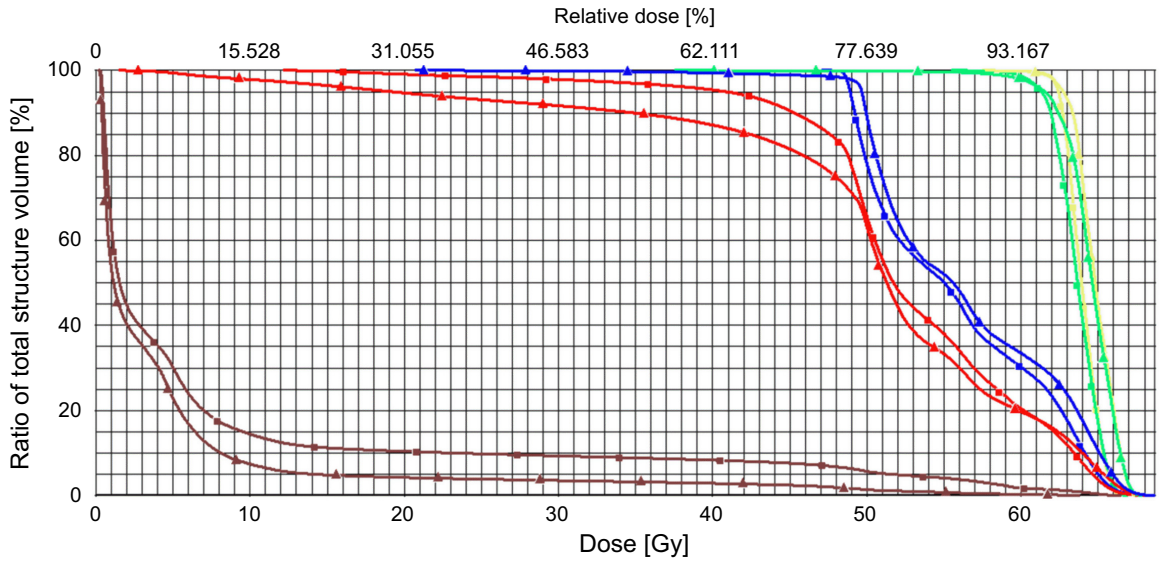
Discussion

In this study, the setup error measured with EPID and the use of scar wire matching were investigated in nine breast cancer patients receiving SIB treatment. After assessment of the in-field images, the setup error results were applied to the margin formula to calculate the safe CTV-PTV margins required for adequate dose coverage of the boost volume. The average of the margin results (Table 3) of 0.4 cm is within the CTV-PTV margins currently used as per the department procedure and therefore no additional imaging is required. This value is a generous representation due to the exclusion of the MLC penumbra. The MLC penumbra was excluded in order that the margin calculation was independent of collimator angle since collimator angles of 0° and 90° are used for SIB fields. As the in-field oblique acquisition angles varied (80–110°) and were not always orthogonal angles we understand that these results may not represent accurate 3D displacements. Due to these geometric uncertainties the calculated margin represents a generous safe margin. Future studies that involve increased frequency of imaging and the use of orthogonal images would result in a more accurate representation of treatment margins to consolidate these results. The

Table 2. The measured translational displacement averages and standard deviation of simultaneously integrated boost in-fields.

	Patient	Sessions (EPIs)	Vertical, cm Average (SD)	Longitudinal, cm Average (SD)	Lateral, cm Average (SD)
	1	5	−0.20 (0.17)	−0.11 (0.35)	0.16 (0.47)
	2	6	−0.03 (0.08)	−0.03 (0.31)	0.00 (0.10)
	3	5	−0.14 (0.17)	−0.2 (0.32)	0.06 (0.08)
	4	7	−0.07 (0.13)	0.01 (0.24)	0.20 (0.20)
	5	5	−0.18 (0.48)	−0.24 (0.22)	0.31 (0.34)
	6	7	0.09 (0.16)	0.11 (0.29)	−0.17 (0.13)
	7	7	0.01 (0.14)	−0.03 (0.23)	0.17 (0.10)
	8	6	−0.03 (0.05)	−0.35 (0.25)	−0.09 (0.11)
	9	5	0.27 (0.27)	0.45 (0.47)	−0.16 (0.18)
Total average	9	5.9	0.15 (0.18)	0.23 (0.30)	0.17 (0.19)

EPIs, electronic portal images; SD, standard deviation.



Structure	Structure Status	Coverage [%/%]	Volume	Min Dose	Max Dose	Mean Dose	Modal Dose	Median Dose	Std Dev
CTV BOOST	Approved	100.0 / 100.0	62.0 cm³	57.7 Gy	67.4 Gy	64.8 Gy	64.0 Gy	64.8 Gy	1.3 Gy
PTV BOOST	Approved	100.0 / 100.0	124.3 cm³	37.6 Gy	67.9 Gy	64.5 Gy	64.3 Gy	64.6 Gy	1.8 Gy
PTV eval	Approved	100.0 / 100.0	939.6 cm³	20.7 Gy	68.7 Gy	56.5 Gy	49.9 Gy	55.6 Gy	6.2 Gy
PTV	Approved	100.0 / 100.0	2018.6 cm³	1.5 Gy	68.7 Gy	50.1 Gy	49.9 Gy	51.3 Gy	12.6 Gy
Both Lungs	Approved	100.0 / 100.0	2548.6 cm³	0.2 Gy	63.8 Gy	4.4 Gy	0.4 Gy	1.1 Gy	9.1 Gy
CTV BOOST	Approved	100.0 / 100.0	62.0 cm³	57.5 Gy	66.4 Gy	64.0 Gy	63.4 Gy	63.9 Gy	1.0 Gy
PTV BOOST	Approved	100.0 / 100.0	124.3 cm³	55.5 Gy	67.0 Gy	63.6 Gy	63.5 Gy	63.7 Gy	1.4 Gy

Original Plan
Adjusted plan to represent maximum position deviation

Figure 3. Effects of maximum position deviations of patient 5 as shown on the dose volume histogram as retrospectively planned in the Eclipse treatment planning system.

margin formula used assumes 3D geometric error but does not account for patient rotation and shape variation. Van Herk et al. states that the derived margin recipe should therefore be considered as a lower limit for safe radiotherapy.[12] Furthermore, minor user variability in scar wire placement may have occurred between time of CT and/or treatment-imaging fractions.

Table 3. Application of results to the margin formula $m_{ptv} = 2.5\Sigma + 0.73(\sigma - 0.32\ \text{cm})$.

	α	Σ	β	σ	σ_p	Total
Lateral (cm)	2.5	0.146	0.73	0.217	0.32	0.29
Longitudinal (cm)	2.5	0.232	0.73	0.306	0.32	0.57
Vertical (cm)	2.5	0.170	0.73	0.225	0.32	0.36
Total average (cm)						0.41

m_{ptv}, the calculated margin based on the formula $2.5\Sigma + 0.73(\sigma - 0.32\ \text{cm})$; α, the value to ensure 95% of patients receive the prescribed dose with the assumption of 3D errors; Σ, the overall average displacement in stated direction; β, the value selected for the boost volume to receive 77% of the 14 Gy boost dose in order to receive 95% of the total prescribed 64.4 Gy; σ, the standard deviation; σ_p, this value represents the penumbra and assumes no multi-leaf collimator shielding.

Many patients selected by convenience sampling for inclusion in the study were excluded largely due to non-compliance of staff with respect to scar wire placement and imaging frequency, therefore providing insufficient data for study analysis. This resulted in a small sample size and this was the study's greatest limitation. Occasionally, due to collision risks of the EPID at certain gantry angles, imaging of some SIB fields was not possible and therefore patients were excluded from this study. Although our sample size is small, our margin calculations are comparable to other studies with sample sizes varying from 20 to 38 patients.[5,8,10,11] A detailed comparison is difficult due to different components of the geometric uncertainties included in different studies.[11]

In this study, the scar wire was used for matching purposes as a surrogate for surgical clips. Many studies investigate the use of surgical clips for accurate SIB treatment verification; however, the majority of patients at this department do not receive surgical clips and therefore we investigated an alternative treatment verification method. A study by Topolnjak et al. suggests that breast surface matching compared to a bony anatomy matching reduces position uncertainties of the boost target.[11] This supports the use of the scar wire for

breast surface matching as used in our investigation. A comparative study between surgical clip matching and that of scar wire matching and of a larger sample size in the future would further consolidate our results.

The maximum translational error as seen in this study in the longitudinal direction is also comparable to other studies. However, both Sijtsema et al. and Topolnjak et al. suggest that the use of EPID underestimates the longitudinal setup error for SIB treatments in comparison to CBCT matching.[5,11] Topolnjak et al. propose a larger margin to be used in the longitudinal direction to account for this variation.[5] With a larger sample size and increased imaging in future studies our department may be able to reduce or asymmetrically vary our CTV-PTV margins to account for this variation.

Conclusion

Based on the MV in-field boost images acquired and the application of these results to the Van Herk margin formula, we conclude that the current CTV-PTV margins and treatment verification-imaging protocol used in our department are appropriate for the accurate treatment of the SIB boost volume without the need for additional in-field imaging. This study demonstrates an alternative method of treatment verification when conventional methods such as surgical clip matching on kV imaging or CBCT are not available.

Conflict of Interest

The authors declare no conflicts of interest.

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