

Reduced Contralateral Breast Dose using TomoDirect™ and Daily MVCT Imaging

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Introduction

Breast conservation surgery followed by radiation therapy is being used with increasing frequency in the treatment of early stage breast cancer. As screening improves, more women, especially younger women, are being diagnosed earlier and electing breast conserving therapy. A potential benefit of primary irradiation is that it allows treatment of the cancer with good cosmetic results. A number of important and challenging technical issues have been shown to influence successful outcome of this therapy. These include (a) homogeneity and distribution of dose, (b) coverage of a highly complex target, and (c) ease of setup (2-4). Other important considerations include dose to normal tissues including the heart, lungs, and contralateral (untreated) breast. Radiation therapy is associated with a small increase in risk of secondary cancer developing in the contralateral (untreated) breast in breast cancer survivors. This is especially for those under 45 years of age at initial diagnosis (ref 1), where risk increases with delivered dose (ref 2). A study by Stovall *et al* in 2008 (ref 3) showed that women under 40 years of age who received a radiation dose greater than 1.0 Gy to the contralateral breast had an elevated, long-term risk of developing a second primary contralateral breast cancer. The risk was shown to be inversely related to age at exposure and to be dose dependent.

This report describes a study which assessed the dose received by the contralateral breast from a course of TomoTherapy® treatment delivered using the TomoDirect™ modality compared to the dose received from a course of treatment using a conventional linear accelerator using comparable treatment goals. The study is a phantom based study conducted in conjunction with the University of Wisconsin Comprehensive Cancer Center.

Treatment beams and imaging beams both contribute to contralateral breast dose, with the magnitude of each and relative contribution of each depending on treatment and imaging techniques. In this study, the dose contribution from the corresponding imaging technique used for setup is included in each case. Since imaging is performed at different frequencies (daily MVCT for *TomoDirect* modality and weekly portal imaging for conventional), comparisons of dose due to imaging and of dose due to treatment plus imaging must be in terms of the entire course rather than per fraction.

In a separate study of the dosimetric effects of uncorrected setup errors in breast treatments using helical *TomoTherapy* (TomoHelical™) delivery, published in *Radiotherapy and Oncology*, it has been found that imaging on a daily basis has benefit in terms of PTV dose coverage (ref 4). That study concludes that the benefits of correct daily soft-tissue imaging outweigh the issue of increased dose due to imaging. On the other hand, surface imaging approaches – which incur no additional dose – may prove suitable in many situations. In that case, contralateral breast dose is of course limited to that from the treatment beams. This should be remembered in interpreting the results of this study where treatment and imaging dose is measured separately.

The *TomoDirect* treatment delivery technique uses two or more fixed gantry angles, as distinct from the *TomoHelical* technique where a continuous helical beam trajectory is used. *TomoDirect* delivery is able to create a dose distribution very similar to that resulting from fixed-gantry IMRT, wedged, or compensated beam techniques used with a conventional linear accelerator. During a *TomoDirect* delivery, many overlapping, transversely-oriented, narrow beam projections contribute dose to the target during continuous longitudinal couch translation at a given gantry angle. The binary multi-leaf collimator is used to

define the transverse beam extent and achieve the level of beam compensation required at each projection. Two opposing tangential *TomoDirect* treatment beams were used for this study. The *TomoDirect* delivery mode is available as an option on Hi-Art® systems, and as a standard feature on the TomoHD™ treatment system.

The hypothesis being tested here is that although daily MVCT imaging incurs a higher contralateral breast dose than weekly portal imaging, overall contralateral breast dose from treatment and imaging is still comparable or lower for the *TomoDirect* course. The key to this being true is a lack of leakage and scatter radiation being incident on the contralateral breast – this coming about because of a high degree of shielding provided by the collimation geometry (jaws and binary multileaf collimator) and minimization of head scatter via a narrow beam geometry and lack of a flattening filter. Peripheral dose per monitor unit has been shown to be low for a *TomoTherapy* beam compared to that for conventional linear accelerator (ref 5). While most of the contribution to peripheral dose is from leakage (scatter contributes only a few percent), the 23 cm of tungsten shielding provided by the jaws and MLC appropriately compensates for the increase in monitor units relative to conventional delivery.

It is beyond the scope of this study to compare the overall quality of the respective dose distributions; however both were able to achieve a relatively homogeneous and conformal plan for the simulated left-breast treatment used in this example.

Methods and Materials

Detector geometry

A thorax phantom with detachable breasts was used for treatment planning and dosimetry. Optically-stimulated luminescent dosimeters (OSLDs) were used for all measurements. The OSLD reader used was a commercial InLight™ microStar system, manufactured by Landauer, Inc. These detectors consist of small plastic disks infused with carbon-doped aluminum oxide. Energy stored during irradiation is released as luminescence when the OSLD is illuminated with light at 540 nm wavelength (ref 6). OSLDs are a modern and more convenient alternative to thermo-luminescent dosimeters (TLDs). Uncertainty in OSLD readings is approximately 3%.

Five detectors were placed on the surface of the breast and five more under the breast in locations approximately directly posterior to the surface detectors. Table 1 lists the locations of each detector.

Figure 1 indicates the detector locations diagrammatically, in CT scans and in a photograph. As indicated in the diagram, the detectors are located such that the center surface position is nine cm lateral to the phantom’s mid-line, at approximately mid-breast in the superior-inferior direction. The other surface detectors are displaced five cm in each direction from this point. MVCT scans were performed with small lead fiducial markers placed at the designated detector locations. The markers were removed prior to treatment and imaging dose measurements.

Table 1. Detector positions used for this study (also see Figure 1).

Detector #	Location
1	Medial surface
2	Superior surface
3	Lateral surface
4	Inferior surface
5	Center surface
6	Medial under
7	Center under
8	Superior under
9	Lateral under
10	Inferior under

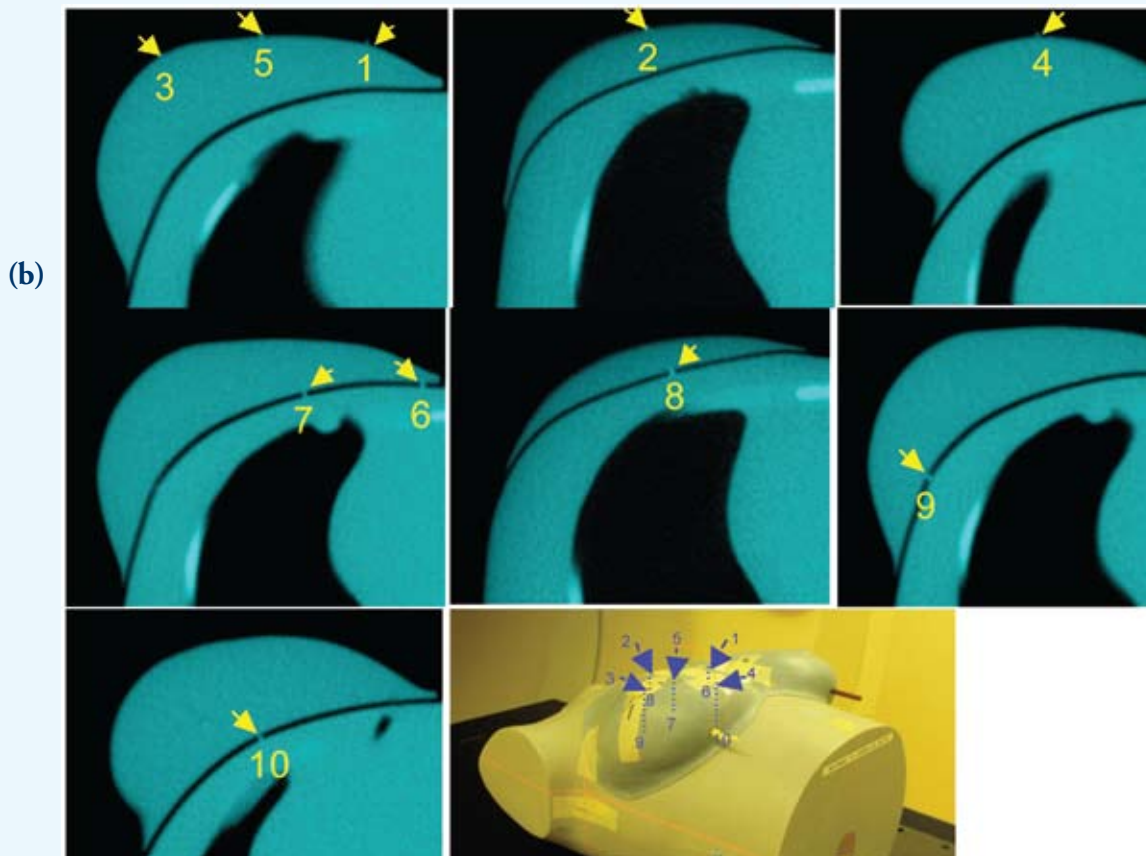
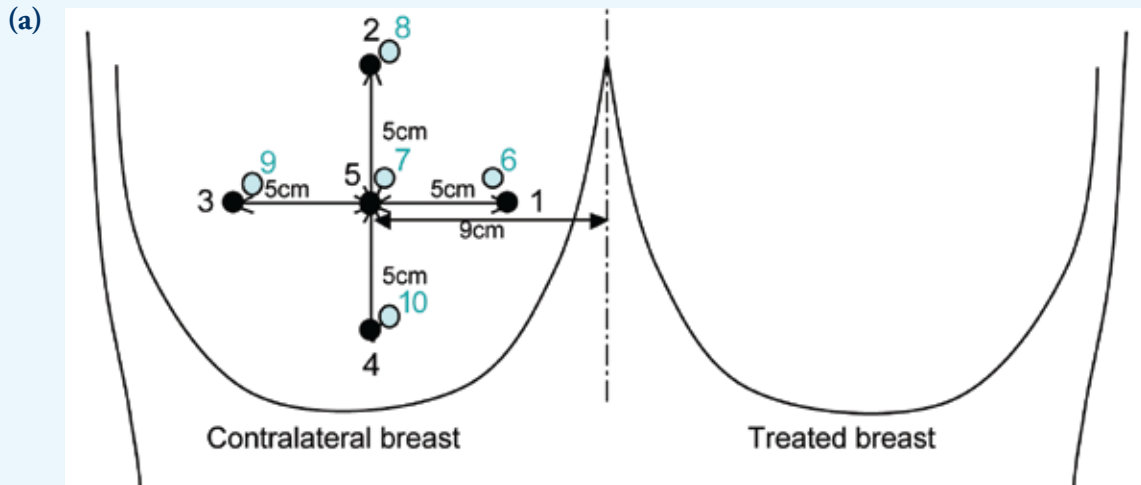


Figure 1. Five detectors were placed on the surface of the breast and five under the breast. As indicated in (a), the detectors are located such that the center surface position is nine cm lateral to the phantom’s mid-line, at approximately mid-breast. The other surface detectors are displaced five cm in each direction from this point. As shown in (b), MVCT scans were performed with lead fiducial markers at each location.

***TomoDirect* treatment plan**

During *TomoDirect* treatment planning, a dose of 48.6 Gy to the whole left breast in 27 fractions (1.8 Gy per fraction) to 95% of the planning target volume was prescribed. The planning target volume (PTV) was 14.8 cm in length. Planned dose in the treated breast ranged between 47 Gy and 52 Gy. Maximum dose outside the target also did not exceed 52 Gy. Two tangential beams at gantry angles of 314 degrees (medial tangent) and 123 degrees (lateral tangent) were used. **Figure 2** shows the beam configuration. Maximum extents of each beam, as shown, correspond to the maximum extents of PTV on all slices. The axial plane shown corresponds to that of detectors 1, 3 and 5. Note that a “flash” region consisting of two MLC leaves was used for each beam (in clinical use this accounts for target excursions due to respiratory motion). The “3DCRT” mode of delivery was selected (as opposed to IMRT). In this mode, dosimetric constraints are limited to prescription dose in the target as a dose-volume-histogram (DVH) point. In this case 48.6 Gy to 95% of the PTV volume was specified. There are no dosimetric goals available for regions at risk (RARs), as distinct from IMRT mode. RARs can be designated as “blocking” the beam at the entrance side (a directional block) or at both entrance and exit sides (a complete block). For this plan, no RARs were used as blocking structures.

A 2.5 cm jaw width was selected, with a “pitch” of 0.25. Physically, this means that there is considered to be one beam projection per couch translation of 6.25 mm (2.5 cm x 0.25). During beam delivery, MLC leaves open for the planned duration per projection over each 6.25 mm interval. Couch translation is continuous and at constant velocity throughout the delivery of each beam (a single gantry angle). Couch translation is 17.5 cm for each beam, corresponding approximately to the PTV length plus the jaw width. Total time between start and end of beam delivery for this plan is 4.2 minutes.

The *TomoDirect* treatment dose distribution is shown in Figure 3, in the same axial plane as **Figure 2**. This plane corresponds to that of detectors 1, 3 and 5 (note that the corresponding fiducial markers can be seen in **Figure 3**).

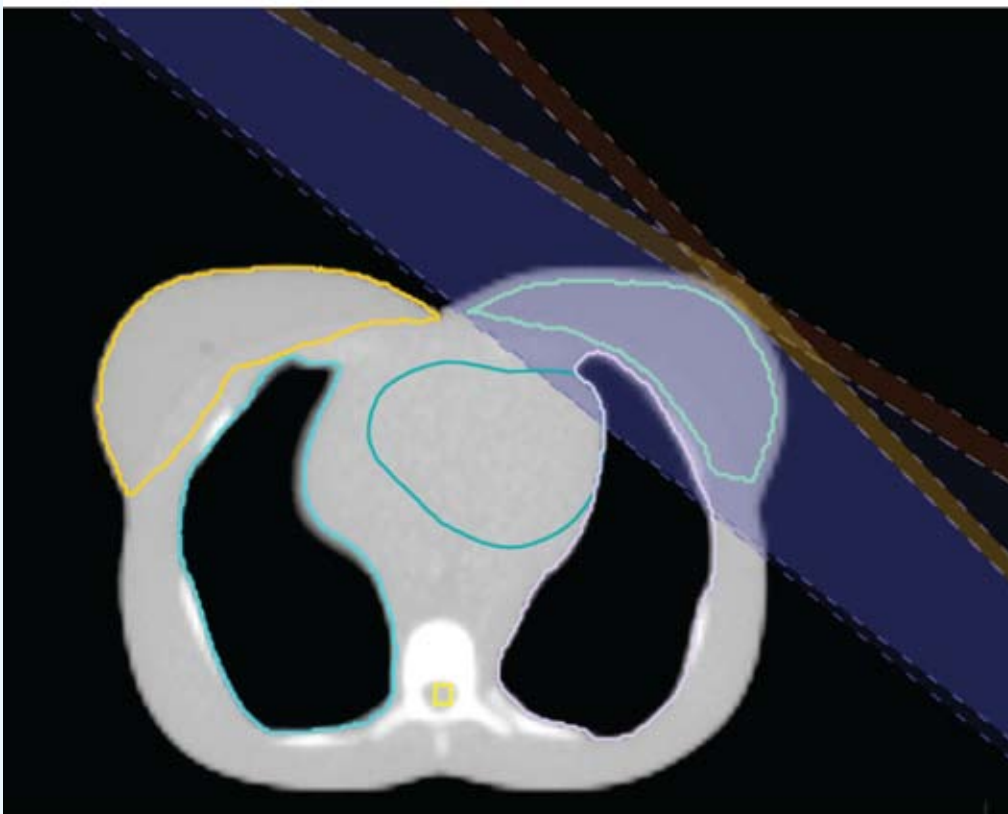


Figure 2. Beam configuration for the *TomoDirect* treatment. Two tangential beams at gantry angles of 314 degrees (medial tangent) and 123 degrees (lateral tangent) were used. The axial plane shown corresponds to that of detectors 1, 3 and 5.

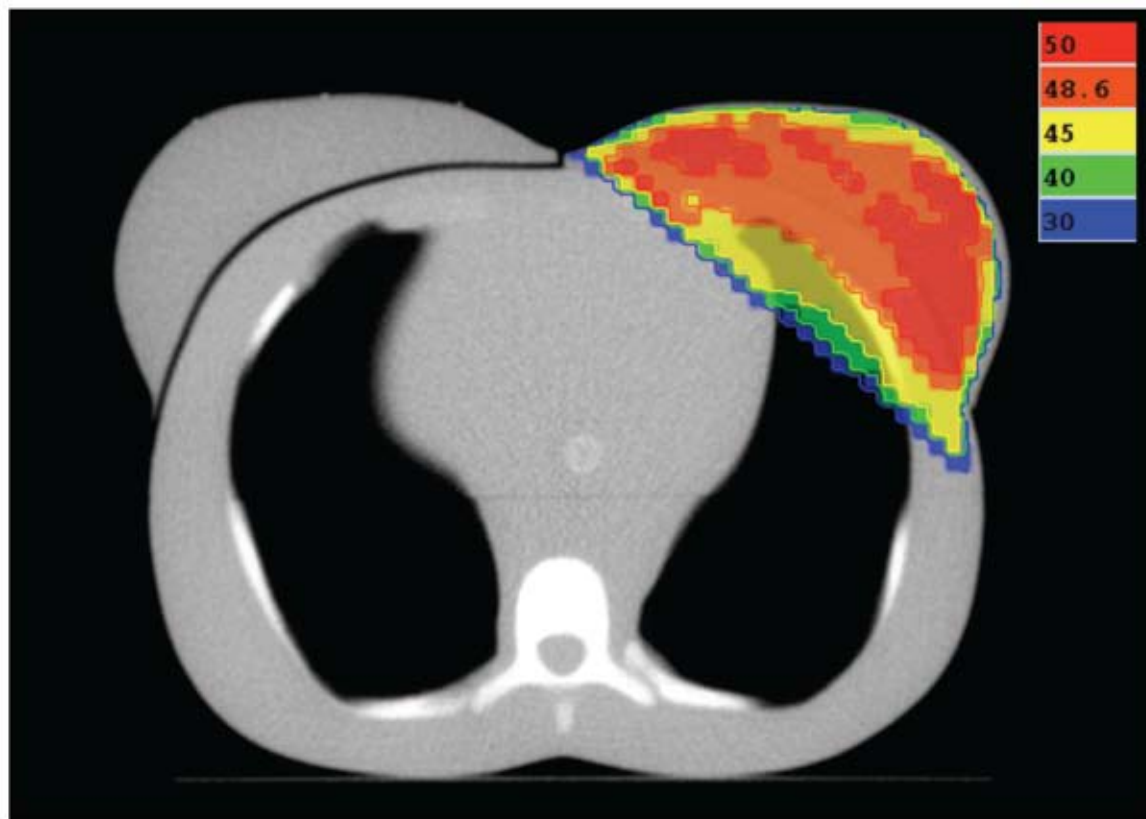


Figure 3. *TomoDirect* treatment dose distribution in the same plane as Figure 2. (Note that fiducial markers at locations 1, 3 and 5 can be seen).

Varian treatment plan

A pair of 6 MV tangential beams was used for the conventional plan, completed using a Pinnacle planning system, version 9.0 (Philips Laboratories, Milpitas, CA) and delivered on a Varian 21 EX linear accelerator (Varian Medical Systems, Palo Alto, CA). The dose distribution was optimized using a single 30 degree wedge for the lateral tangent. A wedge was not used for the medial beam in order to avoid exposure of the contralateral breast to the scattered radiation originating in a wedge. This technique has previously been shown to yield reduced contralateral breast dose compared to paired wedges and similar to that resulting from IMRT techniques (ref 7).

Beam angles were chosen such that the posterior edges matched those of the corresponding *TomoDirect* treatment beam. Gantry angles set for the lateral and medial beams were 51 degrees and 235.6 degree respectively. Converted to the same angle convention used for the *TomoDirect* beams, these angles correspond to 129 degrees (lateral) and 304.4 degrees (medial). Note that the differences in gantry angle compared to the *TomoDirect* treatment plan (123 degree and 314 degrees) are mostly due to the *TomoDirect* treatment isocenter being more posterior and the effect of beam divergence.

48.6 Gy in 1.8 Gy fractions was prescribed to correspond to 95% of the dose at the calculation point. Dose distribution characteristics achieved within the treated breast were similar to that for the *TomoDirect* plan. The lateral and medial beams required 178 monitor units and 106 monitor units respectively, to be delivered at a dose rate of 400 monitor units (MU) per minute. Beam configuration and dose distribution for the conventional tangent plan are shown in figure 4 and figure 5 respectively.

***TomoDirect* treatment delivery and MVCT imaging**

The phantom was positioned centrally on the treatment couch prior to image-guided setup. A MVCT scan encompassing the whole breast was initially performed at “fine” resolution (2 mm slice spacing). At this step, fiducial markers were placed at the detector locations so that these points could be identified on images (see Figure 1). Fine resolution was used for best visualization of the markers. The markers were then replaced with a set of ten OSLDs and another whole-breast scan at “normal” resolution (4 mm slice spacing) was performed. This scan was used for image registration and to record imaging dose. After phantom repositioning, the OSLDs were replaced with another set. Treatment delivery was performed, exposing the second set of OSLDs. Imaging and treatment dose were thereby recorded separately and could be summed for overall dose.

It should be noted that although normal resolution was used in this study, it is also common to use “coarse” scan mode (6 mm sliced spacing), in which case imaging dose is reduced by approximately 1/3rd. It is assumed here that MVCT imaging is to be performed clinically for every fraction.

Varian treatment delivery and portal imaging

The portal imaging procedure used for checking patient position is performed on the first day of treatment and repeated once per week. For this reason, imaging dose and the sum of treatment and imaging dose is reported and compared with the *TomoDirect* results on a per-course basis. The summation of treatment and imaging dose is performed by multiplying measured treatment dose by 27 (daily treatments) and imaging dose by six (weekly images). Two sets of portal images were acquired for each of the tangential fields using a double exposure technique (1 MU for each beam). The first exposure was set to an open field of 10x10 cm² and the second was set to the treatment field shape using the MLC.

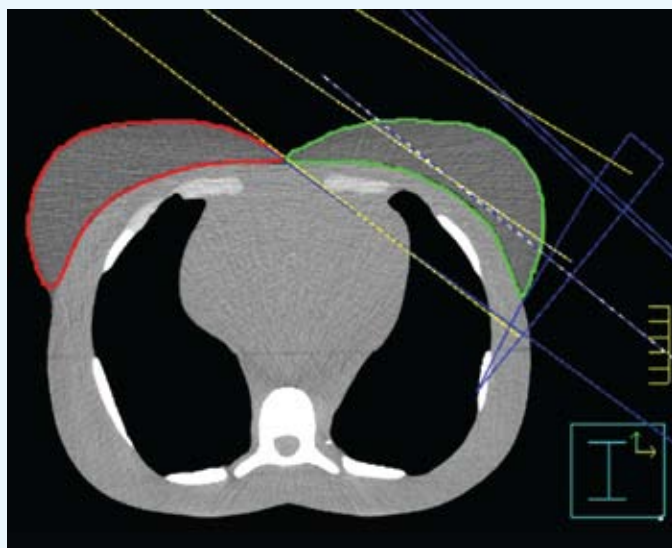


Figure 4. Beam configuration for the Varian plan. Gantry angles set for the lateral and medial beams were 51 degrees and 235.6 degree respectively. Converted to the same angle convention used for the *TomoDirect* beams, these angles correspond to 129 degrees (lateral) and 304.4 degrees (medial).

Results



Figure 5. Dose distribution for the Varian plan. Prescribed dose is 48.6 Gy, corresponding to 95% of the dose at the calculation point.

Measured treatment dose, imaging dose and the summation of these two components are reported here as a percentage of prescription dose over the course of treatment. Table 2 gives these results for each detector position. Averages over all 10 positions are also given. Note that *TomoTherapy* imaging dose is a result of daily MVCT (27 image sets) and Varian imaging dose is a result of weekly portal imaging (6 image sets).

Table 2. Treatment dose, imaging dose and combined dose, as a percentage of the 48.6 Gy prescribed dose, for each detector position, over the course of treatment. Averages over all 10 detector positions are also given.

Position	Treatment		Imaging (course)		Treatment and Imaging (course)	
	Tomo %	Varian %	Tomo %	Varian %	Tomo %	Varian %
1	5.89	10.96	0.59	0.35	6.48	11.31
2	2.54	4.89	0.61	0.07	3.15	4.97
3	2.32	3.91	0.57	0.07	2.88	3.98
4	3.21	5.96	0.69	0.24	3.89	6.20
5	3.64	6.11	0.75	0.03	4.39	6.13
6	4.11	7.94	0.89	0.32	4.99	8.27
7	1.58	2.63	0.84	0.03	2.42	2.65
8	1.33	2.19	0.90	0.02	2.23	2.21
9	0.78	1.02	0.93	0.01	1.71	1.03
10	1.20	1.98	0.75	0.02	1.95	2.00
Average %	2.66	4.76	0.75	0.12	3.41	4.88

Table 3 gives average treatment, imaging and combined dose for each technique, expressed in cGy per fraction and per course (27 fractions of 180 cGy in this case). Note that for both techniques treatment dose is a much more significant contributor than imaging dose to combined contralateral breast dose. Average Varian treatment dose contribution to contralateral breast dose is 79% higher than for *TomoTherapy* treatment dose and average Varian combined dose is 43% higher than *TomoTherapy* treatment.

Table 3. Average treatment dose, imaging dose and combined dose, expressed in cGy per fraction and per course (27 fractions of 180 cGy in this case). Varian imaging dose and combined dose per fraction is listed as not applicable because imaging is performed only weekly. Average Varian imaging dose per day on which it is performed is 0.95 cGy. Average Varian treatment dose contribution to contralateral breast dose is 79% higher than for TomoTherapy treatment and average Varian combined dose is 43% higher than TomoTherapy treatment.

	Treatment		Imaging		Treatment and Imaging	
	Tomo (cGy)	Varian (cGy)	Tomo (cGy)	Varian (cGy)	Tomo (cGy)	Varian (cGy)
Per fraction	4.79	8.57	1.35	n/a	6.14	n/a
Per course	129.33	231.39	36.5	5.67	165.7	236.9

Figure 6(a) shows the treatment dose data for each detector from Table 2. Note that the *TomoTherapy* treatment dose is lower at all points and by a fairly consistent proportion. The largest absolute dose reductions are at the medial locations (#1 and #6), closest to the PTV. It is at these locations, where contralateral breast dose is naturally highest, that the largest reduction in terms of absolute dose is seen. **Figure 6(b)** represents the data in Figure 4(a) as a percentage difference relative to the prescription dose.

Investigation into the origin of contralateral breast dose with the *TomoDirect* delivery technique is a possible topic for further study. Possible sources are radiation leakage through the collimation geometry, head scatter (particularly from the medial tangent) and phantom scatter (particularly from the lateral tangent). Previous work indicates that the majority of the dose contribution outside of the irradiated region is due to leakage rather than scatter (ref 5), however that study pertained to a region inferior to the treated volume, rather than in the same axial plane.

Figure 7(a) shows the combined treatment and imaging dose data for each detector from Table 2. The *TomoTherapy* treatment dose is lower at 8 out of 10 locations, despite higher imaging dose. **Figure 7(b)** represents the data in Figure 5(a) as a percentage difference relative to the prescription dose. Note that the medial locations still show the greatest reduction in dose even when treatment and imaging dose are combined.

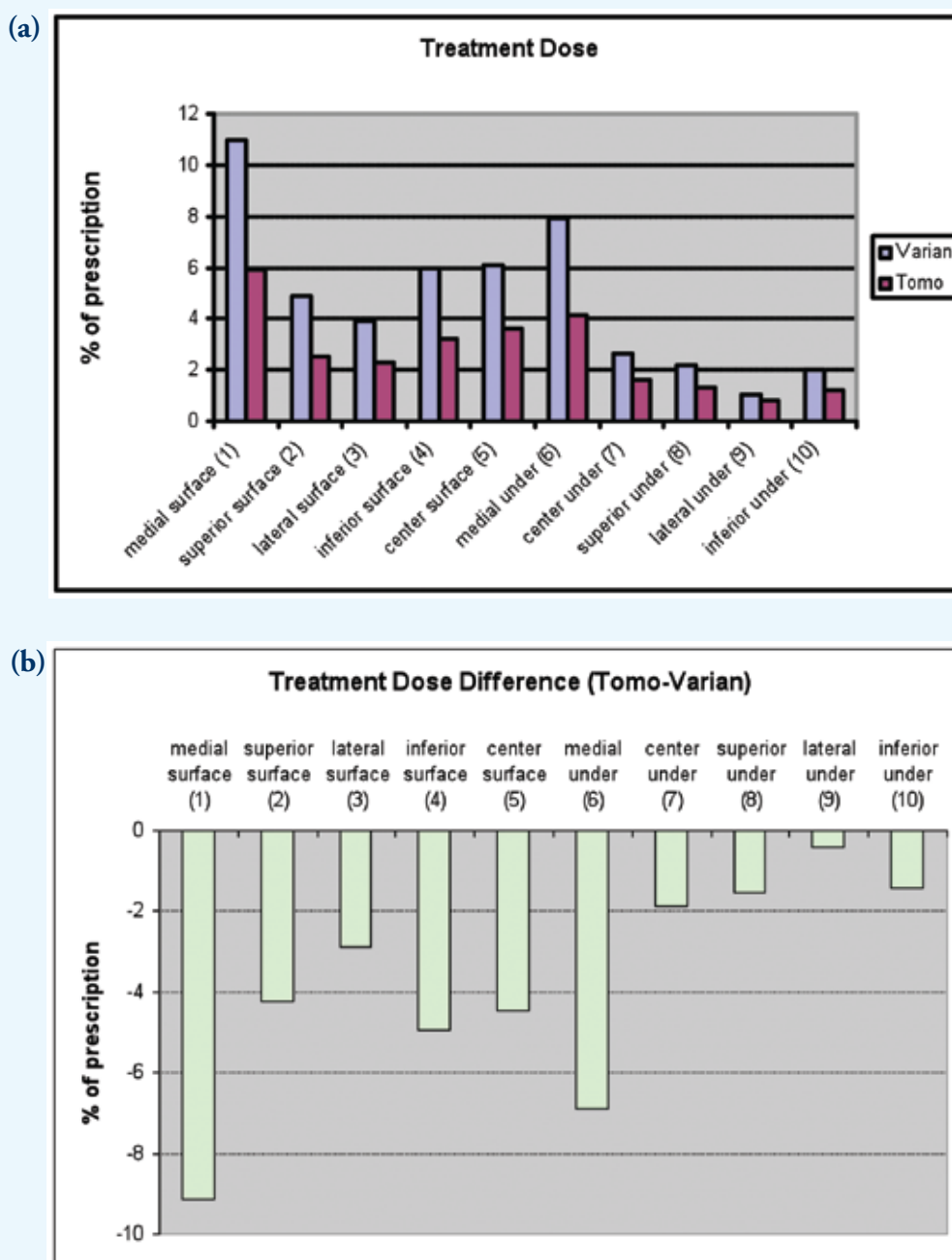


Figure 6. (a) Treatment dose as a percentage of prescription dose for each detector position; (b) the data in (a) represented as a percentage difference relative to the prescription dose.

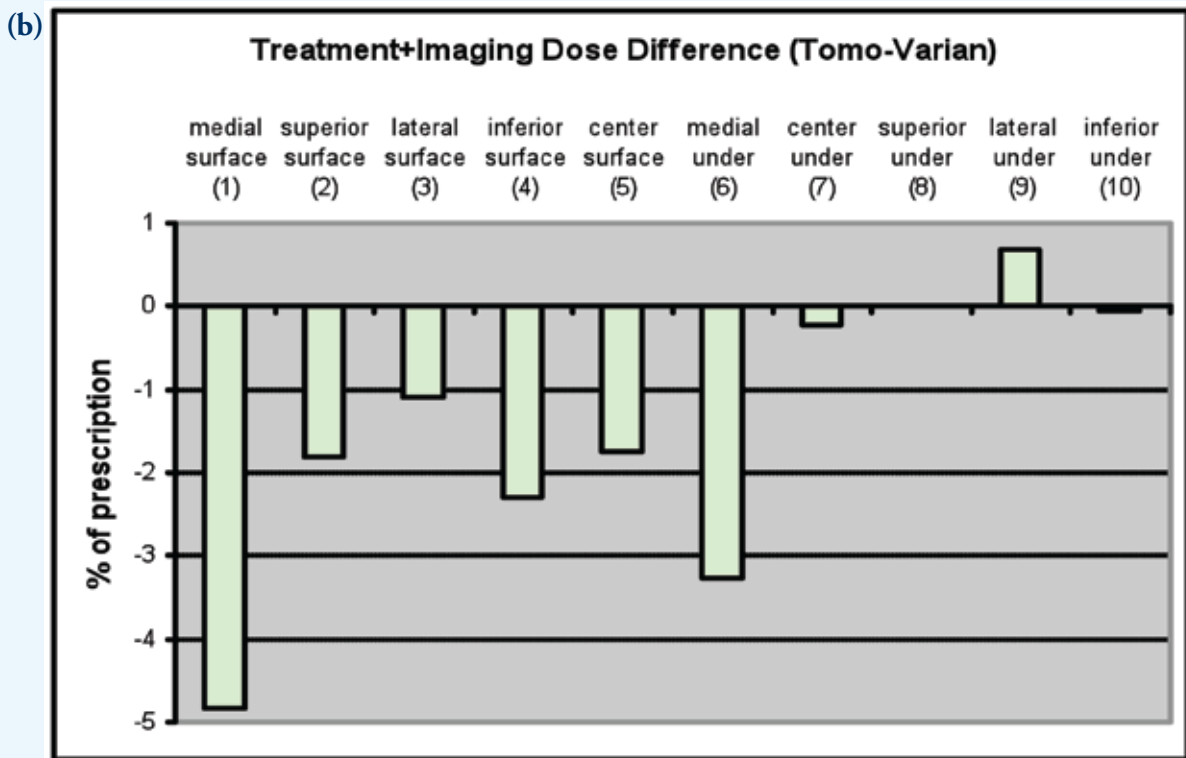
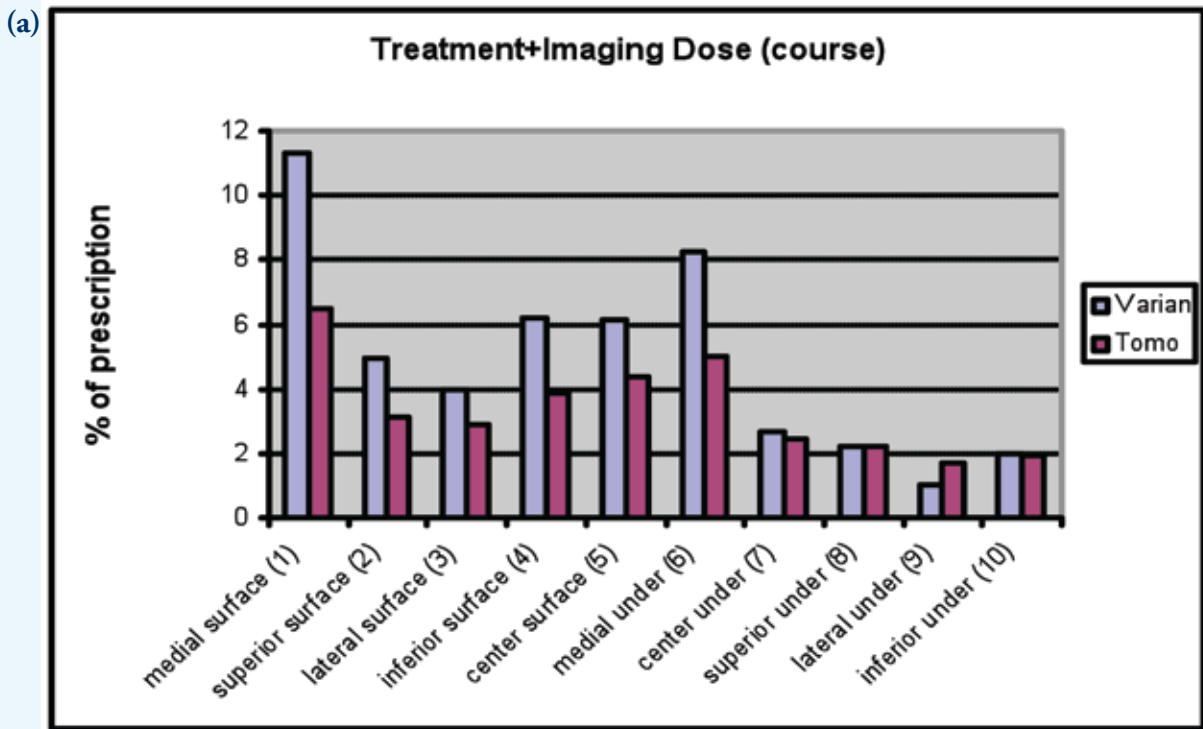


Figure 7(a) Combined treatment and imaging dose as a percentage of prescription dose for each detector position; (b) the data in (a) represented as a percentage difference relative to the prescription dose.

Finally, **Figure 8** shows the average dose data from Table 3. The contribution from treatment dose is clearly the most significant, making the influence of imaging dose on combined dose relatively small.

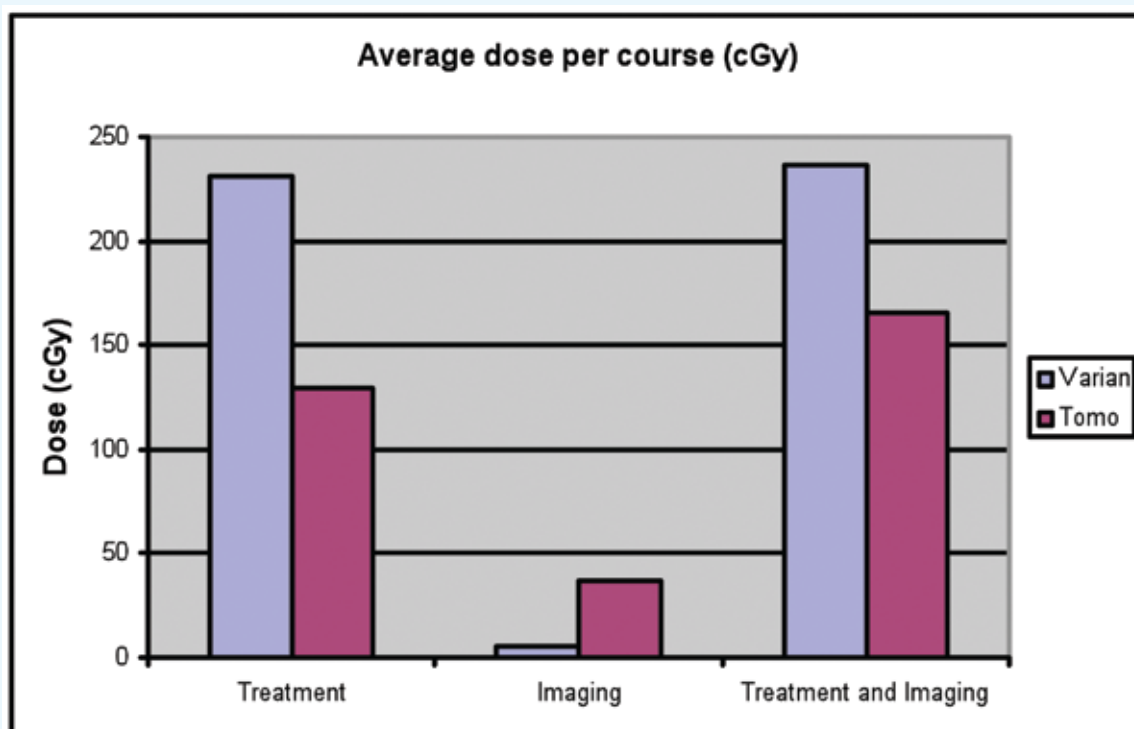


Figure 8. Average treatment, imaging and combined doses per course for each technique. The contribution from treatment dose is the most significant, making the influence of imaging dose on combined dose relatively small. Average Varian treatment dose is 79% higher than TomoTherapy treatment dose and average Varian combined dose is 43% higher than TomoTherapy treatment dose.

Conclusions

The *TomoDirect* treatment delivery technique incurs a relatively low contralateral breast dose. This is very pertinent given the usual practice of daily MVCT image guidance. The hypothesis being tested here – that a low contralateral breast dose due to treatment mitigates the dose incurred by daily imaging – appears to be confirmed. Average combined treatment and imaging dose is significantly less than for the conventional tangent technique used for comparison, which itself is designed to yield a low contralateral breast dose via omission of a wedge in the medial beam. It is notable that the proportional reduction in treatment dose compared to the Varian plan is similar across all detectors. This suggests that the relative dose distribution in the contralateral breast, for each technique, is similar.

This result is encouraging for the use of *TomoDirect* in whole breast irradiation. Further work should be carried out to investigate the potential benefits of beam configurations other than simple opposed tangents. For example, use of three closely-spaced tangents per side has been shown to have benefits in terms of target dose homogeneity and conformality as well as in reducing the maximum dose outside the PTV (ref 8). In that work, treatment dose on the surface of the contralateral breast was found to be similar with two and six tangents. Given the dominance of treatment dose over imaging dose found in the current study, it is worthwhile investigating how this component can be minimized via treatment beam configuration while maintaining or improving quality of the dose distribution inside and outside of the PTV.

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