Irregular surface compensation for radiotherapy of the breast: correlating depth of the compensation surface with breast size and resultant dose distribution

D J EMMENS, MSc, MIPEM and H V JAMES, MSc, MIPEM

Department of Radiotherapy Physics, The Ipswich Hospital NHS Trust, Heath Road, Ipswich, Suffolk IP4 5PD, UK

ABSTRACT. Irregular surface compensation uses dynamic multileaf collimators to modify the fluence to an irregular surface along the cranio-caudal axis. The depth of the compensation surface can be varied by specifying a user-defined parameter called the transmission penetration depth (TPD). In our institution, a review has been carried out of 60 breast patients treated using irregular surface compensation of the tangent fields. The effect of changes in the TPD on the dose distribution was investigated, and the optimum TPD was correlated with the maximum field separation ($S_{\max}$) along the posterior border. Reducing the TPD below 50% pushes the dose towards the front of the breast. This reduces hot spots at the medial and lateral regions next to the posterior border of the tangential fields, particularly for patients with large separation. In 23/60 patients, with a mean $S_{\max}$ of 23.9 ± 1.6 cm, a TPD between 35% and 45% was used to reduce the proportion of the planning target volume receiving more than 107% of the prescribed dose by $3.4\% \pm 2.8\%$. Our department protocol states that, subject to an acceptable dose distribution, a TPD of 40% is used if $S_{\max}$ is greater than 24 cm; for smaller separations, a TPD of 50% is used.

Received 30 March 2009

Revised 5 June 2009

Accepted 11 June 2009

DOI: 10.1259/bjr/65264916

© 2010 The British Institute of Radiology

It has been shown that dose-based compensation can improve dose homogeneity within the breast compared with standard wedged deliveries [1–12]. Minimising dose inhomogeneities can reduce late adverse effects such as changes in breast cosmesis, induration and acute toxicity [13–15], particularly in women with large breasts, for whom inferior cosmetic outcomes using the standard wedged technique have been reported [16, 17].

One approach is electronic compensation of the tangent fields [9–12, 18]. In this technique, dynamic multileaf collimators (MLCs) vary the fluence across each field to deliver a homogeneous dose to a compensation surface defined along the cranio-caudal axis.

Our institution has been using electronic compensation in radiotherapy of the breast since December 2001. Initially, plans were created using the CADPlan treatment planning system (TPS) (Varian Medical Systems, Palo Alto, CA), defining the compensation surface by the midpoint of the beamlets intersecting the treatment volume. In 2005, the irregular surface compensation algorithm (ISCOMP) on the Eclipse TPS (Varian Medical Systems) was commissioned. The ISCOMP algorithm allows the depth of the compensation plane for each of the tangent fields to be varied, providing an additional degree of optimisation to the user.

This study describes how irregular surface compensation has been implemented in our radiotherapy department. A planning study investigated how changes in the depth of the compensation plane affect the coverage of

the planning target volume (PTV) and dose homogeneity. The optimum compensation depth was correlated with the patients' breast size.

Methods and materials

Between September 2005 and May 2007, 77 patients were treated with radiotherapy of the breast using Eclipse irregular surface compensation (algorithm dose volume optimiser (DVO); version 7.5143, 7.518 or 8.03). All plans underwent pre-treatment quality assurance (QA) to verify the fluences delivered. To minimise this additional workload, the patients selected for this technique were limited to those requiring cardiac shielding or for whom a conventional wedged-pair did not produce an acceptable plan.

Patient localisation and beam positioning followed our standard department protocol for breast treatments. Patients underwent a CT scan (with 0.5 cm slice width) and were localised on an angled breast board with both arms abducted to the level of the sternum. Standard tangential fields with non-divergent posterior borders were applied using AdvantageSim (GE Healthcare, Chalfont St. Giles, Buckinghamshire, UK) virtual simulation software. Field sizes, gantry angles and isocentre positions were selected to cover the whole of the breast tissue, allowing no more than 2 cm of lung in the beam's-eye view (BEV). The risk of radiation pneumonitis is low using this technique [19] and our maximum lung depth is similar to that adopted in other centres [6, 9, 18]. Collimator twists of up to 10° were applied to ensure that the volume of lung irradiated was uniform. A field-based

Address correspondence to: D J Emmens, Department of Radiotherapy Physics, The Ipswich Hospital NHS Trust, Heath Road, Ipswich, Suffolk IP4 5PD, UK. E-mail: daniel.emmens@nhs.net

PTV was generated automatically by the software for dose-reporting purposes by contouring a volume 0.5 cm inside the body contour, 1 cm inside the posterior field border and 1.5 cm inside the superior and inferior field borders. All plans were treated with either 6 MV or a dual-energy combination of 6 MV and 18 MV weighted in the ratio 2:1, resulting in nominal 10 MV beams. Dose was calculated on the Varian Eclipse external beam TPS with pencil beam convolution (algorithm PBC; version 7.5143, 7.518 or 8.03) and a dose calculation grid size of $0.25 \times 0.25 \times 0.5 \text{ cm}^3$. Dose was normalised to a reference point defined by the Standardisation of Breast Radiotherapy (START) trial protocol [20] or, if necessary, to the mean dose to the PTV.

Beam fluences were optimised to deliver a homogeneous dose to an irregular compensation surface along the cranio-caudal axis. The compensation surface for each field intersects the individual beamlets at a user-specified transmission penetration depth (TPD), defined as a percentage of the geometric path length of the beamlet through the patient. Thus, a TPD of 50% defines the midpoint of each beamlet; reducing the TPD moves the compensation plane closer to the surface of the breast. In each plan, the compensation surfaces for the lateral and medial fields had the same TPD. When optimising the plans, the TPD was varied to achieve pre-defined dose constraints of: (i) 95% of the PTV receiving at least 95% of the prescribed dose ($\text{PTV}_{95\%} > 95\%$), as recommended by the International Commission on Radiation Units and Measurements (ICRU) Report 50 [21]; (ii) no more than 3% of the PTV receiving more than 107% of the prescribed dose ($\text{PTV}_{107\%} < 3\%$); and (iii) no more than 2 cm^3 of the body receiving more than 110% of the prescribed dose ($\text{Body}_{110\%} < 2 \text{ cm}^3$).

To compensate for potential underdosing owing to respiratory motion, a skin flash was performed by

extending the fluence 15 mm beyond the body surface. Cardiac shielding was achieved by setting the fluence to zero over the projection of the heart in the BEV. For patients in whom there was significant overlap between the heart and the PTV, the cardiac shielding rendered it impossible to achieve 95% coverage of the PTV for any TPD. In these cases, the decision whether to accept the planned dose distribution relied on the judgement of the planning and clinical staff, based on the position of the tumour bed.

Individual patient fluences were verified before treatment using the amorphous silicon electronic portal imaging device and Varian Eclipse Portal Dosimetry Prediction software tool, which has been described previously in the literature [22]. The predicted and measured fluences were analysed using a gamma analysis tool [23, 24], with the acceptance criterion that 95% of pixels were to be within a distance to an agreement of 3% or 2 mm using a minimum dose threshold of 5%.

Varying the transmission penetration depth

A retrospective review was carried out to assess how the transmission penetration depth affects the dose distribution and how the optimum TPD correlates with breast size. This review was restricted to those patients (60/77) for whom cardiac shielding had not compromised the PTV coverage. To eliminate any variations caused by different versions of Eclipse, all plans in this review were recalculated using version 8.03 of the PBC and DVO algorithms. For each patient, multiple plans were created using TPDs ranging from 50% to 25% in 5% increments. For each plan, $\text{PTV}_{95\%}$, $\text{PTV}_{107\%}$ and $\text{Body}_{110\%}$ were recorded. Breast size was recorded by

Figure 1. Maximum transmission penetration depth ($\leq 50\%$) required to achieve the dose-volume constraints as a function of field separation.

Figure 2. Proportion (%) of the planning target volume receiving greater than 95% of the prescribed dose (PTV_{95%}) as a function of the transmission penetration depth.

measuring the field separation ($S_{\max}$) along the posterior border on the transaxial slice, where this separation was largest.

Results

A total of 60 patients were replanned using varying TPDs. The mean $S_{\max}$ (± 1 standard deviation) was 21.9 ± 2.1 cm (range, 17.3–26.6 cm).

Figure 1 shows a negative correlation (Spearman's rank correlation = -0.781) between the maximum TPD ($\leq 50\%$) required to meet the dose–volume constraints and the maximum field separation. 23/60 patients required a TPD less than 50% and their mean $S_{\max}$ was 23.9 ± 1.6 cm (range, 20.1–26.6 cm). In 22 of these patients, the reduction in TPD was necessary to reduce the high dose volumes. There was one outlier with a below average $S_{\max}$ of 20.1 cm. In this patient, a 45% TPD was required to achieve 95% coverage of the PTV.

Table 1 shows the effect of using a shallower compensation surface for these 23 patients. With TPDs ranging from 35% to 45%, PTV_{107%} was reduced by $3.4\% \pm 2.8\%$ compared with the dose distribution using a compensation surface at the depth of mid-separation (TPD = 50%). Body_{110%} was reduced by 20.2 ± 24.0 cm³ and there was only a small change in PTV_{95%} ($-0.4\% \pm 1.7\%$).

Figures 2 and 3 show how PTV_{95%} and PTV_{107%} varied with TPD for three patients. Figures 4 and 5 show how the dose distribution in the transverse and sagittal planes varied with the depth of the compensation plane. When TPD = 50% (Figure 4a), the hot spots were located in the medial and lateral regions next to the posterior field border. As the TPD decreased, these hot spots reduced in size and magnitude (Figure 4b) and eventually shift anteriorly towards the apex of the breast (Figure 4c). The

net result was that decreasing the TPD below 50% reduced PTV_{107%} until it reached a minimum. At this point, further decreases in TPD will enlarge PTV_{107%} as the anterior hot spots increase (Figure 4d). This is shown quantitatively in Figure 3.

The sagittal views (Figure 5) show that, as the TPD is decreased, the dose is effectively concentrated at the apex of the breast. Consequently, for very low TPDs (Figure 5c), there is a loss of PTV coverage by the 95% isodose. This is shown quantitatively in Figure 2.

Number of monitor units

Out of the 23 patients who required a TPD less than 50%, the mean change (relative to TPD = 50%) in the number of monitor units (MU) per 2 Gy fraction was -1 ± 11 MU for the lateral field and -1 ± 8 MU for the medial field.

Portal dose prediction

A total of 156 fields were delivered clinically. When using portal dose prediction to verify the fluence, 154 fields had at least 95% of their pixels within a distance to agreement of 3% and 2 mm. All fields had at least 95% of the pixels within 5% and 2 mm.

Discussion

Irregular surface compensation is patient shape specific and missing tissue can be compensated on a beamlet by beamlet basis along the cranio-caudal axis. By modulating the fluence to give a uniform dose on a curved

Figure 3. Proportion (%) of planning target volume receiving greater than 107% of the prescribed dose (PTV_{107%}) as a function of the transmission penetration depth.

surface, it is possible to deliver a more homogeneous dose to the breast compared with standard wedged tangent fields. Chui et al [9] used this technique to reduce by 3% the isodose level encompassing 5% of the PTV. In their paper, they defined the compensation surface by the midpoint of each pencil beam segment through the breast. In this work, we extend this concept by examining how changing the position of the compensation surface can be used to modify the dose distribution.

The depth of the compensation surface is specified by the TPD, expressed as a percentage of the geometric path length of the beamlet through the patient. As the TPD is decreased from 50%, the dose moves anteriorly towards the front of the breast, reducing the size and magnitude of hot spots in the medial and lateral regions next to the posterior field border.

These results can be explained by considering the transaxial slice in Figure 6. Compensation surfaces for a diverging tangential beam, represented by beamlets A and B, are shown for two TPDs. The shape of the surface takes into account the asymmetric breast contour. To deliver a homogeneous dose to this surface, the fluence will be larger at the posterior field border (beamlet A) than at the anterior border (beamlet B) because of the difference in geometric path length ($a-b$) from beam entry to the compensation plane. Decreasing the TPD will move the compensation plane closer to the skin, such that $(a_1 - b_1) < (a_0 - b_0)$. This reduces the variation in fluence across the field, and the dose at the apex of the breast relative to the chest wall will be increased.

This effect is advantageous for patients with large field separations. Figure 1 indicates that, for patients with $S_{\max}$ greater than 24 cm, a TPD of 40% is appropriate. In these patients, the path length a is large, with the resulting fluences causing larger hot spots in the medial

and lateral regions next to the posterior border. It is desirable to reduce these dose inhomogeneities as they are related to late radiation-induced changes in breast appearance and the development of palpable induration. In a clinical trial reported by Donovan et al [15], patients were randomised into a standard two-dimensional (2D) wedged plan or three-dimensional (3D) intensity-modulated radiotherapy (IMRT) using multiple static fields. Those receiving the 2D plan were 1.7 times ($p=0.008$) more likely to have late changes in breast appearance, and this was significantly associated with the presence of regions receiving doses greater than 105%.

It is important to note that, by changing the TPD, there is often a compromise between minimising the maximum dose and maintaining PTV coverage. It is unlikely to be beneficial to use a TPD much less than 35–40% without reducing below 95% the volume of PTV receiving greater than 95% of the prescribed dose. However, there may be instances when pushing the 95% isodose forward can improve the PTV coverage anteriorly without compromise elsewhere, provided that the change in TPD is small enough. This is the reason for the outlier in Figure 1, for whom the TPD was reduced to 45% to satisfy the minimum dose constraints to the PTV. Cases like these demonstrate that, although field separation is a good indication of an appropriate choice of TPD, the final dose distribution will always depend on the full 3D outline of the patient.

Dose compensation by way of the irregular surface compensator is ideal for patients who require cardiac shielding, as this can be achieved by nullifying the fluence over the heart in the BEV. It also reduces dose to the lung and contralateral breast compared with conventional wedged plans, owing to reduced fluence through low-density tissue and a reduction in scatter [9].

Figure 4. Dose distributions on the central axial slice for different transmission penetration depths (TPDs). The planning target volume is shown in blue. Isodoses shown are 95% (green), 100% (yellow), 105% (orange) and 110% (red). (a) TPD = 50%; (b) TPD = 40%; (c) TPD = 35%; and (d) TPD = 25%.

For 14 patients, the cardiac shielding made it impossible to achieve 95% of the PTV receiving 95% of the prescribed dose. It is important to note that the PTV in

this study is defined from the posterior field border and the body contour, and does not adhere to the definition quoted in ICRU Report 50 [20]. This approach reduces

Table 1. Difference in PTV coverage and dose homogeneity, relative to TPD = 50%, when a TPD less than 50% is used. Results are shown for patients in whom TPD = 50% did not meet the dose constraints

TPD (%)	n	$\Delta\text{PTV}_{95\%}$ (%), (mean $\pm$ SD)	$\Delta\text{PTV}_{107\%}$ (%) (mean $\pm$ SD)	$\Delta\text{Body}_{110\%}$ (cm ³) (mean $\pm$ SD)
44–45	12	0.2 $\pm$ 1.2	−1.8 $\pm$ 1.0	−4.6 $\pm$ 3.8
40	9	−0.5 $\pm$ 1.8	−4.1 $\pm$ 2.3	−29.3 $\pm$ 19.0
35	2	−3.4 $\pm$ 0.9	−9.9 $\pm$ 1.8	−72.8 $\pm$ 21.5
All	23	−0.4 $\pm$ 1.7	−3.4 $\pm$ 2.8	−20.2 $\pm$ 24.0

n, number of patients; PTV, planning target volume; SD, standard deviation; TPD, transmission penetration depth; $\Delta\text{PTV}_{95\%}$, change in volume of planning target volume receiving greater than 95% of the prescribed dose; $\Delta\text{PTV}_{107\%}$, change in volume of planning target volume receiving greater than 107% of the prescribed dose; $\Delta\text{Body}_{110\%}$, change in volume of body receiving greater than 110% of the prescribed dose.

Figure 5. Dose distributions on a sagittal slice for different transmission penetration depths (TPDs). The planning target volume is shown in blue. Isodoses shown are 95% (green), 100% (yellow), 105% (orange) and 110% (red). (a) TPD = 50%; (b) TPD = 35%; and (c) TPD = 25%.

the workload on the clinical oncologist but still allows a means by which dose to the breast can be reported and dose distributions compared. The definition is obviously limited in cases in which the heart overlaps the PTV but, in these instances, knowledge of the position of the tumour bed and the clinical oncologist's judgement determine whether the PTV coverage is acceptable.

The experience gained of irregular surface compensation reported in this study has instructed the development of a department protocol for this technique. Irregular surface compensation is used as an alternative to wedged fields in which cardiac shielding is required or it offers improved homogeneity. Patients who have maximum field separations along the posterior border that are smaller than 24 cm are planned using a TPD of 50%. For separations larger than 24 cm, a TPD of 40% is

used. If the dose constraints cannot be met, then the depth will be adjusted accordingly, guided by knowledge of how the penetration depth affects the dose distribution. These changes can be implemented with only a small change in monitor units. The majority of patients are treated with 6 MV but the technique has been implemented for dual energies, equivalent to 10 MV, for unusually large patients.

Planning times may be 5–10 min longer for irregular surface compensation compared with standard wedged tangents to allow for the planner to apply a skin flash and erase the fluence over the heart. Plans undergo QA of the fluence delivery using portal dose prediction. Completion of this process takes an additional 20 min per patient, but this can be reduced by batching several patients in one QA session. The additional resource

Figure 6. Transaxial slice of an asymmetric breast showing the irregular compensation surface (red) for a diverging tangential field, represented by beamlets A and B. TPD, transmission penetration depth.

overheads for this technique have been managed in the department with relative ease and are felt to be justified given the potential benefits to the patient.

Conclusions

The Eclipse irregular surface compensation algorithm is used in our institution for all breast patients requiring cardiac shielding. The position of the compensation surface is defined by a transmission penetration depth. The TPD required to achieve 95% coverage of the PTV and reduce the high dose volumes depends on the size of the patient based on the maximum field separation along the posterior border. Larger separations require smaller penetration depths. Based on these findings, our department protocol states that, subject to acceptable dose distributions, a TPD of 40% is used if the maximum field separation is greater than 24 cm. For smaller separations, a TPD of 50% is used.

References

1. Aref A, Thornton D, Youssef E, He T, Tekyi-Mensah S, Denton L, et al. Dosimetric improvements following 3D planning of tangential breast irradiation. *Int J Radiat Oncol Biol Phys* 2000;48:1569–74.
2. Carruthers LJ, Redpath AT, Kunkler IH. The use of compensators to optimise the three dimensional dose distribution in radiotherapy of the intact breast. *Radiother Oncol* 1999;50:291–300.
3. Donovan EM, Johnson U, Shentall G, Evans PM, Neal AJ, Yarnold JR. Evaluation of compensation in breast radiotherapy: a planning study using multiple static fields. *Int J Radiat Oncol Biol Phys* 2000;46:671–79.
4. Evans PM, Donovan EM, Partridge M, Childs PJ, Convery DJ, Eagle S, et al. The delivery of intensity modulated radiotherapy to the breast using multiple static fields. *Radiother Oncol* 2000;57:79–89.
5. Lo Y-C, Yasuda G, Fitzgerald TJ, Urie MM. Intensity modulation for breast treatment using static multi-leaf collimators. *Int J Radiat Oncol Biol Phys* 2000;46:187–94.
6. Kestin LL, Sharpe MB, Frazier RC, Vicini FA, Yan D, Matter RC, et al. Intensity modulation to improve dose uniformity with tangential breast radiotherapy: initial clinical experience. *Int J Radiat Oncol Biol Phys* 2000;48:1559–68.
7. Van Asselen B, Raaijmakers CPJ, Hofman P, Lagendijk JJW. An improved breast irradiation technique using three-dimensional geometrical information and intensity modulation. *Radiother Oncol* 2001;58:341–7.
8. Hong L, Hunt M, Chui C, Spirou S, Forster K, Lee H, et al. Intensity-modulated tangential beam irradiation of the intact breast. *Int J Radiat Oncol Biol Phys* 1999;44:1155–64.
9. Chui C-S, Hong L, Hunt M. A simplified intensity modulated radiation therapy technique for the breast. *Med Phys* 2002;29:522–9.
10. James HV, Poynter AJ, Crosbie JC, MacKenzie LC, Boston SL, LeVay J. Electronic compensation for CT planned breast treatments. *Radiother Oncol* 2002;64:S133–4.
11. LeVay JH, James HV, Poynter AJ, MacKenzie LC, Boston SL. Optimising the delivery of radiotherapy for early breast cancer by the use of IMRT. *Clin Oncol* 2003;15:S14.
12. James HV, Scrase CD, Poynter AJ. Practical experience with intensity-modulated radiotherapy. *Br J Radiol* 2004;77:3–14.
13. Taylor ME, Perez CA, Halverson KJ, Kuske RR, Philpott GW, Garcia DM, et al. Factors influencing cosmetic results after conservation therapy for breast cancer. *Int J Radiat Oncol Biol Phys* 1995;31:753–64.
14. Vicini FA, Sharpe M, Kestin L, Martinez A, Mitchell CK, Wallace MF, et al. Optimizing breast cancer treatment efficacy with intensity-modulated radiotherapy. *Int J Radiat Oncol Biol Phys* 2002;54:1336–44.
15. Donovan E, Bleakley N, Denholm E, Evans P, Gothard L, Hanson J, et al. Randomised trial of standard 2D radiotherapy (RT) versus intensity modulated radiotherapy (IMRT) in patients prescribed breast radiotherapy. *Radiother Oncol* 2007;82:254–64.
16. Gray JR, McCormick B, Cox L, Yahalom J. Primary breast irradiation in large-breasted or heavy women: analysis of cosmetic outcome. *Int J Radiat Oncol Biol Phys* 1991;21:347–54.
17. Moody AM, Mayles WPM, Bliss JM, A'Hern RP, Owen JR, Regan J, et al. The influence of breast size on late radiation effects and association with radiotherapy dose inhomogeneity. *Radiother Oncol* 1994;33:106–12.
18. Caudell JJ, De Los Santos JF, Keene KS, Fiveash JB, Wang W, Carlisle JD, et al. A dosimetric comparison of electronic compensation, conventional intensity modulated radiotherapy, and tomotherapy in patients with early-stage carcinoma of the left breast. *Int J Radiat Oncol Biol Phys* 2007;68:1505–11.
19. Lingos TI, Recht A, Vicini F, Abner A, Silver B, Harris JR. Radiation pneumonitis in breast cancer patients treated with conservative surgery and radiation therapy. *Int J Radiat Oncol Biol Phys* 1991;21:355–60.
20. START Trial Management Group. Standardisation of Breast Radiotherapy (START). A randomised comparison of fractionation regimens after local excision or mastectomy in women with early stage breast cancer. Final Protocol – July 1998. London: The Institute of Cancer Research, 1998.
21. International Commission on Radiation Units and Measurements. ICRU Report 50. Prescribing, Recording and Reporting Photon Beam Therapy. Bethesda, MD: ICRU, 1993.
22. Van Esch A, Depuydt T, Huyskens DP. The use of an aSi-based EPID for routine absolute dosimetric pre-treatment verification of dynamic IMRT fields. *Radiother Oncol* 2004;71:223–34.
23. Low DA, Harms WB, Mutic S, Purdy JA. A technique for the quantitative evaluation of dose distributions. *Med Phys* 1998;25:656–61.
24. Depuydt T, Van Esch A, Huyskens DP. A quantitative evaluation of IMRT dose distributions: refinement and clinical assessment of the gamma evaluation. *Radiother Oncol* 2002;62:309–19.