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Comparison of CT-volumed supraclavicular fossa radiotherapy planning and conventional simulator-planned defined by bony landmarks for early breast cancer☆

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ABSTRACT

Aim: A comparison of techniques, CT planning of the supraclavicular fossa and field based simulation. We highlight CT planned SCF radiotherapy which would be useful for a centre introducing the technique.

Background: Development of radiotherapy technique includes a move from field-based simulation to CT planning.

Materials and methods: We conducted a retrospective review of the first 50 patients receiving radiotherapy according to the 3D CT planning protocol. Production of the previous field based technique, by virtual simulation methods on the same 50 patient CT data sets allowed both techniques to be compared for beam energy, field size, planning target volume (PTV) minimum and maximum, mean doses, depth dose normalisation, V40% lung volume and brachial plexus.

Results: 88% CT-volumed plans received mean dose within ICRU recommended limits compared with only 8% using previous conventional technique. 76% required 10 MV to improve coverage and one patient (2%) an opposed posterior field. The mean normalisation depth was 4.5 cm (range 1.9–7.7 cm) compared with pre-set 3 cm of the conventional technique. With CT-volumed technique the whole lung volume exposed to V40%, including the tangential fields, reduced from 10.79% to 9.64% ($p < 0.001$) but the mean maximum brachial plexus dose increased from 48.9 Gy to 51.6 Gy ($p < 0.001$).

Conclusions: Dose coverage of the SCF PTV was greatly improved for plans produced from 3DCT volumes compared to field based techniques.

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☆ The work was carried out at the Royal Stoke University Hospital.

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1. Background

Breast cancer is a common condition with the lifetime risk of developing breast cancer for women in the United Kingdom (UK) calculated as 1 in 9. In 2007 there were 50,286 (44,782 invasive) new cases of breast cancer diagnosed in the UK of which over 99% were women.[1] The majority of these cases are early breast cancer. The loco-regional management consists of surgery and radiotherapy. Radiotherapy is given to the breast/chest wall and also to nodal drainage areas in selected cases, particularly the SCF.

Radiotherapy to the SCF has generally been given when four or more axillary lymph nodes are positive on axillary node clearance[2] and is established as reducing local recurrence and the risk of metastases.[3,4] The EBCTCG meta-analysis of individual patient data of 1314 patients with 1–3 positive nodes following mastectomy and axillary dissection showed an advantage for radiotherapy to the chest wall and regional lymph nodes[5] and the indications for SCF radiotherapy are increasing. The morbidity from conventionally fractionated radiotherapy is low,[6] with the addition of nodal radiotherapy it is important to anticipate the small increase in risk for pneumonitis, lymphoedema and brachial plexus injury.

UK radiotherapy centres were audited[7] about their supraclavicular techniques and indications for use in 1999. Landau and Laing reported that 10% indicated no routine use of SCF radiotherapy, 15% used it for all node-positive patients and 75% were guided by the pattern of axillary nodal involvement. In 2009 in our department we treated the SCF of 71 breast cancer patients, 25 (35.2%) also had axillary radiotherapy. 90% of centres in the UK in 1999 were treating with a single anterior field of which one-third routinely angled away from the spinal cord.[7]

Adjuvant radiation used to be delivered to the breast and SCF at our hospital using a conventional technique which consisted of planned isocentric tangential fields to the breast and a direct field to the SCF. We had the concern that conventional planning might lead to inadequate coverage of the SCF. By December 2005 confidence in 3D conformal techniques in our department for other cancer types had grown to the extent that it was decided to take a similar approach for breast cancer patients. Initially this approach was used for the breast, then the chest wall and finally the nodal drainage areas. Some patients have level 3 of the axilla irradiated in addition to the SCF, either because a level 2 clearance was performed or the surgical changes are only noted up to level 2 on the CT-planning scan. For this study we decided to evaluate those having the SCF irradiated as the only nodal drainage area.

2. Aim

This study aims to evaluate the dosimetric differences between the direct field approach to SCF planning and dose distributions produced from a CT-planned volume.

3. Materials and methods

A consecutive cohort of 50 patients was identified retrospectively from the initial patients receiving 3D treatment planning to the SCF (all patients also had breast or chest wall radiotherapy using 3D planning) in accordance with the new protocol. Patients receiving axillary radiotherapy in addition were excluded. A retrospective detailed comparison of both techniques was undertaken by comparing two plans for each patient. The first plan was the actual treatment plan produced according to the new protocol and the second plan was generated using virtual simulation on the acquired CT volume data sets using our previous planning parameters. The new planning protocol required that both breast/chest wall and SCF CTVs/PTVs were delineated on the planning CT scan. Radiotherapy to the whole breast or chest wall was delivered using asymmetric, parallel opposed tangential fields half beam blocked to the lung edge (posterior). Radiotherapy planning was to conform to the requirements of ICRU50[8] regarding dose variation with the reference point, as defined by the START trial[9] half way between the lung surface and the skin surface on the perpendicular bisector of the posterior beam edge. The prescription was 50 Gy in 25 fractions over 5 weeks in 43 patients and 40 Gy in 15 fractions over 3 weeks (which is now the standard prescription for all our patients) in 7 patients. Compensation is made where hotspots greater than 107% occur using forward planned IMRT (field-in-field technique).

The CTV for the SCF is marked up according to the boundaries in Table 1. The PTV for the SCF is generated with margins from the CTV determined for the individual patient. For the majority of patients this is 1 cm superior and lateral and 0.5 cm medial margin. The inferior margin is usually nil inferiorly (unless there is a gap from the tangential fields allowing up to a 1 cm margin as in 9 patients) and up to 1 cm as anatomy allows on the other margins. The plan usually consists of an anterior isocentric field which may be angled if necessary to avoid treating the spinal cord. A posterior field is used if the separation is large or the SCF volume is particularly deep. Care

Table 1 – Supraclavicular fossa boundaries.

Margin	CT scan margins	Conventional
Superior	Up to but excluding the thyroid gland and cartilage	To allow at least a 1 cm corridor of skin
Anterior	Deep surface of sternocleidomastoid muscle and deep cervical fascia	Skin
Medial	Lateral edge of trachea	Lateral bony edge of the vertebrae
Posteromedial	Carotid artery and internal jugular vein	
Posterolateral	Anterior scalene muscle	Lateral 2/3 of the clavicle
Inferior	Subclavian artery	Inferior aspect of sternoclavicular joint

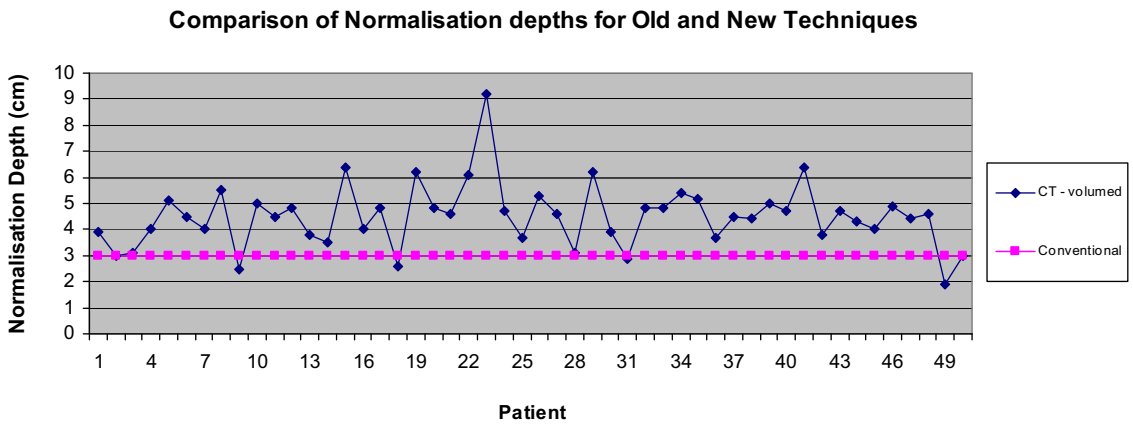

Fig. 1 – Comparison of normalisation depths for the conventional and CT volumed techniques.

is taken to avoid any overlap of the SCF fields onto the tangential fields of the breast and in most cases the intention will be to achieve a match plane at the junction. However, occasionally a slight overlap (1–2 mm) may be clinically necessary to give optimum dose coverage of the contoured target volumes. A non-divergent edge to the superior border of the tangential fields is ensured by applying corrections to gantry, collimator and couch angles to match the lower border of the SCF field which is half-beam blocked. The field shape is conformed to the PTV with multi-leaf collimators (MLCs).

The previous technique consisted of tangential fields to the whole breast half-beam blocked to the lung edge with a non-isocentric supraclavicular field (i.e. at fixed F.S.D. of 100 cms) half-beam blocked to the inferior edge. The SCF was identified using the anatomical boundaries as per Table 1. The dose for the supraclavicular field was calculated at a depth of 3 cm using depth dose charts at 100 cm F.S.D. for a 6 MV beam as standard and positioned with a calculated gap between the inferior edge of the supraclavicular field and the superior edge of the tangential fields. Treatment plans were generated using commercial software (Eclipse, version 7.2.34, Varian, Palo Alto, CA) for the previous technique. The SCF field was positioned without reference to the PTV of the CT-planned volume using soft tissue and bony landmark definition by the radiographers on our team. The virtually simulated field was positioned at 100 cm F.S.D. As a calculated gap would have been used, it was decided that the tangential fields would be shortened and a gap of 1 cm incorporated for this study. A dose distribution was then calculated for the SCF field and normalised to 3 cm deep as stated in the protocol. The tangential fields were re-calculated at their new field size.

Data recorded for the two plans included beam energy, field size, dose maximum, PTV dose maximum, PTV dose minimum, PTV mean dose, normalisation depth gantry angle and V40% lung. V20 is a quoted figure for 50 Gy in 25 F which is the volume of lung receiving 40% or more of the prescribed dose and to be consistent. V16 was assessed for the 40 Gy prescription patients. A paired *t*-test was used for all comparisons between treatment techniques. A p value ≤ 0.05 was used to indicate statistical significance. The brachial plexus was contoured with a 5 mm diameter paint tool using the technique as described by Hall et al.[10]

4. Results

The mean CTV volume for the SCF was found to be 48.2 cm^3 (range 19.7–74.4 cm^3). The mean PTV volume was found to be 100.3 cm^3 (range 49.5–161.5 cm^3). 76% of patients required a 10 MV plan to be generated to improve coverage of the SCF PTV. Gantry angles ranged from 0° to 25° with 16 (32%) patients having an angle of 0°. Only one patient required an opposing posterior field but 7 (14%) required a planned overlap with the breast fields and 3 (6%) needed a planned gap to achieve dose constraints. It takes an experienced planner or clinician approximately 5 minutes to outline the SCF CTV/PTV.

Fig. 1 illustrates the variation in selected normalisation depths for the two groups. The mean for the CT-volumed was 4.5 cm (range 1.9–7.7 cm). The previous technique had this preset as 3 cm. In spite of the fact that increased field sizes were often needed to cover the PTV in the new technique the use of MLCs meant that a reduction in the mean equivalent square for the SCF fields from 7.4 cm for the conventional technique to 6.67 cm in the new was seen, $p < 0.005$. The volume of the lung in percentage terms receiving V40% for both techniques included the contribution of the tangential fields. The V40% for the old technique is 10.79% and for the new it is 9.64%, this is significant $p < 0.001$.

Fig. 2A shows the mean dose delivered to the SCF PTV for the conventional technique with bars of one standard deviation. Only 4 (8%) patients received a dose which was within ICRU limits (95–107%). Analysis of the PTV coverage using the new technique shows a more homogeneous PTV coverage with 44 (88%) patients receiving a mean dose which was within the ICRU limits (Fig. 2B). The difference in the mean dose to the PTV between the techniques was found to be 2.9–7 Gy ($p < 0.01$). The average median dose for the new technique was 99.6% of the prescribed dose (standard deviation of 2.1) and 92.8% for the old technique (standard deviation of 8.2). The average minimum dose given to 50% of the PTV was 3.4 Gy higher in the new technique and the average minimum dose given to 95% of the PTV was 14 Gy higher. Examination of the high dose volumes or minimum dose given to 5% of the PTV showed an average increase of 3.7 Gy, Table 2 illustrates this in percentage terms.

Table 2 – Mean percentage dose and range given to 95%, 50% and 5% of the PTV.

	D95	D50	D5
Conventional technique	56.9 (3.7–98.1)	92.6 (79.8–125.2)	101.4 (82.2–131.1)
CT volumed technique	85.4 (39.4–96.2)	99.6 (95.1–104.4)	107 (103.2–115.4)

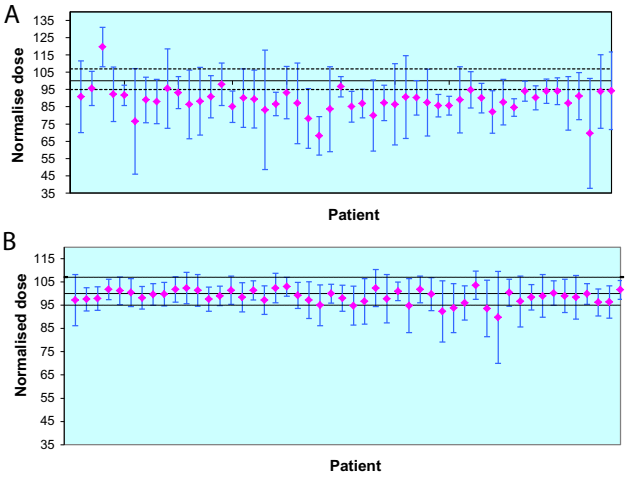

Fig. 2 – (A) Mean dose and bar of one standard deviation to SCF PTV conventional technique. (B) Mean dose and bar of one standard deviation to SCF PTV, CT volumed technique.

We determined the brachial plexus dose received by outlining this structure on all the plans. The mean depth below the skin of the brachial plexus in our cohort is 3.8 cm and the mean depth to the posterior edge of the volume is 6.8 cm. The mean dose to the brachial plexus on the conventional technique is 33.28 Gy and 34.81 Gy on the new, $p < 0.05$. The mean maximum dose is 48.9 Gy and 51.6 Gy on the conventional and new techniques respectively, $p < 0.001$.

5. Discussion

Adjuvant breast radiotherapy is undergoing considerable change. Much of it has been led from within the UK. Fractionation has often been the primary aspect tested such as with the START trial,[9] the NCRN FAST study[11] and currently the NCRN-NIHR HTA-funded FAST-Forward trial. Other aspects of breast radiotherapy are also being studied, the NCRN IMPORT LOW trial is investigating partial breast radiotherapy and the NCRN IMPORT HIGH trial is looking at concurrent boost with dose escalated intensity modulated radiotherapy (IMRT). The techniques used for adjuvant breast radiotherapy planning have developed as an integral aspect of these studies. FAST, for instance, included the requirement for an outlined breast and the option of CT planning. Development of the technique for British breast radiotherapy practice was considered an essential element in the planning stages of the FAST trial. IMPORT HIGH for many UK centres is the first introduction of IMRT into the breast practice. It seemed logical to include the nodal fields whilst developing our CT-voluming technique in Stoke. In the UK the nodal areas are treated with a field-based technique in the majority of centres, but that is about to change with the majority of centres intending to contribute to the FAST-Forward trial nodal sub-study. This trial is using the 2015-published ESTRO guidelines for definition of the nodal volumes.[12] We have adopted these guidelines entirely in our departmental nodal-outlining policy.

The practice of nodal radiotherapy for early breast cancer is increasing in many centres. Sentinel node biopsy is now standard practice and there is a move towards considering radiotherapy instead of further surgery for some lymph node positive patients. This is particularly in response to the EORTC 10891-22023 AMAROS trial showing very low recurrence rates in the axilla with radiotherapy and surgery.[13] The EORTC trial of supraclavicular fossa and internal mammary chain irradiation investigated 4004 patients including 1778 who were node negative.[14] They report that disease-free and distant disease-free survival were improved and breast-cancer mortality and there was a marginal effect on overall survival. The Canadian MA20 study reported on 1832 women who were node positive or high-risk node negative following conservative breast surgery and either an axillary dissection or sentinel-lymph-node biopsy.[15] They report that the addition of regional nodal irradiation did not improve overall survival but reduced the rate of breast-cancer recurrence.

We had developed the CT-voluming approach to radiotherapy for nodal irradiation in other areas initially, such as the lymphoma practice. Our technique development was deliberately progressive with a multidisciplinary review at all stages. As confidence grew the technique has been fully incorporated into our routine practice. A full review of the first 50 consecutive patients who received radiotherapy to the SCF only confirmed to us that this was best practice. In addition we use this technique for breast cancer patients having other nodal radiotherapy, such as SCF combined with axilla and also axilla alone. The CT planning is further enhanced because our breast surgeons often use axillary clips to demarcate the extent of surgery. It is therefore used for irradiating specific areas of the axilla as well as whole lymph node area.

The aim of the CT-volumed technique was to improve the dose homogeneity across the SCF PTV with a single field or with parallel opposed fields. The use of planning volumes meant that DVHs could be analysed in detail to compare the two techniques.

The new protocol allowed variation in gantry angle and beam energy. We have noted that in about 3 in 4 patients a higher energy than our standard 6 MV gives an improved dose due to the depth of the supraclavicular fossa. In this cohort one (2%) patient had an opposed posterior field to achieve a better dose distribution. Subsequent to this cohort of patients we have noticed that our use of opposed fields has increased with, for instance, 15 of the last 47 patients (32%) up until the end of 2011 requiring a posterior field. In 34 (68%) of the patients a gantry angle was used without compromising the SCF volume and allowing confidence that the spinal cord, for instance, had been avoided. Jephcott et al. looked at 4 techniques for regional radiotherapy to the axilla and SCF.[16] Whilst the focus

of their publication was different, it was noted that an anterior field employing 6 MV photons gave poor PTV coverage in 6 of 10 cases. Bentel et al. looked at 49 patients undergoing CT planned radiotherapy and found that the maximum depth of the SCF nodes ranged from 2.4 to 9.5 cm (median 4.3 cm),[17] similar to our mean of 4.5 cm. They found a relationship with the AP diameter of the patient and recommended considering a higher energy beam and/or an opposed posterior field. They also comment on the use of surgical clips which we have advocated. The CT-volumed technique showed that it was often necessary to change and usually increase the depth of the selected normalisation point from where it was in the centre of the volume depth-wise. The normalisation depth was previously set as 3 cm for all patients whereas reality was as deep as 7.7 cm in our cohort, whilst for a few patients it was more superficial than 3 cm. The difference in PTV coverage was significantly different when comparing the two techniques with an improvement in achieving ICRU limits (95–107%) from 8% to 88%. Madu et al. undertook a comparison of their traditional anterior field technique with a CT-volumed approach to the SCF and upper axilla defined as infraclavicular fossa in 20 patients (3 bilateral).[18] The conventional technique had also set the SCF depth as 3 cm and they noted that for SCF nodes the median maximum depth was 5 cm with a range of 3.9–8.3 cm.

Whilst it is noted, that toxicity may increase with the addition of nodal radiotherapy fields, the MA20 trial, which also included simultaneous treatment to the ipsilateral internal mammary nodes reported higher rates of grade 2 (CTC version 2.0) or greater toxicity when compared to whole breast radiotherapy alone, 1.2% vs. 0.2% for pneumonitits and 8.4% vs. 4.5% for lymphoedema.[15] Our new technique allows formal documentation and review of lung DVH's. With the CT-volumed technique the whole lung volume exposed to V40%, including the tangential fields, reduced from 10.79% to 9.64% ($p < 0.001$). Locally the new technique should not increase our current risk for the development of pneumonitis.

Given the concern for brachial plexus damage as an organ at risk, particularly as we suspected higher doses would be given to this structure, we looked at this aspect in detail. The dose to the brachial plexus takes into account not only the dose from radiotherapy to the SCF but also from the tangents whether the fields had a gap, abutted or a minimal overlap as reported. We are reassured that despite the mean prescription depth increasing, the brachial plexus mean dose received has only increased by 1.5 Gy (33.3–34.8 Gy) and the mean maximum dose by 2.7–51.6 Gy. Madu et al.[18] noted that the SCF depth was correlated with the brachial plexus depth. Further they did not detect a concern regarding doses received by the brachial plexus with regard to risks of damage even though like us higher doses are to be expected with better coverage of the SCF volume by the CT-volumed technique. Hall et al.[10] gave a mean maximum dose to the brachial plexus of 69.9 Gy (range 62.3–76.9 Gy) in 2 Gy fractions. This was considered an acceptable dose which gives no concern for the doses using our technique whether 15 or 25 fractions.

We have not looked at side effects formally for this study but we can report that none of this cohort of patients or any treated since in our department has had brachial plexus damage as a result of radiotherapy. 3 of our cohort of 50 patients have had SCF recurrence. One of these 3 patients had nerve-related pain with the recurrence but no loss of function. At 6–8 years from diagnosis 19 of 50 patients from this high risk group (as defined by nodal status) are deceased.

6. Conclusions

Dose coverage of the SCF PTV was greatly improved for plans produced from CT volumes. Dose to organs at risk such as brachial plexus and lung did not cause a concern. A CT-volumed technique is not standard practice in the majority of UK centres for the irradiation of the SCF in breast cancer patients. There is good reason to consider this as a development if a conventional simulator-based technique with a standardised depth prescription is the current standard. We therefore recommend that a CT-volumed technique is considered as standard practice for irradiation of the SCF in breast cancer patients.

Conflicts of interest

None declared.

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