The use of CT in radiotherapy treatment planning

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Summary

A prospective study is reported comparing conventional localisation with computed tomography (CT) localisation of tumours for radiotherapy treatment planning. One hundred and five out of 320 (33%) patients had an alteration in treatment plan and details are given according to the tumour site. CT planning enables more accurate localisation of both tumour and normal organs in addition to providing an accurate body contour and inhomogeneity corrections. Implications for integration of CT into radiotherapy planning practice are discussed and the impact of CT on treatment policy evaluated.

Introduction

The success of radiotherapy in the treatment of malignant disease is dependent upon administering a tumoricidal dose to the precise site and extent of a given tumour. Accurate localisation of the entire tumour is of vital importance if a geographical miss is to be avoided. Surrounding normal organs may limit the dose which can be given to the target volume by providing unacceptable morbidity. Precise delineation of both tumour and normal organs provides the possibility of giving a higher dose to a smaller volume with less normal tissue damage.

In preliminary reports [5,8] we discussed a prospective study for evaluating CT in radiotherapy treatment planning. This involved a direct comparison of the best available methods of conventional tumour localisation with that of CT localisation. The current communication presents the results for the total 320 patients included in the study according to tumour sites head and neck, thorax, abdomen and pelvis.

Method

The study was restricted to patients receiving radical radiotherapy. Three hundred and twenty patients had localisation of tumour and normal organs by conventional means and this was compared with CT localisation performed independently on an EMI 5005 general purpose scanner. Conventional localisation was carried out on a radiotherapy simulator with appropriate contrast media and orthogonal radiographs. It is clearly important that
CT is compared with optimum conventional methods or it will merely reflect the inadequacy of facilities employed. The CT localisation was done using all the available clinical and radiological data on the patient in addition to any new CT information gained from the scan.

Comparison was made between conventional localisation and CT localisation of both the tumour and its proposed treatment volume. This was carried out by the radiotherapist in the CT scanning unit in conjunction with the referring radiotherapist in order to ensure that each tumour had a similar margin making up the treatment volume. Coverage of the tumour was considered inadequate if there was either a direct geographical miss or the tumour extended up to the edge of the treatment volume when compared to CT localisation. The changes recorded were made by the referring radiotherapist as a result of the CT data to ensure adequate coverage of the tumour or to reduce the treatment volume to spare normal tissues.

Diagnostic CT scans are performed under suspended respiration for optimum quality and hence maximum diagnostic information. In contrast, radiotherapy patients receive treatment during quiet respiration as it is not feasible to suspend respiration for the duration of treatment. We scanned patients during suspended respiration and repeated the scans during quiet respiration and examined the difference in body contour at the centre of the treatment volume between the scans.

In addition, body contours were taken by conventional means with Plaster of Paris strips or flexible lead wire and compared with the CT body contour. Any discrepancy was recorded as outlined by the terms of reference above.

Results

Changes due to respiration

One hundred and thirty two patients underwent scanning in suspended and quiet respiration. Nineteen (14%) resulted in a 1 cm or greater change in outline and three (2.3%) had a significant change in mid-point tumour dose (MPD) of 5% or more (Table I). Two of these had abdominal tumours which were treated by an isocentric technique measured from an anterior skin tattoo. When the anterior skin surface moved with respiration the treatment volume moved anterior to the tumour. No significant changes in tumour dose were recorded in the pelvis with respiration. We conclude that, except in the abdomen, CT scanning for radiotherapy planning can be performed in suspended respiration, the body contour used for treatment planning and treatment given in quiet respiration. Abdominal scans should be repeated through the centre of the volume in suspended and quiet respiration and any discrepancy of 1 cm or greater noted. It is then preferable to use a planning technique with the isocentre measured from the posterior skin surface or lateral fields measured up from the couch.

Body contour

Two hundred and sixty one patients underwent a direct comparison of body contour as taken by conventional means and as defined by CT in the treatment position. Thirty nine (15%) had a discrepancy in outline, with six (2%) resulting in a significant change in MPD (Table II). The highest discrepancy was in the abdomen, with 11/38 (30%) of patients showing a difference in outline. The conventional outline in most cases failed to show a posterior air gap caused by an arched back. If the treatment plan involved a posterior field then the change in MPD became significant. Body outline on the CT planning system is performed rapidly and has the ad-

<table>
<thead>
<tr>
<th>Site</th>
<th>Total patients</th>
<th>Changes (\geq 1) cm</th>
<th>Significant change (\geq 5%) MPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thorax</td>
<td>94</td>
<td>13 (14%)</td>
<td>1 (1%)</td>
</tr>
<tr>
<td>Abdomen</td>
<td>38</td>
<td>6 (16%)</td>
<td>2 (5.2%)</td>
</tr>
<tr>
<td>Total</td>
<td>132</td>
<td>19 (14%)</td>
<td>3 (2.3%)</td>
</tr>
</tbody>
</table>
TABLE II
Comparison of body outline by conventional and CT methods.

<table>
<thead>
<tr>
<th>Site</th>
<th>Total patients</th>
<th>Change ≥ 1 cm</th>
<th>Significant change (≥ 5% MPD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thorax</td>
<td>94</td>
<td>13 (14%)</td>
<td>2 (2%)</td>
</tr>
<tr>
<td>Abdomen</td>
<td>38</td>
<td>11 (30%)</td>
<td>2 (5%)</td>
</tr>
<tr>
<td>Pelvis</td>
<td>129</td>
<td>15 (12%)</td>
<td>2 (2%)</td>
</tr>
<tr>
<td>Total</td>
<td>261</td>
<td>39 (15%)</td>
<td>6 (2%)</td>
</tr>
</tbody>
</table>

vantage of showing the complete contour. The CT scan must encompass the entire outline within the viewing aperture at the time of scanning and the patient must be in the treatment position for it to be accurately reproducible. These two requirements may not be met in a diagnostic scan where only part of the cross-section may be reconstructed and the patient’s position is different from that for radiotherapy treatment.

We consider that conventional means of producing outlines are satisfactory except in the abdomen. However CT is more accurate at all sites and is the method of choice provided that a CT scan is being taken for planning purposes.

Comparison of tumour localisation

Table III shows that 94 out of 320 (29%) patients had inadequate coverage of the tumour as localised using conventional methods. The advantages of CT localisation vary according to anatomical sites and these will be discussed in detail.

TABLE III
Conventional versus CT localisation (Royal Marsden Hospital).

<table>
<thead>
<tr>
<th>Site</th>
<th>Number</th>
<th>Inadequate tumour coverage</th>
<th>Total changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head and neck</td>
<td>28</td>
<td>5 (18%)</td>
<td>5 (18%)</td>
</tr>
<tr>
<td>Thorax</td>
<td>94</td>
<td>27 (29%)</td>
<td>28 (30%)</td>
</tr>
<tr>
<td>Abdomen</td>
<td>54</td>
<td>29 (54%)</td>
<td>36 (67%)</td>
</tr>
<tr>
<td>Pelvis</td>
<td>144</td>
<td>33 (23%)</td>
<td>36 (25%)</td>
</tr>
<tr>
<td>Total</td>
<td>320</td>
<td>94 (29%)</td>
<td>105 (33%)</td>
</tr>
</tbody>
</table>

Head and neck

Twenty eight patients with head and neck tumours have been scanned wearing their Perspex treatment cast fixed to the CT scanning couch. This necessitated designing a new head cast system to fit the treatment couch as it was considered essential to obtain the CT scan in exactly the same treatment position with the head fixed. The 28 cases included patients with nasopharyngeal, antral, orbital and ethmoidal tumours and CT led to five changes in treatment volume (18%). Although the CT scanner gave additional diagnostic information in many patients this did not always lead to a change in treatment volume. This reflects the practice of using large fields in many head and neck sites to encompass possible routes of spread and to give prophylactic treatment to adjacent lymph node areas. For instance, treatment for nasopharyngeal tumours often involves wide field irradiation of the primary site and bilateral lymph node drainage in the neck with large lateral fields. CT is unlikely to reveal spread outside these margins. However, one out of nine patients with nasopharyngeal tumours was found to have bone erosion of the skull base and two patients had extension of the soft tissue mass into the parapharyngeal space, all previously undetected.

In three of ten patients with antral tumours extension into the pterygo-palatine fossa was detected by CT having been previously undiagnosed. The posterior margin of the treatment volume had already been chosen to encompass up to the external auditory meatus in one of these patients but the remaining two patients had disease outside the treatment volume. This reflects the fact that for head and neck tumours the natural history of a particular tumour is of paramount importance in deciding on the treatment volume.

Thorax

Ninety four patients with intrathoracic tumours have been scanned. This group of patients presented a problem in positioning because of the limited aperture of the CT scanner. Arms were fully ex-
Fig. 1. Improved localisation of bronchogenic carcinoma by CT compared with conventional means. (a) Lateral chest film taken on simulator. Antero-posterior dimensions tumour not clear. (b) CT transverse section. Tumour clearly seen. Localisation of lungs for inhomogeneity correction easily performed.

The commonest inaccuracy was incorrect localisation in the antero-posterior dimension and this occurred in 12 out of 27 patients. This finding reflects the difficulty experienced by the clinician in interpreting the lateral chest X-ray (Fig. 1).

CT data was used to localise the lungs and provide quantitative density data for inhomogeneity corrections to the dose distribution. Correction can also be made for changes in density due to pleural effusion, consolidation, and atelectasis in the abnormal lung. For 50 patients with intrathoracic malignancy, comparison was made between the dose distribution with an uncorrected plan and a pixel by pixel CT-corrected plan [6]. The mean difference to mid point tumour dose was 10%, but 30% of these plans showed differences of between 12% and 19%. When the inhomogeneity correction was applied, the dose to normal lung and spinal cord was increased, and the uniformity of the dose distribution throughout the target volume was found to be worse. By planning with the use of inhomogeneity correction, it is possible to achieve improved dosimetric accuracy and a better dose distribution.

Abdomen

Sixty six patients with intra-abdominal tumours have been studied of whom 12 were excluded as the clinician had incorporated data from diagnostic CT scans when carrying out the conventional planning. This reflects the inadequacy of conventional radiological techniques for the examination of intra-abdominal structures, particularly the pancreas, and the obvious diagnostic gain from CT scanning. Of the 54 patients in the group studied 24 had carcinoma of the pancreas, 10 had retroperitoneal lymphadenopathy, 11 were receiving renal bed irradiation following nephrectomy for hypernephroma, 5 had retroperitoneal sarcomas and 4 had miscellaneous abdominal tumours. Inadequate tumour coverage by the proposed target volume, was found in 29/54 (54%) of patients and 36/54 (67%) had a change in treatment due to the CT data. The additional seven patients included two who had a change in management due to extensive disease...
shown by CT making the patients unsuitable for local radiotherapy. Four patients had a reduction in volume alone. One patient receiving renal bed irradiation had a change in planning technique to avoid the remaining kidney; this had been inaccurately localised and would have received an unacceptably high dose.

The position of normal structures is of critical importance in the abdomen where the kidneys and spinal cord are dose limiting normal organs in many treatment plans. Comparison of localisation of the kidneys by conventional means using intravenous contrast and CT localisation was made. It was found from the study that 24 out of 54 patients had received conventional localisation of the kidneys by the clinician. Thirteen had been correctly localised and 11 incorrectly localised when checked by CT. Figure 2 shows the localisation of the kidneys on a simulator film with intravenous contrast, in comparison to a CT cross-sectional display and illustrates the obvious advantage of CT. An analysis was made of the alteration in kidney dose which resulted from both a change in treatment volume due to inaccurate localisation of the tumour and from the correct localisation of the kidneys. It was found that 7 out of 24 patients (29%) had a reduction in dose to the kidneys due to the improved localisation using CT.

**Pelvis**

The overall improvement in accuracy of localisation for pelvic tumours is 25% (Table IV). Tumours in the pelvis may be treated initially with large pelvic fields and so the comparison was based on phase II small volume plans. Twelve out of 76 (16%) patients with bladder tumours had a change in treatment volume, this was due mainly to the CT scans revealing previously undiagnosed extravesicle soft tissue disease as illustrated in Fig. 3. The advantage gained by direct visualisation of the prostate gland together with evidence of seminal vesicle involvement is reflected in the 22% incidence of

![Fig. 2. Localisation of kidneys by conventional means and CT in a patient with carcinoma of the pancreas. (a) Intravenous contrast showing pyelogram on lateral simulator film. (b) CT transverse section showing kidney positions clearly.](image)

<table>
<thead>
<tr>
<th>Tumour</th>
<th>No. of patients</th>
<th>Total change in volume</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bladder</td>
<td>76</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>Prostate</td>
<td>18</td>
<td>4</td>
<td>22</td>
</tr>
<tr>
<td>Rectum</td>
<td>30</td>
<td>15</td>
<td>50</td>
</tr>
<tr>
<td>Cervix/uterus</td>
<td>11</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>9</td>
<td>3</td>
<td>33</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>144</strong></td>
<td><strong>36</strong></td>
<td><strong>25%</strong></td>
</tr>
</tbody>
</table>
treatment volume alteration for prostatic tumours.

Fifteen out of 30 (50%) patients with carcinoma of the rectum had inaccurate tumour localisation reflecting the difficulty of assessing rectal recurrence particularly after abdomino-perineal resection. Conventional radiographs and radioisotopic scans demonstrate bony involvement only. CT scanning is the only satisfactory way of detecting presacral recurrence especially in cases where pelvic examination is impossible due to a perineal scar (Fig. 4).

Alterations in the size of the treatment volume were analysed according to site (except in the head and neck where only five changes were recorded). Overall, 33/97 (34%) had a reduction in volume, 42/97 (43%) had an increase and 19/97 (20%) had an alteration in the position of the volume alone (Table V). The major site of volume reduction was the abdomen, due largely to patients receiving treatment for carcinoma of the pancreas. This led to sparing of the surrounding normal tissue such as the small bowel, kidneys and spinal cord. These results differ from Goitein et al. [3] who recorded that 85% of changes were due to an increase in tumour volume.

### Discussion

In assessing the value of CT scanning in radiotherapy planning, a clear distinction must be drawn between its contribution to more accurate tumour

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**TABLE V**

<table>
<thead>
<tr>
<th>Site</th>
<th>Reduction</th>
<th>Increase</th>
<th>Moved only</th>
<th>Total changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest</td>
<td>3</td>
<td>14</td>
<td>11</td>
<td>28</td>
</tr>
<tr>
<td>Abdomen</td>
<td>20</td>
<td>10</td>
<td>3</td>
<td>36*</td>
</tr>
<tr>
<td>Pelvis</td>
<td>10</td>
<td>18</td>
<td>5</td>
<td>33</td>
</tr>
<tr>
<td>Total</td>
<td>33 (34%)</td>
<td>42 (43%)</td>
<td>19 (20%)</td>
<td>97</td>
</tr>
</tbody>
</table>

*This includes in addition two patients who had a management change and one who had a change in field arrangement.*
and normal tissue localisation and the impact of that contribution on the therapeutic result. Thus, in a uniformly fatal tumour, a high degree of accuracy in localisation may be achieved without this necessarily influencing the probability of cure as is the case for pancreatic carcinoma. However, despite a lack of immediate application, eventual innovation in treatment approach could render such findings highly relevant. Indeed, the inadequacies of classical planning approaches as demonstrated by CT hopefully explain radiotherapy failure at least in a proportion of patients, although this is likely to be extremely difficult to demonstrate in prospective studies. Improved localisation by CT has been clearly demonstrated at all sites examined in this study. Overall, these results reporting a 33% change in treatment plans correlate well with similar studies at other centres as reviewed by Goitein [2].

In the head and neck region, the size of the treatment volume will continue to be defined at most sites by knowledge of subclinical tumour extension derived from the study of relapse patterns and from surgical pathology. However, diagnostic information provided by CT is important in detecting soft tissue extension of tumour and bone destruction at sites such as the paranasal sinuses, orbit and parotid gland where the full extent of tumour may not be defined by other means [9]. If the facilities are available for scanning this group of patients, immobilised in their perspex shells in the treatment position, then the data can be used directly for producing a treatment plan. In those head and neck sites such as the nasopharynx, where CT findings do not at present influence selection of radiation technique, the findings themselves may be of prognostic value and when further experience is available, lead to more individualisation of treatment approach.

In the thorax, the significance of our finding that 30% of patients with carcinoma of the bronchus have an alteration in their conventional plan following CT scanning, needs to be interpreted in the light of the overall role of radiotherapy in management. This is controversial but it is fair to say that radiotherapy results in, or contributes to cure in only a small minority of patients. It is generally accepted that evaluation of hilar lymphadenopathy is best achieved using conventional tomography but CT provides more information about the extension of the primary tumour into mediastinal structures as well as demonstrating lymphadenopathy, particularly subcarinal, in the mediastinum [4].

On the basis of our observations we would recommend that in patients in whom radical radiotherapy for non-small cell carcinoma of the lung is considered indicated, CT scans should be carried out because treatment planning and dosimetry are made more accurate. In a proportion of patients, CT detection of extensive disease in the mediastinum may contraindicate the proposed radical irradiation. It is also appropriate to consider CT scanning in patients needing mediastinal localisation of rarer tumours including lymphomas, germ cell tumours, sarcomas and thymic tumours, particularly in relation to combined modality therapy where minimisation of irradiation to drug exposed lung is important. CT provides accurate localisation of a small treatment volume on a cross-sectional plane so that the dose to the surrounding heart and lungs can be calculated and corrected for tissue heterogeneity.

The 67% instance of alteration in treatment for intra-abdominal tumours is remarkably high. It reflects the inaccessibility of organs such as the pancreas as well as its varied anatomy, and the inadequacy of conventional localisation techniques. Significant reduction in treatment volume was made in 10 out of 25 patients with pancreatic tumours. The advantages of volume reduction and accurate localisation of the kidneys are essential if advances are to be made in the treatment of pancreatic tumours using high-dose, small volume irradiation schedules or new modalities such as high LET radiation. However, at present more accurate radiation techniques cannot be applied with a great deal of optimism in this poor prognosis tumour.

It is our present policy to CT plan all patients with prostatic and bladder tumours and those with presacral recurrence from a rectal tumour particularly after abdomino-perineal resection. Bimanual examination of the pelvis and a planning cystogram
are commonly used for localisation of bladder tumours but they fail to show the extent of extravesicle soft tissue disease resulting in the risk of a geographical miss [7]. Correlation of CT sections with pathological staging has been carried out using cystectomy specimens and an accuracy of approximately 80% has been reported for CT [10].

In addition to the ease of localisation of prostatic tumours provided by CT, there is also the finding in some patients of involvement of the seminal vesicles by tumour, previously undetected on clinical examination. This necessitates an increase in the treatment volume in the lateral, superior and posterior dimensions to encompass the whole tumour. In carcinoma of the prostate and bladder where radiotherapy clearly has a role, the contribution of CT, although more modest than for example carcinoma of the pancreas, may well contribute to improved treatment results. This might be achieved by minimisation of the irradiated volume facilitating an increase in tumour dose without protraction, with the aim of improving the probability of tumour control.

CT scanning in patients with presacral recurrence from a primary rectal tumour is performed in the prone position as used for treatment. A small target volume can be localised to the soft tissue mass of tumour and adjacent sacrum and sacral nerve roots, thereby avoiding the small bowel lying anteriorly. Whilst treatment using the minimum possible volume is unlikely to influence survival it may reduce morbidity from bowel irradiation and result in improved palliation for the patient.

A new sequence of planning has been developed using CT alone so that initial simulation of the patient with invasive techniques such as a cystogram, is no longer necessary. This reduces the risk of urinary tract infection and urethral trauma and saves time and inconvenience to the patient. CT scanning for radiotherapy planning purposes must be performed under identical conditions to those during radiotherapy treatment. A flat couch must be used with a large gantry aperture to obtain the complete body contour. Lasers are used to align the patient whose position is dictated by the site of the tumour and the subsequent field arrangement to be used. However, in some patients, such as those receiving irradiation to the renal bed following nephrectomy, it may be advantageous to modify the treatment position according to the CT findings. For example, in these patients it may be possible to displace small bowel anteriorly away from the renal bed by repeating the CT scans with the patient lying in the prone position. Certain tumours, such as carcinoma of the breast, are treated in positions unsuitable for CT scanning because they prevent the patient entering the gantry aperture.

The CT data is related to an ink tattoo reference mark placed on the patient’s skin in the CT unit prior to the start of the scan. This is marked with barium paste so that it is visible on the scanogram and CT section at the level of the tattoo, and is used to relate CT information to the treatment plan. The CT data can be transferred directly to a radiotherapy planning computer via magnetic tape or a floppy disc. Using the scanogram, which marks the position of the CT sections in relation to the skin tattoo, and the cross-sectional CT information, the treatment volume can then be localised by a radiotherapist using a technique such as that described by Ash et al. [1]. A plan is produced with the isodose distribution directly superimposed on the CT image allowing assessment of the dose to individual structures (Fig. 5). A CT planning system is also useful for teaching as it provides a dynamic approach with immediate visualisation of the change in isodose contours resulting from alterations in the size, wedge or position of the treatment beams.

CT localisation has significantly improved the radiotherapist’s ability to irradiate the entire tumour volume in about one third of radical cases. This increased accuracy highlights the importance of the patient’s position and attention must now be paid to the reproducibility of treatment conditions so that this improvement in accuracy is maintained throughout the course of radiotherapy. Integrated CT planning provides the opportunity for new programmes which are being developed to achieve improved dosimetry with irregular shaped fields such as are used to treat lymphomas, intracavity therapy particularly for use in gynaecological malignancy.
and electron therapy. In vivo dosimetry measurements are being carried out at certain tumour sites to verify CT dosimetry as new programmes are explored.

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