



## New radiotherapy techniques:

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Discussion papers about the role of recent and emerging radiotherapy techniques in the management of women with breast cancer

Prepared by the Radiation Oncology Expert Advisory Group, Subgroup on New Techniques – a conjoint group of the iSource National Breast Cancer Centre and the Royal Australian and New Zealand College of Radiologists, Faculty of Radiation Oncology

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# Contents

	page
List of abbreviations	1
Foreword	3
Introduction	7
Definitions	10
Intensity modulated radiation therapy and breast cancer radiotherapy: a discussion paper	13
Positioning and immobilisation of women for breast conservation irradiation using intensity modulated radiation therapy: a discussion paper	25
Computed tomography planning for breast cancer: a discussion paper	51



## List of abbreviations

3D	three-dimensional
2D	two-dimensional
CT	computed tomography
CT-Sim	computed tomography simulation
CTV	clinical target volume
DRR	digitally reconstructed radiograph
DVH	dose volume histogram
EPI	electronic portal imaging
EPID	electronic portal imaging device
Gy	Gray
ICRU	International Commission on Radiological Units and Measurements
IMRT	intensity modulated radiation therapy
MLC	multileaf collimator
MRI	magnetic resonance imaging
OAR	organ at risk
PET	positron emission tomography
SBF	stereotactic body frame
Sim-CT	simulator computed tomography



## Foreword

Those clinicians who have the privilege of caring for patients with cancer are excited by the new developments in cancer care. For some the excitement is driven by the promises offered by genetics, molecular biology, targeted systemic therapies and new pharmaceutical agents. Radiotherapy, encompassing the professions of radiation oncology, physics and therapy, presents exciting prospects of enhanced treatment results and reduced morbidity achievable through the use of emerging technologies.

Our specialty began a little over 100 years ago. The greatest improvement in treatment was delivered midway through the last century with the advent of megavoltage treatment by linear accelerator or telecobalt. Now, another half century later, we can predict equally impressive improvements from the development of linear accelerators that can deliver radiation by intensity modulation and sophisticated, fast 3D planning based on multiple computer tomography. As before, the Radiation Oncology Expert Advisory Group decided to assist the progression by investigating and reviewing the literature on the emerging technologies and the facilities needed to utilise them. The Group's object was to review the evidence and present it so it could be readily used by each radiotherapy department.

These discussion papers highlight the emerging technologies in radiation therapy for the treatment of breast cancer. They are a welcome addition to *Radiotherapy and breast cancer*, a resource that was launched in October 1999 by the iSource National Breast Cancer Centre and the Royal Australian and New Zealand College of Radiologists, Faculty of Radiation Oncology.

This project has been a collaborative effort between members of the Radiation Oncology Expert Advisory Group and members of its Subgroup on New Techniques, with input from the disciplines of radiation therapy and radiation physics.

The Group is grateful to all who have contributed to the preparation and review of these papers, which have been developed for use by radiation oncologists, radiation therapists and radiation physicists involved in the delivery of radiotherapy to women with breast cancer.

The Radiation Oncology Expert Advisory Group hopes that these papers will be of assistance in improving the care of women with breast cancer.



Professor Alan Rodger

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# Introduction

Adjuvant breast and post-mastectomy chest wall irradiation make up a significant proportion of the workload of most Australasian radiotherapy departments.

Adjuvant tangential breast and chest wall irradiation, as currently practised, is both effective (in terms of an acceptably low risk of local cancer relapse), and safe (as evidenced by an acceptably low rate of both acute and late treatment-related side effects).<sup>1-3</sup>

In recent years, there have been a number of significant technological advances in the radiotherapy planning systems, computer control capabilities and treatment delivery hardware that can be used to plan and deliver radiotherapy treatments (with the major advances defined below). Any or all of these advances may have applicability to the delivery of radiotherapy to women with breast cancer. Such new technologies have the potential to improve outcomes in any of the three following ways:

1. Improved local control, by allowing either a higher, or more accurately directed, or more homogeneous dose of radiation to be delivered to the breast or chest wall, while maintaining normal tissue complications at their current level.
2. Reduced normal tissue complications, by reducing the dose received by nearby critical structures, while maintaining local control rates at their current level.
3. Quicker treatment delivery times compared with traditional treatment delivery techniques, thus potentially increasing the rate and numbers of patients treated. This would only be an acceptable gain if outcomes did not deteriorate.

Obvious costs inherent in any widespread uptake of these new technologies for the routine delivery of adjuvant breast cancer radiotherapy include:

1. The capital cost of the software and hardware required to allow planning and delivery of radiotherapy treatments utilising newer technologies.
2. Greatly increased treatment planning time required of the radiation oncologist, radiation therapist and radiation physicist before actual treatment delivery; and potentially complex treatment verification and quality assurance procedures.
3. Possible increased linear accelerator treatment time.
4. Possible change to the staff profile in departments.

These discussion papers consist of reviews of a number of aspects of the planning and delivery of tangential breast/chest wall irradiation that will inevitably undergo significant change from current clinical practice, should the newer technologies defined below be adopted by clinics. It is clear that these newer radiotherapy technologies lend themselves most obviously to non-breast cancer clinical scenarios, where there is either good evidence of a radiotherapy dose-response relationship (such that escalating the radiotherapy dose delivered is likely to increase the cure rate), or where nearby critical normal tissues are significantly dose limiting.<sup>4</sup> Neither of these factors has been shown to apply to the situations of adjuvant breast or chest wall radiotherapy with certainty, with the possible exception of cardiac morbidity and mortality. The available literature is therefore heavily skewed towards describing approaches to and clinical experience with these newer treatment techniques in non-breast cancer settings, especially central nervous system, head and neck and pelvic malignancies. Overseas experience suggests that, at least in the early phases of introduction of these newer technologies, their use in the adjuvant breast cancer setting is a low priority. The available breast cancer-specific literature is therefore limited in its scope and applicability to the Australasian radiotherapy environment.

Nevertheless, radiation oncologists and other clinicians involved in the care of women with breast cancer require a good working knowledge of the theoretical and practical aspects of these various recent advances in radiotherapy to enable them to determine whether such advances might represent potential improvements to good radiotherapeutic care for women with breast cancer. To that end, the members of the Radiation Oncology Expert Advisory Group, a conjoint group of the iSource National Breast Cancer Centre and the Royal Australian and New Zealand College of Radiologists, Faculty of Radiation Oncology, have developed these papers not as a blueprint for breast cancer radiotherapy, but in the hope of stimulating consideration of current clinical practice and what changes, if any, might be usefully adopted for women with breast cancer as the availability of these technological advances increases over the coming years.

**Dr David Blakey**

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# Definitions

## **Conformal therapy**

The creation of a radiotherapy dose distribution that closely conforms to the shape of the target volume (= gross tumour volume plus margins for microscopic tumour extension and treatment set-up variations) in three dimensions using customised shielding, while minimising dose to normal tissues.

## **Multileaf collimator**

The multileaf collimator (MLC) consists of two banks of tungsten leaves, situated within the path of the treatment beam, which individually move under computer control to enable static or dynamic variations in the shape of the treatment field, or dynamic variations in the intensity of the treatment beam delivered to the target.

## **Static conformal therapy**

The current state-of-the-art technology for most Australasian radiotherapy departments, whereby conformal therapy is delivered with fixed fields (usually defined by individually fashioned shielding blocks or, less commonly, by multileaf collimators), from multiple individual directions (typically four to eight). After each static field is delivered, the therapist goes in and out of the treatment room to manually change the treatment machine angle, field size, and to insert the new blocks and other beam modifiers.

## **Segmental conformal therapy**

Individual fixed field portals (or 'segments') are treated, as per static conformal therapy, but the multiple segments are treated sequentially and automatically under computer control (ie 'stop and shoot' technique). The therapist does not enter the treatment room at any stage during treatment delivery.

## Dynamic conformal therapy

Rather than delivering treatment by individual static fields, during dynamic conformal therapy one or all of the machine gantry, collimator, MLC leaves or treatment couch are in motion. Movement of the MLC leaves results not only in dynamic variation of the beam shape, but in variation in the intensity of the radiotherapy dose delivered (intensity modulated radiation therapy, or IMRT). The introduction of the MLC thus makes individually constructed shielding blocks, wedges and missing-tissue compensators obsolete. Intensity modulation can also be achieved by segmental stop-and-shoot treatment techniques.

## Inverse planning

Traditionally, the process of planning radiation therapy has used a trial-and-error approach, whereby the radiation oncologist defines a treatment field and beam directions and a dose distribution is calculated, with the radiation therapist or physicist making a 'best guess' about treatment parameters such as beam energy, weighting and degree of wedging. If the dose to the tumour or normal tissues is deemed unacceptable, the process is repeated until an optimal dose and coverage is obtained. In contrast to this traditional approach, inverse planning involves the radiation oncologist defining the tumour volume and specifying a required dose and dose range to that volume, as well as a maximum acceptable dose to nearby normal structures. The computer planning system then generates an optimised treatment plan, defining all treatment variables previously determined by trial-and-error.

## Intensity modulated radiation therapy

Intensity modulated radiation therapy (IMRT) is the use of one or other of the previously described technologies to 'sculpt' a 3-dimensional (3D) dose distribution around the target volume, minimising dose to nearby critical structures.



Intensity modulated radiation therapy  
and breast cancer radiotherapy:  
a discussion paper

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## Summary

- Intensity modulated radiation therapy (IMRT) has the potential to improve dosimetry in complex target volumes such as the breast.
- IMRT is very resource intensive. The use of IMRT in the treatment of breast cancer has significant resource implications, as breast cancer is a commonly treated malignancy in most radiotherapy departments.
- Quality assurance is complex and an essential part of the IMRT process.
- Accurate immobilisation is essential for delivery of IMRT.
- It is most likely that the use of IMRT in the treatment of breast cancer will be introduced in a trial setting, to investigate the implications for reduced morbidity as well as the resources required.

## Background

Adjuvant radiotherapy to the breast has a significant role to play in the management of breast cancer.<sup>1,2</sup> Therefore, it is not surprising that radiotherapy of the breast or the chest wall after surgery constitutes a significant part of the workload in many radiotherapy departments in Australia and New Zealand. The characteristics of current breast cancer radiotherapy treatment can be summarised as follows:

- Techniques are typically based on tangential breast irradiation using open or wedged parallel-opposed fields. This can be supplemented by multiple other fields to treat different areas of lymph-nodes, resulting in 2–5 fields overall.
- Techniques are typically based on tangential breast irradiation using open or wedged parallel-opposed fields. This can be supplemented by multiple other fields to treat different areas of lymph-nodes, resulting in 2–5 fields overall.

- Despite the complex target volume, the radiotherapy treatment planning approach is typically simple, consisting of one or few outlines only to which a standard lung area is usually added. Approximately only one-third of departments in Australia and New Zealand utilise computed tomography (CT) scans as input data for treatment planning.<sup>3</sup>
- The target volume in breast irradiation is one of the most complicated in radiotherapy, resulting in significant dose inhomogeneity in many cases.<sup>4</sup> The degree of dose inhomogeneity is often underestimated because of the limited number of patient outlines on to which isodose plans are projected.
- There is a great variability in patient shape and target size and shape.
- The target volume is surrounded by several organs at risk, notably the lung/s and the heart.
- Reproducible patient set-up is difficult.
- Women typically have a good chance of surviving for a long time after breast cancer radiotherapy,<sup>1</sup> and may survive long enough to exhibit late effects of radiation.<sup>1</sup>
- There is a desire to minimise any cardiac dose and to reduce other side effects of radiation, including its effects on cosmetic outcomes.
- Radiotherapy techniques have developed dramatically over the last decade, and a number of novel treatment approaches have been introduced. One of them, and potentially the most advanced, is IMRT.

## Intensity modulated radiation therapy

Intensity modulated radiation therapy (IMRT) is the attempt to optimise the dose distribution during external beam radiotherapy delivery. Each radiation field is divided into small segments with varying radiation intensity. The choice of segment shape and radiation intensity reflects the anatomy of the patient and allows for target shape, location and the geometry of overlaying tissues. There are different methods for delivering these intensity-modulated fields, some of the differences

arising artificially from different philosophies and capabilities of different manufacturers.<sup>5,6</sup> Conventional intensity modulation has been performed using physical compensators or wedges to alter the beam intensity in different parts of the beam. The term IMRT is usually not applied to these fields, despite the fact that they can in principle achieve similar dose distribution.

IMRT in the 'modern' usage of the term involves the use of a multileaf collimator (MLC), a device that is mounted in the collimator or replaces one of the collimator pairs (again depending on the manufacturer). It consists of movable leaves which can be positioned freely to allow conformal shielding of a target area, or the definition of field segments which can then be treated using an individualised beam intensity defined by the number of monitor units delivered for the particular field segment. IMRT can now be achieved by delivering all segments of a treatment field sequentially, using a 'stop and shoot' approach<sup>5,7,8</sup> or a dynamic movement of the leaves.<sup>6</sup> The latter is typically done in a 'sliding window' fashion where a variable strip of open beam scans over the whole field width.

In general, IMRT consists of many intensity modulated treatment fields to place the tumour in the focus of the beams, thereby minimising the entrance and exit dose to overlaying normal tissues. An interesting variation to the theme of IMRT is therefore tomotherapy. In this approach the radiation source is continuously rotated around the patient, and dose-delivered from appropriate angles in appropriate portions of a fan beam. Similar to diagnostic computed tomography (CT) scanning, the process can be done slice by slice ('serial tomotherapy') or in a spiral/helical continuous fashion.

Modern IMRT fields are too complex for manual dosimetry, and must be designed using computer aided optimisation. This is often referred to as 'inverse treatment planning'. Conventional planning defines and manually adjusts the radiation beams used for a particular treatment and calculates the resulting dose distribution. In inverse treatment planning, the clinician defines the target and critical structures and specifies the desired dose distribution and then computer designs the radiation fields required to achieve this goal. Weights to different aspects of the treatment objectives determine the final beam arrangements. For example, the clinician can request a tumour dose to be at least 70Gy; the dose to organ at risk (OAR) A not

more than 30Gy; the dose to a maximum of 20% of OAR B not exceeding 40Gy; and the nodes to be between 45 and 55Gy. Alternatively, clinicians can specify the shape of a dose volume histogram (DVH) to the target and other structures. In this context, two different approaches are possible:

1. A conformal target approach, where the dose to the target volume is optimised.
2. A conformal avoidance, where the dose to specified OAR is minimised.

IMRT therefore constitutes a completely new radiotherapy approach characterised by the following:

- Requirement for modern high-resolution diagnostic information (CT scans)
- Highly customised treatments with small margins
- A truly three-dimensional (3D) approach with inclusion of non-co-planar fields
- Requirement of clinicians to define their treatment dose objectives and communicate this to a computer
- Design of treatment fields and monitoring of units by a computer (as there is often no intuitive way to verify the fields, verification strategies must be carefully considered)
- Treatment fields truly optimised according to the objectives given (as such, the dose distributions can be significantly better than with conventional approaches)
- Ability to treat different target areas simultaneously to different dose levels (eg lymphatics, breast and tumour bed can all receive different total doses in the same number of treatment fractions)
- Transferral of the treatment data to the treatment unit using a computer network
- The need for specifications for equipment and the quality assurance procedures to be significantly better than in conventional radiotherapy, because small uncertainties in treatment unit performance may cause significant problems in the actual treatment delivery (eg collimator leakage, tongue-and-groove effect)

- Need for highly accurate patient immobilisation (and knowledge about potential organ movement must be worked into the optimisation criteria)
- Treatment verification, typically using computer predictions (such as digitally reconstructed radiographs)

## Intensity modulated radiation therapy and breast cancer

From a technological point of view, breast radiotherapy is one of the most challenging treatment scenarios. As noted above, this is due to a complex clinical target volume, the inclusion of tissue heterogeneities and the variations in irradiation geometry between patients. Patient immobilisation is difficult and may interfere with the treatment (eg increased skin reactions due to build-up in the breast immobilisation device).

### Benefits

Considering these issues, and provided the challenges listed in the next section can be overcome, IMRT offers three major benefits for patients:

1. Better dose distribution in the target volume – as dose inhomogeneities in breast treatment are larger than in the clinical target volumes of most other radiotherapy treatments, breast treatment has more scope (and need) to improve. Dose inhomogeneities have also been shown to correlate with worse cosmetic outcomes.<sup>9-11</sup> The highly customised approach of IMRT will also suit the wide variety of different patient shapes and target sizes.
2. The dose to normal tissues is reduced, and can be distributed as desired (eg all dose away from the heart; lung dose optimised to dose volume considerations). This should result in a reduction of treatment related morbidity and potentially better cosmetic outcomes. It is desirable to reduce dose to organs such as the heart, in particular in combined modality treatment with radiotherapy and chemotherapy<sup>4,12,13</sup> (eg anthracyclines).

3. The improved treatment planning and delivery will result in a better knowledge of the actual dose given. This is essential in the evaluation of clinical trials and the assessment of adverse effects. Only by knowing the dose and its distribution accurately can dose effect curves be determined, and side effects of particular dose levels or the effects of other treatment modalities be attributed.

## Challenges

Despite its potential benefits, IMRT has not yet been widely applied to breast radiotherapy. Possible reasons include:

- If the dose inhomogeneity (particularly the hot spots) are reduced by IMRT, then this may result in a lower dose than used historically (necessitating review of the dose-response relationship)<sup>4</sup>
- Perception of breast radiotherapy as a ‘low dose’ adjuvant treatment which has less scope for IMRT than treatments such as head and neck and prostate, where the importance of high dose and dose response are well established
- Acquisition of CT scans (See *Computed tomography planning for breast cancer: a discussion paper*)
- Variation in patient breast shape and size – the customisation of treatment approach would favour IMRT. It leads to a less standardised set-up from which the optimisation commences and may require very concisely defined dose objectives.
- Patient immobilisation and motion (breathing, heart) – this is a serious problem for the delivery of highly conformal treatment fields. A number of potential solutions have been discussed, including gating the beam or modifying the beam on-line to ‘follow’ the target. All these techniques are currently in experimental stages only. It is therefore more likely that margins will initially have to be modified to take potential target variations into account. (See *Positioning and immobilisation of women for breast conservation irradiation using intensity modulated radiation therapy: a discussion paper*)

- Quality assurance – as the specifications for all equipment in the IMRT treatment chain are much tighter than in conventional radiotherapy, quality assurance procedures need to be reviewed. This includes new quality control measures (eg MLC interleaf leakage) that would not be routine in current practice.
- Treatment verification – in most centres that have introduced IMRT, the field arrangement for each patient is verified in a treatment phantom. While this is a time and resource intensive process, it is necessary because each patient's treatment is highly customised and likely to differ significantly from any other patient's treatment plan. In addition, the number of monitor units and the dose are typically correlated intuitively at the prescription point. In particular, when radiation fields are delivered dynamically, on-line treatment verification is also required.<sup>14</sup> This will typically consist of electronic portal imaging (EPI) and may also include in vivo dosimetry. On-line verification also raises the issue of responsibility – who is responsible to terminate a treatment or accept a small patient movement?<sup>2</sup> This may require additional training.
- Resource implications, eg:
  - Additional CT scans
  - High end radiotherapy equipment
  - Additional hardware (eg EPI devices)
  - Additional software (inverse treatment planning, modified record and verification systems)
  - New hardcopy devices (digitally reconstructed radiograph printer)
  - Clinician time to outline structures
  - More planning time
- Cost-benefit analysis – while it is usually assumed that IMRT increases the costs of radiotherapy, this may be counterbalanced by improved treatment outcomes. In addition, IMRT will minimise side effects.
- Clinical trials – ultimately, clinical trials must establish the role and benefits of IMRT in breast cancer management

## **Moves towards intensity modulated radiation therapy**

It is perceived that IMRT can offer many potential advantages for breast radiotherapy. This fact is reflected in the current use of tissue compensators in many departments to try to correct dose inhomogeneities. These techniques rely on dose optimisation in the central plane between the two tangential beams, a process that can be done in few simple steps using EPI devices (eg Royal Marsden) or isodose plans perpendicular to the central axis of the beam. The resulting intensity-modulated fields, which consist typically of few sections, are the first step to improving the dose distribution in the target on the way to full, inverse planned IMRT. Only the latter will allow the inclusion of treatment of lymphatics and the conformal avoidance of organs at risk.

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Positioning	and immobilisation of women
<hr/> for breast	conservation irradiation using intensity modulated radiation therapy: a discussion paper
	Dr Roslyn Drummond



## Summary

- The aim of intensity modulated radiation therapy (IMRT) is to deliver the radiation dose more uniformly to the whole target volume and to deliver a minimum radiation dose to non-target tissue. To achieve this, treatment field margins are significantly reduced. Accurate and reproducible positioning of the patient and target volume is even more important for IMRT than for conventional radiotherapy.
- A number of factors influence the position of the target volume for breast conservation irradiation:
  - individual anatomical factors
  - respiration
  - body position
  - arm position
- A variety of devices exist for securing the patient and the target volume in position for radiotherapy treatment.
- It is essential to be able to verify the accuracy of the position of the target volume in relation to the radiotherapy treatment beam.
- To achieve the potential benefits of IMRT in breast irradiation, it is critically important to position the target volume (the breast) accurately in relation to the radiotherapy treatment beams.

## Introduction

One of the basic requirements for effective delivery of a multifraction course of radiation therapy is delivery of each fraction to the planned target volume. This results in the target volume receiving the intended total dose of radiation and the surrounding normal tissues receiving the maximum protection from radiation. This is expected to result in maximum tumour control and minimum treatment related toxicity.

The increasing technical sophistication of radiation therapy machinery is resulting in increasingly precise beam definition and beam direction. Maximising the advantage of this mechanical precision is not possible unless the anatomical target for treatment within the patient can be adequately defined and positioned on the treatment couch with the same degree of accuracy for each fraction of radiation dose delivered.

In the spectrum of radiation therapy currently used for breast cancer treatment, the most frequently required treatment is that used for breast conservation radiation therapy after limited surgery for early stage breast cancer. This will be the focus for this discussion paper about the positioning and immobilisation of women with breast cancer for radiotherapy treatment. On occasions, irradiation of the breast is combined with irradiation of the internal mammary, supraclavicular and/or axillary lymph node regions. The positioning requirements, or limitations imposed to enable treatment of these additional areas, will be referred to where relevant. In addition, many of the principles described here apply to post-mastectomy chest wall irradiation.

## Intensity modulated radiation therapy

IMRT techniques offer the potential to deliver a more homogeneous dose of radiation throughout the target volume, regardless of any irregularity in the shape of the target volume. IMRT can also reduce the irradiation of adjacent non-target tissue by tightly conforming the high dose to the target contour. This is expected to decrease the morbidity of radiation therapy because it eliminates areas of excessive dose, eliminates excessive dose per fraction within the treatment volume, and minimises dose to normal tissues outside the target volume.

In breast conservation irradiation, elimination of areas of higher dose within the target volume is expected to result in improved cosmesis and reduced breast pain because of reduced fibrosis within the breast. Minimising dose outside the target volume is expected to reduce radiation-induced cardiac and pulmonary toxicity, thus maximising the survival benefit from reduced breast cancer cause-specific mortality associated with breast irradiation.<sup>1-5</sup>

IMRT generates a dose distribution which closely conforms to the target volume. A significant inherent advantage is that technical margins are narrow. In treatment delivery, this conformal treatment requires that the target volume be precisely in the same position for each treatment. Thus the reproducibility of patient set-up at each treatment is crucial if the dose delivered is to conform to the target volume.

## **I. The breast target volume**

### **I.1 Anatomical and physiological issues**

In radiation therapy for breast conservation treatment of early breast cancer, the whole breast is the target volume for treatment.

Anatomically, the breast is a subcutaneous structure situated on the antero-lateral chest wall. It is not defined by a capsule. As the breast is composed largely of adipose tissue, at normal body temperatures it has a semi-fluid consistency so that the shape and position of the breast on the chest wall are significantly influenced by the woman's position. Other factors such as age, menopausal status and weight also influence breast position on the chest, breast texture, breast shape and mobility.

As the breast is a surface structure external to the rib cage, manual palpation is the usual method employed to define the breast as a target volume for radiotherapy. Because of its texture and lack of capsule, defining the edge of breast tissue requires some experience. The major difficulty is delineating breast tissue from adjacent subcutaneous adipose tissue. Defining the margin of the breast on CT scan is also difficult, as breast adipose merges with subcutaneous adipose of similar radiological density. Skin markers placed at the breast margins defined by physician palpation are usually required to assist with CT scan definition of the breast.<sup>6,7</sup>

The shape of the underlying thoracic rib cage and sternum has a major effect on breast contour and position. This is a significant factor for radiation therapy, as it also has major impact on the volume of lung and heart which may be included within standard radiation fields.<sup>8</sup> Women with major anatomical deformities (eg pectus excavatum deformity, thoracic kyphosis or scoliosis from any cause) may present particular difficulties for standard breast conservation radiation therapy.

## 1.2 Respiration

The movement of the thoracic rib cage with respiration results both in expansion of the diameter of the thoracic girdle and in movement of the anterior chest wall superiorly. Thus the breast position moves both anteriorly and superiorly with respiration. With quiet respiration, the range of movement is small. However, given that anxiety and stress influence respiratory rate, when the woman being treated for breast cancer is anxious (as with first experiences of radiation treatment), the degree of breast movement with respiration is increased. In most cases, the delivery of each fraction of radiation takes longer than the time a woman can reliably hold her breath, so that respiratory motion cannot usually be avoided.<sup>9,10</sup>

## 1.3 Breast contour

The thickness of breast tissue across the chest wall varies, with the greatest depth of breast tissue usually situated deep to the nipple-areolar complex and a larger volume of the breast situated laterally to the nipple than medially. However, this is a generalisation and the location of the breast tissue varies considerably with the position of the woman and between individuals.

The surface contour of the breast target volume is irregularly curved, in both the medio-lateral direction and the supero-inferior direction. In addition, the deep (internal) chest wall contour of the breast target volume is similarly curved in these directions, giving a convex 3D contour to the target volume.

Anxiety and stress also influence patient body position on the treatment couch, and hence breast contour. As the woman's familiarity with the treatment process occurs, usually her stress reduces and the consequential muscle relaxation leads to a more relaxed treatment position. This may result in a change in breast contour as treatment progresses.

## 2. Issues in determining patient position for treatment

### 2.1 Body position

Traditionally, for tangential field irradiation of the breast the woman lies on her back facing upward (ie supine) on the treatment couch, either fully horizontal or on a breast tilt board under the upper half of her body, which elevates the head and shoulders to a variable angle.

#### **Flat-on-back position**

The woman positioned flat on her back (fully supine) is in a stable, easily immobilised position. Provided a suitable arm position is chosen, the woman in this position on a simulation couch will fit through the ‘doughnut’ of a CT scanner during treatment. This position also facilitates treatment of supraclavicular and axillary lymph node regions, with a minimum of lung apex within the additional field. However, the supero-inferior curvature of the thoracic girdle is at its most obvious. Also, a large, mobile breast tends to fall more superiorly, encroaching on the clavicle and thus becoming more difficult to encompass in tangential treatment fields without including the axilla and adjacent arm. The skin fold at the infra-mammary margin is reduced to the maximum degree.

For the flat-on-back treatment position, tangential fields must be modified to account for the supero-inferior chest contour.<sup>11</sup> Either shielding to shape the deep surface of the tangential beam must be added, or the tube head rotated to parallel the angle of the chest wall. The latter creates a second angle in the treatment set-up (double angle technique) and a potential source of set-up error.<sup>12</sup>

## Breast tilt board - lift up position

A specifically designed breast board is attached to or replaces the end of the treatment couch on which the woman's upper body is positioned. The breast board may be elevated and secured at one of a range of angles above the horizontal.<sup>13</sup> A higher backboard angle has the advantage of pushing the breast tissue lower on the chest wall and thus more inferior to the clavicle and lower axilla, and rendering the supero-inferior curvature of the chest wall less marked. It has the disadvantage of increasing the skin fold at the inferior mammary fold of the breast. In addition, the 'doughnut' of many diagnostic CT scanners may not be of sufficient diameter to allow the patient set up in this position to pass through, thus precluding the use of CT scan images as a basis for planning (a CT-simulator will usually not have this problem, but is more expensive).<sup>14-16</sup> When a breast back board is used there is also potential for the woman to slide down the board, so that the chest angle may change during the treatment or vary from fraction to fraction of treatment.

Some IMRT systems may require the woman to occupy the same position longitudinally on the couch when a breast tilt board is used. For example, the use of a 'butt stop' to secure the buttock position and a footrest restricts this longitudinal movement and keeps the woman's position stable.

Additional supports, such as neck supports and knee cushions, can aid patient comfort but should not alter the desired treatment position. Aids to patient comfort are designed to assist the woman's level of relaxation so that she can more reliably resume the same treatment position for each fraction.

## 2.2 Arm position

The ipsilateral arm needs to be abducted to at least 90° at the shoulder to remove it from the path of the tangential beams.

There is some evidence that abducting the arm to a greater degree (eg hands above the head) draws the breast anteriorly on the chest wall, creating a more favourable anatomy for tangential treatment (ie the lateral margin of the breast is more anterior on the chest wall than when the arm is at 90° to the chest).<sup>17,18</sup> This also means that a smaller extent of the chest wall and underlying structures are within the path of the tangential beam.

The great extension of the arm above the head expands and elevates the chest wall, lifting it away from the underlying heart. It can be demonstrated that there is less heart volume within the tangential beams when treating the left breast with a more abducted and elevated arm position.<sup>17,18</sup> For use of CT-based treatment planning, the choice of arm position which enables the woman to pass through the CT ‘doughnut’ is essential, unless a Simulator-CT is used.

Securing the arm position is a means of stabilising the upper body in the described treatment position.

The comfort of the woman needs to be considered when choosing the arm position. Following axillary surgery for breast cancer, most women experience a degree of axillary pain and restricted shoulder movement while their surgical wound is healing. Measures to assist with recovery (eg physiotherapy) need to be implemented early. The adequacy of recovery to ensure that the woman can comfortably place her arm in the desired position needs to be assessed before radiotherapy planning. Simulation may need to be delayed until this requirement is met. Any pre-existing medical condition affecting shoulder movement needs to be accommodated when choosing an arm position.<sup>19</sup>

For stability and symmetry, there may be benefit in securing both arms in the desired treatment position.

### **2.3 Breast position**

The anatomical position of the breast on the chest wall can vary considerably depending upon individual patient anatomy, body position chosen for treatment, and the woman’s age and breast size.

In general, large, soft, ptotic breasts present the greatest difficulty for radiotherapy, as they fall over a larger area of the woman’s chest wall (and upper abdomen) and create more skin folds, which may increase treatment side effects such as moist desquamation of the skin. In addition, the breast mobility reduces the stability of treatment set-up and reproducibility.<sup>20</sup>

Ideally, the breast should be confined to the area over its base on the chest wall, in a comfortable, reproducible device that eliminates skin folds and crevices.

## 2.4 Respiration

The chest wall (and hence the overlying breast) moves during respiration. The chest wall motion is expansile in inspiration and contractile in expiration. Thus there is both antero posterior and lateral motion of the breast with respiration.

Quiet respiration minimises this movement, but allowance for this motion must be included in treatment plans.

As most treatment times exceed the time a woman can hold her breath, this motion cannot be entirely eliminated.

The internal organ contours also change during respiration. As the rib cage expands during inspiration and the lungs expand, the distance between the heart and chest wall increases. It has been demonstrated that a reduction in cardiac volume irradiated can be achieved by treating patients during deep inspiration.<sup>13,14,31</sup> However, it is difficult for many patients to retain a deep inspiration for the duration of the treatment fraction delivery. If respiratory movement is significant, treatment gated to the individual's respiration rate may potentially address this issue.<sup>9,10,21-24</sup>

## 2.5 Lymph nodes

If the target volume includes the supraclavicular and/or axillary lymph node regions, this will place some additional requirements on the treatment position.

It is desirable to avoid axillary irradiation in breast conserving irradiation when the axilla has been surgically dissected.<sup>25-27</sup>

In both the above situations the anatomical location of the axillary lymph nodes needs to be clearly defined for the chosen treatment position, so that it may be included or avoided as desired.<sup>28</sup>

When the internal mammary lymph nodes are to be included in the treatment their position needs to be defined. It should be appreciated that the superior internal mammary lymph nodes are situated more deeply beneath the chest wall than those further down the chain of nodes.<sup>29-32</sup>

Localisation of the axillary, supraclavicular and internal mammary lymph nodes for irradiation is a difficult task because no ideal imaging modality exists.

Irradiation of the axillary, supraclavicular or internal mammary lymph nodes generally includes a large number of non-target tissues, such as brachial plexus, heart, lung, shoulder joint, axillary vessels and possibly spinal cord.

### **3. Devices for patient immobilisation**

#### **3.1 Arm support**

It is essential for reproducibility that the arm support is attached to the treatment couch or breast board. A variety of commercially available arm support devices exist, as well as devices manufactured in-house by radiation therapy departments.

Some consist of curved cradles for the upper arm and forearm, whose position and angle on the breast board can be adjusted for individual patient position. The presence of a scale on the adjustments enables the position for each woman to be recorded and recreated at each treatment.<sup>33</sup>

Other arm supports provide a handle for the woman to grasp with her hand and thus secure the arm position. Arm supports which are integrated into the patient body fixation system are probably preferable to devices attached to the treatment couch, as they are more likely to be in the same place for each fraction.

### 3.2 Breast boards

There is a variety of commercially available breast boards (and in-house manufactured boards) which can be attached to the treatment couch. Desirable characteristics in a breast board include:

- The same board useable for simulation, CT scanning and treatment
- Arm support and immobilisation system incorporated in the board
- An adjustable range of available board angles
- A buttock support bar or similar device to prevent the patient sliding on an inclined board
- Adjustable neck support
- Lateral areas either removable, or designed so no material is present within the axis of the beam for lateral tangential fields
- Board constructed of material lightweight enough to facilitate the patient's removal from the bed, but strong enough to prevent the board sagging under the patient's weight

### 3.3 Foot rest

Longitudinal slip of the patient on the bed can be reduced by securing a footrest board at the patient's feet. At each treatment, this board needs to be secured to the treatment couch at the defined position for the given patient.

### 3.4 Foam body cradle/cast

An individual body cradle or cast of the woman in the required treatment position can be made from a fast-setting foam. This usually includes the upper body and arm or both arms.

If this body cast is not secured to the treatment couch, the potential for lateral and longitudinal movement is considerable. If a flat-on-back position is used for treatment, this may not be a problem. However, if such a body cast is used on an angled breast board, there is scope for considerable position variation on the couch between treatments.

For the casts to provide secure patient immobilisation, the sides of the cast must closely encompass a reasonable proportion of the woman's chest circumference. This may mean that the material encroaches onto the treatment area on the lateral breast.

If the cast does not sufficiently encircle the woman, there is potential for the woman to rotate within the cast.

### **3.5 Vacuum bags**

Vacuum bags of sufficient size to create a partial body cast are available. These are re-useable and may provide a more convenient method of creating an individual body cast of the woman in her treatment position.

The comments made above about body casts apply equally to vacuum bags.

### **3.6 Stereotactic body frame**

The stereotactic body frame (SBF), composed of a stiff lightweight material, is essentially an open-topped, shallow-sided within which the woman lies. This frame provides a reference system that is external to the woman's body. It can be used to localise body tumours in a 3D co-ordinate system. Using this stereotactic reference system, the isocentric co-ordinate of the target can be reproducibly localised during diagnostic examination (with CT or magnetic resonance imaging (MRI)) and treatment.

When using the SBF, reproducibility in the transverse plane is within 5-10 millimetres in the longitudinal plane, compared to conventional radiotherapy precision of 20 millimetres in transverse and 30-40 millimetres in the longitudinal dimensions.<sup>34</sup>

While this system has been advantageous for intrathoracic tumour treatment, it is yet to be evaluated for breast treatment. Arm support and immobilisation are not included in the standard frame.

### 3.7 Breast fixing devices

Because of the desire to have maximum skin sparing when treating the whole breast for breast conservation, in most treatment techniques the breast is allowed to take up the natural position it assumes under the influence of gravity and the arm position chosen for the treatment of the woman.

For the majority of women with small and medium sized breasts this is satisfactory, in that it enables treatment of a minimum of adjacent non-target tissues. However, there is a group of women, either with large, very large breasts or soft, very mobile breast tissue, where the natural position assumed covers a large amount of lateral chest or upper abdomen. Particularly in these cases, there is a desire for a device to contain and confine the breast tissue over the breast gland base on the chest wall in a daily reproducible fashion, so that all the breast is positioned within this area and the irradiated volume can be kept to a minimum. No ideal method of doing this is currently available. All the methods listed below are associated with a loss of skin sparing during irradiation, and hence with more skin toxicity from radiation.<sup>20,35</sup>

- **Strapping**

Strapping of the breast into position with tapes or padding varies considerably from day to day. Reproducibility of breast position and shape is very questionable.

- **Thermoplastic mould**

Heat-sensitive plastic sheets can be moulded to the breast shape and fixed to the breast board to confine the breast, similar to the method used in head and neck radiotherapy. In practice, - construction of the individual mould for a large, soft mobile structure like the breast is very difficult, as the breast cannot be placed and kept in the desired position for the length of time the material needs to cool. In addition, in daily use the breast tissue tends to come out of the mould unless the mould is fitted very tightly.

- **Pre-moulded plastic breast cups**

A system of pre-moulded plastic breast cups in a range of sizes is available. A cup of suitable size is put on to hold the breast before positioning for treatment. It is held in place by a strap around the chest and across the opposite breast. In a supine treatment position, the breast tissue tends to come out laterally beneath the cup. Thus the cup does not always confine or restrict the breast in position.

Breast oedema can develop during the course of treatment, rendering the cup harder and more painful to apply.

- **A woman's own bra**

A bra that the woman has normally worn can be very useful. It is advisable to remove any wire from the bra. The firmness and shape of the bra cup usually prevent breast tissue from sliding out, enabling a reproducible breast position to be achieved. The forward elevation of the opposite breast can be a problem for the medial tangent. If the opposite bra cup is cut out, the opposite breast can fall away to its natural position – outside the medial tangential beam.

## **4. Alternative treatment positions**

### **4.1 Lateral decubitus position**

This treatment position has been used in the Institut Curie.<sup>36</sup> The woman is positioned on her side, with the breast to be treated resting on the treatment couch. The ipsilateral arm is elevated above her head on the bed. The contralateral

breast needs to be strapped out of the path of the treatment fields. The tangential fields to the breast are delivered as a parallel opposed pair of fields from above and below the treatment couch. The advantage of this position is that the breast is drawn away from the chest wall, and hence there is less lung (and heart) tissue within the treatment path.<sup>36,37</sup>

The disadvantage of this treatment position is the inherent instability in the patient position, with rolling of the patient difficult to control. Keeping the opposite breast out of the path of the radiation beam may also be difficult. The chest wall under the breast probably receives little irradiation. It is unknown whether this is desirable. It is impossible to irradiate any regional lymph nodes with this position. It would appear unlikely that the dosimetry advantages of IMRT can be exploited by using this treatment position.

## 4.2 Prone position

Treatment of women in the prone position, particularly those with large or pendulous breasts, has been advocated by McCormack et al. from New York, and a technique has been developed.<sup>38,39</sup>

The woman is treated lying on a frame placed on the treatment couch, with her breast hanging through the frame in a dependent position. The woman is not truly prone but slightly rotated, so that the axillary tail of the breast is in the opening with the contralateral breast and the rest of the body supported on the frame. Lateral treatment beams are applied to the breast.

The advantage of this approach is that for large breasts it pulls the breast away from the chest wall and non-target tissue. The dependent position of the breast elongates and narrows the breast contours, creating a more even dose distribution throughout the breast. The disadvantages are again that no lymph node areas can be irradiated in this position, and matching fields with changing position is most undesirable. The chest wall is probably not irradiated. Also, the ease with which women get into the treatment position is questionable. There is a question about the daily reproducibility of this position, given the lack of control of the woman's rotation, position on the bed and arm position.

As the main reason for using this technique is the more even dosimetry generated through the breast, it seems unlikely that IMRT has much to offer to improve this technique.

## 5. Position verification and quality control

Whichever patient treatment position or immobilisation devices are used, daily reproducibility is crucial to successful treatment. Thus, for each treatment technique and each woman treated, it is necessary to ascertain the level of reproducibility of position of both internal and external contours. If there is variation in patient position, the treatment field margins need to be increased and the potential benefits of IMRT in reducing non-target tissue toxicity will be reduced.

A variety of methods is used to verify the reproducibility of patient positioning. Such methods should be part of each radiotherapy treatment unit's routine quality assurance program applied to all aspects of the medical and radiotherapeutic management of each patient, to ensure the highest quality of patient treatment.<sup>4,40-45</sup>

Some aspects of patient positioning verification are listed below. A particular treatment department needs to use the methods best applicable to the patient position and treatment technique being used. It is important that particular problems and potential sources of error in their own technique are identified and addressed.

### 5.1 Simulation and planning

It is important that the woman has the treatment planning procedures performed while she is in the position in which she will be treated. All immobilisation devices that will be used during treatment should be used to position the patient during simulation and planning.

Data on patient position (which may include simulator films) should be collected to serve as a reference for verification data on position collected during treatment.

Collecting patient contour data (both external contour and internal lung contour) by CT scanning or simulator-CT is convenient. The CT scans can be used directly on the planning computer to determine field placement and field size, as well as for generating dosimetry. The use of surface fiducial markers appropriately placed on scars, breast margin, and other points of interest can assist in incorporating valuable clinical information into the CT planning data. By relying on imaging technology alone, it is possible that important clinical information relevant to the proposed treatment may not be appreciated (eg position of scars, set-up stability, patient comfort). There is some merit in returning the woman to the simulator unit to set up the planned treatment fields. The clinical appropriateness of the field coverage of the breast can be ascertained by visual appraisal. Any potential for patient movement can be assessed and set-up problems addressed before the woman arrives at the treatment unit (this avoids wasting valuable treatment unit time).<sup>7</sup>

Also, a simulator film of each beam can be generated. These films are used as the reference against which portal images taken during treatment can be assessed. Simulator films act as documentation of the anatomical structures encompassed by the treatment fields, and hence fulfil several roles within the quality control of radiation treatment.

## **5.2 Portal images (beam films/electronic portal imaging)**

The treatment beam path within the woman can be verified on the treatment unit either by a beam (or port) film or electronic portal imaging. The frequency with which this should be recorded throughout a course of treatment depends on the reproducibility and stability of the patient position. It is essential that a verification of patient position be performed at the beginning of treatment, to confirm that position agrees with that used for planning. Verification frequency throughout the course of treatment needs to be defined by each unit according to its particular technique.<sup>46,47</sup>

Published data suggests that concordance between treatment and simulation position can be achieved within a few millimetres.<sup>48,49</sup>

Verification does not accurately check the inter- or intrafraction position of the mobile breast or movement with respiration.

### 5.3 Skin marks and tattoos

Skin marks at particular reference points or on field edges can be used to assist with patient positioning as well as with field set-up. No ideal skin marking material exists so that marks are frequently lost from the skin between treatments. Methods used to maintain skin marks (eg re-marking as marks fade) introduce potential for error. Resimulation is the only accurate way to avoid this error. This creates an undesirable increase in the use of simulation resources. If skin marks fade, electronic portal imaging can be used to verify field positioning. Field placement can be verified using pre-treatment imaging and online corrections.

Tattoos provide a permanent reference mark on the skin. If tattoos are used, the point being marked needs to be considered (eg field centre, field edge or other reference point). As cosmesis is a major end point, the use of multiple tattoos is not desirable.

If tattoos are used as aids for patient positioning, sufficient points to create a 3D grid need to be used which can be aligned with the laser light beams in the treatment room. This is to ensure patient positioning can be confirmed in three dimensions.

## Conclusion

In conventional radiotherapy treatment, reproduction of the patient's position used for treatment planning for each treatment fraction is a basic requirement. Various aids and immobilisation devices assist in achieving this reproducibility.

Understanding and measuring the degree of position variation is important to the delivery of quality radiation therapy. Variations in target position, which cannot be eliminated by patient positioning and immobilisation, must be compensated for in treatment by increasing field size margins.

The breast as a target volume for radiation therapy presents some unique challenges for reproducibility of position during treatment, which have been discussed in this paper.

IMRT holds the promise of tailoring the radiation dose to the target volume more precisely. In breast conservation, radiation therapy for early breast cancer the potential benefits of IMRT are better cosmesis, less heart and lung toxicity and possibly reduced treatment related mortality. Reproducibility of the position of the target volume each fraction is critical for IMRT. There are continuing challenges in refining patient positioning and immobilisation methods to address all the technical requirements for application of IMRT to routine breast conservation radiation therapy.

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**Computed** | tomography planning

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for breast cancer:  
a discussion paper

Dr Geoff Delaney  
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## Summary

- The use of computed tomography (CT) planning for breast radiotherapy is increasing
- CT planning has improved the understanding of anatomical relationships between the treatment volume and organs at potential risk of irradiation.
- CT allows a better understanding of the dosimetry throughout the entire treatment volume, and may lead to changes in beam parameters to improve dosimetry.
- CT planning is necessary if intensity modulated radiation therapy (IMRT) is to be used for breast radiotherapy.
- Although there are limited data, the benefits of CT planning appears to justify further use for planning breast cancer treatment.
- The limitations of simulator computed tomography (Sim-CT), such as slow image acquisition time, tube overheating and incomplete acquisition of CT data, make it less useful for planning of treatment for breast cancer than conventional CT or computed tomography simulation (CT-Sim).

## Introduction

The aim of this discussion paper is to consider the use of computed tomography planning with specific reference to simulating and planning for breast cancer radiotherapy. This discussion paper includes:

- A background
- Varieties of methods of CT planning
- The advantages and disadvantages of CT planning compared with 'conventional' planning
- Minimum quality assurance requirements for introduction
- Recommendations

## I. Background

Treatment simulation and planning is a complex process. The particular complexities relating to radiotherapy for treatment of breast cancer include:

- The fact that the breast or chest wall is a complex, 3D structure, making radiotherapeutic dose homogeneity difficult
- The varying amount of tissue inhomogeneity (eg lung tissue within the treatment field)
- Radiotherapy may involve the use of one or more junctions with supraclavicular, axillary and/or internal mammary chain fields
- The breast moves during respiration

Traditionally, radiotherapy simulation and planning for breast cancer have involved the woman being immobilised, (often in a semi-recumbent position), the use of surface identification of the treatment volume (typically breast or chest wall) and the taking of simulation films. They have also included the taking of one or more manual surface outlines of the treatment volume with subsequent hand planning for dosimetry. The degree of inhomogeneity due to treatment beams traversing the lung has either not been considered, (ie no tissue inhomogeneity correction has occurred) or has been estimated from orthogonal simulator films.

Technological advances over the past 10-20 years have resulted in some potential improvements to the simulation and/or planning process, such as improved computerised planning systems and better diagnostic imaging. These advances have resulted in improved treatment precision and reproducibility, more uniform dose distribution and better dose prediction, as well as improved planning efficiency. As a result, this may have reduced treatment-related morbidity such as acute radiation pneumonitis.

The potential benefits for such technological advances include improved patient outcome (eg better tumour control and/or less toxicity), greater understanding of dose distribution and dose response and efficiencies of treatment and planning processes. However, the **direct** impact that technological changes have had on these end points is often either poorly understood or poorly studied.

CT planning involves the use of CT images of the patient in the planning process. This differs from non-CT planning, wherein the relationships of internal organs to the surface anatomy of the patient are derived from plain X-ray images. CT simulation provides several capabilities not available with conventional simulation. Because of the more accurate delineation of target volumes and critical normal structures from CT images, information on the internal and external anatomy of the patient as well as 3D representation of radiation beam geometrics is enhanced.

## Current clinical practice

There are currently no published clinical trials assessing patient outcome with CT planning versus without CT planning. Even if there were, these trials would be confounded by variations in the management of breast cancer over time with respect to pathological assessment, surgical management and the use of adjuvant therapy. However, CT scanning in radiation oncology has radically changed treatment planning and treatment complexity, by virtue of the individualisation of tumour volume localisation and field design in far greater detail than has previously been possible. It has been estimated that 10–40% of all radiotherapy patients may benefit from having CT simulation and planning.<sup>1</sup> However, no data on local control improvements secondary to CT planning have been reported.

CT planning is becoming more widely used throughout the world for breast radiotherapy planning. Kutcher et al.<sup>2</sup> estimated that 30% of 449 departments of radiation oncology surveyed in the United States used CT for breast patient planning, and that this was more common in hospital facilities (41%) compared with free-standing facilities (27%) or academic institutions (19%). In this study, CT was mainly used to obtain a contour of the target volume and a contour of the lung, but was rarely used to determine electron density for pixel-by-pixel inhomogeneity correction. A similar survey of Australian and New Zealand practice identified that approximately one-third of departments used CT for obtaining internal and external patient contours.<sup>3</sup>

## 2. Methods of computed tomography planning

There are three main ways in which CT can be utilised for simulation/planning:

### a. Simulator computed tomography

Simulator computed tomography (Sim-CT) is the use of a standard radiotherapy simulator with an optional CT attachment on the simulator gantry. Appropriate computer hardware and software is required. The amount of modification of the simulator can vary, from digitising the video information from the image intensifier right through to replacing the image intensifier with a linear array of detectors.<sup>1,4,5,6</sup>

Compared with a conventional CT or CT-Sim, image quality is usually considered poorer due to slow image acquisition time. Also, the number of images possible in one simulation session is small (often no more than about four to five slices) before the x-ray tube becomes overheated.<sup>4,5,6</sup> This limitation in terms of number of slices means that it is not possible to create digitally re-constructed radiographs for virtual simulation. Slow image acquisition times will also mean that the CT image is more likely to be distorted by patient movements such as breathing. Advocates of Sim-CT state that this lung motion equates better with the actual treatment,<sup>4</sup> although this has not been substantiated by clinical data.

### b. Computer tomography simulation

Computer tomography simulation (CT-Sim) is the use of a conventional CT array of detectors. The 'simulation' process then involves performing simulation on a computer-generated 'virtual image' of the patient (virtual simulation).<sup>7</sup> This eliminates the need for conventional simulation. Equipment includes a conventional CT scanner, a dedicated computer workstation and some form of laser system that is able to provide localisation verification points. Computer software has been developed to generate images that display the radiation therapy

beams in transverse, sagittal or coronal planes, or to provide reconstructed images from beam's eye view images. These can be used for comparison with simulation images, or even to replace the simulation process and compare with subsequent portal images. In addition, digitally reconstructed radiographs (DRRs) can be produced. DRRs are ray-line reconstructions through a 3D volumetric data set which generates the equivalent of a conventional transmission radiograph. Most contemporary 3D planning systems incorporate CT-Sim as a module of the planning system, thus removing the need for the very expensive dedicated computer workstation at CT. This makes CT-Sim much more affordable than before.

The main advantages of using conventional CT technology, as opposed to Sim-CT, is that image acquisition times are quicker, X-ray tube overheating is not a problem, the image quality is better and a full 3D volumetric set of data is available, allowing accurate dosimetry through the volume and enabling the use of DRRs (not available with a limited CT data set).

One disadvantage compared to with Sim-CT is that a dedicated CT room separate from the simulator is necessary (although virtual simulation using a dedicated CT may remove the need for a simulation room at all).

Another potential disadvantage is that determining the treatment volume is very difficult (if not impossible) at the edges of the breast where the breast merges with the soft tissues of the thoracic and abdominal walls, particularly in obese women. One method that has been reported to overcome the difficulties in defining the anatomical limits of the breast is to place a radio-opaque catheter around the breast tissue prior to CT. This provides a guide for the clinician when assessing the volume of breast tissue.<sup>7-10</sup> Dedicated CTs may also have problems with small aperture sizes limiting the diameter able to be scanned at any one time. However, dedicated CTs with larger aperture sizes have recently become commercially available, although they are more expensive than conventional CTs. A technique where the woman lies flat (as opposed to being on an angled board) may also mean that she can fit through the smaller aperture. Alternatively, the woman may be 'reversed' through the conventional sized aperture.

### **c. A combination of conventional simulation and computed tomography**

This approach involves the use of conventional simulation technology to localise the target volume and to set beam parameters such as field size, gantry and collimator angles and shielding. The patient then undergoes a conventional CT scan in the treatment position, on either a dedicated CT unit within a department or a diagnostic unit (where image data may be transferred to the planning computer by magnetic tape, optical disc or by a computer network). The beams determined in conventional simulation are then placed on the CT image. The CT data set is used as a source of internal and external contours, tissue inhomogeneities and electron densities.

The main advantages of this approach is that the target volume can be determined at conventional simulation. Identification of where the breast tissue stops near the edges of the breast is extremely difficult (if not impossible) to determine using CT, as the tissue density of the breast and surrounding soft tissue are equivalent. In addition, placing a target volume on a full 3D volumetric set can be very time consuming.

Some of the disadvantages of this technique compared with both Sim-CT and CT-Sim is that it involves two treatment set-ups (one in simulation and one in CT). This adds time to the simulation process and also introduces the opportunity for variations in set-up between simulation and CT. It is therefore crucial that a strict, accurate protocol of set-up procedures is established, with set-up parameters recorded in simulation and then followed for CT.

### 3. Possible advantages of computed tomography

The possible advantages of CT include:

- **Provision of accurate internal and external contour data, including lung details**

Studies have shown the importance of using lung correction data to achieve the best estimate of actual dose delivered.<sup>11,12</sup> Accurate assessment of tissue inhomogeneity therefore becomes necessary. However, no study has been performed comparing lung volume estimates with and without CT planning and linking patient outcomes with planning methods. However, it would seem logical to conclude that CT is more accurate than the more historical methods of simulation. CT will result in more accurate data being collected about the treatment dose received in various parts of the breast, and should enable accurate analysis of the relationship between patterns of relapse and treatment dose. It will also allow more accurate knowledge of lung and heart dose, and greater correlation between outcome and dose.

- **Provision of additional information on off-axis dosimetry**

The CT plan (particularly if done using a conventional CT) will enable off-axis dosimetry. This allows the dosimetrist and radiation oncologist to more accurately assess dose inhomogeneities in the off-axis plane. Such inhomogeneity is often worst in the superior or inferior parts of the breast, and can therefore only be corrected if known;<sup>13-15</sup> it is particularly important in women with large breast volumes where very large hot spots often occur.<sup>16,17</sup> Knowledge about these hot spots at planning will allow beam parameter correction through changing field weightings or adding wedges to decrease hot spots, which has the potential for reducing toxicity.<sup>16,17</sup> In one study, 52% of plans would have been improved if

planning had gone from a single central axis outline to using full CT data at 10mm intervals.<sup>16</sup> A further 21% of plans improved by moving from planning from three slices to using full CT data.<sup>16</sup> This would suggest that using conventional CT with the ability to generate a full data set is superior in dose prediction to Sim-CT, where only a limited set of data is available due to the slowness of image acquisition and problems of X-ray tube overheating.

- **Potentially better evaluation of match-plan dosimetry in three or four field techniques**

Edlund et al.<sup>18</sup> have described how a single isocentre technique for three field breast treatments has better evaluation of the match line dosimetry using 3D planning, as opposed to using two-dimensional (2D) planning. The 3D planning is facilitated by having a full 3D data set, as opposed to more limited data sets or manual surface outlines.

- **Omission of conventional simulation**

Conventional simulation may be eliminated with the use of virtual simulation using the full 3D data set and the use of DRRs.<sup>1,7-10</sup> Due to the large amount of breast radiotherapy administered in radiation oncology departments, this would require a dedicated CT unit. This option would only be available for a CT scanner, as opposed to Sim-CT which cannot acquire sufficient images to enable DRR construction.

- **Construction of tissue compensation**

With the use of the full CT data set, particularly the data about tissue contour and volume densities, more accurate compensators can be constructed to allow for missing tissue and tissue density inhomogeneities.<sup>19,20</sup> However, techniques that do not use CT planning have also been described, such as using an electronic portal imaging device (EPID) as a means of generating dosimetric information from which the radiological soft tissue thickness is then deduced. This map of radiological thickness is then used to give the best theoretical compensator.<sup>21</sup> No comparative assessment of these differing techniques has been reported, and nor has there been sufficient information to know whether using EPID is practical.

For the future, CT images will be necessary for the accurate performance of IMRT. Without CT, IMRT would be impossible. Simple MLC beam arrangements for breast irradiation, where better uniformity of dose is achieved, have already been described.<sup>22</sup>

- **Assessment of breast boost dose irradiation**

Various techniques have been described to measure depth from skin to chest wall so that the energy level of the electron boost can be decided. These include estimation by clinical parameters; use of ultrasound;<sup>23,24</sup> and CT.<sup>25,26</sup> The advantage of CT is that often the post operative haematoma or seroma is identifiable, allowing the boost to be positioned more accurately. The use of CT has been shown to improve boost planning by 70-80% compared with clinical mark-up,<sup>25,26</sup> particularly if radio-opaque clips are placed at the time of surgery.

- **Better evaluation of brachytherapy implant geometry**

CT is increasingly being used to assess brachytherapy implant geometry for a number of different treatment sites. This could mean better dose estimations compared with conventional geometry assessments (usually orthogonal films). Further published analysis is required.

- **Use of dose volume histogram data**

By manipulation of the CT data set, full volumetric analysis of lung dose can be achieved. Further research is required into the relationship between risk of pneumonitis and lung volume dose histograms. However, the routine use of such data may be useful to predict pneumonitis risk.<sup>27</sup> The analysis of anterior heart dose and dose to the coronary arteries is also important in examining the association between some radiotherapy techniques and heart dose.<sup>28</sup>

- **Image fusion**

The introduction of software to perform image fusion - whereby an MRI or positron emission tomography (PET) scan image may be ‘fused’ with the CT image from planning - introduces another possible improvement in breast radiotherapy. This image fusion may be achieved using PET or MRI to provide better definition of the extent of the tumour and to allow better definition of that area of the breast that needs a high dose. As yet, no clinical studies have been performed to confirm this, approach, which would be particularly useful for boost treatments for locally advanced/inoperable breast cancers.

#### **4. Possible disadvantages of computed tomography**

The possible disadvantages of CT include:

- **Unproven in the clinical setting to improve outcome**

No data are available on improved clinical outcomes with the use of CT planning for breast cancer. However, such data may be difficult to obtain: as improvements with radiation treatment and delivery occur, so do improvements to pathological assessment of tumours, surgical techniques and systemic treatment, making it difficult to attribute improvements in outcome to any one particular area.

- **Cost**

CT planning adds significant cost in terms of the machinery, software and extra floor space. However, as planning systems become more sophisticated and treatment techniques in radiotherapy become more complex (eg IMRT), a dedicated CT scanner is easier to justify. In addition, there has been a significant increase in the use of CT planning for other tumour sites, so that many departments now have the capabilities within the department to do CT planning for the treatment of breast cancer.

- **Set-up problems**

The aperture size of CT simulators may be too small to allow the patient to enter the aperture in the preferred treatment position. However, techniques with one arm up and one arm down or on a flat bed with both arms above the head can overcome this problem. In addition, as mentioned above, CT scanners with large aperture sizes are now commercially available. Sim-CT has the advantage of usually having sufficient clearance to allow the patient to remain in the set-up position.<sup>4</sup> However, patients can fit into smaller apertures with minor modification of treatment technique, such as having the woman treated with her arms above her head (rather than the ipsilateral shoulder abducted to 90°).<sup>8-10,16</sup> Dedicated CT may require the woman to lie flat (as opposed to being on an inclined board) to allow passage through the CT tunnel. Large aperture sizes may allow a slight incline. However, the only potential advantages of lying on an incline are in the uncommon situation where the woman has a breast that falls superiorly when lying flat, thus making it impossible to adequately treat lymph nodes. Given that many departments successfully treat patients lying flat in most instances, the absolute need of lying patients on an incline has never been proven in clinical practice.

- **Difficulty in defining breast tissue during virtual simulation**

The breast tissue and adjacent soft tissue have similar electron densities on CT scan, and thus appear similar. When placing a treatment volume on the CT, it might therefore be difficult to distinguish between the breast and surrounding soft tissue<sup>8</sup>. The clinician can overcome this problem by placing radio-opaque markers to mark the treatment volume by the clinician before CT.<sup>8-10</sup>

- **Resources**

If CT is added to conventional simulation procedures, then additional human resources may be required. However, if virtual simulation takes place, then usage time of conventional simulators would be reduced or perhaps eliminated.

- **Image quality**

The image quality is improving, particularly for CT-Sim. However, proponents of Sim-CT, which has lower quality images, state that the same degree of quality as diagnostic CT is not necessary for purposes of simulation.<sup>4</sup>

- **Simulation time**

Image acquisition time is particularly slow for Sim-CT. The number of patients able to be simulated is therefore reduced compared with conventional simulation. In addition, overheating of the tube makes it impossible to obtain a complete CT data set.

## **Areas for possible clinical investigation**

As stated above, there are a number of areas in the use of CT planning for breast radiotherapy where there are little or no data providing opportunities for research. These areas include:

- Assessment of clinical impact of CT on local control
- Simulation/planning efficiency with CT compared with conventional Sim (time and motion study and assessment of resource utilisation)
- Correlation between lung DVH and pneumonitis risk
- Correlation between heart DVH and cardiac risk
- Cost-benefit analysis of different forms of CT planning
- The use of image fusion in breast planning
- The reproducibility of breast position using serial CT scans
- The use of prescription points, such as those recommended in International Commission on Radiological Units and Measurements (ICRU) 50/62

## 5. Computed tomography implementation: issues for consideration

It is very difficult to make firm recommendations based on clinical data for the standard use of CT planning in the planning of breast radiotherapy, as clinical outcomes have rarely been examined in past clinical trials of this approach. The advantages and disadvantages need to be assessed, and perhaps a cost-benefit analysis performed on the limited clinical data available. However, there are at least some potentially clinically significant advantages that can be achieved with the introduction of CT for breast cancer:

- Better dose homogeneity
- Better allowance for variations in tissue density
- Better definition of the boost volume
- Facilitation of IMRT

These would justify the further use of CT in the planning of breast radiotherapy. If IMRT is introduced on a routine basis into clinical practice for breast radiotherapy, then CT planning will be essential. Given the significant dose heterogeneity problems encountered in breast planning, a move to IMRT in breast treatment would seem beneficial. It appears that a dedicated CT unit or CT-Sim (as opposed to Sim-CT) offers greater advantages in terms of image quality and number of images that are able to be obtained in a timely fashion.

A number of publications<sup>29-32</sup> have identified recommendations for the implementation of CT. These include:

1. Ensuring software compatibility between the planning system and CT
2. Deciding between the various CT methods (CT-Sim, Sim-CT)
3. Obtaining the largest aperture possible (to allow patient set-up within aperture)

4. Having localisation markers available in the CT room (eg laser lights)
5. Having a flat insert for the couch that enables accurate reproducibility of the treatment set-up. Most couches come with a concave tray
6. Establishing contingency plans for patients unable to undergo CT (either too large or too claustrophobic), or for treatment set-ups that preclude CT aperture entry (eg if a tilt board is needed). These plans might be to perform standard simulation without the use of CT
7. Ensuring accurate couch registration
8. Allowing the largest possible circle of reconstruction to prevent the 'cutting off' of anatomy on the radiological image
9. Utilising rapid scan capabilities with thin CT slices. A spiral CT would be particularly useful for this purpose
10. Ensuring the CT software has capabilities for reconstruction (sagittal and coronal reconstruction as a minimum)
11. Ensuring CT provides high CT number precision, readily convertible to electron density data
12. Using high-quality image analysis software, including CT number statistics, distance measuring rulers, geometric beam, image subtraction and multiple format viewing
13. Establishing a network between CT and the planning computer (although magnetic tape or optical disc can be used instead)
14. Facilitating a large amount of data storage
15. Ensuring that the planning system can produce digitally constructed radiographs and DVHs

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