COMPUTERISED TOMOGRAPHY IN RADIOTHERAPY PLANNING

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COMPUTER TOMOGRAFIE BIJ RADIOTHERAPIE-PLANNING

PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD VAN
DOCTOR IN DE GENEESKUNDE
AAN DE ERASMUS UNIVERSITEIT ROTTERDAM
OP GEZAG VAN DE RECTOR MAGNIFICUS
PROF. DR. J. SPERNA WEILAND
EN VOLGENS BESLUIT VAN HET COLLEGE VAN DEKANEN.
DE OPENBARE VERDEDIGING ZAL PLAATSVINDEN OP
VRIJDAG 30 SEPTEMBER 1983 TE 14.00 UUR

DOOR

PETER COLIN BADCOCK
geboren te London

1983

grafische verzorging:
ROOD DAVIDS
ALBLASSERDAM

PROMOTOREN: PROF. DR. B. VAN DER WERF-MESSING
PROF. DRS. A.H. TIERIE

He loved not fish, though born in a fish town. He was begot (as they say) "behind doors". His father was the tenth and youngest of his grandfather, who was therefore designed to be dedicated to God. His father took great care to send him to an excellent school, which was at Dusseldorf in Cleveland. He studied sometime in Queen's College in Cambridge. He mentions his being there in one of his "Epistles", and blames (criticises) the beer there. He had the parsonage of Aldington in Kent, which is about three degrees perhaps a healthier place than Dr Pell's parsonage in Essex. I wonder they could not find out for him better preferment; but I see that the Sun and Aries being in the second house (in his horoscope), he was not born to be a rich man. He built a school at Rotterdam, and endowed it, and ordered the institution. A statue in brass is erected to his memory on the bridge at Rotterdam. They were wont to say that he was interdependent (suspended) between Heaven and Hell, till about the year 1655 the Conclave at Rome damned him for a heretic after he had been dead (a hundred and twenty) years. His deepest divinity is where a man would least expect it: viz in his colloquies in a dialoque between a butcher and a fishmonger. He was the scout of our knowledge, and the man that made the rough and untrodden ways smooth and easy.

His name was Gerard Gerard which he translated into DESIDERIUS ERASMUS.

Excerpts from "Brief Lives" by John Aubrey 1626 - 97.

The printing of this thesis was supported in part by grants from the Affiliatie Fonds of the Sophia Ziekenhuis, Zwolle and the ten Doeschatefonds of the ziekenhuis "De Weezenlanden", Zwolle.

CONTENTS

ABSTRACT

This study evaluates the effectiveness of computed tomography as an adjunct to radiotherapy planning. Until recently, acquisition of accurate data concerning tumour anatomy lagged behind other developments in radiotherapy. With the advent of computer-tomography (CT), these data can be displayed and transmitted to a treatment planning computer.

205 Patients had their treatment fields simulated using findings from physical examination, Xrays etc. The patients were then scanned under conditions simulating the radiotherapy and the dose distribution was recalculated. The technique is acceptable to the patients but represents an increase in the workload of the radiotherapist, radiographer and physicist. CT scanning was found to be valuable in radiotherapy planning in 58% of the treatment series (field geometry: 36%, dose distribution: 39%).

We have concluded that the greatest inaccuracies in the radiation treatment of patients are to be found in both the inadequate delineation of the target volume within the patient and changes in body outline relative to the target volume over the length of the irradiated volume. The technique was useful in various subgroups (pelvic, intra-thoracic and chest-wall tumours) and for those patients being treated palliatively. With an estimated improvement in cure rate of 4.5% and cost-effective factors of between 3.3 and 5, CT-assisted radiotherapy planning appears to be a worthwhile procedure.

UITTREKSEL

Dit onderzoek evalueert de waarde van computer tomografie bij de radiotherapieplanning. Het verzamelen van gegevens omtrent de anatomie van de tumor liep tot voor kort achter bij de ontwikkelingen in de radiotherapie. Met behulp van de computer tomografie (CT) kunnen dit soort gegevens nu op een ideale manier worden afgebeeld en worden ingevoerd in een computer planning systeem.

Bij 205 patiënten werden de bestralingsvelden ingesteld met behulp van de conventionele methoden (lichamelijk onderzoek, roentgen foto's, etc.). Vervolgens werden de patiënten gescand in exact dezelfde positie als waarin ze zouden worden bestraald. Met behulp van het computer planning systeem werd de dosisverdeling opnieuw berekend. De techniek is aanvaardbaar voor de patiënten maar betekent een toename van de werkbelasting van de radiotherapeut, laborant of fysicus. Bij dit project was de CT van groot belang bij de radiotherapie planning van 118 (58%) van de 205 patiënten (bij de geometrie van de bestralingsvelden: 36%; bij de dosisverdeling: 39% van de bestralingsseries).

Wij constateerden de grootste onnauwkeurigheden in de radiotherapie zowel bij het intekenen van het doelvolume als bij de verhouding tussen de lichaamsomtrek en het doelvolume over de lengte van de bestralingsvelden. De techniek was van waarde bij verscheidene subgroepen (pelviene, intrathoracale en thoraxwand tumoren) en bij die patiënten die palliatief bestraald werden. De kans op genezing wordt verhoogd met 4,5% (geschat); ten aanzien van de kosten is de techniek tevens verantwoord. Daarom lijkt computer tomografie van waarde bij radiotherapie planning.

GLOSSARY OF TERMS

ABSORPTION VALUE as computed and displayed by the CT scanner is the difference between the absorption value for the material at a given point and the absorption value for the material at a given point and the absorption value of water. On the scale water is arbitarily set at zero and other materials related to this in an arbitary but linear fashion, air being - 1000 Hounsfield units and bone being up to about + 1000 Hounsfield units, depending on its density however. Is is difficult to accurately convert the absorption value of a material to its electron density.

CT: computerised tomography, see chapter 2.

IVC: independent viewing console, see chapter 2.

NON-UNIFORMITY OF DOSE is present if the absorbed dose in the target volume (on the the central plane) varies by more than $\pm$ 5% of the target dose.

OFF-AXIS TARGET DOSE is the absorbed dose at the point as defined for the 'target dose' (ie usually at the intersection of the axes of the various beams) but on a plane other than the central plane.

PARTIAL VOLUME EFFECT occurs when a particular structure occupies only part of the thickness of the scan. Density measurements will then be inaccurate because the densities of the surrounding tissues will also contribute to the readings. Delineation of the organ will thus also be compromised.

RELATIVE ELECTRON DENSITY is the electron density relative to that of water.

SCANOGRAM is a projection image of a longitudinal section of the patient's body onto which the levels of the various transverse scan slices are reproduced for easy localisation. The scanogram usually bears a superficial resemblance to a A/P radiograph but other projections are possible i.e.

lateral view for head-and-neck tumours (synonym: scout-view, topogram). Although there is still evidence of beam divergence across the field of view, this is eliminated in the longitudinal direction so making the difference between this image and a conventional X ray photograph.

SIGNIFICANT DISCREPANCY in dose calculation is recorded if the absorbed dose as measured using the CT scan data varies by more than $\pm$ 5% of the target dose as computed by the TPS on the central plane or by more than $\pm$ 10% on other planes.

TARGET DOSE: the absorbed dose which is representative of the dose distribution in the target volume. Its specification depends on the treatment technique ie:

a. for a single beam it is the absorbed dose on the central axis at the centre of the target area;
b. for two opposed coaxial equally weighted beams it is that dose which is absorbed on the central axis midway between the two beam entrances;
c. for other arrangements of two or more intersecting beams the target dose is specified at the intersection of the central axes of the beams.

TARGET VOLUME contains those tissues that are to be irradiated to a specified absorbed dose according to a specified time dose pattern. For curative treatment the target volume consists of the demonstrated tumour and any other tissue with presumed tumour.

THERMOLUMINESCENT DOSIMETRY (TLD) makes use of the property of certain specially prepared crystalline materials which, having been previously exposed to ionising irradiation, are subsequently heated whereupon an amount of light is emitted which is proportional to the absorbed dose of irradiation.

TPS: treatment planning system, see chapter 1.

TREATMENT VOLUME is the volume enclosed by an isodose surface the value of which is the minimum target absorbed dose.

WINDOW LEVEL is the point on the Hounsfield scale about which the selected window is centred. Selection of window level is dependent on the type of tissue being displayed. The total range of tissue attenuation is arbitarily divided into 2000 units from air at - 1000 through water at 0 to + 1000 as a maximum. This range is represented on a photograph with restricted grey scale and can be limited to looking at only a small part of the total scale - the "window" (abbrev. WL).

WINDOW WIDTH displays contrast and its variation allows distinction between tissues of different density. If a small window width is selected, tissues with small Xray attenuation difference are shown as having high contrast difference on the screen. If a large window width is selected, tissues with small Xray attenuation differences are less clearly distinguished from each other whilst tissues with large Xray attenuation differences are shown as having different shades of grey instead of being merely displayed as black or white (abbrev. WW).

CHAPTER 1

INTRODUCTION

In about 30% of patients the initial treatment fails to control the primary malignancy. Not infrequently the assumption is made that the primary tumour does not now represent a major clinical problem but that the only significant problem is metastatic disease. Of 175,500 annual deaths in the US cancer population, Suit (1970) estimated that 58,000 patients died with local failure as the major cause of death. Only those sites were considered for which radiotherapy played a significant role. A deliberate effort was made to be conservative in selecting for each site the proportion of deaths in which regrowth of the primary legion was a significant part of the terminal phase of the disease.

The admittedly crude estimate gave however the minimum number of local failures expected to occur in the US cancer patient population if this population was treated by the best methods currently available. From this estimate it can be appreciated that if research were to lead to radiotherapy techniques which were regularly successful, then some 60,000 patients each year would not experience the tragedy of regrowth of their tumours. This would clearly be an enormous advantage in clinical oncology. The actual reward of better radiotherapy might be even greater than suggested by the local failure figures. Probably in the clinic the tendency is to over-estimate the frequency of metastasis without concommitant recurrence, because the distant metastasis usually dominates the clinical picture from the time that it is detected. After that time little attention may be given to the primary site by the doctor or patient. This clinical fact likely means that we under-estimate recurrence rate, the error being small but real.

During the last seventy years of radiotherapy, advances in technology and in clinical skills have resulted in many improvements in local control figures. In those anatomical sites where the dose delivered to a tumour has not been increased relative to that given to the surrounding normal tissue, local control results have shown little change i.e. cancers of the skin and

larynx. However when improvements in dose distributions have been achieved (due to technology or clinical ingenuity), local control rates have gone up i.e. cancers of cervix, bladder, breast, certain sites in head and neck, Hodgkin's disease etc. Local failure of radiotherapy can be subdivided into edge recurrence (whereby the tumour extended beyond the treatment volume and the subject of chapter 3) and central recurrence (whereby the dose in the treatment volume was less than adequate and the subject of chapter 4).

Successful radiotherapy practice depends on irradiating tumours to a sufficiently high dose to cause their destruction without producing unacceptable damage in the surrounding normal tissue. The last twentyfive years have seen the advent of supervoltage treatment apparatus, improved methods for measuring dosage, therapy simulators, mould rooms and treatment planning computers. With these important developments the planning of radiation treatments had become increasingly sophisticated allowing a better differential between the dose administered to the tumour and that received by the normal tissues. The potential for curing localised malignant disease had thus increased.

Unfortunately the techniques for the acquisition of data relating to the patient's anatomy and tumour location have lagged behind progress made in other directions. For instance, the planning of radiation treatments is usually performed on cross-sections of the relevant part of the body, whilst diagnostic data concerning the anatomy of the tumour is radiologically portrayed in vertical planes, be it coronal or sagittal.

The accuracy of depicting the tumour within the patient is of paramount importance. If it is underestimated, part of the tumour escapes adequate treatment. If it is overestimated, much healthy tissue is unnecessarily irradiated causing side effects to the patient which could have been avoided and, even worse, limiting the dose that can be given to such an extent that underdosage may occur. In both cases active tumour cells survive, grow and cause further symptoms in an already irradiated area that may be impossible to treat further.

The transfer of information from the vertical plane as pictured on X-rays to the horizontal plane on paper tends to be inaccurate as allowance had to be made, for instance, for differences in scale, X-ray beam divergence, obliquity of the beam with respect to the body and difficulty in precisely locating the skin surface. Even in the 1980's radiotherapists still sit daily with pencil and paper, rulers and X-rays, striving towards a precision which the tools of this trade deny them, or accepting with resignation, the undesirable damaging of large volumes of healthy tissue in order to catch and exterminate every last tumour cell.

In our opinion this last step is not only inaccurate and time wasting but can also be superseded. With the advent of the CT scanner, radiotherapists can acquire a more comprehensive assessment of tumour morphology and the position of the tumour in the patient, both portrayed in cross-sections of the body. The purpose of this study was to test the feasability of applying this new imaging technique and make an estimate of the incidence of the insufficiencies made before CT scanning became available by checking patients who have also been planned conventionally.

Radiotherapy

The basis of the value of radiotherapy in the treatment of cancer is that ionising radiation, which is always damaging to living tissue, produces more damage in malignant than in non-malignant tissues. A dose of radiation sufficient to kill cancer cells will produce considerable, but hopefully not irreparable, damage to normal tissue so that the latter recovers whereas the malignant tissue does not.

In clinical practice the therapeutic margin is narrow and you usually have to accept a compromise whereby you accept a certain degree of permanent residual damage as a sequel to the destruction of a lethal tumour. The acceptable extent of such alteration of normal structures varies in different settings; however the integrity of indispensable normal tissues must be maintained. It is one of the major frontiers of radiation research to make radiotherapy more selective. Improvements in the therapeutic ratio can come from either a reduction in normal tissue injury or an increase in effectiveness of tumour treatment (Kramer, 1976). This can, in theory, be achieved by the exploitation of various fractionation schemes, radiosensitisers, radioprotectors and the irradiation of tumours with particles.

Of today's Dutch population, about one third will require treatment for cancer during their lifetime. In 1978 there were almost 28,000 cancer deaths accounting for about 25% of the mortality figures. Each year 3.25 new cancer cases per 1,000 inhabitants are registered and, of these, 1.4 require some form of radiotherapy. Probably these data are an underestimate because a proportion of the cases are not registered. In 1980 there was a national requirement for the irradiation of 20,155 new patients (Staatsblad, 1978 p. 761 and Nederlands Centraal Bureau voor de Statistiek). According to the most recent Dutch studies, about 40% of cancer patients can be cured of their malignancy.

The radiotherapy is planned with the aid of the physicist, who is responsible for dosimetry. Responsibility for treating the patient according to the plan rests with the radiographer. However, this precise division of responsibilities, though useful in some ways, must not be allowed to obscure the fact that radiotherapy is very much a collaborative exercise in which the three disciplines of the radiotherapist, physicist and radiographer must be welded together in the closest possible team work.

In order to give an adequate dose to a tumour deep in the body, without at the same producing excessive doses in more superficial tissues, it is necessary to use a number of beams directed towards the tumour from different directions. The dose of irradiation absorbed by the tumour depends not only on the energy and L.E.T. of radiotherapy given but also on the depth of the tumour from the irradiated skin surface. On a diagram of the relevant cross-section of the patient, the radiotherapist indicates the area which he wishes to treat to a high and uniform dose (the target volume). The position of the various irradiation fields can be marked on the diagram and the contribution of dose from each field can be calculated at various points of interest within this outline. These data can then be presented in diagramatic form so that the irradiation dose can be predicted in various points in the target volume and surrounding normal tissues when the patient is to be irradiated with that particular technique.

Treatment Planning System

Over the past few years there has been increasing use of the digital computer (TPS) to calculate and plot out the isodose lines resulting from multi-field irradiation of a target volume within the outline of a patient's cross-section. They work quickly, save labour and are usually less subject to errors than manual methods; however some inaccuracies always remain, ie. the inability to allow for radiation scattered from adjacent planes. Distributions of radiation dose in any plane, and not merely in the plane of the central beam axes, can be easily investigated. There is little doubt that the computer had an important role to play in radiotherapy as in so many other activities. The provision of more accurate dosage information and treatment plans is of the greatest value to radiotherapy provided that their accuracy can be reproduced during both the obtaining of the basic anatomical information from the patient and during the application of his treatment.

Simulator

The preparatory work and planning of the majority of radiation treatments makes use of the simulator. Using this apparatus various radiotherapy techniques can be tried out whilst visually checking on the image intensifier which organs would be irradiated. The fields which are to be treated can be marked-up on the skin. A safety margin is usually to be allowed for whereby the treatment volume has to be slightly larger than the target volume. Increased knowledge of the characteristics of the tumour (of an invasive behaviour, sites of possible regional metastases) have lead to a more rational treatment policy. The method of applying the ionising irradiation depends on the pathway along which the beams have to transverse the body to reach the target volume. Hereby you try to reduce to a minimum permanent structural and functional damage to important organs. The topography of these organs and of the tumour target is therefore extremely important.

Usually the patient lies on the treatment couch during his radiotherapy. The central axes of the various beams usually run through one plane at right angles to the longitudinal axis of the patient. It is on this plane that the body contour is taken and the anatomical data related to one another. These data are usually obtained by taking two othogonal X-ray photos whilst the patient lies in the treatment position on an imitation treatment couch in the simulator unit. The direction of each X-ray beam which has been used to take the photos is also marked up on the skin and body contour. In many instances the target volume is not visible on the X-ray photos. In order to judge whether this volume lies within the treatment fields, one has to refer back to other structures which can be visualised on the X-ray films. The data (skin contour, skin markings etc) are plotted onto paper in order that the radiotherapist can draw in the various volumes (tumour target, organs to be avoided) after which a distribution of irradiation dose can be computed.

The Aims of this Study

In the context of treatment selection and implementation, CT scanning may make a significant impact to the following stages:

a. tumour detection and staging for determination of treatment goals and modalities;
b. selection of radiation techniques and the configuration of external radiation beams;
c. compensation for the tissue inhomogeneities;
d. dose calculation in three dimensions;

e. monitoring of tumour regression during treatment (experience in other units suggests that this is less simple than one would imagine);
f. follow-up of treated patients.

In this study we have concentrated on steps (b), (c) and (d) provisionally because of the limited time available on the CT scanner. It was at these stages that the accuracy of the various outlines (body, tumour and critical organs) obtained by the CT scanning could be most valuable in the calculations of the treatment planning computer. In order to assess the degree of its contribution, the CT scanner was used to check the irradiation techniques of patients who had already been conventionally planned using the simulator unit.

Remembering the estimates of Suit (1970) we were particularly interested in cases of geographical miss by the radiation beams (chapter 3) and underdosage of the target volume (chapter 4). Regarding normal tissues, we were looking for cases of both overdosage and unnecessary irradiation of large volumes. Using the CT data, the irradiation volumes were also to be planned three-dimensionally so that this evaluation could be extended to areas off the central axis of the irradiation fields. Using experience gained it was hoped to identify the various patient groups for whom CT scanning was most necessary and to assess the errors of conventional planning within the context of the other errors associated with radiation therapy. Furthermore our results would be compared with those previously published by other institutes bearing in mind that their studies were usually smaller and that fewer criteria had been evaluated (see chapters 3, 5, 6 and 8). Furthermore it was hoped to begin to explore other facets such as the peculiar characteristics of tumour tissue which could be used for identification and delineation of malignancies, the changes in these characteristics as an expression of response to treatment and the speed of regression of the tumour after treatment. The provision of CT scanning is expensive but the retreatment of patients with recurrence of their primary tumour is also a large and costly national problem. It was hoped to make an analysis of these various costs.

Despite the high technology and heavy investment in radiotherapy we are still confrtonted with large numbers of patients with recurrence of their primary tumour. Factors such as the number of clonogenic tumour cells, repair, radio-responsiveness and growth-rate play an important role here. The narrow therapeutic margin hinders further advances. Many patients are cured locally of their malignancy but many other with similar tumours are not. Are we overlooking geographical misses by the irradiation fields or imperfect distribution of radiation dose in this latter group? Perhaps CT scanning can offer us some simple answers.

CHAPTER 2

MATERIALS AND METHODS

The CT Scanner

Computerised tomography (CT) is a technique of radiology developed by Godfrey Hounsfield and his team in the sixties and seventies in England. The Dutch radiologist Ziedses des Plantes developed techniques for X-ray tomography in the early 1930's and in 1938 Frank proposed an optical back-projection technique for the reconstruction of transaxial X-ray images. Despite the improvements of Edholm, the limitations of the technique prevented the images from attaining a better quality than that of conventional tomograms. With the invention of rotation radiography by Takahashi it also became possible to make conventional tomograms in the transaxial plane. Much earlier, in 1917, Radon demonstrated that a two or three dimensional object could be uniquely reconstructed from an infinite set of projections.

However it was not until 1956 that image reconstruction from a set of projections yielded useful results when Bracewell and Riddle applied the principle to radioastronomy. In 1963 Cormack described a practical method of applying the mathematics of image reconstruction. All the basic ingredients for CT were available whereby Hounsfield could develop the EMI Mark 1 scanner. The contribution of Cormack and Hounsfield was recognised in the Nobel Prize for Medicine and Physiology in 1979. CT scanning represents a milestone in developments in medical imaging started off when Rontgen produced his first X-ray photo of a hand in 1895. His achievement was crowned with the first Nobel Prize for Physics in 1901.

By conventional radiodiagnostic techniques the image is recordes directly on film and depends on the differential in transmission of the X-ray beam through different structures. The differential is relatively insensitive and can only distinguish between bone, water, fat and air; mammography and xeroradiography being two exceptions. Because CT uses collimated

detectors it is possible to visualise smaller differences in transmission than with conventional tomography. As CT yields images of transverse sections, the technique routinely reveals many normal and pathological structures which would be extremely difficult to visualise by conventional radiography even with the use of contrast media. The success of CT results from the combined application of three unrelated approaches which endow CT imaging with the capability of distinguishing minute differences in X-ray attenuation:

(i) the CT method of reconstructing a sectional image from a series of projections taken at different angles around the objects to be imaged;
(ii) the method of CT data acquisition that is carried out with a collimated detector resultingin a concomitant marked reduction of the contrast depressing effect of scattered radiation;
(iii) the minimisation of noise ("electrical" and "photon") in the data that are utilised in reconstructin the CT image, by using a large number of photons to reduce statistical fluctuations and by employing low-noise detectors.

The CT methods of image reconstruction in the computer utilises a series of projections taken at different angles and it yields a transaxial-sectional image of the part examined. The method of data acquisition in CT can perhaps best be illustrated in an extremely simple form. An X-ray tube produces a beam of radiation which is collimated to a small rectangle. This beam, after passing through the patient and after being further collimated, impinges upon a detector whose connections allow the measurement of an electrical signal. The X-ray tube and detector are rotated about an axis perpendicular to the section to be visualised. The data gathered by this method consist of a series of "profiles" of the attenuation of X-rays in the tissues traversed for each of the angles of scan rotation. The profiles are recorded in a digital form by a computer system from which an image of the transverse section can be reconstructed.

It is this data (skin contour, tumour boundaries, areas of vital normal tissues, volumes of abnormal density) which are needed for accurate radiotherapy planning. Their portrayal in the transverse section of the region to be irradiated permits their direct use in the treatment planning computer without further interpolation of the data and the possibility of concommitant inaccuracies. For this study the patients were scanned on a Philips Tomoscan 300 scanner using a slice thickness of 12 mm and a scan time of 4.2 seconds though most modern scanners could be used for a similar purpose with a minimum of modification.

A few points deserved to be stressed as they appeared important to us.

The patient is scanned in the treatment position which sometimes involves modifying the traditional scanning or, less often, treatment techniques. Patients with breast cancer, for instance, are planned, scanned and treated with the ipselateral hand placed on top of the head. A flat couch top is a prerequisite. In order to display the necessary sections of the body outline, a machine with the largest possible aperture is necessary. From our experience with an aperture diameter of 56 cm, attention to patient aligment is still often necessary when scanning the pelvis. In order to obtain the fullest co-operation of the patient, short scan times (in Zwolle 4.2 seconds) are desirable to complete the procedure within twenty to thirty minutes. A scanogram is of the utmost importance in order to localise the scan slices on an AP or lateral X-ray projection (see glossary of terms).

In order to minimise data processing problems between the CT scanner and the treatment planning system (TPS), these two pieces of equipment were purchased from the same manufacturer. In order to obtain optimum information it is necessary to keep the various reference points in and on the patient in constant positions in the chain simulator-CT scanner-radiotherapy apparatus. The positioning was not yet fully satisfactory but we have started to install identical laser light systems at the three points indicated in the chain. Since the three pieces of equipment: CT scanner, viewing console (IVC) and beam planning computer (TPS) are independent units, different stages in the planning chain of three separate patients can be worked upon simultaneously. Furthermore, once the scanning is completed, the patient may leave the department and the further steps can be undertaken when convenient for the various members of the team.

During the period concerned (one year) it was not possible to use the CT scanner on 4.9 days in connection with repairs and on 5.0 days because of routine service commitments. The mean intervals between field simulation and CT scanning was 5.2 days (range 0 to 22 days). Obviously the irradiation technique cannot then be corrected until the second week of the radiotherapy. Clearly the CT scan data came too late to be used to improve the treatment of some patients.

Patients

About 40% of the patients presenting as new to the radiotherapy department have tumours in either the head and neck region or pelvic region. It is these tumours which generally tend to continue presenting only loco-regional problems; which are difficult to delineate as they occur in areas which cannot

always be adequately examined with the finger, the eye or the radiograph and which present problems of local regrowth after irradiation.

However, in order to evaluate the new planning techniques, tumours in other sites were also assessed using the CT scanner. In twelve months we examined 205 patients. They were all to be treated with telecobalt but similar results could be expected if the same patients were to be treated with a low energy linear accelerator for the treatment beam characteristics are similar in many ways. The median age of the patients was 64 years. Seven patients were aged over eighty, the oldest being 88. The patients can be divided according to the site of the primary tumour:

	Whole project	Chapter 3 "volumes"	Chapter 4 "dosimetry"
Bronchus	59	59	53
Breast	62	62	58
Bladder	17	17	16
Prostate	18	18	17
Uterus (incl. cervix)	11	11	11
Connective tissue	4	4	4
Malignant lymphoma	6	6	6
Ear, nose & throat	4	4	4
Oesophagus	4	4	4
Large bowel	4	4	4
Other	16	12	10
Total	205	201	187

On the other hand they can also can be divided into the following groups according to the region scanned:

	Whole project	Chapter 3 "volumes"	Chapter 4 "dosimetry"
Pelvis	57	54	51
Lung/mediastinum	63	63	57
Chestwall/breast	55	55	51
Abdomen	9	8	7
Head and neck	10	10	10
Skeleton	10	10	10
Other	1	1	1

The first three groups are also separately analysed (chapters 5, 6 and 7). Initially we confined our project to patients who were receiving radical therapy with intent to cure. However many patients are accepted for radiotherapy for whom purely palliative treatment is planned. Whilst this subgroup contains patients from all the above mentioned categories, we considered it interesting to also assess the significance of CT scanning for this special sub-group in its entirety, (chapter 8). This study was performed prospectively. All the patients in this series had histologically proven tumours prior to scanning. In contradistinction to several otherwise similar studies, we have tried to look at consecutive patients who were referred to one radiotherapist for treatment during a period of twelve months.

As with all new projects, new techniques were being developed during the assessment phases. It will be understood that a full evaluation was not performed on the scanning and planning of all the earlier patients. Furthermore mechanical breakdown or the absence of a vital team member sometimes limited the extent of the evaluation. The remaining data would either be unobtainable or would arrive to late to affect the management of the particular patient. It would be a pity to exclude the patients whose assessment was incomplete because they could still contribute much valuable data. It will be noted then that the percentages given relate to a group of patients in which that detail of the technique can be apraised and exclude the minority of cases where evaluation is incomplete or otherwise not possible. This aside, the study is thus be considered to be representative of those patients referred for radiotherapy.

Methods

This study was carried out prospectively and followed the following general plan:

a. appropriate diagnostic tests were performed in order to define the patient's disease conventionally;
b. the therapeutic strategy was selected. The patient's radiotherapy was planned in the simulator and the dosimetry was calculated using a computer treatment planning system if necessary;
c. CT scanning was performed;
d. the patient's treatment plan was re-assessed in light of the CT findings and changed if necessary;
e. the impact of the CT scanning was evaluated by comparing the pre and post-CT treatment plans.

This project focused on the more specific question of whether CT information should be used directly for computerised treatment planning. Thus we tried to eliminate in the evaluation subjective impressions and any possible bias which could make the technique appear better than it was in reality. For instance, the rigid criteria of the ICRU report no. 29 facilitate objective numerical comparisons.

The diagnostic evaluation was divided into various steps. This entailed clinical examination, routine radiology, isotope and ultrasound scanning. Sometimes diagnostic CT scanning was used as a part of this process. Next the radiotherapy was planned using the traditional methods on the simulator unit. A body outline was taken and the target volume was drawn in by the radiotherapist using the data from the X-ray films. Where necessary a central axis dose distribution was plotted using the TPS.

During the first week of the radiotherapy the irradiation fields were assessed using the CT scanner. Because we only have access to the CT scanner during one day per week, CT studies cannot usually be performed before the start of the radiotherapy. Each patient was of course scanned in the treatment position. As in the simulator, various structures such as oesophagus, rectum, bladder and vagina were rendered visible by contrast media. Using lead shot, solder wire and microtrast paste, the irradiation fields and other important land marks were marked out on the skin. Sections at distances 1 to 3 cm apart were scanned over the length of the irradiation volume. A scanogram was of great value in order to localise the scan slices on an AP film. The data was then stored on a floppy disc.

Since this graphic information is meaningless to the treatment planning computer, it had to be recalled from the floppy disc on the screen of the independent viewing console (IVC). The body outline was automatically drawn in by the computer using optimalised window settings. In order to portray the internal organs, window settings were chosen (eg WW: 400H, WL: 0H) (see glossary of terms) whereby the enveloping fatty interstitial tissue was sharply visualised. The volumes of interest could then be drawn onto the monitor screen with a light pen, as were also the inhomogeneities and irradiation fields. Tumour delineation was thought to depend on attenuation coefficients different from those of normal tissues. If this feature is absent then accurate delineation can be impossible unless there is invasion of, and thus disappearance of, the normal fat and other inter-organal planes. Inhomogeneities (air cavities and bones) were both delineated and measured for relative electron density. In the supervoltage range of photon radiotherapy it is these electron densities which primarily determine absorption and scattering of the radiation. These contours could then be

stored on cassette tapes which in turn can be fed into the treatment planning computer (TPS) for beam planning.

Because we scanned a series of horizontal planes over the length of the target volume, we could assess the dose distribution in a three dimensional fashion. In order to assess the effect of inhomogeneity corrections, the mean density of the outlined inhomogeneity was computed by the viewing console (IVS) and the relevant slice can be replanned in the TPS once more using the "effective depth" approach. Unfortunately, as with most treatment planning computers, no allowance can yet be made for scattered irradiation from adjacent planes. This drawback is however present in both conventional and CT-assisted planning whereby meaningful comparisons are still possible.

CT scanning was used to contribute at the following steps in the treatment planning process:

a. definition of the body outline of the patient;
b. localisation of the normal structures;
c. delineation of the tumour and its extensions;
d. evaluation of tissue inhomogeneities;
e. isodose planning on a series of body cross-sections at various levels through the irradiation volume;
f. assistance in the optimisation of dosage.

We tried to estimate the difference CT scanning made to our traditional radiotherapy planning methods having first planned the treatment conventionally and then collected the data anew using the CT scanner and recomputed the dose distribution in the treatment planning system. The following questions appeared on our assessment checklist:

a. Was there a change of fields due to inadequate tumour coverage?
b. Was there a change of fields due to overestimation of tumour size?
c. Was there a change of fields due to unacceptable irradiation of sensitive normal tissues?
d. To what extent did the "improved" dose distribution affect the dosage in the tumour volume?
e. To what extent dit the "improved" dose distribution affect the dosage in the normal tissues?
f. What effect dit inhomogeneity corrections have on the tumour dosage?

In order to be able to meaningfully compare the treatment plans obtained in the traditional manner with those obtained using the data from the CT scanner, we have attempted to adhere to the terminology and recommendations published in the ICRU report number 29. For instance, when quoting a dose for a single beam, a point is chosen on the central axis of the treatment field at the centre of the target volume. For two opposed

coaxial equally weighted beams, the point chosen lies on the central axis midway between the treatment fields. For an arrangement of intersecting beams, the reference point is at the intersection of the central axes of the beam.

The delineation of the target volume requires such considerations as the local invasive capacity of the tumour and its potential to spread to local lymph nodes. Because of limitations in treatment techniques it is impossible to administer the prescribed absorbed dose exclusively to the target volume. In general the volume receiving at least the same absorbed dose as any part of the target volume cannot be made to coincide with the target volume but will be larger and often of a simpler shape. The treatment volume is the volume enclosed by an isodose surface the value of which is the minimum target absorbed dose.

The dose prescribed to treat a patient does not usually reflect the minimum dose necessary to destroy all the tumour but rather the maximum dose that the adjacent critical normal tissues will withstand. A change in the dose in the critical normal tissues was only recorded if the area of overdose was more than 2 cm^2 (1 cm^2 in the case of the spinal cord) and also if overdosage was not evident on the conventional plans. Two square centimetres represent both the smallest area for which the absorbed dose can be confidently calculated with a computer and also the smallest volume of tissue to which the dose limiting effects of tissue tolerance need to be applied.

CHAPTER 3

TARGET AND TREATMENT VOLUMES

Introduction

Firstly we considered how effectively we were encompassing the tumor within the radiation fields, or in other words, how the treatment volume compared with the tumour target volume when we used the CT scan data to check the conventional treatment plans. Small inaccuracies in tumour localisation can have major consequences on tumour control, Allt (1969). When geographical miss was recorded, it did not necessarily occur for all the fields of the same treatment or it may only have taken place during the boost phase of the radiotherapy. In any case a portion of the edge of the tumour target would receive a dose less than that which was desired and the theoretical relevance of this will be discussed later. Firstly we wished to evaluate the incidence of this phenomenon.

Materials and Methods

In twelve months we were able to examine 201 patients for this facet of the whole study. They can be divided into various groups, see chapter 2. By assessing both the coverage of the tumour target by the treatment fields and the unnecessary irradiation of normal tissues we could evaluate the "efficiency" of the prescribed radiotherapy.

Results

In 43 patients (21%) a portion of the tumour lay outside the treatment volume (major miss). From our observations this untreated segment represented an average 22% (range 10 - 50%) of the whole tumour volume. In a further 29 (14%) of the patients, the macroscopic tumour reached to the very edge of the

treatment volume (minor miss) and one could expect that there was invisible microscopic infiltration of the tissue in an area of low irradiation dose (table 1). In 57 patients (28%) the treatment volume was increased by increasing the dimensions of the irradiation fields. In just 5 cases could the size of the fields be diminished.

Table 1: Target Volume Miss

	Major miss	Minor miss
Whole group (201 patients)	21%	14%
Pelvic tumours (see ch. 5)	31%	15%
Intrathoracic tumours (see ch. 6)	27%	27%
Chest wall tumours (see ch. 7)	2%	0%
Palliative treatments (see ch. 8)	16%	11%

Why did we have to change the treatment fields in such a high percentage of cases? In 48 cases this was due to the discovery of unexpected infiltration by the tumour of the surrounding normal tissues. In 8 cases we found unexpected pathologically enlarged regional lymph nodes. In 7 cases non-lymphatic metastases were diagnosed within the limited section of the body which was scanned. Thus even after a complete traditional staging procedure and despite the fact that our aim was not to assess tumour morphology per se, we were still gaining information which had both prognostic and therapeutic significance in the management of the patient (table 2). Because of these findings whereby the tumour appears more extensive than originally supposed, the aim of the radiotherapy sometimes has to be changed from a radical to a palliative goal.

Table 2: Reason for Change in Irradiation Fields

Primary tumour infiltration	48 cases
Regional lymph nodes	8 cases
Non-lymphatic metastases	7 cases
Non-optimal coverage of target volume	11 cases
Over-estimation of target volume	10 cases

On average 22% (range 10 to 50%) of the tumour target lay outside the treatment volume. However this group could be further sub-divided. In the majority of these patients the treatment fields were just too small and needed increasing in size. However in 11 (5%) patients the fields could remain of the same size whilst the treatment fields were shifted to come into better alignment with the target volume.

The aim of the project is to see if we can irradiate tumours to a higher dose whilst diminishing the dose to the adjacent normal tissues. The results above pinpoint the inadequacies in the irradiation of the tumour target volume. Unfortunately we were able to spare a significant portion (10% to 30% of the treatment volume) of the surrounding normal tissues in only 10 cases.

In order to further improve local tumour control rates, it is common practice in many institutes to give an extra 'boost' dose of irradiation to the largest tumour masses. The strategy is to concentrate the highest doses on the relatively radioresistant hypoxic cells in the tumour whilst minimising the volume of normal tissue that is irradiated by reducing the field sizes to cover only the macroscopic tumour. In this project we scanned and re-planned 16 such cases. In 10 cases we reported a 'miss' whereby on average 27% (range 10 - 30%) of the tumour lay outside the treatment volume. In 8 cases the treatment volume was increased by 10 - 30% (mean 18%). In the most cases the fields were shifted to cover the tumour better requiring just a moderate increase in size. Extra normal tissue could be spared in only 1 case. A change in the treatment fields was recorded in 11 of the 16 patients receiving boost treatment.

Discussion

Changes have occurred in the total volume of tissue irradiated to high doses. Usually these changes results, at least in part, from post-CT changes reflecting inadequate tumour coverage in the pre-CT treatment plan. The extent of the volume change is often substantial. Since the majority of the cases in which the irradiated volume is changed involves inadequate tumour coverage, there is a tendency for the CT scanning to lead to an increase in the volume of tissue irradiated. Only 10 (14%) of 72 changes resulted from normal tissue considerations alone. Goitein et al (1979) found this figure to be 11% in their series of 77 patients. Originally one believed that CT scanning had a great potential for sparing uninvolved adjacent tissues but our studies have not been able to realise this.

Results of this study are in general agreement with those of Sheedy et al

(1976), Stanley et al (1976), Munzenrider et al (1977), Goitein et al (1979) and Hobday et al (1979) (see tables 3 and 4). Emami et al (1978) found that CT was essential for the radiation therapy planning in 17 (53%) of 32 patients with bronchus carcinoma. Brizel et al (1979) judged CT scanning to be of significant help in the radiotherapy planning of 44 (61%) of their 72 patients with pelvic malignancies. In his group of 120 patients, Leer (1982) found that CT scanning was superior to traditional methods in 57% of cases. This was mainly due to an improved anatomical insight requiring a correction of the target volume. Seeing that the various independent studies give comparable results suggests that the substantial error rates detected in pre-CT treatment plans result neither from the policies of particular institutions nor from strong biases in patient selection. Radiotherapy planning in Zwolle has not been any less accurate than in many larger centres.

Table 3: Analysis of Alteration in the Radiotherapy

	This study	Goitein M et al (1979)	Munzenrider J et al (1977)
Total patients	201	77	75
Radiotherapy required alteration	58%	52%	55%
1. Fields changed because tumour lay partially outside treatment volume (table 4)	35%	42%	47%
a) major miss	21%	31%	20%
b) marginal miss	14%	10%	27%
2. Fields reduced to spare normal tissues	5%	5%	-
3. Significant difference in tumour target dose	35%	-	-

One might well anticipate that CT scanning would be especially useful in designing boost treatments where field margins are reduced to encompass only the volume of bulk disease whereas these margins can be more generous

during the locoregional phase of radiotherapy. Of 16 patients treated with boost fields, inadequate tumour coverage occurred in 11 cases contrasting with 35% for the entire group of patients. In their series of 77 patients, Goitein et al, 1979, reported a tumour miss rate of 63% during boost-field irradiation compared with a rate of 42% for the whole group.

Table 4: Field plan changed because the Tumour Volume lay partially outside the Treatment Volume

Primary tumour	This study		Hobday P et al (1979)	
	Total pat.	Plan changed	Total pat.	Plan changed
Bladder and prostate	35	44%	48	17%
Uterus incl. cervix	11	27%	10	10%
Bronchus	59	59%	30	20%
Head/neck	10	30%	9	33%
Chest wall	55	2%	-	-
Other	31	34%	26	54%
Total	201	36%	123	26%

What sort of effect will a reduced dose have on the tumour cell kill rate? Theoretically, if the tumour unexpectedly extends beyond the edge of the treatment volume, then some of the malignant cells will receive significantly less irradiation than the prescribed target dose. The risk of edge recurrence will then rise. There are certainly not sufficient data to allow an estimate of the dose response characteristics for specific tumours but there are now several studies which can offer us information towards attaining an "average" dose response curve: Schukovsky (1970), Herring and Compton (1971), Withers (1973), Morrison (1975). Their message is that small decreases in radiation dose (i.e. 5%) result in larger decreases in tumour control rates (8% to 19%).

Conclusions

CT scanning was found to be valuable in the planning of the geometry of the

radiation fields in 36% of the 201 treatment series evaluated in this part of the project (pelvic tumours: 48%; chest wall tumours: 2%; intrathoracic tumours: 54%; palliative treatment group: 27%). In the small group of boost-field treatment these inaccuracies were even more marked (69%). Generally CT scanning lead to an increase in the size of the target volume and only very rarely to a decrease in the volume of normal tissue that was irradiated.

CHAPTER 4

THE PLANNING OF DOSE DISTRIBUTION

Introduction

Optimal utilisation of dedicated radiation treatment planning computers (TPS) depends on increasingly the accuracy and precision of the clinical data with which they are supplied. Various contour-taking techniques have been used in the past to obtain surface contours over the area of interest. Atlases of cross-sectional anatomy and data from physical examination, radionuclide scans, ultrasonic scans and roentgenographic studies have then been employed to locate the position of the tumour and normal structures within the volume defined by the contour. These methods obtained an approximation to the true contour and the location of the tumour and normal structures which did not match the accuracy of the computer planning system.

Materials and Methods

At this part of the study we have data from 187 patients. They can be divided into various groups, see chapter 2.

Results

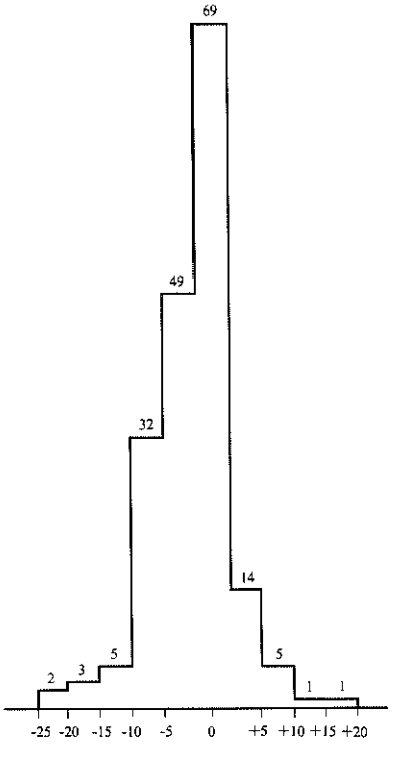
Table 5 shows that in 49 (27%) of 181 patients in this study, changes in the body outline resulted in a greater than 5% change in target dose in the midplane (patients with a single direct vertebral field are not included here). On average, the absolute alteration in target dose was 6.5% and usually resulted in the tumour receiving a lower dose than had been calculated using the traditional methods, although some target doses were increased by up to 16% (diagram 1).

Table 5: Percentage of Patients in which CT Scanning resulted in an Alteration in Central Axis Target Dose of more than 5%

Whole group	27% (n=181)
Intrathoracic tumours	29% (n= 63)
Pelvic tumours	27% (n= 51)
Chest wall tumours	10% (n= 40)
Palliative treatments	39% (n= 41)

DIAGRAM 1

Number of patient in which CT scanning revealed a discrepancy in central axis target dose (n=181)

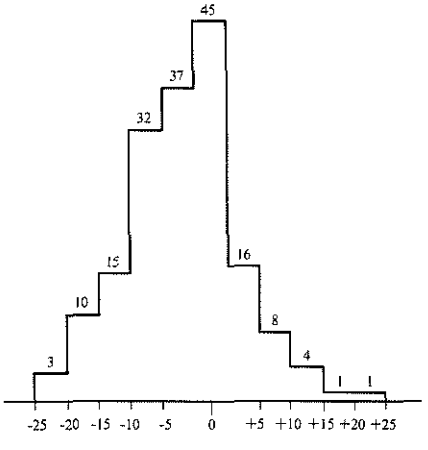


Percentage change in central axis target dose.

Because we scan a series of transverse planes over the length of the target volume, we could assess the dose distribution in three dimensions. We recorded an inaccuracy in off-axis target dose in 127 (74%) of 172 patients of which the average alteration was 9.5% of the central axis target dose (diagram 2). In 74 patients this dose alteration was greater than 5% of the target dose and in 34 patients was the dose change greater than 10%.

DIAGRAM 2

Number of patients in which CT scanning revealed a discrepancy in off-axis target dose (n=172)



Percentage change in off-axis target dose.

Next we checked for non-uniformity of dose within the target volume on the central axis. However this was only reported in the checklist if there was significantly more non-uniformity on the plans computed with the CT scan

data than on those obtained in the traditional manner. In 4 of 99 patients we found non-uniformity of greater than ± 5% of the target dose (patients treated with either parallel opposed fields, whose uniformity is often assumed, or a single direct field are not included here).

In only 1 of the patients was it felt that the CT scan data had exposed an unacceptably high dose in one of the sensitive surrounding organs. It must be remembered however that the treatment fields were usually arranged routinely during conventional planning procedures to avoid excessively sensitive tissue and that a certain safety margin is allowed for when treating other unavoidable normal tissues.

In order to concentrate the highest radiation doses on the relatively resistant cells, the treatment fields are sometimes reduced at a certain stage in the therapy to cover only the macro-scopic malignancy in the hope of gaining extra local control without unacceptable damage to the surrounding normal tissue. In this series we scanned and re-planned 16 such cases. The mean discrepancy in target dose calculation was found to be - 4.5% with a range of -8% to + 4%. Thus the tumour was usually receiving a lower dose than that calculated using traditional methods. Off the midplane these figures were -8% and -2% to -30% respectively. In no case did we find a change in the dose in a critical normal tissue. A significant change i.e. 5% in the dosage was recorded in 6 of 16 patients.

Considering the whole patient group momentarily and taking all the measured factors into account, we shall be concluding that the CT scanning was of value in the planning of the radiation therapy in 118 (58%) of the various treatment series entered in the whole project. As far as dose distribution in concerned, we found that CT scanning exposed significant inaccuracies in 72 (39%) of 187 patients in this series (pelvic tumours: 31%; chestwall tumours: 22%; intrathoracic tumours: 58%; palliative treatment group: 46%).

In this study the effect of tissue inhomogeneities on the midplane dosimetry was appraised in 52 cases (20 thorax, 32 pelvis). The inhomogeneities were drawn in on the midplane section using the light pen. The mean density was computed and the effect of the inhomogeneities on the target dose can be assessed by planning the section both with and without application of the tissue correction. In this series the mean relative electron density of the lung tissue including the tumour was 0.40 (range 0.27 - 0.60) and of the pelvic bones was 1.28 (range 1.14 - 1.39). In the thorax the mean target dose was increased by 10.6% (range 3 - 20%) after lung correction. In the pelvis we found that bone correction causes a mean decrease of target dose of 4.3% (range -1% to -10%), (table 6).

Table 6: Effect on Target Dose of Planning with and without Inhomogeneity Correction

	Mean relative electron density of inhomogeneity	Mean target dose
Thorax (n=20)	0.40	+ 10.6% (range 3 to 20%)
Pelvis (n=32)	1.28	- 4.3% (range -1 to -10%)

Discussion

Precise control of the radiation dose to be delivered to specified areas in the patient is essential for therapy. Although our knowledge is inadequate to predict tumour response in many situations, curves of "average" response to dose have been proffered for some malignacies: Schukovsky (1970), Herring and Compton (1971), Withers (1973), Morrison (1975). Their message is that small decreases in radiation dose (i.e. 5%) result in larger decreases in tumour control rates (8% to 19%). Thus even small errors in calculating or delivering the irradiation can lead to failure to control the malignancy. Normal tissues may also have a similarly steep dose response curve and furthermore they may be more radiosensitive than the tumour. This can be shown for the spinal cord (Boden, 1948 and Philips and Buschke, 1969), the lung (Wara et al, 1973) and the kidney (Kunkler et al, 1952). The demands for increased accuracy in dose application are concisely defended by Kramer (1976).

Our study has highlighted two sources of inaccuracy in calculating the target dose. In the simulator unit, our methods of taking a body contour consistently underestimate to skin-tumour distance. Leer (1982) also found inconsistencies of up to 2 cm in the anteroposterior diameter and 1 cm in the transverse diameter. This would account for a 5% target dose deficiency in a three field telecobalt plan on the central axis and a 7% dose deficit by irradiation with opposing fields. Secondly, little attention can usually be taken of variations in body contour over the length of the treatment volume because this is so timeconsuming for the patient and staff of the simulator unit.

Several investigators have prosposed using CT scans for the calculation of dose (Geise and Mc Cullough 1977; Jelden et al, 1976 and Thieme et al 1975). However fully three dimensional dose calculations in an inhomogenous medium are still in their infancy. Inhomogeneity corrections can naturally be used to obtain better prediction of dose within the target

volume and to eliminate areas of overdosage in critical tissues. However we must be more circumspect when applying them to the target dose considering that for eighty years most radiotherapists have derived dosage schemes which take no account of such inhomogeneities.

Conclusions

Mathematical methods have been developed elsewhere to evaluate the response of a tumour to irradiation. These indicate that small variations in dose have a larger influence on the probability of cure. Furthermore the dose received by patients undergoing curative radiation treatment is often close to the tolerance dose of healthy tissue. In this prospective study we found that changes in body outline resulted in a greater than 5% change in target dose on the central axis in 27% of the patients. Significant inaccuracies in dose calculation somewhere within the tumour volume were exposed in 39% of the 187 patients. Tissue inhomogeneity can further effect the precision of traditional methods of computing target dose.

CHAPTER 5

PELVIC TUMOURS

Introduction

A role of CT scanning for radiotherapy of patients with pelvic malignancies is to define those limits of locoregional disease which are not accessible to the finger. For instance, CT can demonstrate gross prostatic gland morphology and extraprostatic masses but it cannot distinguish prostatic hypertrophy from neoplastic tissue; Shapiro and Chiu (1977). However in the presence of biopsy proven primary tumour, an enlarged or irregular prostate gland or seminal vesicle or otherwise extension of a mass into the soft tissues towards the pelvic sidewall, is a significant finding and has treatment planning and prognostic consequences: Wittenberg et al (1978). Similarly bladder wall thickening is a non-specific finding. It does not always represent malignancy but may be oedema or normal tissue responses to surgery i.e. TUR. In results reported elsewhere, CT has been effective in evaluating the upper extent of the tumour both within and outside the bladder wall: Seidelman et al (1977), Levitt et al (1978).

In 1970, Suit estimated the percentage of dying patients with local failure as their major cause of death for various tumour groups and found the following rates:

cervix uteri	- 60%
corpus uteri	- 57%
ovary	- 84%
bladder	- 50%
prostate	- 61%

No indication of distribution of tumour stage is given however and the figures suggest that Suit was confronted with many cervix and corpus malignancies in an advanced stage (Suit 1982).

Our target volumes usually include both the site of the primary tumour and the intra-pelvic lymph nodes below the bifurcation of the common iliac

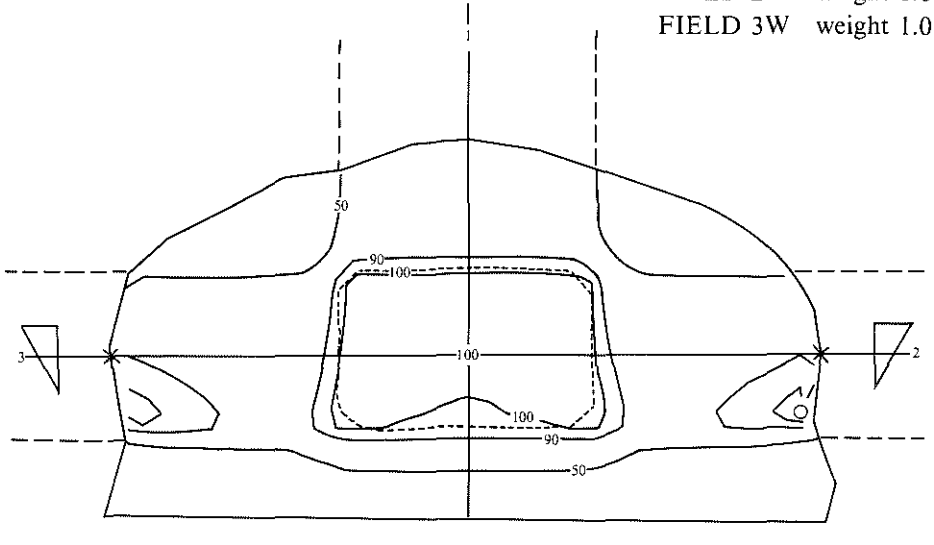
arteries. The usual treatment technique for this series of patients is two opposed wedged lateral fields and an anterior field (diagram 3), although some of the patients receiving lower doses were irradiated with anterior and posterior opposed fields. The median field dimensions were (cm):

	Anterior field	Lateral fields
Bladder tumours: regional fields	12 x 10	9 x 10
boost fields	8 x 8	7 x 8
Prostate tumours: regional fields	12 x 10	9 x 10
boost fields	9 x 8	7 x 8
Uterine tumours (cervix and corpus)	12,5 x 11	8 x 11

As regards distressing acute and late complications, the critical organs in this region are the bladder and rectum. Whilst treating tumours in the anterior part of the pelvis, the posterior half of the rectum usually lies outside the target volume. During the treatment of the tumours in the posterior part of the pelvis the anterior half of the bladder is usually not included in the target volume.

Diagram 3

FIELD 1 weight 1.0
FIELD 2W weight 1.0
FIELD 3W weight 1.0



Materials and Methods

In one year we examined 55 patients with intra-pelvic malignancies and they could be further sub-divided according to tumour stage, topography and histology as will be been in tables 7 and 8. With a tunnel diameter limited to 56 cm, it was these patients whose alignment was most critical during the CT scanning.

Table 7: Distribution of Pelvic Tumours According to Topography and Histology

	Adenocarcinomas	Transitional	Anaplastic	Other
Colon	3	-	-	-
Rectum	1	-	-	-
Connective tissue	-	-	-	1
Cervix uteri	-	-	1	1
Corpus uteri	8	-	1	-
Vagina/vulva	-	-	1	1
Prostate	18	-	-	-
Penis	-	-	-	1
Bladder	-	12	3	2
Malig. lymphoma	-	-	-	1

Table 8: Distribution of Pelvic Tumours According to TNM Classification

	NO	N1	N2	N3	N4	NX
T1	9	0	1	0	0	2
T2	9	0	1	0	0	5
T3	7	1	1	0	1	9
T4	1	2	0	0	0	0

(also cases of the following: primary tumour recurrence (2), sarcoma (1), metastasis (1), malignant lymphoma (1), incomplete staging (1),)

Results

We began our assessment with the most obvious of inaccuracies i.e. when a portion of the target volume lay outside the treatment volume. This "major miss" was found in 17 patients (31%) and from our observations this untreated segment represented an average 22% (range 10 to 50%) of the

whole tumour volume. In a further 8 (15%) of the patients, we recorded a "minor miss" whereby the macroscopic tumour reached to the very edge of the treatment volume. On average the treatment volume was increased by 20% (range 10 to 50%) in these patients. In only one case could the size of the fields be diminished.

The following reasons were given for changing the treatment fields in such a high percentage of cases. In 11 cases this was due to the discovery of unexpected infiltration of the surrounding normal tissues by the tumour. In 3 cases we found unexpectedly pathologically enlarged regional lymph-nodes. Also in three cases we diagnosed non-lymphatic metastases within the limited section of the body which was scanned. In 2 cases the treatment volume was of an adequate size but required shifting to bring it into better alignment with the target volume. In only 3 cases were we able to spare a significant portion (20% to 30% of the treatment volume) of the surrounding normal tissues (tables 9 and 10). Considering the field geometry as a whole we made changes in 26 (48%) of the evaluable patients.

Table 9: Analysis of Alteration in the Radiotherapy

Inadequate tumour coverage	: 25/54 patients (46%)
Field alteration to spare normal tissues	: 3/54 patients (6%)
Significant difference in central axis target dose	: 14/51 patients (27%)

Table 10: Reason for change in Irradiation Fields (N=55)

Primary tumour infiltration	: 11 patients
Regional lymph node involvement	: 3 patients
Non-lymphatic metastases	: 3 patients
Non-optimal coverage of target volume without change in field size	: 2 patients
Overestimation of target volume	: 1 patient

A change in target dose was recorded in 31 (61%) of 51 patients. The mean alteration in target dose was 5% but more often than not this was downwards. Although some target doses were increased by up to 11%, the majority (26 of 31 cases) were reduced by factors up to 12%. In 14 patients this dose alteration was greater than 5% of the target dose. Furthermore the dose distribution was assessed three dimensionally. Off the central axis, we

recorded a change in target dose in 30 (62%) of 48 patients. In 18 patients this dose alteration was greater than 5% of the target dose; the dose change was greater than 10% in 9 patients. A non-uniformity of greater than ± 5% of the target dose was found in no patient even on the off axis scans. Considering the dose calculations as a whole, we found that CT scanning exposed significant inaccuracies in 16 of 51 patients.

The 12 cases receiving an extra "boost" dose of irradiation to the largest tumour masses could by assessed reparately. In 8 cases we reported a "miss" whereby on average 28% (range 20 - 30%) of the tumour lay outside the treatment volume. In 5 cases the treatment volume was increased by 20 - 30% (mean 28%). In the other 3 cases the fields were shifted to cover the tumour but remained of the same size. Extra normal tissue could be spared in only 1 case. A change in the treatment fields was recorded in 9 of 12 patients receiving boost treatment. In only 3 of the 12 patients did a correction in body outline have a greater than 5% effect on the midplane target dose. The mean target dose change was -4% (range -1 to -8%). Off the midplane the mean change in target dose was -9%. In no case did we find a change in the dose in a critical normal tissue. A significant change in the dosimetry was thus recorded in 5 of the 12 patients. CT scanning made a valuable contribution to the planning of 10 of the 12 patients receiving boost radiotherapy.

Taking all the measures of the factors into account and considering the whole patient group, we found that CT scanning had exposed various inaccuracies in the treatment planning in 35 (64%) of the treatment series (table 12).

Discussion

Given the number of patients involved, we conclude that CT scanning is approximately equally valuable in improving tumour coverage in the pelvis as in other regions of the body. This is in conflict with the findings of Munzenrider et al (1977) who concluded that the value of CT was less pronounced in the pelvis but especially helpful in the abdomen. However they indicated that their findings in the pelvis related to the 'regional' portion of treatment and suggested that CT might be valuable in the boost phase. Indeed in our limited study of boost phase evaluation, failure of tumour cover is found extremely frequently. Of course one might anticipate that CT scanning would be of greater value in evaluating boost treatments where fields are reduced to encompass only macroscopic tumour compared to the regional phases of treatment where field margins are generous. Nevertheless

there were a significant number of "misses" and "marginal misses" in the regional phases of treatment.

We found that tumour coverage was inadequate in 31% of patients and marginal in a further 15%. This total compares with figures of 40% (Brizel et al 1979) and 32% (Goitein 1979). It is quite impressive that these independent studies should give such comparable results. This fact suggests that the substantial error rates detected in pre- CT treatment plans result neither from the policies of particular institutes nor from a strong bias in patient selection (table 11).

Table 11: Essentiality of CT scanning during Radiotherapy Planning

Author		Scanned sites	No. of patients	Tumour Coverage Major Miss	Minor Miss	Essentiality CT scanning
Munzenrider	1977	pelvis	17	6%	29%	41%
Brizel	1979	pelvis	72	40%	-	61%
Hobday	1979	pelvis	65	18%	-	31%
Goitein	1979	pelvis	41	32%	-	44%
Leer, Badcock	1982	pelvis	30	57%	-	57%
(whole project)		mixed	205	21%	14%	*58%
This study		pelvis	55	31%	15%	*64%

*Studies in which a three dimensional assessment of inaccuracies in dose distribution were performed

Unsuspected tumour extension to contiguous and regional tissues was shown in 29% of the cases. Brizel et al, 1979, reported a figure of 43%. They found that the increased spread of local tumour demonstrated by CT led to an increase in the stage of the tumour in 25% of their cases. This had obvious prognostic significance and was a selection factor for various treatment modalities, not only radiotherapy but also chemotherapy and surgery. With upstaging, for instance, of bladder tumours due to unexpectedly extensive extravesical disease, the treatment goal becomes more palliative, sparing the patient a protracted radical course of treatment with inappropriate extra boost irradiation.

The changes in treatment volume suggested by the CT scans are usually associated with cases in which the tumour coverage is inadequate. We believed that CT scanning had great potential for sparing uninvolved adjacent tissues but the figures in this study cannot confirm this hypothesis. It is unusual that field adjustments can be made to reduce the volume of normal

tissue irradiated. Furthermore in 29% of the patients, CT findings led to significant adjustments in the dose distribution principally because of changes in body outline.

Because of the small numbers of patients in each particular tumour group it is unfortunately not valid to attempt to specify the usefulness of the CT scanning according to tumour site and histology. Suffice it to say that no criteria could be established for pre-selection of those who would benefit most or least by the application of these techniques. However in those 12 patients treated with boost fields the innaccuracies were found particularly often.

Conclusions

Local failure is a particular problem in the treatment of intra-pelvic tumours and imperfections in local treatments such as radiotherapy, must be regarded as a cause of this. The CT scanner is better able to distinguish between tissues, both healthy and malignant, of slightly differing radiological density than traditional radiography. This characteristic is especially valuable in the pelvic regions. Computed tomography proved to be of such value in improving the accuracy of both the localisation of the target volume (48% of the patients) and the calculation of the dose distribution (31% of the patients) that it is recommended for all patients with pelvic malignancies who are referred for radiotherapy (table 12).

Table 12: Summary of Results

Change in field geometry	: 26/54 patients (48%)
Change in tumour dose calculation	: 16/51 patients (31%)
All factors	: 35/55 patients (64%)

CHAPTER 6

INTRA-THORACIC TUMOURS

Introduction

It is often assumed that the primary tumour in the thorax does not represent a major clinical problem but that the only factor of significance is metastatic disease. From the figures of Suit (1970) 9% of patients dying with bronchus tumours and 35% of patients dying with oesophageal tumours died with local tumour failure as the major cause of death. Whilst it is true that the prognosis of these tumours usually depends on the presence or absence of distant micro-metastses at the time of primary treatment, the quality of life is often a reflection of the degree of control of the loco-regional tumour complex.

In a study of Salazar et al (1976) the regression of the primary tumour was unequivocally dose-related within the usual range of radio-therapeutic dosage. By increasing the nominal standard dose (NSD) by a factor of just 23%, the chance of gaining more than 50% tumour regression increased from 15% to 75%. Perez et al (1980) performed a similar study using various irradiation doses in the treatment of inoperable, non-oat-cell carcinoma of the lung. They found that the incidence of intrathoracic recurrence was 33% for patients treated with 60 Gy but almost 50% for those treated to 40 Gy only.

Local tumour recurrence is an expression of unsuccessful local treatment. That this is partially dose-dependent underlines the importance of precision in computation and delivery of the radiation dose. But local recurrence on the edge of the treatment volume is not related to tumour dose but to field size. A high incidence of edge-recurrence signifies that one's treatment fields are too small. It is these two factors (tumour dose and tumour volume) which we primarly try to assess with the help of the CT scanner for both are equally important in deciding the rates of loco-regional tumour control.

CT scanning has considerable theoretical application to the lungs and

some practical impact has already been shown. The technique may help distinguish between benign and malignant tumours and between tumours, infarct and pneumonia: Stanley et al 1976, Sagel et al 1976. It can also demonstrate occult effusions, distinguish collapsed or consolidated lung from pleural fluid and define tumour spread in the pleura: Kreel 1977. Nonetheless neither the value nor the accuracy of CT scanning of the lung has yet been documented. In mediastinal disease CT scanning has demonstrated the extent of lymphadenopathy: Alfidi et al 1977. Although CT scanning provides some additional information in the staging of bronchus carcinoma, the technique cannot be expected to detect micrometastes in the mediastinal lymph nodes (Stanley 1976).

Materials and Methods

In one year the radiotherapy planning of 63 patients with intrathoracic carcinoma was re-assessed using the CT scanner. The usual technique for irradiating this group of patients was parallel opposed fields although some of the oesophagus tumours were irradiated with two opposed wedged lateral fields and an anterior field. Routinely the target volume included both the primary tumour and the regional lymph-nodes in the mediastinum. The median field dimensions were 13 cm lang and 10 cm wide. Non-involved lung tissue and the spinal cord were judged to be the most critical normal tissues as far as early and chronic radiation damage was concerned. Sub-division of the tumours according to their histology and TNM classifications can be found in table 13 and 14.

Table 13: Intrathoracic Tumours: Histological Classification

Bronchus:	Squamous cell	23
	Undifferentiated	14
	Oat cell	12
	Adenocarcinoma	2
	Unknown	8
Oesophagus:	Squamous cell	3
	Adenocarcinoma	1
	Total:	63

Table 14: Distribution of Intrathoracic Tumours according to TNM classification

	N0	N1	N2	N3	NX
T1	2	0	0	1	0
T2	4	6	5	0	7
T3	5	5	11	1	9

(Also cases of: metastases (2)
primary tumour recurrence (1)
incomplete staging of oat cell tumours (4),).

Results

As usual we firstly made an evaluation of the encompassing of the tumour by the radiation fields. In 17 patients (27%) we recorded a major miss and in a further 17 patients the macroscopic tumour reached to the very edge of the treatment volume. In no case could the size of the field be diminished. In those cases where the field size was inadequate, the treatment volume was increased by an average of 16% (range 10 to 40%).

In 3 cases we found pathologically enlarged regional lymphnodes. Within the limited section of the body which was scanned, we diagnosed non-lymphatic metastases in 4 cases. However the great majority of field changes (29 cases) was due to the discovery of unexpected infiltration of the surrounding normal tissues by the tumour (table 15). In 7 (11%) patients the treatment volume did not require enlargement but only re-alignment to cover the tumour target better. Unfortunately in only 5 cases were we able to spare a significant portion (10 to 20% of the treatment volume) of the surrounding normal tissues (table 16). In 34 (54%) of the 63 evaluable patients, CT scanning led to changes in the field geometry.

Table 15: Reason for Change in Irradiation Fields (N=63)

Primary tumour infiltration	: 29 patients
Regional lymph node involvement	: 3 patients
Non-lymphatic metastases	: 4 patients
Non-optimal coverage of target volume without change in field size	: 7 patients
Overestimation of target volume	: 0 patient

Table 16 shows that in 18 patients (29%) a change in the body outline resulted in a greater than 5% change in target dose on the central axis. Of all the 40 patients in which we recorded a change in target dose, we found a mean alteration of 6% (range +4% to -16%) which usually resulted in the tumour receiving a lower dose per fraction than had been calculated using the traditional methods. Off the central axis, we recorded a change in target dose in 46 (73%) of the patients of which the mean alteration was 10% of the target dose. Although some of these dose were increased by factors up to 24%, the majority (31 of 46 cases) were reduced by factors up to -20%, because of non-uniformity in the antero-posterior diameter of the thorax. Considering the dose calculations as a whole, we found that CT scanning exposed significant inaccuracies in 33 (52%) of 63 patients in this series.

Table 16: Analysis of Alterations in the Radiotherapy (N=63)

Inadequate tumour coverage	: 34 patients (54%)
Field alteration to spare normal tissues	: 5 patients (8%)
Significant difference in central axis dose	: 18 patients (29%)

In this project we scanned and re-planned 4 cases receiving an extra boost dose of irradiation. CT scanning made a valuable contribution to the treatment of all of the 4 patients receiving boost radiotherapy for the technique picked up a target miss in two cases, an underdosage of the target in a third case and a tumour in the other lung of the fourth case which, having been confirmed by conventional tomography, lead to a change in management policy in the fourth case.

Considering the whole patient group once more and taking all the measured factors into account, we concluded that CT scanning was of value in the planning of the radiation therapy in 53 (84%) of the treatment series entered in this project (table 17). The results of correcting for tissue inhomogeneities, as discussed in Chapter 4, have not been included in this figure.

Table 17: Summary of Results

Change in field geometry	34/63 patients (54%)
Change in calculated target dose	33/63 patients (52%)
All factors	53/63 patients (84%)

Discussion

In the majority of patients CT scanning more clearly delineated the tumour extent compared with plain chest radiography. Furthermore the information is presented in the cross-sections often required for dosimetry calculations. As with conventional radiography, problems are still met whilst delineating the tumour volume when atelectasia or effusions are present. This difficulty can occasionally be reduced using intravenous contrast media. Additional experience is still needed to define the criteria for recognition of pathologically enlarged lymph nodes in the mediastinum and to evaluate the use of contrast enhancement techniques to separate tumour masses from normal structures. As experience grows we shall probably find that we have underestimated the figures for both tumour miss and the contribution of CT scanning.

In 27% of the patients direct extension of the tumour into previously unsuspected areas was seen. Emami et al (1978) found this figure to be 28% in their series of 32 patients. Unsuspected mediastinal nodes were found in only a few of the patients reflecting the difficulty of discovering small tumour masses in solid tissues with similar attenuation coefficients. The treatment volume required alteration in 54% of the cases and generally the fields had to be larger; in none of the patients were smaller fields judged to be adequate.

The contribution of CT scanning to the radiotherapy of intrathoracic tumours is surprising especially when we remember those factors which are considered to favourably effect the interpretation of traditional chest radiography compared with soft tissue studies on other parts of the body. Despite the intensive use of tomography, CT scanning allows not only better delineation of the tumour extent in a majority of patients but also the acquisition of transverse sections as required for radiotherapy planning. Lesions are more readily visualised on the CT scans as the problem of superimposition of bony and cardiovascular images over the tumour is eliminated. However our experience with this group of patients broadly agrees with the findings in other institutes where CT scanning has been used on mixed groups of patients to assess the planning of the radiation therapy (table 18).

Comparing the treatment plans derived from the CT data with those based on traditional methods, we find variations in target dose of as much as 24%. Although we have not measured this specifically, one can expect similar discrepancies in spinal cord dosage in those patients treated with the traditional anterior and posterior opposing field techniques. One has already seen that a 5% reduction of dose somewhere in the tumour reduces the local

Table 18: Essentiality of CT scanning during Radiotherapy Planning

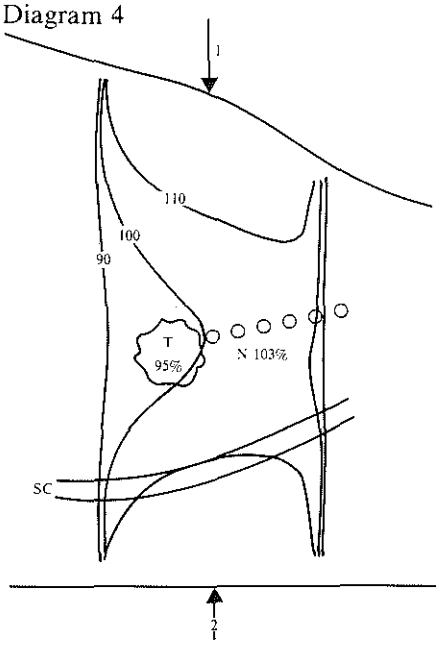
Author	Scanned sites	No. of patients	Tumour coverage Major miss	Marginal miss	Essentiality CT scanning
Muzenrider et al, 1977	thoracic	21	24%	29%	67%
Emami et al, 1978	thoracic	32	28%	-	53%
Hobday et al, 1979	thoracic	30	20%	-	27%
Goitein et al, 1979	mixed	77	31%	11%	52%
Leer, 1982	thoracic	21	6%	-	29%
Badcock (whole project)	mixed	205	21%	14%	*58%
This study	thoracic	63	27%	27%	*84%

* Studies in which a three dimensional assessment of inaccuracies in dose distribution were performed

cure rate by between 8% and 18% according to several studies. The risk of necrosis is magnified by a similar factor by a 5% dose increase (Chapter 4).

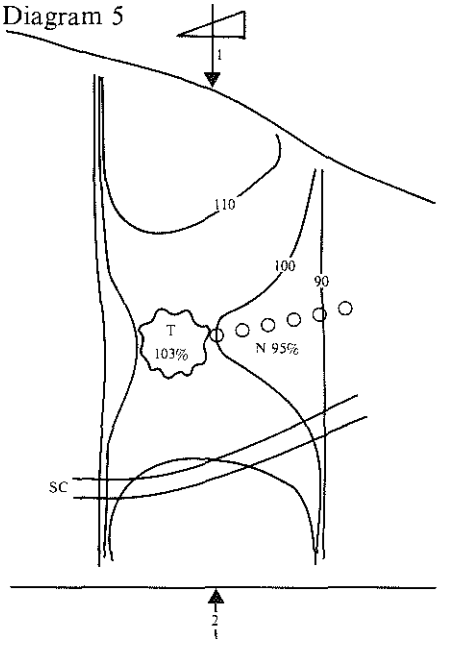
The antero-posterior diameter of the chest at the thoracic inlet is usually considerably less than at the hili. Because there is less tissue to penetrate, it is obvious that the irradiation dose is higher in those areas of microscopic malignancy in the paratracheal nodes than in the areas of bulk disease at the level of the hili. However it is these larger tumour masses which require a higher dose for their destruction. The CT scanning alerted us to the magnitude of this problem. In order to reverse this undesirable state of dosage affairs it is now usual to include a thin wedge filter in the anterior irradiation field whereby the radioresistant tumour cells are subjected to a higher dose than the sensitive micrometastases. Furthermore hot-spots in the spinal cord and oesophagus are eliminated so reducing the risk of local late complications (see diagrams 4 and 5).

Diagram 4



(without compensatory wedge)

Diagram 5



(with compensatory wedge)

Diagrams 4 & 5

Longitudinal section through the irradiation volume of a patient with an intra-thoracic tumour showing percentage dose lines.

T : primary tumour
N : paratracheal lymph nodes
SC : spinal cord
1 : anterior radiation field
2 : posterior radiation field
◿ : compensating wedge in radiation field

Conclusions

CT scanning allows clearer demonstration of the loco-regional disease and exposes undesirable inhomogeneities of radiation dose. In 54% of the patients there were changes in the field geometry usually necessitating an enlargement of field size. Because of this up-staging of the tumour, the treatment goal often became more palliative sparing the patient a protracted course of radical treatment with inappropriate boost irradiation. In 52% of the patients the dose distribution was improved often by the inclusion of a

wedge in the anterior treatment field. The use of the CT scanner can result in both better local control of the tumour and a lower risk of treatment complications. These improvements wil probably affect prognosis only to a small extent but should well reduce morbidity (cough, dyspnoea).

CHAPTER 7

THE CHEST WALL AND BREAST

Introduction

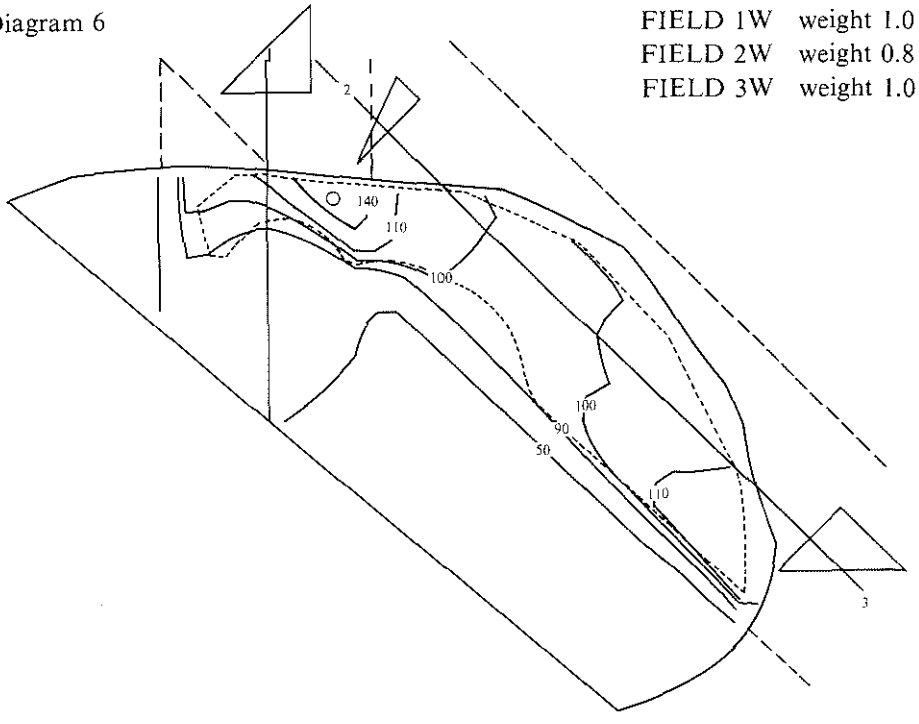
CT scanning is a useful technique of the determination of chest wall thickness for radiation treatment planning. Accurate knowledge of the pleura-lung interface in relation to the skin surface is necessary in order to ensure a sufficiently high radiation dose to all areas of the chest wall (and breast) with minimal dosage to the lung. In telecobalt therapy the chest wall is usually irradiated by two parallel opposed beams tangential to the chest wall (diagram 6). The target volume usually includes the full thickness of the antero-lateral chest wall from the skin to the pleural surface and includes also the lymph nodes behind and lateral to the sternum and of the lower part of the axilla. The line parallel to the beam axes and tangential to the pleura-lung interface is thus a vital parameter in the dosimetry. Those institutes treating the chest wall with direct electron fields could use the same technique to modify the electron beam energy to suit the thickness of the chest wall. The aim is, of course, to sterilise the chest wall of tumour cells whilst irradiating as little lung as possible in order to minimise radiation fibrosis.

Chest wall thicknesses, from the skin to the pleural surface, vary enormously according to the build of the patient, the operative technique and the site on the chest wall. Measurements have been taken in many centres using a wide variety of techniques such as radiography, autopsy studies, ultrasound and transverse axial tomography. The reported thicknesses vary between 7 and 47 mm! In irradiating this area adequately it is obvious that each patient had to be assessed individually in order to treat the full thickness of the chest wall without irradiating unnecessarily thick slices of the underlying lung.

The internal mammary nodes were assumed to be located 25 mm lateral to the midsternal line. Lymph node scintigraphy has shown their location to be variable. For instance Rose et al 1977, determined the average lateral

displacement from the mid line to be 25 mm (range 0-53 mm). Usually advocated is a direct irradiation field giving the prescribed dose to a depth of 30 mm. Whilst inaccuracies in measurement of the chest wall thickness have some effect on the dosage if one considers a direct photon field, these inaccuracies are much greater if other techniques such as electron irradiation or oblique fields are used; inadequate estimation of node depth can result in this potentially tumour-bearing region receiving almost no irradiation.

Diagram 6



Materials and Methods

In one year we examined 55 patients with chest wall and breast malignancies. The primary tumours were all breast carcinomata whose TNM classifications can be seen in table 19. A not inconsiderable minority of the patients had not been operated upon because either the tumour was deemed to be inoperable or the disease was already known to be incurable. Since the tunnel diameter of the scanner is 56 cm, scanning in the traditional treatment position was impossible. Patients were thus both scanned and treated with their hands behind their heads. Scans were performed first through the centres of the tangential telecobalt fields and then over the length of these

fields with special attention to the first few intercostal spaces. The usual technique for this series of patients was three wedged telecobalt fields: two arranged tangentially across the chest wall and one direct anterior field for the parasternal region (diagram 6).

Table 19: Distribution of Chest Wall and Breast Tumours according to TNM Staging.

	N0	N1	N2	N3	NX
T1	4	2	2	0	0
T2	12	5	4	9	0
T3	0	1	0	2	0
T4	2	3	0	3	1

(Also 5 cases of tumour recurrence or metastasis in the chest wall)

Results

Firstly the treatment and target volumes were compared in order to assess how effectively the tumour bearing area was being covered by the radiation fields. In only 1 patient a portion of the tumour lay outside the treatment volume (major miss). In none of the rest of the patients did the macroscopic tumour reach to the very edge of the treatment volume (minor miss). In none of the patients was the treatment volume increased by increasing the dimension of the irradiation fields. The aim of the project is to see if we can irradiate tumours to a higher dose whilst diminishing the dose to the adjacent normal tissues. The results above pinpoint the adequacy of the irradiation of the tumour target volume. Unfortunately we were not able to spare a significant portion of the surrounding normal tissues. Considering the field geometry as a whole we have made changes in only 1 of the 55 evaluable patients.

We found in only four (10%) of the 40 patients with tangential fields in this series that changes in the body outline resulted in a greater than 5% change in target dose in that section of the chest wall which was treated with the tangential fields. Remaining on the central axis of the treatment fields and allowing for the changes in chest wall thickness, we recorded a greater than 5% change in target dose in the parasternal area in 13 (34%) of 38 patients of which the mean alteration was -13% of the target dose with a range of +6% to -25%. As usual the dose distribution was also assessed three dimensionally. In the other planes we recorded a change in target dose in 28 (70%) of 40 patients of which the average alteration was -9% of the target

dose with a range from -25% to +10%. In 15 patients this dose alteration was greater than 5% of the target dose and in 8 patients was the dose changed greater than 10%. In 4 (11%) of 35 patients we found an unexpected lack of uniformity of dose of greater than ± 5% of the target dose. In none of the patients was it felt that the CT scan data had exposed an unacceptable high dose in one of the sensitive surrounding organs. Considering the dose distribution as a whole, we found that the CT scanning exposed significant inaccuracies in 15 (29%) of the 51 assessable patients in this series.

Discussion

The role of radiotherapy is local control and to maximise this whilst minimising complications, the true extent of the tumour target volume and its relationship to sensitive organs must be known. Suit (1970) had estimated that of patients dying with breast cancer, about 14% die with local failure as the major cause of death. Because distant metastases dominate the clinical picture when they occur and little attention may be given to the primary site by the doctor and patient in such situations, we may assume that the percentage of patients dying with an uncontrolled loco-regional tumour complex is greater than the 14% of Suit.

The chest wall is irregular in thickness. The minimum thickness measured was 5 mm occurring in the scan after a radical mastectomy. The maximum measured thickness in post-mastectomy cases occurred well alway from the scar. We observed an obvious difference between simple and radical mastectomy cases for, in the former group, the maximum thickness is to be found at the upper end of the anterior axillary line over the still intact pectoralis muscle. Many cases had a variation in chest wall thickness of more than 3 cm. There is also considerable patient variation lined not only to the operative technique but also the body build.

Our inaccuracies in the estimation of the chest wall thickness are revealed in the inconsistencies in radiation dosage when this region is re-planned using the CT data. The treatment technique using opposing tangential telecobalt fields is luckily reasonably resistant (90% acceptability) to our inaccurate assessments but when one considers the parasternal area which is only treated with a direct field, it appears that we consistently underestimate the depth of the lymph node target (66% acceptability). Many institutes treat both these regions with direct electron fields whose fall-off in dose is much steeper than with telecobalt irradiation. In their case underdosage of the tumour-bearing areas would not only occur more frequently but also be much more severe than in our series.

Disappointingly internal mammary nodes are not routinely seen on transverse CT scans and abnormalities consistent with node enlargement were seen in only 4 (7%) of the patients (2 more cases can be judged as "suspicious"). Høst and Brennhovd (1977) reported that the five year survival figures in patients with involved axillary nodes was improved by telecobalt irradiation to the internal mammary and supraclavicular areas. This was most marked in a group of patients with medially situated primary tumours and with four or more involved axillary nodes. Provided the disease in the axilla and on the chest wall can be controlled, adequate treatment of the internal mammary nodes may contribute to increased life expectancy in these patients. Accurate assessment of this lymph drainage region is desirable and entails also the accurate measurement of the chest wall thickness from the skin to the pleural surface.

The CT scanner is not exposing cases of internal node metastasis. However this is not unexpected for a scan series shows only enlarged nodes and can not be expected to detect micrometastases. Moreover the distribution of abnormal cases according to the site of the primary tumour in the breast in our series corresponds with Handley's findings (1969). Although histological proof was not obtained from our patients it seems likely that the abnormalities which we visualise represent massively involved internal mammary lymph nodes.

Isotopic scintigraphy as described by Ege (1976) may allow increased accuracy of nodal staging since probably only massively enlarged internal mammary nodes are visualised during CT scanning. Our own limited experience with the technique has yet however to identify the larger patient groups with internal mammary metastases. Reports have shown that ultrasound is useful in measuring chest wall thickness in post-mastectomy patients for radiation purposes (Jackson 1970; Rhyne 1973; Brascho 1977). That technique is simple to perform and less costly to the patient that CT. However the transferal of ultrasonic data to a treatment planning computer is less advanced than in the case of our CT system. Moreover in those patients who are to be treated with radiation alone, ultrasonic scanning over the breast can produce technical problems.

Conclusions

The thickness of the chest wall varies considerably but measurement of this parameter is essential for the planning of adequate electron irradiation without damaging an excessive volume of lung tissue. Although the

treatment volume was changed in only one patient, significant inaccuracies in dose distribution were exposed in 15 (27%) of the 55 patients entered into this part of the project and most often this related to an underdosage of the internal mammary lymph node regions. Whilst the internal mammary node metastases were only rarely visualised, the depth at which they would lie could be measured. A combination of ultrasound or CT scanning (for the depth measurements) and isotope scanning (for the lateral displacement and evaluation of tumour involvement) seems indicated. The CT scanning would have an even more dramatic contribution for patients being treated in those institutes using direct electron fields.

CHAPTER 8

PALLIATIVE RADIOTHERAPY

Introduction

The terminal stages of a patients life are usually a time when active treatment has ceased. Palliative radiotherapy can, however, be helpful during this period if it is applied skillfully. If misapplied, it can be harmful. The purpose of such palliative radiotherapy must be to relieve distressing symptoms quickly and thus improve the quality of the remaining life.

The aim of palliative radiotherapy is to relieve symptoms with the lowest possible dose in the fewest possible treatments. Such treatment has an important part to play in the relief of pain from bone metastases, most commonly those from a primary breast or bronchial carcinoma. Similarly the presence of bleeding can be very disturbing to a patient and a short course of radiotherapy to the chest or pelvis can be used to relieve haemoptysis, haematuria or vaginal bleeding. Patients are unfortunately not infrequently seen with disseminated carcinomatosis associated with a primary breast tumour which is either fungating or about to fungate. Such a tumour, even if quite large, can often be controlled, with some healing of the ulceration, by a few doses of irradiation. Other tumours fungating onto the surface of the body may warrant iraadiation in an attempt to reduce a profuse discharge. Cough and dyspnoea from an advanced primary bronchus carcinoma can often be improved by a course of palliative radiotherapy. Threatened spinal cord compression due to metastasis may also be prevented.

The principles of treatment are dictated by the limited expectation of life and the need to avoid causing the patient additional discomfort. Palliative radiotherapy at this stage of the disease should have few side-effects. Of the normal tissues, the gastrointestinal tract is one of the most radiosensitive. Irradiation of the abdomen will often cause nausea and diarrhea. This is just one example of how optimal treatment implies delivering an adequeate radiation dose to all of the tumour with a minimum dose to the surrounding

normal structures. To reach these goals, accurate localisation of the tumour and the surrounding normal structures is required. The purpose of this study is to evaluate the effectiveness of CT scanning as an adjunct in radiotherapy planning in cases requiring palliative treatment. It seems worthwhile to consider this group separately because these patients usually need a different treatment policy from those who are to be treated for cure.

Materials and Methods

The distribution of patients and tumour types is shown in tables 20 and 21.

Table 20: Indication for Palliative Radiotherapy

	Primary Tumour Including Recurrence	Massive Lymph Node Infiltration	Bone Metastasis	Lung Metastasis
Oesophagus	1	-	-	-
Colon	2	-	-	-
Larynx	-	1	-	-
Bronchus	3	1	1	3
Breast	11	-	8	1
Cervix uteri	1	1	-	-
Vulva	-	1	-	-
Bladder	1	1	-	-
Kidney	1	-	-	-
Unknown primary	-	-	1	-
Malig. lymphoma	1	5	-	-

Table 21: Regions Scanned:

Thorax	9
Chestwall	14
Abdomen	4
Pelvis	8
Vertebral column	6
Other	4
Total	45

Most of the treatment set-ups were simple i.e. a parallel opposed pair of telecobalt fields but multi-field plans were often also used in order to cover bulk disease adequately whilst sparing as much normal tissue as possible. In these cases dose distribution, with and without the CT scan data, was calculated in the treatment planning computer.

Results

Firstly we considered how effectively we were encompassing the tumour within the radiation fields. In 7 patients (16%) a portion of the tumour lay outside the treatment volume (major miss). From our observations this untreated segment represented an average 30% (range 10 - 50%) of the whole target volume. In a further 5 (11%) of the 45 patients, the macroscopic tumour reached to the very edge of the treatment volume (minor miss) and one can expect that there was invisible microscopic infiltration of the tissues in an area of low irradiation dose (tables 22 and 23). In 9 patients (20%) the treatment volume was extended by increasing the dimensions of the irradiation fields. In no case could the size of the fields be diminished.

Table 22: Analysis of Alterations in the Radiotherapy

Inadequate tumour coverage	: 12/45 patients (27%)
Field alteration to spare normal tissues	: 2/45 patients (4%)
Significant difference in central axis target dose	: 16/41 patients (39%)

Table 23: Reason for Change in Irradiation Fields (N=45)

Primary tumour infiltration	: 8 patients
Regional lymph node involvement	: 1 patient
Non-lymphatic metastases	: 0 patient
Non-optimal coverage of target volume without change in field size	: 3 patients
Overestimation of target volume	: 0 patient

We still have not yet explained all the changes in the radiotherapy fields. You could imagine that the treatment fields, and thus the treatment volume were of the correct size to irradiate a given target volume but that the centres

of the two volumes did not coincide. Often the fields could remain of the same size whilst the whole treatment volume was shifted to come into better alignment with the target volume. In 3 (7%) patients this was the only cause of changing the fields arrangement for in these cases we discovered no unexpected tumour infiltration or metastases.

The aim of the project is to see if we can irradiate tumours to an adequate dose whilst diminishing the dose to the adjacent normal tissues. The results above pinpoint the inadequacies in the irradiation of the target volume. Sadly in only 2 cases have we been able to spare a significant portion (30% and 50% of the treatment volume) of the surrounding normal tissues. Considering the field geometry as a whole we have made changes in 12 (27%) of the 45 evaluable patients.

We recorded a change in central axis target dose in 30 (73%) of 41 patients. The main alteration in target dose was 9% and this was usually downwards. In 16 of 41 patients (39%) this dose alteration was greater than 5% of the target dose on the central axis. In other planes we recorded a change in target dose in 28 (74%) of 38 patients of which the average alteration was -10% of the target dose with a range from +20% to -25%. In 16 patients this dose alteration was greater than 5% of the target dose and in 10 patients (26%) was the dose change greater than 10%. In none of 16 patients was non-uniformity of dose found of greater than $\pm$ 5% of the target dose. 24 patients were treated with parallel opposed fields and homogeneity of dose was assumed to be present. In none of the patients was it felt that the CT scan data had exposed an unacceptably high dose in one of the sensitive surrounding organs. Considering the dose distribution as a whole, we found that CT scanning exposed significant inaccuracies in 19 (46%) of the 41 assessable patients in this series.

Taking all the measured factors into account we conclude that CT scanning was of value in the planning of the palliative radiation therapy in 25 (56%) of the 45 treatment series entered in this project (table 24).

Table 24: Summary of Results

Change in field geometry	: 12/45 patients (27%)
Change in tumour dosimetry	: 19/41 patients (46%)
All factors	: 25/45 patients (56%)

Discussion

The extent of the impact of CT scanning on palliative radiotherapy is quite startling. Our experience broadly agrees with the findings in other institutes where the majority of those patients who are examined with CT are to be treatment radically (table 25). For instance approximately half the patients studied have changes in therapy as a result of the CT scans. We can conclude that CT scanning is approximately as valuable in our group of patients who are to be irradiated palliatively as for mixed groups of patients reported elsewhere who were to be mainly treated to cure.

Why must we change the treatment fields in such a high percentage of cases? In 8 cases this was due to the discovery of unexpected infiltration by the tumour of the surrounding normal tissues. In 1 case we found unexpectedly pathologically enlarged regional lymph nodes (table 23). Thus even after a traditional staging procedure and despite the fact that out aim was not to assess tumour morphology per se, we are still gaining information which has both prognostic and therapeutic significance in the management of the patient. Because of these findings whereby the tumour appears more extensive than originally supposed, the aim of the radiotherapy sometimes has to be changed from a long-term to a short-term palliative goal. Unfortunately in only two cases could a significant amount of surrounding normal tissue be excluded from the treatment volume because of the CT findings.

Whilst there had been reports in the literature by Brascho (1975), Badcock (1977) and others describing the uses of diagnostic ultrasound in radiation therapy planning, an efficacy study of a large patient population with radiotherapy fields determined by means other than ultrasound (X-rays, surgery, clinical examination etc) was not reported until 1976. Carter et al evaluated the effectiveness of B-mode ultrasound scanning as an adjunct to radiotherapy planning in patients with large abdominal and pelvic malignancies: 61% of their 51 patients had evidence of tumour extension beyond the field edges. This was often due to "iceberging" i.e. when the deep portion of the tumour was considerably larger than the palpable margins of the superficial portion. In only 4% of their patients could the field size be reduced. In contradistinction to the various CT series cited above, they restricted their report to patients irradiated palliatively. Their rate rate of field change was considerably higher than in our series but the precise percentage can depend on the region scanned. In our group of 55 patients with pelvic tumours we report a change in field geometry in 48% of cases. With their research using ultrasonics, Carter et al, have spurred reassessment

Table 25: Essentiality of CT Scanning during Radiotherapy Planning

Author	Scanned sites	No. of patients	Therapy R = radical P = palliative	Tumour Coverage Major miss	Marginal miss	Essentiality CT scanning
Munzenrider et al, 1977	mixed	75	R/P	20%	27%	55%
Emami et al, 1978	lung	32	R/P	28%	-	53%
Brizel et al, 1979	pelvis	72	R/P	40%	-	61%
Hobday et al, 1979	mixed	123	R	26%	-	38%
Goitein et al, 1979	mixed	77	R/P	31%	11%	52%
Badcock whole group	mixed	205	R/P	21%	14%	58%
This study	mixed	45	P	16%	11%	56%

of the precision in radiotherapy planning. However technical problems prevent ultrasonics taking over the task of CT scanning in several important regions of the body (eg, lung, bone).

Initially we confined our project to patients who were receiving radical therapy with intent to cure. However many patients are admitted for radiation treatment for whom the chance of cure is small or nil. Often the CT scan indicated that the chance of cure was even less than initially hoped for, but it suggested treatment modifications which maybe would lead to more effective palliation. Not only were considerable portions of the tumour bulk missed in many patients but the CT scanning exposed significant inaccuracies in dosage. Patients for palliative radiotherapy tend to be treated with a few large fractions. Under-dosage may mean that the treatment is ineffective and over-dosage can lead to distressing acute complications. Brizel et al (1979), in looking for selection criteria for requesting CT scans, observed that the technique seemed to be of value for both curative and palliative treatments. Our experience with a series of 205 consecutive patients both for radical and palliative radiotherapy tends to conform this conclusion. This X-ray examination is not too taxing for the patient.

Conclusions

The results of this study suggest that a significant percentage of patients undergoing palliative radiotherapy have one or more margins of the tumour volume which extend beyond the radiation fields as determined by traditional techniques. Even though this was not our aim, we were still gaining information of therapeutic and prognostic significance during the CT scanning. As with icebergs, one is frequently confronted with the phenomenon that the deep portions of the tumour are more extensive than the superficial manifestations suggest. CT scanning appears to be superior to the usual methods of siting the radiotherapy fields if one wishes to ensure that no part of the tumour lies outside the radiation treatment volume whilst treating only a minimum of normal tissue. Routine simulator techniques however appear adequate in preventing the irradiation of both an unacceptable volume of normal tissue and of radiosensitive organs to excessive doses. It can be seen that CT scanning was not only quick, safe and non-invasive but also offered the effective help in the planning of 56% of the palliative treatments for the 45 patients in this series.

Assessment in terms of quality of survival, local control of the malignancy and treatment complications wil require a longer period of follow-up. We have however evaluated the improvement in precision whilst

attempting to treat a tumour volume to a prescribed dose. Computed tomography proves to be of such value in localising the tumour target volume (27% of patients) and in dose distribution (46% of patients) that it should be considered in the planning stages of most patients referred for palliative radiotherapy.

CHAPTER 9

ANALYSIS OF COST EFFECTIVENESS

Introduction

When "income" is used for the measurement of "contribution", we find that various groups (children, the elderly, women, low-wage earners) are undervalued such that a cost-benefit analysis is unusable and socially unacceptable. However the assessment of various priorities in health services remains a problem and alternatives to this form of analysis are scarce. An effectiveness: cost ratio may offer a possible alternative.

Our study has proposed that the use of CT scanning will improve radiotherapy results with longer patients survivals, improved local control rates and fewer complications. For the first time CT scanning allows accurate visualisation of tumour volumes in transverse body sections together with the delineation of the adjacent normal tissues. Corrections for tissue inhomogeneity can be directly applied to these data. Employing greater use of beam modifying techniques one can achieve a hitherto unattainable precision in dosimetry.

Polyscannery, like polypharmacy, is a highly infectious condition. To some the blunt charge that "overinvestigation is a form of physical cruelty" (Asher, 1949) will seem an exaggeration. In speaking of "safe, easy, non-invasive investigation" however, it must be remembered that some patients have a low threshold for discomfort and anxiety. Perhaps as CT scanning in radiotherapy planning, like other technical advances, places still further temptations in our path, we should spend a little time examining the possible benefits.

Method

Evaluation of health care is a difficult but increasingly important problem in this poor economic climate. The traditional methods, fraught with physician

and politician bias, has been called autoreputational analysis i.e. several respected figures prefer technique A over B. Of course a more objective approach is to measure the impact of the new techniques on the outcome of the treatment process. In radiotherapy one could look at 5 year survivals and local tumour control rates for instance. Unfortunately, as progress is being made continuously on many fronts, it proves impossible to isolate out the contribution of one new technique in an ever changing situation. Futhermore having to wait several years for results (both positive and negative) may be difficult to justify.

In order to overcome these objections one can perform a process-analysis instead of an outcome-analysis. Radiotherapy planning is a system suitable for such an evaluation with its welldefined elements of tumour and normal tissue localisation as well as dose computation (chapters 3 and 4). In our project we have found that CT scanning was of significant help in the planning of the radiotherapy in 118 (58%) of the 205 patients (field geometry: 36%, dose-calculations: 39%). How should the costs of a new technology be calculated? It must be admitted that CT scanning is expensive, but this is but a small proportion of the total costs of a course of radiotherapy and the necessary follow up.

Cost-benefit analysis has major limitations when applied to medical care for such an analysis demands the putting of a money value on such factors as the increase in morbidity and mortality resulting from inappropriate treatment. To compare the costs and benefits of, for instance, the use of CT scanning in radiotherapy planning, one could place a monetary value on the lives saved (Weinstein and Stason, 1977). Although this can be attempted (Rice and Cooper 1967, Cooper and Rice 1976), this price can be challenged. Supposing that a benefit: cost ratio could be computed, what would be its significance? The analysis would attempt to demonstrate that money would be well spent on the technique, but compared with what? One can only conclude that the money is better spent on this technique than on other cancer control methods with lower benefit: cost ratios. The distribution of scarce medical resources is however often not determined in the cool study of statistics but in the cut-and-thrust of politics. Perhaps this is the reason that so few radiotherapy institutes have access to the CT scanners which they claim they need. However cost: benefit analyses can be very helpful in giving structure to the problem and allowing consideration of the consequences of various decisions.

The major disadvantage of the cost : benefit calculation is that human lives and the quality of human life has to be valued in monetary units. On the contrary, an effectiveness : cost ratio requires only that the outcome be

expressed in commensurate units. Resource costs are usually measured in monetary units and effectiveness is expressed in some unit of output. The level at which one is no longer willing to pay the price for the benefits achieved becomes the cut-off for permissible cost per unit of effectiveness.

In order to facilitate international comparisons I propose to make use of parts of the model of Goitein (1979, 1980). His goals for CT-assisted radiation therapy planning generally coincided with ours. Furthermore our two groups of patients exhibit a similar general diversity of tumour histologies and treatment aims. Some of his calculations are essentially model independent and his results are relatively insensitive to, for instance, the steepness of the dose response curve; facts that can only reassure when one tries to draw parallels between the two series. The various financial considerations are expressed in local units of currency: American dollars ($), Dutch guilders (f) and British pounds (£). For our study we have used costings for the year 1980 not only because that was the year of our study but also because more up to date figures are scarcely obtainable.

Results

The effect of CT scanning on radiotherapy planning appears to be dramatic but one can not assume that the percentages will be reflected in terms of cure rates. Firstly, even optimilisation of the target coverage of the 36% of the patients whose fields were inadequate (chapter 3) would still not have guaranteed loco-regional tumour control. In Goitein's series of 77 patients with a similar diversity of tumours as in our material it was estimated that local control would be maximally 52%. Averaged over our entire patient group, local control would be improved by maximally 36% x 52% = 19%. Secondly in most cases all of the tumour received some dose of irradiation for it was not often that all the fields were inadequate. Using Goitein's calculation that in only 28% of cases would local failure arise from poor coverage of target volume, the figure for improved local control rate is further reduced to 36% x 52% x 28% = 5%.

Unlike the analysis of Goitein, we have also performed a three dimensional analysis of inaccuracies in computation of target dose. This figure (39% of our patients) reflects not the inadequacy of the field boundaries but inaccuracies in measurement of the surface-target distance whereby generally a lower dose is given to the tumour than was wished (chapter 4). Once more using the irradiation dose - local tumour control probability curve of Goitein, I estimate that local failure would have occurred in an extra 3% of the patients due to this factor alone. The

improvement in local tumour control rate due to CT scanning for our patient group was 5% + 3% = 8%.

Is a benefit of this magnitude worth the cost of the procedure? Attempting to answer this question I shall try to compare the ratio of the costs of the CT scanning and the anti-cancer treatment with the projected improvement in treatment result due to the use of CT scanning. A body scan costs approximately *f* 290 in the Netherlands. The cost of the therapy is more difficult to estimate and I am using figures based on the local situation (table 26) assuming that the initial treatment is succesful. The figures for the United Kingdom are £ 69 for the cost of the CT scanning (Wrighton, 1981) and £ 1475 for the cost of the whole treatment (Maquire et al, 1982). The figures for the cost of treatment are unfortunately not comparable for whilst the British figure underestimates the medical and nursing costs, it does include the social costs which could not be calculated for the Dutch situation. A minority of patients also recieve a complimentary but expensive treatment with chemotherapy. The costs of this and also the follow-up are so variable per patient that no attempt has been made to include them in the calculations for fear of increasing the inaccuracies and producing a distorted picture. The CT scan represents thus 3.1% (Netherlands) or 4.7% (UK) of the cost of the entire initial treatment.

Table 26: Average Cost of Initial Treatment

Cost of In-Patient Care during Admission of Average Duration	*f* 5250
Average Medical Fees (Surgeon and Anaesthetist)	*f* 706
Radiotherapy (Van de Hoek, personal communication)	*f* 3400
	f 9356

The proportional benefit it bestows is the ratio of improvement in local control due to CT (8%) to the probability of local control for the whole treatment (52%). According to our estimates CT improves the locoregional result by 8/52 = 15.5%. CT-assisted radiotherapy planning appears to justify its cost for its proportional benefit (15.5%) exceeds its proportional cost (3.1% in the Netherlands or 4.7% in the UK) by factors of 5 and 3.3 respectively. Having made a large expenditure for obtaining a 52% local tumour control rate and despite the law of diminishing returns, one makes a not inconsiderable improvement at little extra cost (table 27).

Table 27: Effectiveness-Cost Ratios of CT-assisted Radiotherapy Planning

	This study		Goitein (1979/1980)
	Netherlands	UK	USA
Probability of achieving local control (a)	52%	52%	52%
Improvement in local control rate due to CT: by correction of treatment volume	5%	5%	6%
by correction of target dose	3%	3%	-
total (b)	8%	8%	6%
Proportional benefit (b/a) due to CT (c)	15.5%	15.5%	11.5%
Cost of initial cancer therapy	*f* 9,356	£ 1,475	$ 12,000
Cost of CT body scan: actual	*f* 290	£ 69	$ 250
fractional (d)	3.1%	4.7%	2.1%
Effectiveness: cost ratio (c/d)	5	3.3	5.5
Estimated improvement in cure rate due to CT	4.5%	4.5%	3.5%

Discussion

The cost of health care continues to rise and is now reaching levels which embarrass governments in many parts of the world. It is easy to blame research, or its outcome, for the increasing costs of health services but research does not necessarily make treatment more expensive. The control of many diseases, including cancer, is in many instances less expensive in the long term, as well as more humane, than the continued course of the disease.

Theoretically if improved precision of radiotherapy diminshes local tumour recurrence and local tumour complications, an increased proportion of cured patients may results. Accordingly large cost savings in the care of patients with neoplasia may also occur. Stewart and Simpson (1977) have indicated that if only an additional 5% of patients with cancer were cured as a result of CT-assisted planning, the cost of the CT scanning in all patients would be covered. If by reducing normal tissue sequelae, such as radiation myelitis, expensive long term care is avoided, another cost advantage will be realised.

Many techniques have been heralded as great advances and applied widely before their consequences were known. It is curious that monitoring

of new treatments by drugs has achieved much more acceptance than the monitoring of surgical, or even many radiotherapeutic, procedures. Medical and public enthousiasm for technically awe-inspiring treatments often continues in circumstances which would cause at outcry against a drug which achieved identical inadequate results. The dispelling of the attractions of an apparently glamourous procedure and the evaluation of its true benefit has been the aim of this study.

It must not be forgotten that many cancer patients achieve local tumour control but die of distant metastases. Assuming similar rates for Goitein's and our patients and making using his figure of 44% probability of local control but distant metastasis, the average improvement in cure rate due to the use of CT can be estimated at 8% x (100% - 44%) = 4½% for our patient group (table 27). With this figure the almost incredible effects CT scanning has on radiotherapy planning are reduced to a realistic order of magnitude and it becomes clear that a conventional clinical trial would be scarcely able to demonstrate what is just one more of those small but real improvements which have helped boost cancer cure rates in the last forty years.

Local tumour control is one of the factors necessary for achieving a patient cure. However even for patients who are destined to die of distant metastases, local tumour control represents an improvement in the quality of life. Although important for this group of patients, this is often regarded as "spin-off" by us. I myself, have made no allowance for this in my analysis of the effectiveness of CT with the consequence that the palliative goal of local treatment appears once more to be overlooked. Quantification of this factor is however often subjective, but would certainly have led to a further increase in the effectiveness: cost ratio to the benefit of CT. Yet even if one restricts the assessment to those patients who could achieve a cure, CT assistance during the radiotherapy planning appears to be cost effective.

Conclusions

The cross-sections displayed by computed tomography are an ideal basis for radiotherapy planning because the bodycontour, tumour target and adjacent normal tissues are accurately visualised. Using this format, dose distribution plans can be computed using an integrated radiotherapy planning system and these techniques make an important contribution to the management of many tumours. With an estimated improvement in cure rate of 4.5% and cost-effective factors of 5 (Netherlands) and 3.3 (United Kingdom), CT-assisted radiotherapy planning appears to be a worthwhile procedure.

CHAPTER 10

TECHNICAL NOTES

I IN VIVO TLD MEASUREMENTS

There is a limited number of studies in which the internal dose absorbed has been measured within the trunk of a phantom during CT scanning (Wall and Green 1979). Whilst the Alderson-Rando anthropomorphic phantom can undoubtedly be extremely useful for medical dosimetry in radiotherapy, it has been shown that corrections to the dose distributions observed for diagnostic qualities of radiation may sometimes be necessary to allow for departures from tissue equivalence (Shrimpton et al, 1981). For this reason, rectal measurements of dose were made using TLD sachets (Badcock 1984) in four patients during the scanning of the pelvic region using the otherwise standard techniques described in chapters 2 and 5.

The average depth dose absorbed per slice during CT scanning of the pelvis is in the order of 12 mGy although this is probably influenced by the size of the patient and the degree of bone shielding of the measurement site. Taking account of scattered irradiation during a multiplane examination, the absorbed dose in the volume of interest is c.13 mGy when the distance between slice-centres is twice the slice thickness and rises to c.18 mGy when this distance is reduced to 1.5 slice thicknesses. When the slices abut we recorded doses of c.25 mGy. This corresponds with the depth doses associated with the taking of a few conventional Xray photos. These doses are obviously not relevant for our patients who are anyway to receive doses of up to 65 Gy but they may be an important factor for consideration during diagnostic scanning.

II TISSUE CHARACTERISTICS

Precise definition of the tumour boundaries is an essential step in CT assisted

radiotherapy planning. As in the case of traditional planning using the simulator unit, CT is most often used to detect anatomical abnormalities in order to define the target volume. By way of a pilot study we have examined several patients with large tumours hoping that the radiological characteristics of the neoplasm might also be used for delineating the malignant tissue.

Materials, Methods and Results

Firstly absorption values were measured at various points in a series of large tumours (diameter greater than 4 cm). One sees in table 28 that we are dealing with various organs and histological types. The tumours were scanned during the planning stages of the radiotherapy and measurements of absorption value were made both in the centre and at the edge of the tumour mass. Patient no. 7 was re-examined at the end of the palliative radiotherapy during a period of clinical regression of the tumour (no. 7a).

Table 28: Attenuation Coefficients of various Tumours

Patient no.	Tumour histology	Involved Normal Tissue	Absorption Value (in Hounsfield No.) Tumour Centre	Tumour Edge
1	adenocarcinoma	breast	+30	+12
2	lymphoma	lymph node	+15, +23, +25	-
3	seminoma	lymph node	+53	+46, +50
4	anaplastic ca.	lung	+23	-169
5	oat cell ca.	lung	+46	-66
6	anaplastic ca.	lung	+21	+18
7	adenocarcinoma	caecum	+48	+36
7a	ditto		+36	+33
8	lymphoma	lymph node	+42	-
9	transitional cell ca.	bladder	+21	+28
10	adenocarcinoma	bone	+46	+53
11	not known	lung	+21	+54

Secondly many of the patients together with others with less easily definable masses (ie in the mediastinum) were injected with contrast (60 ml i.v. "Telebrix" bolus) in the supposition that this technique may aid tumour

definition such as one sees by CT scanning of the brain. Because of the rapidity of these effects, determination of changing absorption values proved impossible and we were reduced to subjective impressions of the visual images. Contrast enhancement of normal tissues occurred rapidly, was easily visualised and was already disappearing with four minutes. Contrast uptake by large tumours was much slower and much less intense. Furthermore it was much more patchy presumably due to areas of a vascular necrosis especially in the centre of the tumour. The "wash-out" phase in the tumour was often not even apparent by the end of the examination.

Discussion

Invasion of the prostate gland by a bladder tumour cannot be visualised because there is no fat plane visible between the two tissues whose absorption values are also so similar as to prevent definition of the common boundary between the organs. Intravenous contrast injection provides no solution to the problem. During CT scanning of the mediastinum one is often confronted with a round structure not knowing whether this is vascular or a lymph node. Intravenous contrast rapidly allows differentiation since uptake in the node is minimal during the first four minutes after injection compared with the blood concentrations.

Unfortunately measurement of absorption values of malignant tissue cannot be used to differentiate them from normal tissues. This is not altogether surprising for the cellular constituents are, of course, similar. Furthermore tumours are not homogenous seeming to contain areas of lower and higher attenuation perhaps explained by necrosis and calcification or haemorrhage respectively. Lastly the measurement of the CT number itself is not without inaccuracy. The area of tumour, whose absorption value is to be measured, is delineated on the scan slice. Usually a 1 cm diameter circle was used. One can check visually that this area contains only tumour tissues. Nevertheless in two patients (no. 4 and 5) this area obviously included some of the surrounding air-filled lung because the values obtained were so low.

One would expect that tumours, in general, would enhance less rapidly and less efficiently than normal tissues because of their poorer vascularisation. However we were dealing with rapidly changing states in a heterogenous group of tumours and normal tussues whereby these subtle differences could not be appreciated. Whilst performing this pilot study we came to the conclusion that a fuller understanding of the practical implications of densitometric CT programmes and a strictly standardised procedure, namely in terms of timing of the contrast media injections, are

necessary to obtain relevant results. Even then it is open to discussion whether one has a practical solution to the difficulty in differentiating between malignant and normal tissues.

Conclusions

Precise localisation of macroscopic tumour involvement is crucial to radiotherapy planning. Unfortunately, in many cases, the tumour and the normal tissue it occupies or abuts have similar attenuation coefficients such that visualisation is often inadequate. Research into methods of enhancement of tumour / soft tissue contrast in CT scanning is still needed. Until then, delineation of the tumour volume depends on appreciation of anatomical abnormalities as depicted on the scan slices, making use of such features as boundaries with air and liquids, bone destruction, tumour capsules and the loss of the normal fat planes between the various organs.

CHAPTER 11

GENERAL DISCUSSION

Radiotherapy is often used for the treatment of internal tumours. Photons in the dose levels used in radiotherapy inevitable damage any tissue, normal or diseased, through which they pass. So the task of the radiotherapist is to focus the irradiating team onto the tumour in such a way that the surrounding healthy tissues receive the lowest possible dose. To do this, the radiotherapist needs to know precisely where the tumour is located and the usual way of gaining this data is to take conventional diagnostic Xray pictures from two directions at right angles (i.e. anterio-porterior and lateral). Measurements taken from these pictures should reveal the size of the tumour and its depth below the body surface.

Although this approach sounds perfectly sensible in theory, in practice it is less than ideal for accurately aligning the irradiating beams. Until recently radiotherapists have usually only thought in two dimensions and have inadequately allowed for the irregularities in the body surface. It is these irregularities which have a significant effect on the dose of irradiation which the tumour is going to receive. Using the CT scanner and the treatment planning computer we can calculate the tumour dose in planes off the central axis. From radiobiological experiments elsewhere one sees that the risk of losing tumour control is increased when the irradiation dose is reduced by a factor of as little as 5%. By such a dose reduction, the tumour control rates are affected by factors of up to - 19%. Small discrepancies in tumour dosage are reflected by greater discrepancies in the rate of tumour cell kill.

The use of CT scanning overcomes many small but important planning inaccuracies because images are produced which are unlike those of conventional radiography. A normal Xray image is akin to shadowgraph of what lies within the body. The CT scan is a cross-sectional view and allows much more accurate measurement of the position of the tumour. Because the CT scan reveals the soft tissues in greater detail it is often also more useful in localising the extent of the malignant tissue.

Application

Until we were personally convinced of the benefits of the application of CT scanning in the planning of radiation treatments we conceded that this new technique should not displace the conventional methods. For these studies we have used this new technique as a method of checking the traditional planning and treatment procedures. This control application became available in Zwolle in February 1980, although smaller, less comprehensive projects were reported from a few mainly Americain and British institutes in the late seventies.

It has not been considered necessary to train therapy radiographers to operate the general purpose CT scanner but they are essential for the positioning of the patient prior to the production of the therapy scans. Time has been allotted for treatment planning in radiotherapy on a sessional basis. Whilst involving a delay of a few days before the optimised radiation therapy can be started, this arrangement has been found to be necessary for the efficient working of both the heavily taxed radiotherapy department and the busy CT scanning unit. The introduction of CT scanning places an additional workload on many of the personnel of the Radiotherapy Centre and this could have staffing and funding implications which are unavoidable.

The CT scanner is not purpose-built for this application. Most apparatus can by used for these new techniques without much modification. The scans are not technically difficult to apply to the treatment planning. With this new generation of scanner one is not beset with the earlier problems of the need to use bolus or with inordinately long scan times. The third advance is the scanogram which gives the location of the CT slice on an AP Xray projection. The latest step forward is naturally the development of a tape cassette system to transfer the CT data to the treatment planning computer.

However more extensive modifications will be necessary before the CT scanner can render the functions of the simulator unit obsolete. A technique has been described by Ash et al. (1983) whereby only a minimum of extra equipment is necessary. This has the disadvantage that the CT data has to be processed in the planning computer whereupon the details from the print-out have to be transferred manually onto the skin of the patient with the same inherent inaccuracies as those with which we are confronted in the simulator unit. Most radiotherapists will be reluctant to abandon the simulator unit at some point in the planning process until the CT scanner can directly indicate where one should draw the various markings on the skin. This reversal of the flow of the information has yet to be achieved but does deserve serious

consideration in order to realise the full potential of CT scanning in radiotherapy planning.

Treatment Philosophy

At this stage I would like to underline a cautionary note of Leer (1982) made during a similar study on 120 patients. A universal conclusion can not be drawn from our studies for the analysis can only assess the value of CT scanning during radiotherapy planning under the circumstances pertaining at that moment. A change in treatment technique or in the goals of the therapy will be reflected in a change in contribution of the various components that make up the treatment; CT scanning is no exception to this rule. In general, the various institutes in Europe and the U.S.A. have produced similar figures but the few discrepancies are usually explained by a difference in policy. Furthermore, our figures tend to be higher than those from some centres; using the CT data to plot three dimensional dose distribution exposes some inaccuracies in our therapy plans which would be overlooked in other institutes.

Before treating any patient with radiotherapy, the doctor should have considered five points:

1. whether he sould interfer with the patient at all and, if so
2. what alteration in the patient's condition he hopes to achieve
3. that the technique he intends to use is capable of bringing this about
4. what other effects the radiotherapy may have and whether these may be harmful
5. whether the likelihood of benefit, and its importance, outweighs the likelihood of damage, and its importance.

The treatment techniques and goals could be so summarised, for instance:

aims elimination of present symptoms;
prevention of future symptoms, especially those which are life-threatening.

means destruction of the tumour locoregionally;
exploitation of the therapeutic ratio so that the percentage of patients with long-term functional damage due to the treatment is restricted to 5%;
combination with other treatment modes to achieve synergism;
avoidance of over-treatment.

Human Fallibility

In radiotherapy one aims to deliver the correct amount of absorbed energy in the desired distribution to the target volume. This I have stated previously and is deceptively simple. In fact we are looking at not just one action but a whole assembly line, each step involving the manipulation, interpretation and recording of data. At every stage we can be confronted by mistakes due to human fallibility.

The I.C.R.U. Report no. 24 contains a short review of the frequency of errors and mistakes in radiotherapy. Mistakes of more than 5% in accumulated tumour dose have been recorded in 7 to 10% of treatments given in several centres (Herring et al, 1970; Kartha et al, 1972). Included in these figures are factors such as imperfect calibration, linearity or scaling of meters; time lags in the operation of relays; small irregularities in tabulated data and parallax on a meter reading. These physical errors can be divided from human mistakes such as inattention, misunderstanding, misjudgement or carelessness.

Risking some resentment in a busy department, one can check every isodose plan and treatment card in order to determine where the errors occur and take practical steps to prevent them. Sutherland (1980) found that the majority of mistakes are either self-correcting (because they are so obvious) or small in magnitude (less than 5% of the total target dose). The literature of occupational psychology contains many examples of investigations into rates of human fallibility in repetitive tastes of many kinds, i.e.:

1-2%: in entering digits into keyboards (Klemmer and Lockhead, 1962; Minor and Revesman, 1962)

4.2%: in drug prescribing and administration (Hill and Wigmore, 1967)

2-5%: according to environment and time of day in various tasks requiring attention to visual and mathematical detail (Blake, 1967; Colquhoun, 1972).

Radiotherapy is relatively "mistake-free" when compared with these data especially with regular checking or data handling using a minicomputer, Sutherland (1980).

There is however no cause for complacency for this checking does not include two important sections of the treatment chain i.e. the verification of the actual machine parameters during treatment and the tumour localisation. Modern technology offers us monitoring systems to combat the former. The latter has been the subject of our study. We are confronted by the conclusion that the dosimetry system and the radiation functions of a therapy system must perform at a level such that the total uncertainty in tumour dose and in

the critical structures receiving doses close to their tolerance levels is less than ± 5% (Herring et al, 1970; ICRU report nr. 24, 1976). In 58% of the patients in our series this leeway had already disappeared before the patients had arrived in the treatment room for his first treatment. In these patients the ± 5% margin had already been absorbed by inaccuracies of tumour localisation within the body contour over the length of the treatment volume. Mistakes in arithmetic, pre-setting of the dose or recording of the dose data may only further compound the innaccuracies in target dose. These mistakes occur much less frequently than the inaccuracies which we have exposed using the CT scanner and are now generally avoidable.

Inaccuracies in Conventional Techniques

What evidence have we gained in practice that the use of the CT scanner would improve the accuracy by which the tumour-bearing region is irradiated to a given dose? In one year we have scanned a group of 205 unselected patients who could be judged to be typical of what a general radiotherapist sees in his practice. We have looked at two factors in particular.

The first was how often a section of the tumour lay outside the treatment volume? In 36% of the patients tumour somewhere was missed by the radiotherapy. What is particularly interesting is that this figure was even higher in those cases with intra-thoracic tumours where one would think that conventional techniques were more than adequate because of the favourable factors which have promoted the development of chest radiography. However CT scanning has disproved this assumption.

Secondly we looked at the tumour dose. In 27% of the patients we found that there was a discrepancy of greater than 5% in calculated dose when comparing the conventional and CT-assisted plans. Most often this would have resulted in an under dosage of the tumour in practice. These figures refer only to dose discrepancies on the central axis. Using the CT scanner and three- dimensional plotting of the dose distribution, we exposed more (43% of patients had a greater than 5% dose difference) and larger (up to 35% change in prescribed dose) inaccuracies in dose application to the target volume. For practical reasons only a few patients can be three dimensionally planned in the conventional simulator unit. Generally little correction is made for changes in body contour over the length of the target volume. Using the CT scanner and the TPS, an assessment of the neccessary compensation now becomes a practical proposition for most patients.

In the foregoing chapters these data have been subdivided according to body region, on- and off-axis dose distribution and normal tissue dosage. With the use of systemic treatments it may become possible to eradicate micrometastases. Population screening is aimed at discovering tumours before metastases are produced. Because of these two developments, the importance of loco-regional control of malignant tumours, without disabling treatment complications, has become increasingly important. Radiotherapy is used almost exclusively as a loco-regional treatment and its failure can be divided into two categories. Edge recurrence of the malignancy occurs when the treatment volume fails to cover all the tumour being due to inadequate field size or misalignment of the treatment and target volumes. Central recurrence of the malignancy occurs when the target dose is too low being due to the prescription of an inadequate dose for fear of overdosing adjacent normal tissues, or to the underestimation of the depth of the tumour under the irradiated skin surface or to the ignoring of excessive absorption by an intermediate inhomogeneity of high relative density. Some of these factors will be now briefly discussed.

The Target Volume

In 21% of the patients macroscopic tumour extended beyond the limits of the treatment volume. In a further 14% one may expect that there was microscopic infiltration outside the high-dose volume because macroscopic tumour reached to the very edge of the treatment volume. In 5% of the cases this was due to misalignment of the treatment and target volumes whereby the former could be shifted without enlargement of the radiation fields.

This indicates that in the remaining 30% of the cases the treatment volume had to be enlarged due to unexpected deeper infiltration by the primary tumour (24%), unexpected involvement of the regional nodes (4%) or unexpected non-lymphatic metastases (3.5%). Noteworthy is that this additional diagnostic information with both prognostic and therapeutic significance was found even in patients who where considered to be completely staged prior to scanning. Because the surgical explorations necessary to validate the new information are not clinically justified, we assume that the CT data is correctly interpreted. However conventional radiology usually substantiates our suspicions. It must also be acknowledged that the ultimate influence of the new data depends on the energy and receptiveness of the team.

Leer (1982) found in a number of cases (ie 12 of his 16 patients with prostatic cancer) that a "standard" change in his standerd target volume

rendered his traditional simulator techniques adequate once more. This augmented anatomical knowledge could only be applied in a minority of his cases and we have found no such subgroups in our series where a standard change rendered the CT scanning less necessary. Even in our third year of operation, approximately 35% of our treatment plans are still CT assisted. This figure would be higher if we had more CT sessions for some of our patients cannot wait a week for the extra data.

Longitudinal Resolution

It is also of interest that in some of the sub-sets (palliative treatment and tumours of the head and neck, pelvic, skeletal regions) the treatment volume was less often extended lengthwise than in the transverse diameters. This could be attributed to the transverse orientation of the scan slices. Sagittal or coronal reconstructions may have increased the rate of change in the length of the treatment fields. However these techniques demand more scan slices per linear 10 cm than was usual for this project in order to achieve adequate resolution. Certainly problems of tumour definition in the longitudinal direction might disappear using a longitudinal reconstruction facility but only at the cost of prolonged examination times and higher patient doses. This problem did not present itself in patient with intrathoracic tumours.

Normal Tissues

We had hoped that better tumour localisation would allow improved sparing of the surrounding normal tissues. We have to acknowledge that this goal could not be realised for in only 5% of cases was a significant portion of healthy tissue excluded from the pre-CT treatment volume. Furthermore in only 1 patient was it felt that the CT scan data had exposed an unacceptably high dose in a critical organ. The shattering of this ideal appears to be common in similar projects and is not surprising for the pre-CT target volumes are much more often under than overestimated according to the CT scans. Provisionally conventional simulator techniques seem adequate for the protection of surrounding critical normal tissues.

Inhomogeneithy Corrections

Many pitfalls can be encountered whilst using the CT data for radiotherapy planning calculations whereby the dose at a given point is computed taking

account of inhomogeneities. Generally in the calculation of the absorption value (in Hounsfield units) only one effective energy is used whereas, in practice, the effective energy varies with both the nature of tissue through which the radiation passes and the pathway length in that tissue. Secondly, the partial volume effect (see glossary) causes discrepancies in the Hounsfield numbers; a phenomenon which is safely disregarded during "diagnostic" scanning. Thirdly the detector is hit not only by the primary beam but also by secondary radiation. The influence of the simplified models on the use of the CT data during radiotherapy planning needs to be investigated before the relevance of inhomogeneity corrections can be assessed. For these corrections the team at the Royal Marsden Hospital have used both an "effective pathlength in water" method (Parker et al, 1979) and a "tissue/air ratio technique" (Cassell et al, 1981). Velkley et al (1980) and Tatcher et al (1981) both came to the conclusion that the "equivalent tissue/air ratio" technique gave the more accurate results.

It is known that small errors in Hounsfield number can have a dramatic effect in the computation of inhomogeneity corrections. One would expect an even greater effect when considering electron irradiation but the lack of calculation algorithms has hindered attempts to quantify these inaccuracies. It can be concluded that much still has to be done to develop inhomogeneity correction algorithms within a reasonable range of precision, using a small dedicated radiotherapy planning computer and the now fixed geometry of the CT scanner. It may well be that existing correction methods for photon beams are already satisfactory but this has yet to be substantiated in vivo. However the more complicated methods which are being developed for electron beams will be able to be adapted with little trouble to allow more accurate compensation for inhomogeneities in photon radiotherapy.

Cost Effectiveness

The CT scanning equipment is very costly so that a general application of this enterprise would not be cheap. In a few centres cost-benefit analyses have been attempted. To justify the cost of the extra CT facilities it has been calculated that one needs to be able to cure an extra 5% of cases. Is this feasible? We have found from our figures that CT scanning is extremely helpful in the radiotherapy planning of 58% of the patients. Of course one would not defend the proposition that an extra 58% of cases are going to be cured of their malignancy but one could certainly justify that a small proportion of that 58% would be saved. Using the model of Goitein, the improvement in cure rate due to CT was estimated to be 4.5% in our series

and was cost-effective when compared with the costs and benefits of the radiotherapy itself.

NMR: an Alternative to CT?

Many of the medical imaging techniques in use today depend on reconstruction of an image from a set of measurements, rather than direct recording of the image on film. Such techniques include ultrasound, radio-isotope examinations and CT scanning. A recently developed technique of this type is tomography based on nuclear magnetic resonance (NMR). The earliest images so obtained bear a superficial resemblance to the earliest crude CT scans and the reconstruction methods are virtually identical. However the measurements from which they are derived do not depend on absorption or scattering of radiation applied from outside the body or from emission of radiation from radiopharmaceuticals introduced into the body. The NMR images are derived from radio signals emitted by substances resonating in the body in response to an applied high frequency radiosignal. The resulting images show the distribution of protons within the body and additional information can be obtained on chemical structures and flow rates. No adverse biological effects have been found from the applied magnetic fields. Consequently NMR has aroused interest as a potentially safe technique for visualising internal structures by determining their cellular chemistry in vivo.

The NMR radio signals are proportional to the amount of water in the tissues; fat also gives signals. NMR techniques may also yield information of a different kind although this is a complex and as yet poorly understood phenomenon. This second source of information depends on the time the atomic nucleus takes to return from its "excited" to origonal state ("relaxation time"), although the relevance of this is not yet fully elucidated.

NMR is important for two reasons: it seems likely that its use will not carry the same risks of permanent damage as ionising radiation and it may also provide information not obtainable with Xray tomography because it is measuring different parameters. Broadly speaking it gives an indication of the way organs are functioning rather than the static physical structure as shown by Xrays. The major technical problem is to get large enough magnets to fit people inside and to ensure that the magnetic field is held at the required value. It will take several more years to develop the technique to as mature a state as the CT scanner for the resolution is still being improved and the average scan time is about 5 minutes. However the mapping of tumours using their physiological rather than their anatomical characteristics is an exciting

possibility for the future and may just offer some improvement on the already refined CT methods.

Problems encountered during this Project

Returning to the reality of the present from the fantasies of the future, we should perhaps discuss at this stage those difficulties and criticisms of the project which to some extent have only been partially confronted and solved. We have maintained that until recently the weakest link in the treatment chain was the delineation of the tumour target volume. Having re-enforced this stage in the planning process by using the CT scanner, the next weakest link in the chain has been exposed when one tries to produce in the patient what one has so painstakingly computed on paper.

But how accurate and reproducible are these computations? The setting-up of the patient on the CT scanner has recently been improved by the installation of a laser light system. To extend the benefits of this system, similar apparatus will need to be installed at other points in the planning and treatment chain ie in the simulator unit and on the treatment machines. Plastic masks are used in many radiotherapy departments to immobilise cases of head and neck cancer during irradiation. In our department we use such a system which is free of metal components so that we are not confronted with the problem of reconstruction artefacts during the CT scanning. Problems of immobilisation and reproducibility of set-up are encountered during the treatment of other body regions. The abdomen may exhibit various degrees of distension during the weeks of irradiation. Poor relaxation of the muscles in the buttocks leads to inaccuracies during treatment of the pelvis. Perhaps the extension of mould-room techniques to these regions will offer some solace. During the period of this study these accessories were not available.

It order to assess the inaccuracy of treatment set-ups under these conditions, the reproducibility of field arrangement was checked on the CT scanner. The distance between the axes of the two apparently non-isocentric, opposing fields was measured in the case of two common irradiation techniques. Postoperative radiotherapy of the chest wall involves the treatment of two opposing tangential fields whilst irradiation of the pelvis is usually planned with an anterior and two lateral opposing fields. There are thus two areas which are routinely treated with fields whose axes can be simply checked using the CT scanner (table 29).

CT scanning obviously also requires a revision by the radiotherapist of his anatomical knowledge and for some this may involve the relearning of

Table 29: The Distance Between the Axes of Two Apparently Opposing Non-isocentric Fields

Total cases	Chest Wall (N=25)	Pelvis (N=41)
Distance less than 5 mm	8	15
5 to 10 mm	11	11
more than 10 mm	6	15

this knowledge in transverse cross-sections. Although the radiotherapy radiographers quickly learn how to set up the patient in the treatment position for the CT scanning, the extra involvement of the radiotherapist in the various stages of this new planning process can only mean the further increase in the work involved in his treatment of the patient. Whilst the frequency of startling results should enhance his productivity the eventual tedium of the technique will probably have an opposite effect. Should his concentration lapse or his precision decline then any benefits of these techniques would be readily lost.

We have also been confronted with other difficulties which appear less easy to surmount. Microscopic invasion of the tissues by the primary tumour and micrometastases remain invisible and so cannot be included within the target volume without making use of both our knowledge of pathology and the rules of chance. From our limited experience, patients being treated with small boost fields of radiotherapy appear to benefit most from CT scanning. The limitations of scanning on a sessional basis may however mean that the data arrives too late to allow a timely correction of the treatment. Being a general radiotherapist I have been able to assess patients with various tumour types in almost every region of the body whereby I can claim a superficial but wide experience. However the number of cases in each tumour group is limited and this project would need to be extended for many years before an adequate statistical evaluation could be performed.

Uses of CT Scanning in the Radiotherapy Planning

Good radiotherapeutic practice has always required that the patient is thoroughly evaluated, classified and staged in a logical fashion, treated with care and precision and the results evaluated by both survival free of cancer and control or failure in the irradiated volume. Some of us may consider that precision in radiotherapy has progressed far enough, whilst other believe that we have only scratched the surface. But we do know that within the limits of tissue tolerance there is a direct relationship between increasing dose and

local cure in various malignancies. We know that large fields cover regional disease extensions more effectively resulting in better local control and overall cure rates in both head and neck and pelvic tumours. But a balance has to be struck for larger fields also require a reduction in dosage if tissue tolerance is to remain acceptable. We have shown that CT scanning can be of value in deciding the best radiation field arrangement allowing one both to plan in a three dimensional manner and to estimate the effect of the various tissue inhomogeneities.

Results of this project were usually in agreement with those from other institutes scattered throughout the world but mainly concentrated in the United Kingdom and USA. The contribution of the CT scanning is thus apparently not particularly tied to the policies of the various institutes. Because of various factors we would maintain that this project has not only corroborated data from elsewhere but also made a humble contribution to the pooled experience of the various centres involved in using this technique. Our patient series is not only one of the largest reported to date but involved no selection of the patients thus eliminating previous value-judgements and prejudices. Each patient has been subjected to a larger battery of assessments than appears in most published series. Furthermore the dose distribution within the target volume has been evaluated three-dimensionally. It would thus be not unexpected if we did not discover more inaccuracies in the traditional radiotherapy planning and sometimes the CT scanner appears to make a contribution to a larger percentage of the patients in our project when compared with other series.

Only time will tell if increased accuracy of palliative irradiation can be of benefit to the patient in the pre-terminal and terminal stages of his life. Certainly one cannot expect increased cure rates because of the improved precision of the radiotherapy of intra-thoracic tumours. However one could accept more readily that the quality of life should be improved. Theoretically, the greatest contribution from the CT scanning should be seen during the treatment of intra-pelvic malignancies. In the majority of cases the problem here is still limited to the loco-regional complex.

One would expect even greater benefits during the treatment of retroperitoneal tumours for they cannot be even reached by rectal and vaginal examination. Biologically retroperitoneal tumours can be as responsive to irradiation as tumours elsewhere in the body but the clinical results have generally been poor. With the present knowledge, these poor results can probably now be explained by poor localisation of the target volume. Unfortunately these tumours are often not referred to the radiotherapist because of the unsuccessful results of irradiation in the past.

Extending now into the realms of theory, one could imagine that CT scanning is also important when patients are being treated with particle irradiation (protons, π-mesons). The depth doses exhibit a Bragg curve effect and by these irradiations more than any other it is of paramount importance to know both the size of the tumour and its precise depth under the irradiated skin surface.

Returning to our more every day needs, much more study is needed into the tissue characteristics of tumours as they appear on the CT scans. Our approach of measuring CT numbers is obviously much too naive and, as we have shown, there can be no criterion for differentiation between malignant and healthy tissues. Only when this faced is solved will we be able to delineate tumour tissues more accurately and plot their response to various treatments. The behaviour of a tumour before, during and after treatment should prove to be not only biologically fascinating but should also have important prognostic and therapeutic consequences for the patient.

Patient Acceptability

A CT scan for radiotherapy planning takes between twenty and thirty minutes to perform. The examination was generally well tolerated despite the patient's anxiety for yet another new piece of technology, the firmness of the flat couch top and the warmth and humidity of the scanning room. Of 205 patients, only two were unable to complete the desired examination. This is remarkable considering the poor condition of some of the patients of whom 60% was older than 60 years (seven patients being over eighty) and that 22% of the patients was to be treated palliatively.

Role of CT Scanning

There have been many well-documented published evaluations of the clinical applications of computed tomography in the fields of the neurosciences, ophthalmology, ENT, gynaecology, lymphatic disease, disorders affecting the lungs, the mediastinum and genito-urinary diseases. The American Society for Computed Body Tomography has published a Special Report outlining their new indications for the application of Computed Body Tomography as practised in the USA (Alfidi et al, 1979). At the present time there is an evident need for considerable adequately funded research and assessment of the value of general purpose scanning in many areas. This type of work will need a high priority before the value of a general purpose body scanner is fully evaluated.

Whole-body CT scanning is now essential for adequate staging and treatment planning for many tumours and it is also essential for monitoring treatment by radiotherapy or chemotherapy. The use of one scanner for several purposes imposes a great logistic burden. The following major users have been identified:

a. neurosciences;
b. oncology, (diagnostic, radiotherapy planning and treatment assessment);
c. general medical and surgical services including emergency cases;
d. research.

Provision of independent viewing facilities is very helpful but the capturing of the data needs the personal attention of the diagnostic or therapeutic radiologist for each patient.

It is important to give proper consideration and weight to the information that has been or could be obtained on individual patients by the use of complementary diagnostic techniques i.e. conventional radiology, isotopes and ultrasound. These techniques are not superseded by CT scanning and they can give, in many cases more cheaply, adequate diagnostic information on the presence of a lesion, its nature, its site and its spread as well as monitoring the regression or progression of the tumour with treatment and time. CT scanning is one of a number of imaging modalities employed in diagnostic management and its place in the hierachy of radiological investigations must always be carefully considered. It is too precious to be used necessarily as means of primary diagnosis.

CT, properly incorporated into the treatment planning system, will have an impact at several levels:

1. improvement of the clinical assessment of tumour extent and of the location of adjacent critical organs;
2. provision of an ability to systematically improve the accuracy of dose distribution;
3. improvement in judgement when one prescribes the maximum tolerable dose once the dose distribution has been optimalised;
4. focussing of attention on what now becomes the weakest link: the accurate reproduction in the patient during every treatment of what has been so painstakingly planned on paper.

If one considers figures coming from various other radiotherapy institutes in the world it is quite remarkable that Zwolle is producing similar data and drawing conclusions compatible with those of other centres. Between a half and two thirds of radiotherapy plans are improved by the application of CT scanning. One must therefore conclude that traditional radiotherapy planning has been inaccurate the whole world over, that

radiotherapy planning in the Netherlands is no more and no less inaccurate than elsewhere and that those centres which do not yet make use of CT scanning will be inaccurate as we previously were in Zwolle.

Tumours that are difficult or impossible to detect with conventional Xray apparatus become readily visible during CT scanning. This makes the CT scanner ideal for the accurate localisation of many tumours and gradually CT scanning is becoming accepted as an invaluable tool in departments of radiotherapy and oncology. The accuracy obtained in the CT images complements the precision strived for in radiotherapy departments. Direct use of the CT data, as the basic information for a sophisticated dose calculation model, allows the replacement of a weak link in the chain, namely the treatment planning. Hereby is a considerable improvement in the quality of the radiation therapy to be expected.

SUMMARY

Successful radiotherapy practice depends on the irradiation of tumours such that their destruction follows without unacceptable damage of the surrounding normal tissues. Until recently the accurate acquisition of data concerning the tumour anatomy lagged behind other developments in radiotherapy. Since the arrival of the CT scanner, these anatomical data can be displayed ideally for transmission into a computerised treatment planning system. The CT scan information concerning tumour location, irradiation volume and dosimetry was compared with results obtained using traditional planning methods.

CT scanning proves to be an effective method for imaging normal and pathological anatomy. It provides quantitative, 3 dimensional demonstration of the tumour, its local and regional extension and its true relation to surrounding normal tissue. For the first time in the treatment planning process itself, CT scanning offers a sophistication of tumour localisation equal to the demands of treatment planning computers and supervoltage therapy capabilities. It has been incongruous in the past to use relatively precise and complex treatment algorithms when tumour localisation was, at best, just an indirect estimate.

In order to assess the place of computed tomography in radiotherapy planning, the tumour target volumes are localised both be conventional techniques and with CT scanning under conditions simulating the radiotherapy. A comparison between the two methods has been made in a group of 205 patients with tumours at various sites. Firstly the diagnosis and staging is defined in order to localise the malignancy and decide the treatment policy. Those cases which are to be irradiated are then planned using the conventional simulator techniques and a computer plan of the radiotherapy dose distribution is produced.

Next, under guidance of the radiotherapy department personnel, a few scan slices of the region of interest are made of the patient using the CT

scanner in order to delineate the tumour and the surrounding normal tissues. If one requires optimum information, the patient must be scanned in the therapy position on a special flat couch top. Using microtrast paste or wire, important features and the irradiation fields can be marked out. The oesophagus, rectum and vagina are rendered visible by contrast media (barium or gastrografin).

A scanogram is taken over the length of the treatment volume. Onto this AP or lateral reconstruction the scan slices will be projected for their easy localisation. Scan slices are then made every 2 to 3 cm over the length of the irradiation fields with, of course, a slice through the field centres. The data are stored on a floppy disc. These data are recalled on the special viewing console. The various outlines (body, tumour, lymph nodes, normal organs, radiation fields) are then drawn onto the TV screen using a light pen. It is these outlines which are the transferred onto tape cassettes. The information in this form can be relayed into the computer planning system in order to calculate the dose distributions. Corrections for tissue inhomogeneity can be applied at this stage using measurement of the electron densities of bone and lung on the relevant CT-scan slices.

We found that in 43 patients (21%) a portion of the tumour lay outside the treatment volume (major miss). From our observations this untreated segment represented an average 22% (range 10 - 50%) of the whole tumour volume. In a further 14% of the patients, the macroscopic tumour reached to the very edge of the treatment volume (minor miss) and one can expect that there was invisible microscopic infiltration in the tissues in an area of low irradiation dose (table 30). Patients with tumours in certain regions (thorax: chapter 6; pelvis: ch. 5; chest wall: ch 7) have also been separately analysed. Patients with tumours in various regions but who were treated palliatively are discussed as a group in chapter 8.

Table 30: Target Volume Miss

	Major miss	Minor miss
Whole group (201 patients)	21%	14%
Intrathoracic tumours (n=63)	27%	27%
Pelvic tumours (n=54)	31%	15%
Chest wall tumours (n=55)	2%	0%
Palliative treatments (n=45)	16%	11%

The question now is why we have to change the treatment fields in such a high percentage of cases. In 48 cases this was due to the discovery of unexpected infiltration by the tumour of the surrounding normal tissues. In 8 cases we found unexpectedly pathologically enlarged regional lymph nodes. In 7 cases non-lymphatic metastases were diagnosed within the limited section of the body which was scanned. Thus even after a complete traditional staging procedure and despite the fact that our aim is not to assess tumour morphology per se, we are still gaining information which has both prognostic and therapeutic significance in the management of the patient. Because of these findings whereby the tumour appears more extensive than originally supposed, the aim of the radiotherapy sometimes has to be changed from a radical to a palliative goal (table 31).

Table 31: Reason for Change in Irradiation Fields (n=201)

Primary tumour infiltration	48 cases (24%)
Regional lymph nodes	8 cases (4%)
Non-lymphatic metastases	7 cases (3%)
Non-optimal coverage of target volume	11 cases (5%)
Over-estimation of target volume	10 cases (5%)

An aim of the project is to see if we can irradiate tumours to a higher dose whilst diminishing the dose to the adjacent normal tissues. The results above pinpoint the inadequacies in the irradiation of the tumour target volume. Alas in only 10 cases have we been able to spare a significant portion (10% to 30% of the treatment volume) of the surrounding normal tissues.

In order to further improve local tumour control rates, it is common practice in many institutes to give an extra "boost" dose of irradiation to the largest tumour masses. The strategy is to concentrate the highest doses on the relatively radioresistant hypoxic cells in the tumour whilst minimising the volume of normal tissue that is irradiated by reducing the field sizes to cover only the tumour bulk. In this project we have scanned and re-planned 16 such cases. We have found even higher rates of inaccuracies in this subgroup. In 10 cases we can report a "miss" whereby on average 27% of the tumour lay outside the treatment volume. In 8 cases the treatment volume was increased by 10 - 30%. In the most cases the fields were shifted to cover the tumour better requiring just a moderate increase in size. Extra normal tissue could be spared in only 1 case. A change in the treatment fields was recorded in 11 of the 16 patients receiving boost treatment.

Considering the field geometry for the whole group we have made changes in 72 (36%) of the 201 evaluable patients.

Accepting that measurements made on the CT scan data are more accurate than those made by hand in the treatment simulator we found in 27% of the patients in this series that changes in the body outline resulted in a greater than 5% change in tumour target dose in the midplane (patients with a direct spinal field are not included here), (table 32). Remaining on the central axis of the treatment fields and allowing for all the changes in body contour, we recorded a change in target dose in 57% of the patients of which the mean alteration was 6.5% of the target dose, this being usually an underdosage. In 49 patients this dose alteration was greater than 5% of the target dose.

Table 32: Greater than 5% Alteration in Central Axis Target Dose

Whole group	27% (n=181)
Intrathoracic tumours	29% (n= 63)
Pelvic tumours	27% (n= 51)
Chest wall tumours	10% (n= 40)
Palliative treatments	39% (n= 41)

Because we scan a series of transverse planes over the length of the target volume, we can assess the dosimetry in a 3-dimensional fashion. In the other planes we recorded a change in target dose in 74% of the patients of which the average alteration was 9.5% of the target dose with a range from + 24% to - 35%. In 42% patients this dose alteration was greater than 5% of the target dose and in 20% patients was the dose change greater than 10% (table 33).

Table 33: 3-Dimensional Dosimetry

Average variability from central axis target dose ± 9.5% (range + 24% to - 35% of target dose)
Variability from central axis target dose: greater than 5% in 42% of patients
greater than 10% in 20% of patients (N=172)

This was particularly frequent in patients with long fields where no allowance was made for changes in body contour over the length of the treatment volume. Three dimensional planning appears to be particularly important for these patients.

Considering the dosimetry as a whole, we find that CT scanning exposed significant inaccuracies in 72 (39%) of 187 patients in this series.

Accurate quantification of the different densities of tissues within the irradiated section of the body is also portrayed. For supervoltage irradiation lung and bone are the structures most relevant in this context. CT scanning falicitates the development of accurate programmes to correct for the effects of tissue inhomogeneities on dose distribution (table 34). In the thorax the mean target dose in increased by 10.6% (range 3 - 20%) after lung correction. In the pelvis we find that bone correction causes a mean decrease of target dose of 4.3% (range - 1% + 0 - 10%).

Table 34: Effect on Target Dose of Inhomogeneity Corrections

	Mean target dose
Thorax (N=20)	+ 10.6% (range 3 to 20%)
Pelvis (N=32)	- 4.3% (range -1 to -10%)

Conclusions

We have been able to conclude that the greatest inaccuracies in the radiation treatment of patients are to be found in both the inadequate delineation of the target volume within the patient and in the inaccurate drawing of the body outline. Three-dimensional radiotherapy planning becomes a practical prosposition for many more patients when one has the use of a CT scanner. The technique is acceptable to the patients and appears to be cost-effective. There appear to be no standard changes to be made to our routine simulator techniques and approximately 35% of our treatment plans are still CT assisted. Now that the desired accuracy has been achieved at this stage of the whole therapy, attention must next be turned to the other causes of treatment failure such as poor reproducibility in the treatment room and a small therapeutic ratio due to imperfect exploitation of the biological

characteristics of the tumour and its environs. Facets of this study which were examined by other investigators in smaller series have yielded comparable results whereby it can be concluded that traditional radiotherapy planning in Zwolle was no more inaccurate than in many larger institutes. In this project we have found that CT scanning was useful to the planning of the radiotherapy in 118 of 205 patients (table 35).

Table 35: Value of CT scanning in Radiotherapy Planning

Field geometry	: 36% (N=201)
Dosimetry	: 39% (N=187)
All factors	: 58% (N=205)

SAMENVATTING

Een geslaagde toepassing van radiotherapie houdt in dat de tumor zodanig wordt bestraald dat dit leidt tot de vernietiging ervan zonder dat het gezonde weefsel onaanvaardbaar wordt aangetast. Het verzamelen van gegevens omtrent de uitbreiding van de tumor liep tot voor kort achter bij de ontwikkelingen in de radiotherapie. Met behulp van de CT scanner kunnen dit soort gegevens nu op een ideale manier worden afgebeeld en worden ingevoerd in een computer-planning-systeem. In dit onderzoek wordt de CT informatie betreffende tumorlokalisatie, bestralingsvolume en dosisverdeling vergeleken met de uitkomsten van de traditionele planningsmethode.

CT scanning blijkt een effectieve methode te zijn om normale en pathologische anatomie in beeld te brengen. Het geeft de mogelijkheid de tumor kwantitatief en driedimensionaal af te beelden, evenals de lokale en regionale uitbreiding ervan en de relatie met het omringende gezonde weefsel. Ten behoeve van het planningsproces geeft de CT de mogelijkheid tot een zodanige verfijning van de tumorlokalisatie te komen dat de vereiste nauwkeurigheid wordt bereikt, zowel voor een adequate berekening van de bestralingsdosis per computer als voor een aanvaardbare megavolt-therapie. In het verleden bestond de inconsequente situatie dat geraffineerde behandelingstechnieken waren gebaseerd op een hooguit indirecte schatting van de tumorlokalisatie.

Om de waarde van CT scanning in de radiotherapieplanning te beoordelen is een vergelijkend onderzoek verricht bij een groep van 205 patiënten met verschillende tumoren, waarbij de conventionele lokalisatiemethode parallel liep met een lokalisatiemethode waarbij CT scanning werd gebruikt. Allereerst werden de diagnose en stadiumindeling vastgesteld om het proces te localiseren en het behandelingsbeleid te bepalen. Indien tot radiotherapie werd besloten, werden met conventionele methoden de bestralingsvelden aangetekend en gesimuleerd, waarna een computerplan voor de bestralingsdosis werd opgesteld.

Vervolgens werden, onder toezicht van het personeel van de afdeling Radiotherapie, een aantal CT-scans gemaakt om de lokalisatie en begrenzing van de tumor vast te leggen. Wil men optimale informatie krijgen voor de planning met behulp van CT scanning, dan moet de patient in exact dezelfde positie gescand worden als waarin hij wordt bestraald. Hierbij wordt een special vlak tafelblad gebruikt. Met tinsoldeer, loodkorreltjes of microtrast pasta worden de bestralingsvelden en herkenningstekens op de huid van de patient aangetekend. De slokdarm, vaginatop of het rectum worden eventueel zichtbaar gemaakt met behulp van contrast-stof, bv. barium of gastrografin.

Over de gehele lengte van het te bestralen gebied wordt een scanogram verricht. Op deze reconstructie worden de scansneden ter lokalisatie geprojecteerd. Om de twee à drie cm. van het bestralingsveld wordt een scansnede gemaakt en uiteraard één door het centrum van het veld. Deze informatie wordt vastgelegd op een "floppy disc". Deze gegevens kunnen worden geprojekteerd op een TV-scherm in de bekijk-unit waarbij de omtrekken van het lichaam, de tumor, de lymfeklieren, stralingsgevoelige organen en bestralingsvelden met een lichtpen worden aangegeven. Deze gegevens worden vastgelegd op cassettes. In deze vorm kan de informatie ingevoerd worden in het computer-planning-systeem om de dosisverdelingen te berekenen. Correcties voor inhomogeniteiten van de weefsels kunnen toegepast worden met behulp van de meting van de electronendichtheid van bot en long op de betreffende scansneden. Het onderzoek liet de volgende resultaten zien.

De instelling van de bestralingsvelden werd bij 43 patiënten (21%) veranderd aangezien een deel van de tumor buiten het bestralingsveld lag. Gemiddeld lag 22% (range: 10-50%) van de tumor buiten het bestralingsgebied. Bij nog 14% van de patiënten kwam de tumor tot aan de rand van het bestralingsveld zodat te verwachten is dat microscopisch klein tumorinfiltraat aanwezig was in een gebied dat een lage dosis kreeg (tabel 30). Deze patiënten kunnen worden ingedeeld naar het gebied waarin de tumor zich bevond. Verschillende gebieden worden in afzonderlijke hoofdstukken behandeld (thorax: hoofdstuk 6, bekken: hoofdstuk 5, thoraxwand: hoofdstuk 7). In hoofdstuk 8 zijn de resultaten bewerkt van patiënten die in aanmerking kwamen voor palliatieve radiotherapie.

Waarom moesten de bestralingsvelden zo vaak aangepast worden? Bij 48 patiënten was dit het geval omdat een onverwachte infiltratie van de tumor in de directe omgeving werd aangetroffen. Bij 8 andere patiënten vonden we vergrote lymfeklieren en bij 7 patiënten werden niet-lymfatische metastasen gediagnosticeerd binnen het beperkte gebied dat was gescand. Dus zelfs na

Tabel 30: Het doelgebied werd deels gemist

		De tumor lag deels buiten het behandelingsvolume	Veldgrenzen waren marginaal
Gehele groep	(n=201)	21%	14%
Intrathoracale tumoren	(n= 63)	27%	27%
Intrapelviene tumoren	(n= 54)	31%	15%
Thoraxwand tumoren	(n= 55)	2%	0%
Palliatieve behandelingen	(n= 45)	16%	11%

een volledige traditionele stageringsprocedure en ondanks het feit dat het ons doel niet is om tumormorfologie op zich vast te stellen, ontvingen wij informatie die zowel prognostische als therapeutische betekenis heeft voor de patiënt. Aangezien de tumor in een aantal gevallen uitgebreider was dan verwacht, moest het doel van de radiotherapie soms veranderd worden van radicaal naar palliatief (tabel 31).

Tabel 31: Het behandelingsvolume werd aangepast (n = 201)

Lokale infiltratie door primaire tumor	48 patiënten (24%)
Regionale lymfkliermetastasen	8 patiënten (4%)
Niet-lymfatische metastasen	7 patiënten (3%)
Niet-optimale dekking van het doelvolume	11 patiënten (5%)
Overschatting van het doelvolume	10 patiënten (5%)

Een van de doelstellingen in het onderzoek was na te gaan of tumoren met een hogere dosis bestraald konden worden en de bestraling van het omliggende weefsel verminderd kon worden. De eerdergenoemde resultaten illustreren de tekortkomingen in de bestraling van het doelgebied. Helaas konden wij bij slechts 10 patiënten een belangrijk deel (10 - 30% van het doelgebied) van het gezonde omliggende weefsel sparen. Om het tumorvernietigende effect te verhogen is het in veel behandelcentra gebruikelijk om een "surdosage" in te stellen op de grootste tumormassa's. De strategie hierbij is de betrekkelijk resistente zuurstof-arme cellen in de tumor aan de hoogste dosis bloot te stellen met een zo gering mogelijke bestraling van het omringende gezonde weefsel, m.a.w. het bestralingsveld zoveel mogelijk te beperken tot de tumormassa zelf. In dit onderzoek hebben

wij 16 patiënten bij wie dit van toepassing was. Met behulp van CT-scanning constateerden wij bij deze patiënten zelfs nog grotere onnauwkeurigheden in hun behandeling. Bij 10 patiënten lag gemiddeld 27% van de tumor buiten het bestralingsgebied. Bij 8 patiënten moest het bestralingsgebied met 10-30% worden vergroot. Bij de meeste patiënten moesten de bestralingsvelden worden verplaatst en in slechts geringe mate worden vergroot om de tumor beter te "raken". Slechts bij één patiënt kon meer gezond weefsel gespaard blijven. Samenvattend moest de veldinstelling bij 11 van de 16 met "surdosage" behandelde patiënten gewijzigd worden.

Wat betreft de geometrie van de bestralingsvelden van de totale onderzochte groep (n = 201) moesten bij 72 daarvan (36%) wijzigingen worden aangebracht (hoofdstuk 3).

Aangenomen dat metingen op basis van CT-gegevens meer nauwkeurig zijn dan die welke op de "treatment simulator" zijn gedaan, dan resulteren veranderingen in lichaamsomtrek bij 27% van de patiënten in een meer dan 5% verschil van de tumordosis (tabel 32). Hierbij zijn de patiënten met een veld op de wervelkolom buiten beschouwing gelaten. Gemiddeld was de dosiswijziging 6.5% variërend van +6% tot -35%.

Tabel 32: Wijziging groter dan 5% in doeldosis op de centrale stralen

Gehele groep	(n=181	27%
Intrathoracale tumoren	(n= 63)	29%
Intrapelviene tumoren	(n= 51)	27%
Thoraxwand tumoren	(n= 40)	10%
Palliatieve behandelingen	(n= 41)	39%

Aangezien ieder onderzoek met behulp van de CT een reeks dwarse sneden omvat, is het mogelijk een indruk te krijgen van de dosisverdeling in drie dimensies. Bij 74% van de patiënten moest de bestralingsdosis gewijzigd worden met percentages die variërden van +24% tot -35%. De onnauwkeurigheid was bij 42% van de patiënten groter dan 5% en bij 20% zelfs groter dan 10% (tabel 33). Driedimensionale planning is blijkbaar vooral belangrijk bij patiënten met lange bestralingsvelden.

Samenvattend worden met behulp van CT-scanning bij 72 (39%) van de 187 patiënten onnauwkeurigheden gevonden met betrekking tot de dosisverdeling.

De informatie van de CT scan wordt omgezet in maten voor

Tabel 33: Driedimensionale dosisverdeling

Gemiddelde onnauwkeurigheid op de centrale stralen: ± 9,5% (range +24% à -35% van doeldosis)	
Onnauwkeurigheden elders in het doelvolume:	
	> 5% bij 42% van de patiënten
	> 10% bij 20% van de patiënten (n=172)

electronendichtheid, waarmee de "treatment planning" computer een bestralingsplan kan berekenen met correcties voor weefselinhomogeniteiten (long, skelet). Bij bestraling van intra-thoracale tumoren is de bestralingsdosis gemiddeld met 10,6% verhoogd, waarbij de percentages variëren van 3 tot 20. De dosis werd bij intrapelviene tumoren verlaagd met een gemiddeld percentage van 4,3; variërend van -1 tot -10 (tabel 34).

Tabel 34: Effekt van inhomogeniteiten-correcties op doeldosis

	Doeldosis
Thorax (n=20):	+ 10,6% (range +3 à +20%)
Bekken (n=32):	- 4,3% (range -1 à -10%)

Concluderend constateerden wij de grootste onnauwkeurigheden in de radiotherapie-planning bij zowel het verkrijgen van de lichaamsomtrek als bij het intekenen van het doelvolume. Drie dimensionale radiotherapieplanning is bij meerdere patiënten te verwezenlijken, wanneer men gebruik kan maken van een CT-scanner. De techniek ervan is aanvaardbaar voor de patiënten en daarnaast blijkt het ten aanzien van de kosten effectief te zijn (hoofdstuk 9). Ten gevolge van de CT-scanning zijn er geen routinewijzigingen aan te brengen in onze traditionele simulatortechnieken; reden waarom nog steeds ± 35% van onze radiotherapieplanning wordt verricht met behulp van de CT-scanner. Is de gewenste nauwkeurigheid in dit deel van de gehele behandeling bereikt, dan heeft het zin ook aandacht te besteden aan de overige aspecten waardoor de radiotherapie kan falen. Onze gegevens kwamen vaak overeen met de (veelal kleinere) ervaringen van andere oncologische centra waarbij de traditionele radiotherapieplanning in Zwolle niet minder nauwkeurig bleek dan in andere, maar grotere centra. Bij dit

project was de CT van groot belang bij de radiotherapie-planning van 118 (58%) van de 205 patiënten (tabel 35).

Tabel 35: De waarde van CT-scanning bij radiotherapieplanning

Geometrie van de bestralingsvelden	: 36% (n=201)
Dosisverdeling	: 39% (n=187)
Alle factoren	: 58% (n=205)

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ACKNOWLEDGEMENTS

This project was undertaken in the Department of Radiotherapy (Sophia Ziekenhuis, Zwolle) in conjunction with the Stichting Computer Tomografie Regio Zwolle and the Department of Clinical Physics (Sophia Ziekenhuis). Many people have cooperated with this study and this thesis could not have been completed without their encouragement. I would like to acknowledge my debt of gratitude to them.

Several co-workers and co-thinkers deserve a special mention:

the radiographers, both diagnostic and therapy, for their interest, enthousiasm and consideration whilst exploring and developing these new techniques;

Mr. Theo v. Deursen, physicist, who resolved many of the teething problems on the planning side and whose stamina and patience allowed so many recalculations of dose, both 3-dimensionally and with corrections for tissue inhomogeneities;

the management committee of the Stichting Computer Tomografie Regio Zwolle for their foresight in allocating time on the CT scanner to the Radiotherapy Department for a project that was not only new to Zwolle but almost to the whole country;

Miss M. Zuyderduyn and Mrs. Llinos Evans who typed and retyped sections of the text at great speed;

Mrs. L. Biekart-Hanhart, librarian, and her staff who have traced and photocopied countless references which have guided and stimulated this project;

Dr. E. Oostdam for his advice and for his translation of the summary into Dutch;

the patients who patiently cooperated with the study despite the occasional technical hitch.

However this list cannot remain limited to the Zwolle region:

Professor Dr. B. v.d. Werf-Messing and Professor A. Tierie have proved

invaluable for their supervision, constructive criticism and encouragement; Mr. H. v. Kleffens made many useful contributions and paid special attention to the physics details.
More than anyone else these three colleagues have nurtured and directed the evaluation of the results. The following may however not go unmentioned:
Messrs. P. v.d. Hoek (Nationaal Ziekenhuis Instituut, Utrecht) and R. Bennet (King Edward's Hospital Fund, London) provided some of the financial data for chapter 9;
Messrs. W. Elsenaar and P. Ruys commented on chapters 4 and 9 respectively;
Mr. M. West (Royal Postgraduate Medical School, London) calibrated the TLD sachets (chapter 10);
Dr. T. King (the London Hospital) provided this then newly-qualified doctor with an example of logical thinking, self-discipline, precision and attention to detail which he still hopes he may be able to emulate;
Dr. R. Morrison (Hammersmith Hospital) and Dr. S. Leeman and the late Prof. R. Oliver (Royal Postgraduate Medical School) started me off along this path by using ultrasound to check the radiotherapy planning.
I have however not forgotten the many indirect contributions in the form of probing questions during my years' work in radiotherapy and I would like to quote from Rabbi Judah Ha-Nassi who lived in the 2nd. century: "Much I have learned from my teachers; more from my colleagues; and from my students more than from them all" (Talmud - treatise Makkot 10a).

CURRICULUM VITAE

The writer was born on 6th. October 1945 in Hammersmith Hospital, London; the institute to which he was to return much later for his post-graduate training in the Department of Radiotherapy and Oncology in 1973. Having completed his secondary education at Dulwich College in 1964, he went on to the London Hospital Medical College to study medicine. After qualifying in 1969, he followed the traditional British system of gaining some experience in several fields of medicine (internal medicine, general surgery, gynaecology, neurosurgery etc.) at the London Hospital, St. Margaret's Hospital (Epping), and the Royal Free Hospital. Having completed his post-graduate training in Radiotherapy and Oncology in 1977 and gained the Fellowship of the Royal College of Radiologists by examination, he widened his horizons in a post as specialist and scientific worker in the Radiotherapy Department of the Vrije Universiteit in Amsterdam. Since 1979 he is radiotherapist to the Sophia Ziekenhuis and Ziekenhuis "De Weezenlanden" in Zwolle.