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IMRT_Two Isocenter Technique infield output Consistency

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Diagnostic: Ca.Nasophrynax
Treated Region: Head Neck.

Abstract: Radiotherapy procedure in itself does not guarantee any favourable outcome. It is through meticulous planning and careful implementation of the needed treatment that the potential benefits of radiotherapy can be realized. The ideas presented in this book pertain to the clinical, physical, and technical aspects of procedures used in radiotherapy treatment planning. Two isocentre process that involves the determination of treatment parameters considered optimal in the management of a patient's disease. In radiotherapy, these parameters include target volume, dose-limiting structures, treatment volume, dose prescription, dose fractionation, dose distribution, patient positioning, treatment machine settings, online patient monitoring, and adjuvant therapies.

The monoisocentric (MIT) and dual isocentric (DIT) techniques are compared for the mastectomy patients undergoing Head & Neck radiotherapy, and a new practical method is suggested for determining the dose calculation reference point to be used in the MIT. Head and neck patients having Nasophrynx radiotherapy were used. To find the appropriate dose calculation reference point for the MIT, the target tissue was divided into nine regions withTwoIsocentres points as the appropriate candidates. After finding the best reference point for the MIT, dose calculations were made for each patient based on the MIT and DIT to determine the dose distributions of the target volume and organs at risk. The lateral component of the dose calculation reference point was found to be located at one-third of the distance between the geometrical center and the lateral border of the neck in the lateral direction toward the outer border. The longitudinal component of this point was found to be located at the geometrical center of the Head and neck with a depth located around 2–3 cm under the patients' skin. There was no significant difference between the two radiotherapy planning techniques (MIT and DIT) regarding the dose distributions in the organs at risk and the 95% of the prescribed dose coverage of the target tissue. However, a significant difference for the 105% of the prescribed dose coverage, maximum dose delivered to the target tissue, and the level 2 lymph nodes dose was found, with the DIT showing higher values.
Because Two Isocentre and three isocentre observed between the treatment fields in the MIT, it was expected and confirmed that the hot and cold regions (with higher and lower doses than the prescribed dose) with the MIT are significantly fewer than that of the DIT. Therefore, to perform a better conformal radiotherapy for the patients having mastectomy, it could be recommended to use the MIT instead of the DIT and other conventional techniques.

Keywords: Isocenter, IMRT, Dose, Computer treatment planning, monoisocentric (MIT), Dual isocentric (DIT), Conformal radiotherapy (3DCRT)

I. Introduction

In this study I have researched Nasopharynx cases in Head & Neck cancer Patients. Two methods are commonly used in three-dimensional conformal radiotherapy (3DCRT), including the MIT and the DIT. Because of the overlaps of the treatment fields encountered in the DIT, the regions with higher or lower doses than the prescribed doses appeared at the junctions of treatment fields. On the other hand, in the MIT, the dose distribution cannot be normalized to the isocenter point, since this point is located under the jaw edge of the linear accelerator collimator. Therefore, one of the most important problems required to be solved in the MIT is to find an appropriate dose calculation reference point for it. In an investigation(3) in which an MIT was introduced for the patients undergoing the breast radiotherapy (without mastectomy), a dose calculation reference point was proposed without giving any explanation/reason for choosing its location. They compared their proposed MIT with a traditional DIT. The patients were placed in supine position on the tilt board. The board was inclined until the patients' chest wall was visually parallel to the table top. The physician then marked the position of the match line, the medial, and lateral dorsal beam edge entrance points on the patient's skin. On the contour graph, a line was drawn connecting the medial and lateral dorsal beam edge entry points. Finally, a perpendicular line was drawn from this dorsal line, bisecting the treatment volume.

With this arrangement recurrences in the low neck are uncommon but if nodal volumes are delineated as described above, a 6MV anterior photon beam will not provide adequate coverage of nodal volumes (Fig. 8.7). In most patients the risk of recurrence in the low neck is low, and we recommend continuing with an anterior beam. The lateral border is 1 cm lateral to the intersection of the first rib and clavicle on a

posteroanterior radiograph and the inferior border is at the inferior head of the clavicle. If the target volume is unilateral the medial border is 1 cm from midline to avoid the cord, pharynx and larynx. If it is bilateral, 2 cm midline shielding is added. MLC shielding is used inferior to the clavicle to spare the apex of the lung Conformal volume-based radiotherapy of head and neck cancers requires knowledge of anatomy and patterns of spread of disease, which are often specific to each tumour site. This chapter explains the common principles of treatment of these tumours. Radiotherapy alone with daily 2 Gy fractions is no longer regarded as standard for locally advanced head and neck cancer. Altered fractionation or the addition of chemotherapy or targeted agents improves outcomes in patients able to tolerate a more intensive approach.

The proposed dose calculation reference point was positioned on the perpendicular line and was further dictated by the field width, chosen to allow 1.5–2 cm flash beyond the anterior extent of the breast (head and neck). In another study,(4) the dose calculation reference point was placed in the Twoisocentre of the neck. where the isocenter of the more than five fields in the DIT was located. Then, the true isocenter was placed in the same coordinates as the dose calculation point, except its Y component (at both of the up and down directions). It was claimed that it would be more beneficial for the dose distribution and treatment planning if the true isocenter and dose calculation point have the same X and Z coordinates. In another investigation with no introduction and discussion regarding the dose calculation reference point, several treatment planning techniques were studied for irradiating the cervical spinal cord and breast in which a three-field technique, similar to the MIT, was used for the breast and supraclavicular irradiation with half beams. The authors attained several equations for finding the gantry, collimator, and treatment couch angles for tangential fields where the isocenters were assumed to be located at specific points. Some equations were introduced for finding an isocenter when the field apertures were assumed to be constant. In another study, the dose distributions in the breast and organs at risk (lung and heart) were assessed with the MIT compared with a traditional matching technique. It was reported that the dose values in the fields' junction areas are more than the prescribed doses and, in some regions in a tumor, the dose is under the 95% of the prescribed dose with the traditional technique. On the other hand, with the MIT, the hot and cold areas claimed to disappear and the doses to the organs at risk and normal tissues decreased. Furthermore, for the patients who didn't have a mastectomy, a general formula for exact geometric matching in the radiotherapy of the breast and supraclavicular fossa is presented.

The proposed method does not require additional shielding to eliminate divergence other than the four independent jaws. Other investigators compared various dose calculation algorithms of treatment planning systems (TPSs) with each other and used Monte Carlo calculations as the reference.

In these studies, 6 and 15 MV photon beams were compared for different tissues having quite different densities like the bone, soft tissues, and lungs. The best agreement reported with the TPS results was for the IMRT (TWOISOCENTRE) convolution (CCC) TPS algorithm. However, to our knowledge, there is no investigation presenting any technique or equation for finding the appropriate dose calculation reference point with the MIT for the patients having a mastectomy despite their anatomical analogies. In addition, there is no investigation in which the two common conventional treatment techniques (MIT and DIT) used for the chest wall radiotherapy of mastectomy patients would have been compared with each other. Hence, the purpose of this study was to fill the above gaps encountered in clinical situations by applying the above radiotherapy techniques on relevant patients and compare the outcomes based on the dose distributions in the target and critical organs.

Uncertainty of CTV are the uncertainties of target volume localization in space and time. An image-based GTV, or the inferred CTV, does not have static boundaries or shape. Its extent and location can change as a function of time, because of variations in patient setup, physiologic motion of internal organs, patient breathing, and positioning instability. A planning target volume (PTV) is therefore required, which should include the CTV plus suitable margins to account for the above uncertainties. PTV, therefore, is the ultimate target volume—the primary focus of the treatment planning and delivery. Adequate dose delivered to PTV at each treatment session presumably assures adequate treatment of the entire disease-bearing volume, the CTV. Because of the importance of accurate determination of PTV and its localization, the International Commission on Radiation Units and Measurements (ICRU) has come up with a systematic approach to the whole process.

II. Materials and Methods

Two Isocentre and three Isocentre IMRT Planning Calculation. A. Computer treatment planning The computer treatment planning system used in this study was the eclipse varian 11.01. The algorithm used for dosimetry calculations was the CCC, since previous studies have confirmed it as an appropriate algorithm to be used in breast cancer radiotherapy in which the effect of in homogeneities is also considered.. Images with 1 mm resolution taken from the patients with a CT simulator were acquired and exported to the computer TPS database in the DICOM format. The target tissue of the patients defined by the radiotherapy oncologist was located at the mastectomy region. The lymph nodes were irradiated with a Head & ncek field with the same

prescribed dose as that of the target tissue. The prescribed dose was 50 Gy delivered to the target tissue of the patients in 25 fractions. First, the DIT plan was designed (in three dimensions) with the wedges by using two tangential fields each one delivering 25 Gy (50% of the prescribed dose) to the mastectomy location on the chest wall, and one supraclavicular field delivering 50 Gy to the regional lymph nodes located at the local levels of 1, 2, and 3. Then, one isocenter was assumed for both of the tangential fields and another isocenter for the supraclavicular field, each considered as their dose normalization points. The isocenter of the tangential fields was usually located at the same distance from the superior and inferior border of the target tissue and at a depth which typically ranged from 2 cm to 3 cm from the surface of the chest wall; it was increased up to 4.5 cm for some of the patients with thicker chest walls. The isocenter of the supraclavicular field was usually located at the center of the field and at a depth of 2 cm to 3 cm from the patient's skin. For the MIT, the isocenter point was placed at the end of the superior edge (with the same distance from the lateral and medial borders) of the chest wall. The tangential and supraclavicular fields were then set by this isocenter. When the tangential fields were set, the superior half of the beam was closed while, for the supraclavicular field setting, the inferior half of the field was closed by the collimator jaw. With this condition no divergence or overlapping occurs.

The importance of accurate determination of PTV and its localization, the International Commission on Radiation Units and Measurements (ICRU) has come up with a systematic approach to the whole process.

The reader is referred to ICRU Reports 50, 62, and 71 for the underlying concepts and details of the system.

Fractionated course of radiotherapy, variations in patient position and in alignment of beams will occur both intra- and inter-fractionally, and a margin for set-up error must be incorporated into the CTV-PTV margin. Errors may be systematic or random. Systematic errors may result from incorrect data transfer from planning to dose delivery, or inaccurate placing of devices such as compensators, shields, etc. Such systematic errors can be corrected. Random errors in set-up may be operator dependent, or result from changes in patient anatomy from day to day which are impossible to correct. Accuracy of set-up may be improved with better immobilisation, attention to staff training and/or implanted opaque fiducial markers, such as gold seeds, whose position can be determined in three dimensions at planning, and checked during treatment using portal imaging or IGRT. Translational errors can thereby be reduced to 1 mm and rotational errors to 1°.

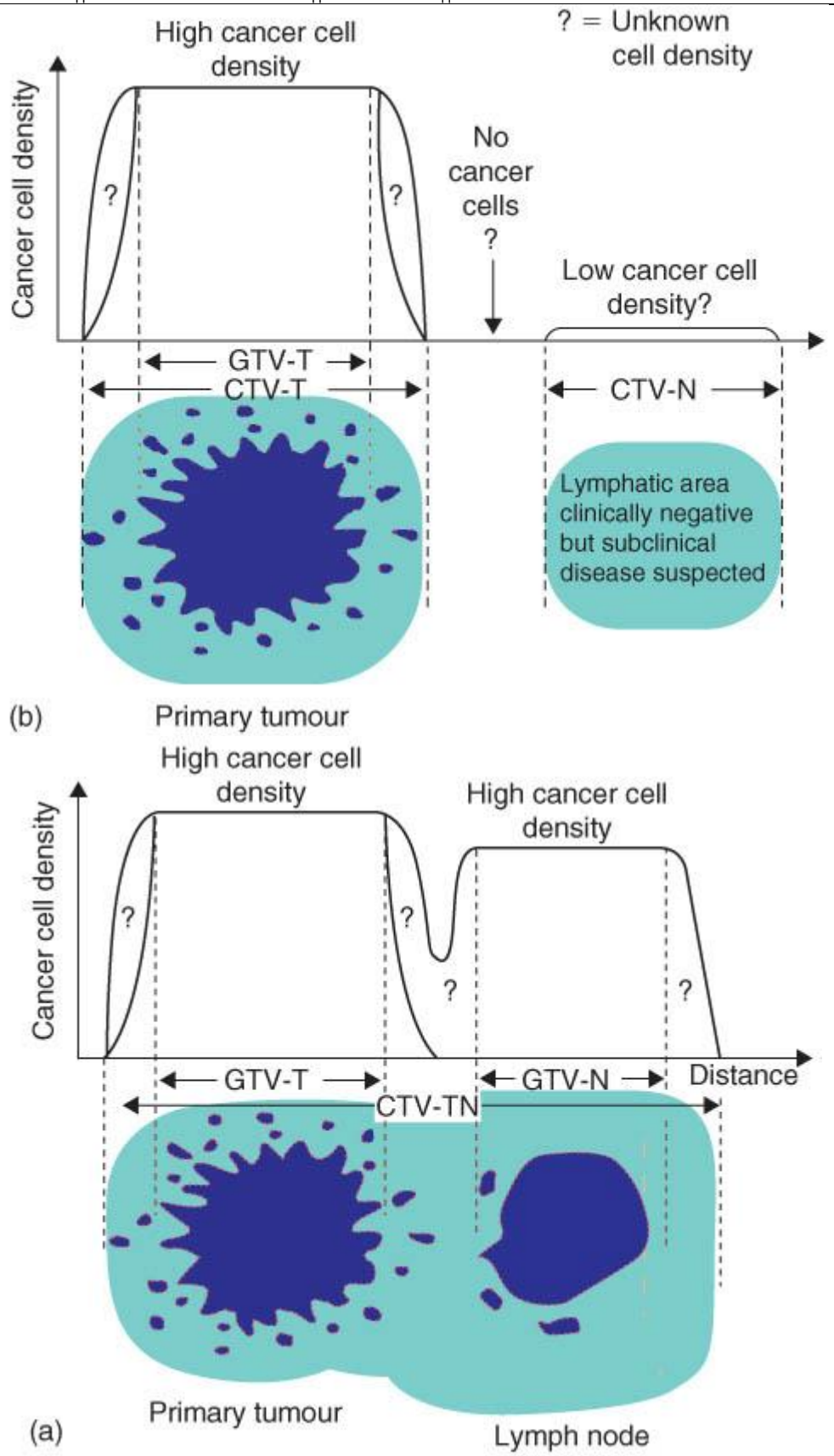
Each department should measure its own systematic and random errors for each treatment technique by comparing portal imaging and digitally reconstructed radiographs (DRRs). These measurements are then incorporated into the CTVPTV margin using the formula devised by Van Herk, where the CTV is covered for 90 per cent of the patients with the 95 per cent isodoses.

Finding the dose calculation reference point for the MIT

65 Gy to PTV70, 60 Gy to PTV60 and 50.4 Gy to PTV50 in 30 fractions given in 6 weeks.

The superior, inferior, lateral, and medial borders of the mastectomy location were defined by the radiotherapy oncologist. These borders (located at the X-Y plane) with a thickness of tissues located above the lung (at the Z direction) specified the chest wall. Then, a coronal plane at the middle of the maximum thickness of the chest wall was chosen and divided into nine region.

After planning the treatment fields, the dose calculation reference point was assumed to be located at every one of these regions and their boundaries with the central region. The outer boundaries of the regions were not studied since the doses would have been higher than the limited values where the dose calculation reference point is very far away from other regions in the target. The reference depth position was found to be located around 2–3 cm beneath the chest wall depending on the thickness of the patients' chest walls. For defining the location of these regions, the longitudinal component (Y) of the superior and inferior borders of the chest wall was attained. The distance between the borders was divided by 2 to determine the Y component of the central point. Likewise, the (X) lateral component of the central point of the chest wall in the X-Y midplane was determined. Then, the final rectangle area was divided into nine regions


? = Unknown cell density
High cancer cell density
Cancer cell density
No cancer cells ?
Low cancer cell density?
GTV-T
CTV-T
CTV-N
Lymphatic area clinically negative but subclinical disease suspected
(b)
Primary tumour
High cancer cell density
High cancer cell density
Cancer cell density
GTV-T
GTV-N
Distance
CTV-TN
Primary tumour
(a)
Lymph node

The dose calculation reference point must not be placed in the bones, under a shield, or in the lungs for the supraclavicular field. In such cases it will be better to place the dose calculation reference point at the center of an open field and a depth ranged from 2 cm to 3 cm.

Treatment regimen, such as the use of IMRT, a dose increase or addition of chemotherapy or biological agents, will change the therapeutic ratio. The challenge for the radiation oncologist is to ensure that this change improves the ratio and that an increase in dose is not counteracted by an increase in unmanageable acute or serious late effects. TCP (tumour control probability) and NTCP (normal tissue complication probability) are mathematical models used to predict effects of such changes. However, to know whether a new treatment has really produced better outcomes overall, and to inform and improve the reliability of these modelling estimates, good clinical data must be collected, not only for outcome measures relating to tumour control, but also for acute and late normal tissue damage.

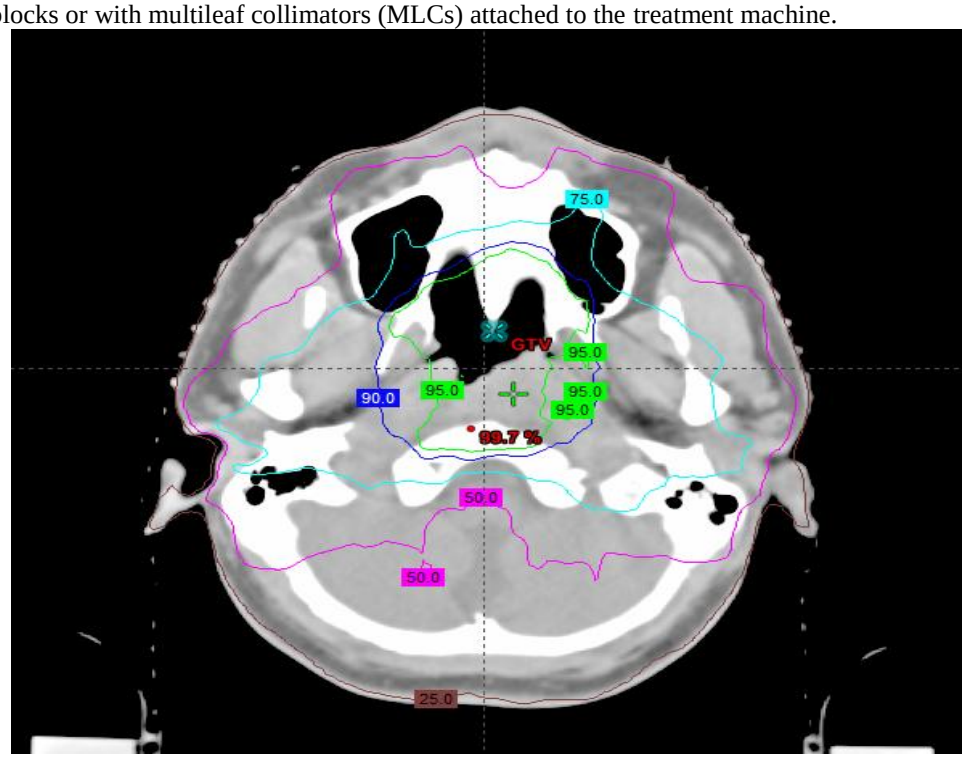
The integrity of complexity of the IMRT dose delivery technique relies on quantification of the coincidence of the planned and delivered intensity-modulated radiation therapy dose distributions. The aim of this study was to ascertain how to identify the coincidence of the planned and desired isodose curves and experimental film results, without visual inspection but using a mathematical method to estimate the error between the planned and measured values.

Dosimetric parameters

We introduced a parameter, representing the distance between the geometrical center of the midplane of the chest wall and its lateral border. Some other parameters were required to be assessed for evaluating the dose distributions.

Beams used for radiotherapy have various shapes that usually represent a compromise between the actual target shape and the need for simplicity and efficiency in beam shaping. Four general groups of field shape are used in radiotherapy: square, rectangular, circular and irregular.

Square and rectangular fields are usually produced with collimators installed in radiotherapy machines, circular fields with special collimators attached to the treatment machine and irregular fields with custom made shielding blocks or with multileaf collimators (MLCs) attached to the treatment machine.



Any change to a treatment regimen, such as the use of IMRT, a dose increase or addition of chemotherapy or biological agents, will change the therapeutic ratio. The challenge for the radiation oncologist is to ensure that this change improves the ratio and that an increase in dose is not counteracted by an increase in unmanageable acute or serious late effects. TCP (tumour control probability) and NTCP (normal tissue complication probability) are mathematical models used to predict effects of such changes.

Before any form of predicted dose in a phantom or patient can be calculated, a parameterization of the characteristics of the delivery machine and radiation modality must be performed. Typically, this is called beam modelling and can be broken down into two main components; the definition of a set of energy-dependent depth dose curves and a corresponding representation of the angular-spatial distribution of the beam for each energy.

For the dose calculation, the energy-dependent depth dose curves are usually represented as integral depth dose curves. That is, the dose at any depth is the integral dose deposited at that depth in an infinite plane perpendicular to the incident direction of the beam. Although based on measured data, such depth dose curves are generally converted into a numeric representation (such as a depth-dependent look-up table) using analytical or empirical fitting algorithms . In contrast, the beam width is dependent on two components—a model for MCS in the medium and an analytical representation of the beam width in air (the A0, A1, A2 parameters in Although beam broadening due to MCS is determined solely by physics considerations, the beam width in air will need to be measured and the A parameters then derived from these measurements using data fitting techniques. However, in addition to being dependent on energy, for scanning gantries, beam width in air could well be also dependent on both the beam deflection and gantry angle.

Isodose curves are lines that join points of equal dose. They offer a planar representation of the dose distribution and easily show the behaviour of one beam or a combination of beams with different shielding, wedges, bolus, etc.

Isodose curves can be measured in water directly or can be calculated from PDD and beam profile data. A set of isodose curves is valid for a given treatment machine, beam energy, SSD and field size.

While isodose curves can be made to display the actual dose in grays, it is more common to present them normalized to 100% at a fixed point. Two such common point normalizations are as follows:

- Normalization to 100% at the depth of dose maximum on the central axis;
- Normalization at the isocentre.

Advanced Optimization

Up to now, we have looked at two modes of optimization for PBS plans; SFUD and IMPT. However, given the number of pencil beams available to the optimizer (typically thousands to tens of thousands of pencil beams per field), the optimization problem is inherently degenerate. That is, there are many different sets of PBS fluences that could give quite similar dosimetric results. This aspect of SFUD/IMPT optimization is discussed in detail elsewhere and won't be elaborated on here. However, the degenerate nature of the optimization process means that other aspects of field definition and design may be something that can be exploited.

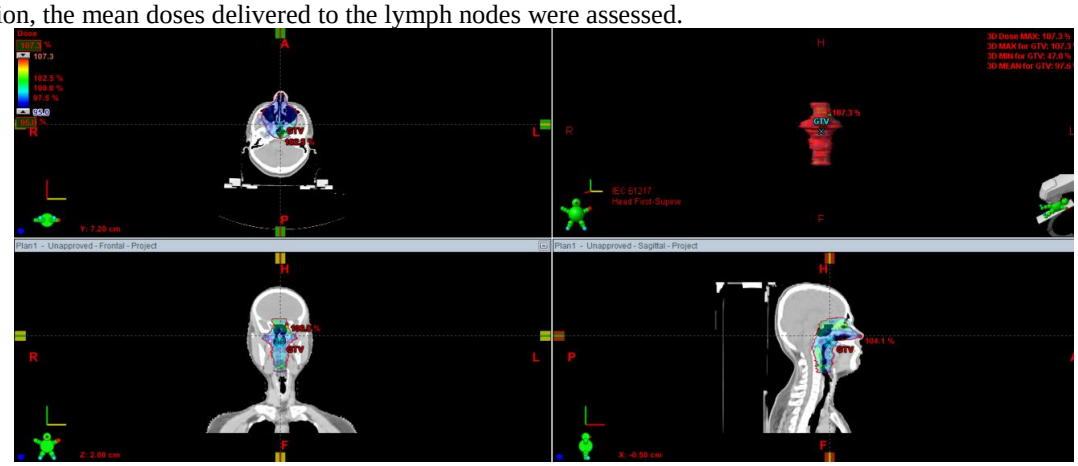
One sees that the majority of BPs have generally very low fluencies after the optimization process. Based on this, the question arises whether these BPs are required, or whether clinically acceptable plans could be delivered with less pencil beams per field. Indeed, this idea has been proposed very early on in the work . In the original paper the concept of distal edge tracking (DET) was proposed, in which BPs are only deposited at the distal edge of the PTV. Although there is no way that such a reduced number of BPs in a field can deliver a homogeneous dose from one field, the use of multiple DET fields, together with IMPT type optimization, have been shown to be able to deliver clinically acceptable plans in which the integral dose to normal tissues can also be somewhat reduced, at least for centrally located tumors. An expansion of this work has also been reported by in which a so-called "spot-reduction" method was incorporated into the optimization loop that automatically switches low-weighted pencil beams off, sequentially reducing the number in the plan as the optimization progresses.

This approach has been shown to be able to reduce the delivered BPs for plans with a small number of fields (where the pure DET approach has too few degrees of freedom) while approaching the DET approach (and further) for plans with many fields. However, due to fears about the robustness of such plans to delivery errors, at the time of writing, such "spot-reduction" techniques are not used clinically. Indeed, robustness itself is a parameter that can also be included into the optimization process, either indirectly or directly. In the work by Albertini et al. mentioned above, an indirect approach was taken in which the starting conditions of the optimization "force" the optimizer to a robust solution. Direct robust optimization methods, on the other hand, use robustness criteria.

Lymph node delineation

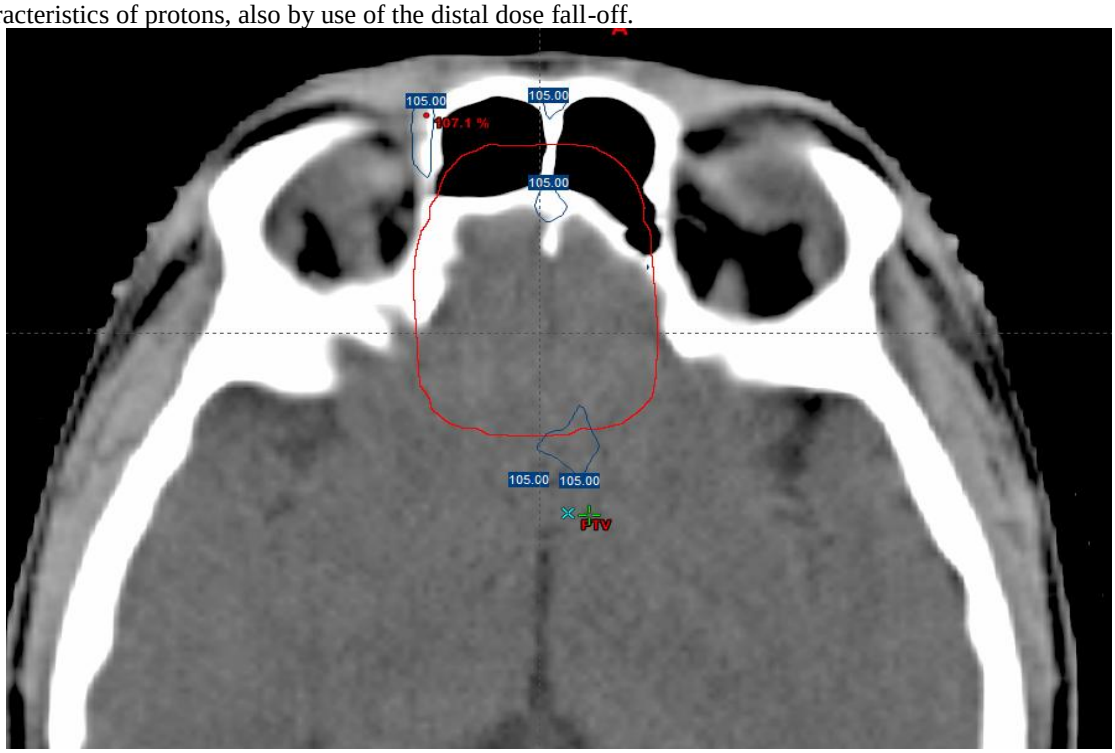
There are published guidelines for delineation of nodal CTVs in the node negative, node-positive and postoperative neck. It is very useful to have these guidelines available when defining nodal CTVs. The consensus guidelines for the node-negative neck are available as an online atlas and specify CT anatomy of nodal levels in the neck. The retropharyngeal nodes, levels Ia, Ib and II–V, are defined according to CT-based anatomical criteria which correspond closely to the surgical definitions of nodal levels.

These parameters derived from relevant dose volume histograms (DVH) included the V95% (the percentage of the target tissue volume irradiated to ≥ 95% of the prescribed dose), the V105% (the percentage of the target tissue volume irradiated with ≥ 105% of the prescribed dose), the V20% and V30% (the percentage of the ipsilateral lung volume receiving 20 Gy and 30 Gy doses, respectively), and finally the V10% and V40% (the percentage of the heart volume receiving 10 Gy and 40 Gy doses, respectively). Figure 6 show an example of the DVHs plots of the target tissue and organs at risk for one of the patients with the MIT (a) and DIT (b). In addition, the mean doses delivered to the lymph nodes were assessed.



Beam Selection and Plan Design

Due to its ability to deliver a more or less homogeneous distribution to the target from a single direction, it is not absolutely necessary to treat with multiple fields, even if this is highly recommended. This characteristic of proton therapy has a number of consequences. First, the number of fields for a typical proton plan can be quite small, and second, there is a lot of flexibility in the choice of these directions as all can, at least theoretically, deliver a homogeneous dose to the target. In practice, however, there are a number of issues that should be taken into consideration when selecting field directions, which will be briefly outlined in this section. The most obvious consideration is the avoidance of critical structures. Although all normal tissues in a patient can be considered "critical" in one way or another, some tissues are more critical than others, and one of the easiest ways of ensuring that dosimetric constraints are met is to avoid bringing treatment fields through these. This can be achieved by avoiding the structures with the lateral edge of the field and, given the stopping characteristics of protons, also by use of the distal dose fall-off.



Statistical analysis

Relevant statistical tests were performed by using the SPSS software. The nonparametric was initially performed to determine the normality of data distributions. The paired sample t-test was then performed to examine significant difference between the MIT and the DIT results for every dosimetric parameter of interest.

OAR are outlined in a similar fashion to the GTV – on serial axial CT slices. Ideally, the tumour volumes should be hidden or turned off so that they do not compromise OAR definition. Depending on the location of the PTV, OAR contours will include the spinal cord, parotid glands, optic nerves and chiasm, lacrimal glands and lenses. With more information on how DVHs relate to side effects, contouring of other structures such as the pharyngeal constrictor muscles may be useful in the future. Owing to the catastrophic effect of late spinal cord damage, the spinal cord PRV is usually defined either by adding an isotropic 5 mm margin round the cord or by contouring the bony spinal canal as a surrogate for the cord PRV. Some centres also recommend adding a 3–5 mm margin to the optic nerves and chiasm to create PRVs.

III. Results

The point providing the closest dose to the 100% of the prescribed dose to the target tissue (with 95% confidence interval), as well as the least dose to the organs at risk (the ipsilateral lung and heart), was regarded as the best candidate for the dose calculation reference point. The points meeting these criteria were the point number 13 and 12 for the patients with the right and left breast mastectomy, respectively (Fig. 5). For the patients having either right or left breast mastectomy, the Y component of the dose calculation reference point was the same as that of the geometrical center point.

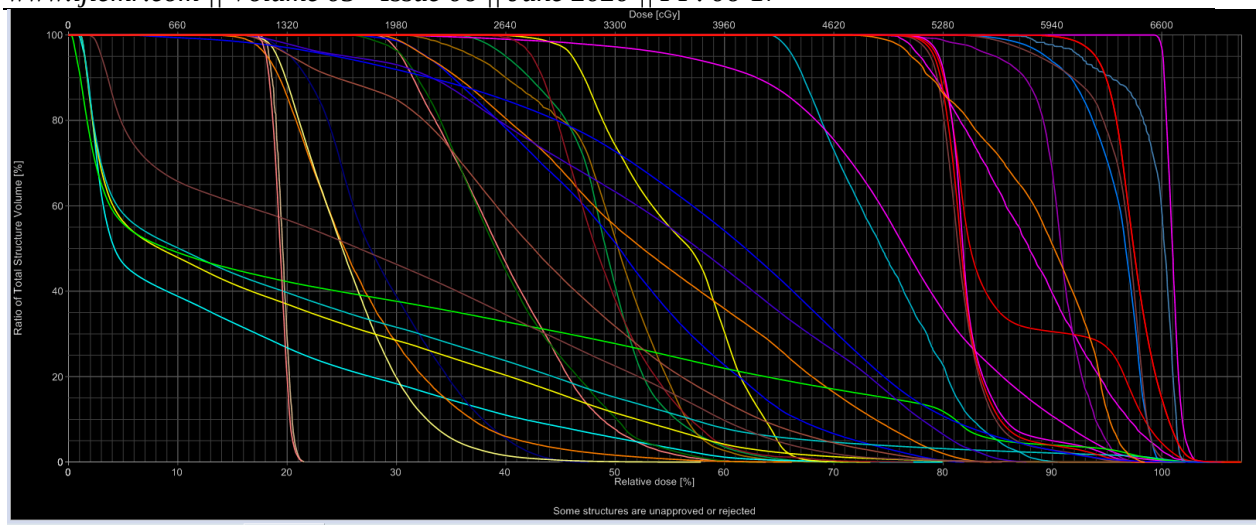
The most elegant solution – which deals with both problems – is to use a single isocentre technique. Both the anterior neck beam and the plan superior to it use only half the beam (the other half shielded by an asymmetric jaw) so that they match at the isocentre without penumbra or beam divergence. Another technique is to calculate angles required so that both beam edges diverge perpendicular to the match plane. This will result in slight overlap at depth as the width of the penumbra increases. Simpler solutions are to match the beams at the 50 per cent (light beam) isodose or to leave a gap of 5–10 mm on the skin surface.

Both will produce a perfect match at one depth but underdose anterior to this and overdose posteriorly where the divergent beams overlap. The level at which the anterior beam is matched depends on the PTV. Ideally it should be below the high dose PTV or in between nodal CTVs as matches overlying the PTV risk underdosing disease at the match plane. If this is unavoidable the junction can be moved by 1 cm half way through the course of treatment to blur this match.

The X component of the dose calculation reference point for all the patients was located at one-third of the length of the K toward the lateral border of the chest wall. The depth of the reference point was determined at 2–3 cm under the patient skin. The results of the all the dosimetric parameters follow the normal distribution with a 95% confidence interval, enabling us to use required, presents the results of statistical tests used to examine the significant differences between the two techniques for one parameter with a 95% confidence interval. Differences are meaningful when the "significant" (Sig.) value is smaller than 0.05. The means and ranges of the dosimetric parameters resulted from the implementation of both of the MIT and the DIT for the treatment planning of the patients. It must be noted that the dosimetric parameters reported in the table for the heart as a critical organ are calculated just for the patients having the left breast mastectomy (10 women). As can be noted from the data presented in all the dosimetric parameters show no significant differences between the MIT and the DIT, except the three parameters of the "maximum dose in the fields junctions", "V105% for the target tissue" and "the mean dose of the level 2 lymph nodes", indicating quite significant lower values for the MIT.

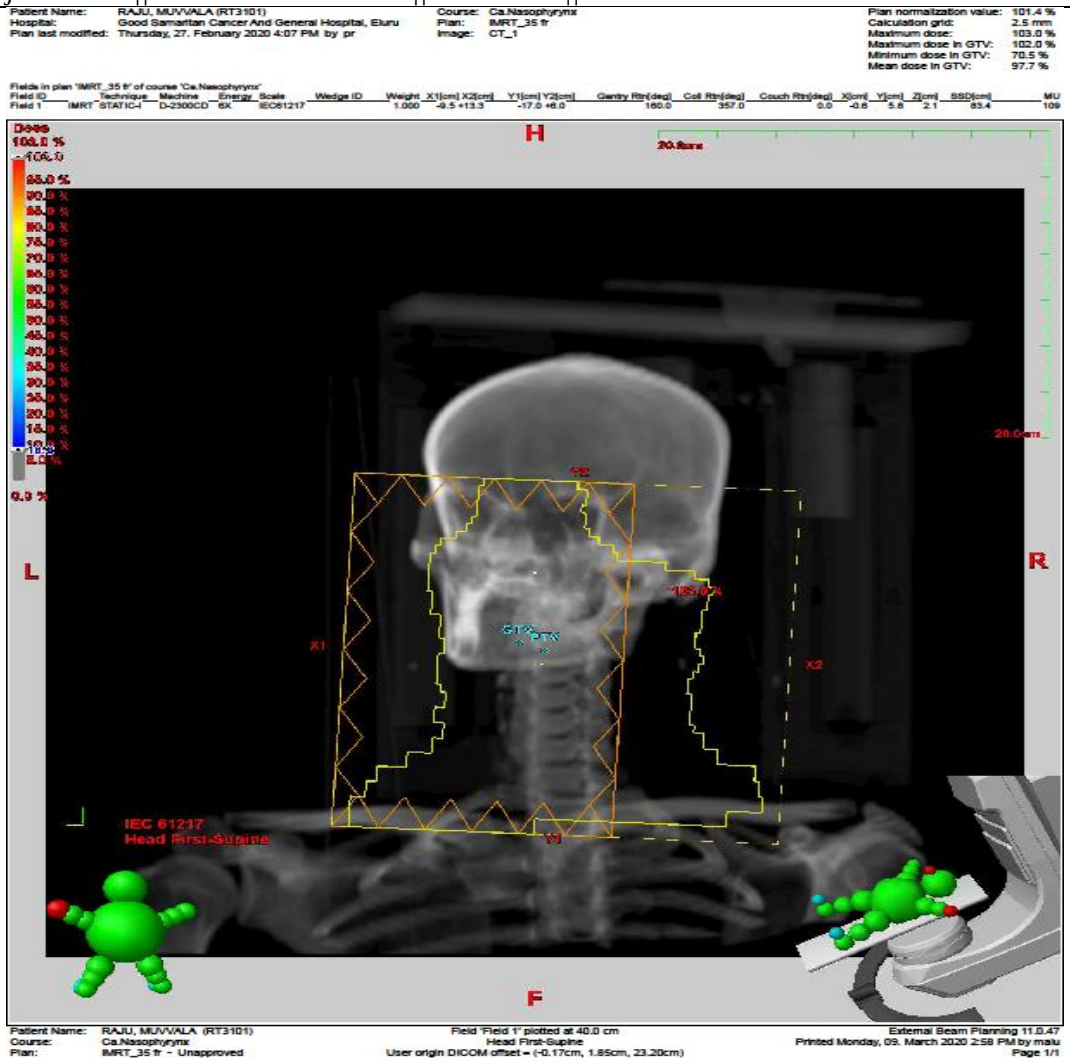
Fluence Optimization

The fluences shown have been assigned using a precalculated, onedimensional weighting scheme based on the SOBP concept. Such fluences, if assigned to a field planned to a rectangular box in water, would then provide a homogeneous dose across the target, and indeed such fields are a way by which a machine can emulate . However, when applied to an irregular target in a nonhomogeneous patient with a nonflat skin surface, then this simple fluence assignment approach is insufficient, as can be seen . This shows the dose distribution resulting from the set of BP and fluences shown in, calculated using the ray-casting analytical approach (see above). Although the 95% isodose covers most of the PTV in the slice shown, there are clear areas of under-dosage (<<95%) at the edge of the PTV. In order to improve this situation, an optimization of the fluences is required, by which the fluence of each selected BP in the field is iteratively modified, with the goal of making the resultant dose distribution as homogeneous as possible across the target volume.



IV. Discussion

The treatment fields in the MIT are very similar to the DIT when the mastectomy patients are treated at supine position. Significant differences are noted in the regions of the field junctions, collimator, and treatment couch angles. Therefore, it was expected that there would be no noticeable difference between these techniques for the V95% parameter as these regions do not have a large volume compared with the entire volume of the target tissue (chest wall). The reported similar results for this parameter between the MIT and traditional techniques. As a result of using the asymmetric fields in the junction regions of the tangential and supraclavicular treatment fields in the MIT, there is a good matching and no divergence between the fields. But, in the DIT, because of using the full fields, there is a divergence in the region of the fields' junctions. The fields cannot match very well in these regions and there would be an overlap of the treatment fields. Hence, it will be obvious to observe the regions with higher dose than the limited prescribed dose. Results also showed noticeable difference for the 105% dose coverage or even higher level of doses for the DIT compared with the MIT. Previous investigations have reported similar findings. Because of the reasons outlined above, it was expected and confirmed that the maximum dose in the fields' junction and overlap regions for the DIT is significantly higher than the MIT. Previous investigations have also reported similar findings in this regard. Despite the lack of appropriate matching between the treatment fields in the DIT, it will be hard to rotate the collimator or treatment couch to a desired angle in the MIT, because it will cause the divergence and overlap of the fields in the regions of the fields' junctions. In patients whose chest walls are curved, a portion of the lung may be placed under the treatment field which is needed to be shielded by blocks; therefore, the dose distributions (in critical organs) will be similar for both of the MIT and DIT for some dosimetric parameters.



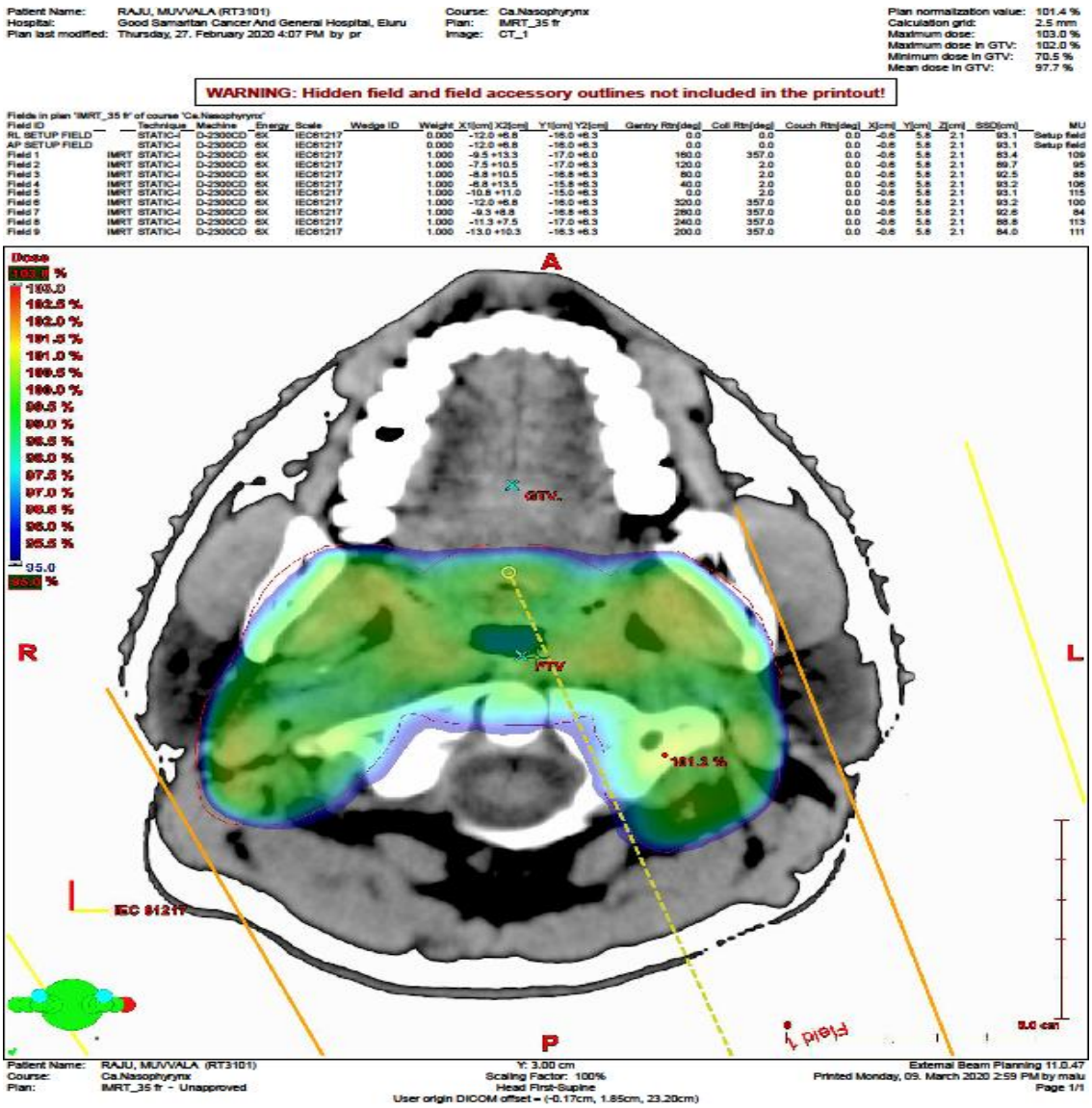
Plan Evaluation

The final stage of the treatment planning process is the clinical and physics review of the plan, before being released for delivery to the patient. For the most part, the clinical review will be very similar to that for conventional therapy. Certainly, target coverage and doses to critical structures will need to be reviewed, through both a visual assessment of the dose distribution in all relevant slices and DVHs. However, given the potential for increased RBE values in some parts of the plan, then perhaps an additional clinical assessment of the plan from the point of view of RBE should be performed. For instance, are highly weighted fields stopping directly against a critical structure? If so, is this acceptable, or should the dose constraints to the structure be reduced to allow for this? The differences are somewhat more when assessing a plan from the physical point of view, however. One area, which we have not discussed in this chapter up to now, is the effects of delivery uncertainties on PBS proton plans. This has been an area of considerable research in recent years, and has recently. We will not go into details here, other than to outline the two main uncertainties; positional and range.

Positional uncertainties are of course present in any form of external beam radiotherapy, but are a particular problem for fractionated treatments. Inevitably, the accuracy of patient set-up over many days cannot be as accurate as that of a single treatment, despite image-guided techniques to improve this. In practice, therefore, positioning inaccuracies of a few millimeters day-to-day have to be expected. Typically, such uncertainties are managed through the use of a PTV (see above), with estimation of the potential effects of positional uncertainties being restricted to evaluating dose coverage of the PTV. However, more sophisticated approaches to this are now being developed, allowing for more direct visualization of dosimetric uncertainties in three dimensions and in relation to the patient geometry.

Although some of the first work in analyzing treatment uncertainties was for photon treatments , much of the more recent published work has concentrated on proton therapy, either as a metric for robust optimization

or for evaluating the robustness of plans outside of the optimization process . Many of these provide uncertainty distributions, estimated by recalculating dose on a number of instances of the nominal geometry shifted in space to simulate potential treatment set-up errors. The uncertainty distribution is then calculated at each point by generating dose error bars at each dose calculation point through the combination of the multiple dose values into a uncertainty band, typically by displaying the difference in the maximum and minimum values of all calculated doses at each point . Although this approach can be used for comparing the robustness of two different plans, it is a very conservative approach which basically assumes that positional errors will be systematic in nature.



The level 1 and 3 lymph nodes are usually located in supraclavicular region. Therefore, as expected, the mean doses received by these nodes from our MIT and DIT didn't differ significantly. But, since the level 2 lymph nodes were located in the region of the fields' junction, the mean dose delivered to these nodes by the MIT and DIT were significantly different with the MIT, giving a lower dose well within the dose limit (45–50 Gy) recommended for them.

V. Conclusions

The dose distribution in the lung, heart, and the mean doses of the level 1 and 3 lymph nodes resulted from the MIT and the DIT did not indicate any significant difference. In addition, the dose distribution of the

95% of the prescribed dose coverage and the dose distributions in critical organs with the MIT were identical with that of the DIT.

This quantitative rather than qualitative comparison done by fractal dimension numerical analysis helps to decrease the quality assurance errors in IMRT dosimetry verification.

However, regarding the 105% dose coverage, the mean dose received by the level 2 lymph nodes and the maximum dose in the fields' junctions were noticeably lower and clinically closer to the prescribed doses with the MIT. Therefore, to achieve a better chest wall conformal radiotherapy for the patients having mastectomy, it could be recommended to use the MIT as developed in this study, instead of the DIT and conventional radiotherapy techniques.

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