S.R. Mahdavi PhD[1]
A.R. Nikoofar MD[2]
H.R. Mirzaei MD[3]
B. Mofid MD[3]

The Role of CT-Based Radiotherapy Planning on Dosimetric Correction

Background/Objective: The dose distribution is affected by tissue inhomogeneities. The objective of this study was a dosimetric evaluation of the potential corrective role of computed tomography (CT) data in radiotherapy treatment planning (RTP) for various anatomical sites of the body (head and neck, abdominopelvis and thorax), separately.

Patients and Methods: Fifty-four cases of head and neck, pelvis, abdomen and breast cancers were included in this study. All of the patients were scanned with the same CT machine. Each case was planned with and without CT-based density correction by a two-dimensional ALFARD RTP system. Analyses of dosimetric parameters were performed for with and without inhomogeneity corrections based on the effective path length method. Dosimetric parameters were dose uniformity (Te), the average (Davg), minimum (Dmin) and maximum (Dmax) doses for both the planning target volumes and organs at risk. These parameters with and without CT-based density correction were compared in the head and neck, abdominopelvic and thoracic regions, separately.

Results: The mean difference of Te and Davg between these two methods was statistically significant in the thoracic region (7.13±5.55; p=0.001 for Te and 4.65±6.59; p=0.04 for Davg). Measurements of Te, Davg, Dmin and Dmax in the head and neck and abdominopelvic regions showed no statistically significant differences between the two methods (all p values ≥0.05).

Conclusion: In some parts of the body, if the CT correction for density variation was not applied, the dose deviations could be out of the tolerance limits defined by the standards for tumors and normal tissues.

Keywords: Radiotherapy Planning, Density Correction, Target Volume, Organ at Risk, CT Planning

Introduction

Availability of computed tomography (CT) data compatible with radiotherapy treatment planning systems (RTPS) is a problem in the majority of Departments of Radiotherapy Physics. However, planning without correction for variation in the densities of different organs is still possible. On the other hand, internal organ localization and maximizing the dose to the planning target volume—while minimizing the dose to normal tissues—are the basis of an effective treatment planning in radiotherapy.[1-17] Progress in medical imaging over the past three decades has revolutionized the calculation and controlled delivery of radiation therapy. Examining the sources of uncertainty in the radiation process provides insight into ways in which imaging can be used to improve the treatment. Uncertainties in the process begin with those associated with target delineation and pass from the methodology of dose calculation and distribution. The initial studies on the use of CT in the treatment planning documented that tumor coverage without a CT was inadequate in 20% of patients, marginal in another 27%, and adequate in 53% of the studied population. Defining the extent of the target volume in an accurate, consistent, and efficient way is clearly important.[2]

A second source of uncertainty is prescribing the appropriate dose sufficient for local control. A more accurate knowledge of the physical and electron densities

1. Assistant Professor, Department of Medical Physics, Iran University of Medical Sciences, Tehran, Iran.
2. Assistant Professor, Department of Radiation Oncology, Iran University of Medical Sciences, Tehran, Iran.
3. Assistant Professor, Department of Radiation Oncology, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
Corresponding Author:
Seyed Rabi Mahdavi
Address: Department of Medical Physics Iran University of Medical Sciences, Tehran, Iran.
Tel/fax: +98-21-8896-6052
Email: srmahdavi@hotmail.com

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of normal and pathological tissues can lead to delivery of higher doses to the tumor while sparing normal structures, with resultant better local control without increasing treatment-induced morbidity.[3-5]

In this article, a dosimetric quantitative approach to the corrective role of CT-based treatment planning is presented. The effect of various tissue inhomogeneities was assessed on the dose distribution within the irradiation volume, while the radiation field and other setup parameters were kept constant. The objective of this study was to evaluate the potential corrective role of CT data in RTP for different anatomical parts of the body (head and neck, abdominopelvis and thorax), separately.

Patients and Methods

CT scan (Siemens, Germany) of the interested regions was performed for 54 patients who were treated with a ^{60}Co machine. The patients consisted of 17 with head and neck (31.5%), 15 with pelvic (27.8%) and 22 with chest wall (40.7%) malignancies. The digital imaging and communications in medicine (DICOM) format of the CT raw data was sent to a two-dimensional treatment planning (2D ALFARD RTP) system. The validity of the planning system was routinely checked against dosimetry in the same geometric condition. Two methods of planning were used for dose calculation, both in planning target volume (PTV) and organs at risk (OAR); 1) Treatment planning based on CT data (DICOM format) corrected for bulk heterogeneities by means of effective path length method (group I) and 2) Planning based on CT images (JPEG format), which were not corrected for tissue heterogeneities (group II).

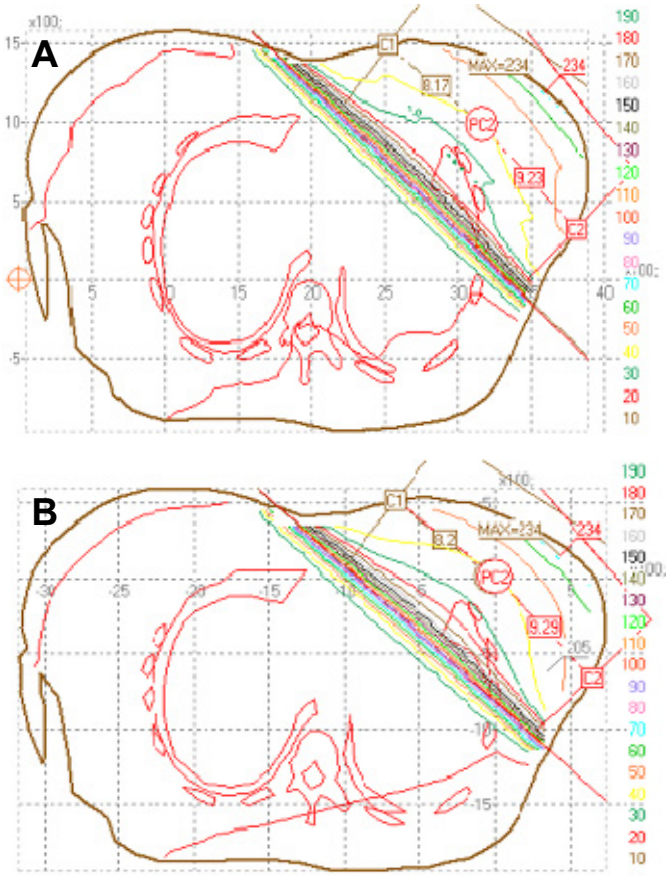

Figure 1. Dose distribution in the left breast and chest wall is shown. Dose differences around the lung are considerable. Image (a) is corrected for density from CT numbers and image (b) is not corrected for density differences.

Dose distribution parameters consisting of the distribution uniformity factor (Te), average dose (D_{avg}), and minimum (D_{min}) and maximum dose (D_{max}) were calculated using both planning methods. Paired *t* test was used to compare the results obtained by the two methods

Results

Various dosimetric parameters were compared both qualitatively and quantitatively after the calculation of dose distribution, with and without tissue inhomogeneity correction. Typical qualitative findings from chest wall irradiation are shown in Figure 1. The same assessments were obtained for the head and neck as well as the abdomino-pelvic region. The effect of CT data on planning and iso-dose distribution is shown in Figure 1a. Various tissues in this section have their unique densities. The iso-dose lines represent the dose distribution based on the inhomogeneities existed in the irradiation area. Planning based on the homogeneous target area shows different iso-dose line distributions in target volumes (*e.g.*, left breast tissue) and other organs at risk (*e.g.*, left lung) (Fig. 1b). Point of D_{max} and geometry of radiation tangent fields are also shown in these figures.

Quantitative analysis of the dosimetric variables consisting of mean differences and standard deviations (SD) with their appropriate probability values are shown in Tables 1 and 2.

Table 1. Dosimetry Results of Treatment Planning With and Without Correction for Density in Various Irradiated Fields

Dosimetric Parameter	Chest Wall M% (SD) (P-value)	Pelvis M% (SD) (P-value)	Head and Neck M% (SD) (P-value)	Overall M% (SD) (P-value)
Difference in Te	7.13 (5.55) (<0.001)	-1.59 (3.78) (0.30)	0 (3.54) (0.50)	2.52 (5.93) (0.001)
Difference in D_{avg}	4.65 (6.59) (0.04)	-0.99 (4.69) (0.52)	0.012 (2.02) (0.05)	2.00 (5.47) (0.06)
Difference in D_{min}	1.79 (7.44) (0.3)	-0.89 (7.12) (0.91)	0 (10.08) (0.99)	0.39 (4.21) (0.40)
Difference in D_{max}	-1.61 (7.43) (0.10)	1.29 (2.40) (0.05)	0 (3.38) (1.00)	-0.21 (5.32) (0.25)

M%: mean percent, SD: standard deviation

Table 2. Dosimetry Results of Treatment Planning With and Without Density Correction for Organs at Risk in Different Irradiated Fields

Dosimetric Parameter	Lung M% (SD) (P-value)	Rectum M% (SD) (P-value)	Head and Neck M% (SD) (P-value)
Difference in Te	11.03 (10.10) (0.01)	-0.024 (0.10) (0.41)	3.73 (14.42) (0.24)
Difference in D_{avg}	4.70 (21.31) (<0.01)	-0.013 (0.085) (0.04)	0.38 (14.51) (0.31)
Difference in D_{min}	11.18 (9.37) (<0.01)	-0.030 (0.059) (0.50)	-4.07 (8.57) (0.18)
Difference in D_{max}	7.50 (7.20) (<0.01)	0.005 (0.092) (0.02)	3.97 (24.08) (0.61)

M%: mean percent, SD: standard deviation

The percent of mean differences between Te's before and after inhomogeneity correction for chest wall irradiation is 7.13% (±5.55% and $p < 0.001$) with the significant value of 2.46. The mean differences of D_{avg} is 4.65% (±6.59% and $p < 0.05$) and the same statistical quantity for maximum and minimum doses are controversial (Table 1).The lung represents as the OAR in the treatment of the chest wall. Analysis of the obtained data for the lung shows significant differences before and after density correction for air encompassing within the irradiated volume (Table 2).

Findings after pelvic irradiation revealed mostly negative changes after inhomogeneity correction encountered within the irradiation field. The mean differences of Te, D_{avg}, D_{min} and D_{max} are -1.59%, -0.99%, -0.89% and 1.29%, respectively (Table 1). Data analysis for OAR (rectum) in the treatment of pelvic regions showed small differences between the calculated doses with and without density correction (Table 2).

Findings of the head and neck treatment fields showed unexpected results; the differences in the Te, D_{avg}, D_{min} and D_{max} calculated from the two methods were not statistically significant (Table 1). The results of OAR's for the treatment of various malignancies in the head and neck region were calculated (Table 2). The overall changes in the dosimetric parameters encountered in the treatment planning evaluation after tissue inhomogeneity correction are also shown in Table 1.

Discussion

The types of changes necessitated by CT planning as compared to conventional planning are summarized in Table 3. Overall, about 40% of the plans are altered with the greatest percentage—roughly 30%—being due to inadequate prescribed dose coverage of the target volume.[17]

There are two types of tissue interface most important in radiotherapy— that between any low-density inhomogeneity and soft tissue and that between bone and soft tissue.

In our experience, treatment planning for almost

Table 3. Changes in the Treatment Plan as a Result of CT Data (all sites)

Study	No. of Patients	Inadequate or Marginal Tumor Volume No.(%)	Volume Made Smaller No.(%)	Any Change No.(%)
Brizel [5]	72	29 (40%)	4 (6%)	44 (61%)
Emami [6]	32	10 (31%)	2 (7%)	17 (53%)
Goitein [7]	77	32 (42%)	—	40 (52%)
Hobday [8]	123	29 (26%)	5 (4%)	47 (38%)
Lee [9]	22	3 (14%)	—	3 (14%)
Munzenrider [10]	75	35 (47%)	18 (24%)	41 (55%)
Pilepich [11]	97	21 (22%)	—	21 (22%)
Prasad [12]	50	11 (22%)	2 (4%)	6 (26%)
Schlagar [13]	21	6 (29%)	—	6 (29%)
Seydel [14]	23	4 (17%)	2 (9%)	6 (26%)
Van Dyk [15]	60	—	—	36 (60%)

any tumor sites can benefit from CT-based planning. However, the plans are likely to improve the treatment of some sites more than others (Tables 1 and 2). The head and neck is a region where CT is very useful for quantitating the tumor extent and consequently for disease staging. This appears to be especially helpful in regions that cannot be palpated or directly visualized, *e.g.*, the paranasal sinuses. However, it is unlikely that CT scanning will significantly change the treatment volume, as most head and neck tumors are treated with large fields that encompass all known regions at risk. CT is valuable in designing field arrangements that spare normal tissue in head and neck cancer, *e.g.*, coned-down wedged oblique fields to avoid the spinal cord. CT can also be useful for determining tissue inhomogeneities especially in areas such as the paranasal sinuses. However, it seems that variations in densities especially in the paranasal region cancel each other out. We believe that this is the most important cause of the minimal difference observed between before and after dosimetric parameters in the head and neck region.[17-21] According to the American Association of Physicists in Medicine (AAPM) report No. 85, underdosing effects occur at both the distal and proximal air cavity interfaces. The magnitude of underdosing depends on the cavity size, location, and the energy level delivered. Experimental data are therefore required to quantify the magnitude of the dose reduction near air-tissue interfaces.[1]

The present study showed a dose distribution discrepancy of greater than 7% ($p<0.001$) in chest wall irradiation after tissue inhomogeneity correction. Clinical radiobiology indicates that based on the tumor dose-response curve with the gradient of 3, a decrease of 4% in dose can lead to 12% decrease in a specific end effect of tumor response. This study also reported that the dose-response curve is not a constant function of dose and small variations in the absorbed dose may severely change the income of radiation therapy.[18] Different methods have been discussed in the literature. The effects of inhomogeneities may be classified into two general categories: a) changes in the absorption of the primary beam and the associated pattern of scattered photons; and b) changes in the secondary electron fluence.[2] Our findings further indicated that the difference of average doses in target volume between the two dose calculation methods was more than 4% ($p=0.04$) which has to be considered during the clinical treatment planning. This result is well comparable with the values reported for beyond-lung and in-lung dose correction.[2] Wong and Purdy[22] provided measurements for ^{60}Co, demonstrating the dependence on the proximity of low-density regions to points of interest. Loss of electron equilibrium within and adjacent to low density materials can result in a dose reduction along the central axis and near the beam edge for megavoltage photon beams.

Abdominopelvic organs are highly sensitive to radiation and are considered as dose limiting organs. These organs have fairly similar physical properties regarding atomic number and density so they mimic a uniform and homogeneous volume of tissues. Because of the homogeneity and the energy of photon beam (1.25 MeV) in the present study, there were no significant differences between dosimetric parameters

after electron density variation correction. However, the major impact of CT in the abdominopelvic region is still on the geometry, organ localization and selection of the irradiation technique.[20-24]

In its simplest form, the patient might represent in RTP systems as having only one or a few contour lines outlining the skin. These could be acquired in a number of ways, from solder wire surface contours to contours acquired from CT. The contours entered or digitized into the planning system, represented the skin outline in two or three dimensions. Such procedures resulted in the patient being represented as a homogeneous composition (usually water) but do allow surface corrections to be applied. Patient heterogeneities could be represented in simple ways such as closed contours, like the surface representation. Each inhomogeneity had to be outlined individually, with a density assigned. This could usually be done semi-automatically on CT images for tissue such as lung or bone or for air cavities, where the contrast between tissues was sufficiently high. The electron density assigned to the region could be inferred from the CT number.[25] The problem with this approach was that tissues such as the lung and the bone are not themselves homogeneous; there is a variation of approximately 50% in both bone and lung densities. The lung density varies because of the blood pool resulting from hydrostatic pressure differences.

Use of CT shows two benefits in advanced radiotherapy treatment planning procedures: First, accurate two- and three-dimensional localization of tumor and organ at risk, and second, potential use of CT quantities for corrections including tissue inhomogeneity, beam modifiers as well as evaluation of the dose distribution. The role and the amount of density correction based on CT data in some treatment fields are not negligible.

Application of CT data in treatment planning can be more effective for some parts of the body. Although providing CT facilities may be a serious financial problem for Departments of Radiotherapy, its potential benefits in terms of dosimetric correction and subsequent increased probability of tumor control and decreased probability of normal tissue complications may ultimately compensate for the expenses.

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