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Radiation dose differences between thoracic radiotherapy planning CT and thoracic diagnostic CT scans

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ABSTRACT

Purpose: To compare the absorbed dose from computed tomography (CT) in radiotherapy planning (RP-CT) against those from diagnostic CT (DG-CT) examinations and to explore the possible reasons for any dose differences.
Method: Two groups of patients underwent CT-scans of the thorax with either DG-CT ($n = 55$) or RP-CT ($n = 55$). Patients from each group had similar weight and body mass index (BMI) and were divided into low (<25) and high BMI (>25). Parameters including CTDIvol, DLP and scan-length were compared.
Results: The mean CTDIvol and DLP values from RP-CT (38.1 mGy, 1472 mGy cm) are approximately four times higher than for DG-CT (9.63 mGy, 376.5 mGy cm). For low BMI group, the CTDIvol in the RP-CT scans (36.4 mGy) is 6.3 times higher than the one in the DG-CT scans (5.8 mGy). For the high BMI group, the CTDIvol in the RP-CT (39.6 mGy) is 2.5 times higher than the one in the DG-CT scans (15.8 mGy). In the DG-CT scans a strong negative linear correlation between noise index (NI) and mean CTDIvol was observed ($r = -0.954$, $p = 0.004$); the higher NI, the lower CTDIvol. This was not the case in the RP-CT scans.
Conclusion: The absorbed radiation dose is significantly higher and less BMI dependent for RP-CT scans compared to DG-CT. Image quality requirements of the examinations should be researched to ensure that radiation doses are not unnecessarily high.

Introduction

Since its inception in 1973, the role of computed tomography (CT) in diagnostic radiology has expanded. In Norway, approximately 918 000 CT examinations were undertaken in 2008; currently CT accounts for approximately 21% of all radiology procedures.[1] This is a large increase from 2002, when it accounted for 11%.[1] In the last decade, the use of a CT scan prior to radiotherapy treatment (RP-CT) has also increased. Radiation exposure from CT has been of growing concern in recent years.[2]

CT based simulation and treatment planning using 3D anatomy, has been advantageous to achieve a wider therapeutic window.[3] CT-based simulation provides accurate volumetric determination of target and normal anatomy, which provides treatment planning with a point-by-point description of the patient, as there is close relationship between CT number and electron density.[4,5] However, the use of newer radiotherapy techniques such as Intensity Modulated Radiotherapy (IMRT) relies on accurate target volume delineation to avoid marginal tumour recurrences.[6] This has led to an increased demand of image quality in CT examinations used for radiotherapy planning. Maintaining high quality CT images and including a larger CT examination area in a pre-radiotherapy CT examination than the radiation treatment area may expose cancer patients to higher and perhaps unnecessary CT dose.

In addition, new CT scanner designs provide novel applications that have the potential to decrease radiation exposures to patients

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while maintaining the same image quality.[7] Anecdotal observations within radiotherapy planning CT units suggest there is little concern for high radiation doses from RP-CT. Nevertheless, the potential risks of radiation-induced carcinogenesis from CT should not be ignored. Several factors highlight the need to examine this topic; i) the existing high radiation potential of contemporary CT systems, ii) including a larger CT examination area than radiotherapy treatment area in pre RP-CT examination iii) the need for high quality CT images in pre radiotherapy planning CT examination and iv) the perceived lack of attention to CT-dose saving strategies in radiotherapy departments.

The initial aim of this study was to investigate the CT-dose differences in a sample of patients examined with diagnostic CT (DG-CT) and RP-CT. As part of this aim possible reasons for CT dose differences between a diagnostic and radiotherapy thoracic CT scan, when using the same scanner technology, will be assessed.

Materials and methods

Study population

Between April 2013 and May 2014, 110 thoracic CT scans from 110 patients were identified. Fifty-five scans (50%) were CT thorax examinations acquired as part of RP-CT. The other 50% were thoracic DG-CT examinations. Inclusion criteria were i) patients scanned to either a RP-CT or DG-CT thoracic protocol ii) all of the scans had been acquired on the same GE Light Speed PRO CT machine and iii) each pair (DG-CT & RP-CT) of patients included were approximately matched for weight and height independent on gender and iv) patients underwent thorax CT scans v) both sets of scans had image quality which was determined by acceptance from the reporting radiologist/radiation oncologist.

Of the patients who underwent DG-CT scans, 17 were men and 38 were females; Patients from the RP-CT group included 29 males and 26 females. Descriptive statistics for height, weight and Body Mass Index (BMI) of the illustrated patients are shown in Table 1.

There was a statistically significant difference for the height distribution, mean/standard deviation (SD) height for RP-CT group was 170/9 cm whereas for the DG-CT group it was 174/8 cm ($p = 0.009$). There was no significant difference in weight and BMI between the two included populations.

The impact of BMI on CTDIvol in each CT scan protocol was assessed by dividing each study population into two groups: low BMI group with BMI <25 and the overweight and obesity,[8] high BMI group with BMI ≥25.

CT scanning protocols

For the DG-CT scans, the protocols were individually optimized based on patient size (large, medium and small) and a dose level (high, medium and low dose) was selected on the basis of the clinical indication. In addition, contrast media were used if clinically indicated. The high-dose protocol used a tube-voltage of 120 kVp, the medium 100 kVp and the low dose 80 kVp. None of the DG-CT scans in this study used the low dose protocol. Automatic tube current modulation was applied by setting a noise index (NI) and a minimum mAs value based on both the clinical indication and patient size. Scan parameters are indicated in Table 2. All DG-CT-scans were acquired with a single breath-hold helical CT-technique in cranio-caudal direction from the top of the apex and just below the diaphragm. The image noise and dose levels of the scans were dependent on the combination of NI and limitations in minimum and maximum mAs values as indicated in Table 2. The maximum mAs available was always 650 mAs for the DG-CT scans. However, the minimum mAs was set to 50, 80, 100 or 150 mAs depending on the patient type and clinical indication. The employed NI was 70, 55, 45 or 38 and again reflected individual scenarios. All DG-CT scans used a pitch of 0.984:1, the full z-axis width of the detector (40 mm) and with 64 0.625 mm slices per rotation the resultant table speed was 7.872 cm/s. For the RP-CT scans the mAs limitations were from 100 to 380 at a low NI; 2.8 or 4, or no limitations (from 10 mAs to 440 mAs) at the higher NI; 11.5. To capture the tumour movement along patient's breathing cycles the table speed is set low in the DG-CT scans. This is done by a collimation of 10 mm with 2 or 4 slices and a small pitch of 0.875:1 or 0.625:1. However, in one scan, a pitch of 1.25 was used. The pitch, number of slices, collimation and the resulting table speeds are seen in Table 2.

Table 2
CT-scan parameters for the RP-CT and DG-CT examinations.

Scan parameter	RP-CT	DG-CT
kV	120 kVp	100 or120 kVp
Pitch	0.625:1 0.875:1 1.35:1	0.984:1
Rotation time	1 s	0.5 s
Scan FOV	Large body	Large body
Slice thickness	2.5 or 5 mm	0.625 mm
# of slices per rotation	4 or 2	64
Collimation	10 mm	40 mm
Table speed	0.625, 0.875 or 1.35 cm/s	7.872 cm/s
Noise index	2.8, 4 or 11.5	38, 45, 55 or 70
Minimum mAs	10 or 100	50, 80, 100 or 150
Maximum mAs	380 or 440	650

Statistical analysis

Height and scan length were normally distributed in the two groups and a two-tailed independent Student t-test compared these parameters. The relationship between height and scan length were assessed using the Pearson correlation coefficient. Weight, BMI, CTDIvol and DLP were not normally distributed and therefore the relationship between these parameters was assessed using the non-parametric Spearman's rank correlation coefficient. Mann

Table 1
Patient height, weight and BMI of the 55 patients with radiotherapy planning thorax CT scans (RP-CT) and the 55 patients with diagnostic thorax CT-scans (DG-CT).

	RP-CT[a]		DG-CT[b]		p-values[c]
	Mean (St. Dev)	Range (median)	Mean (St. Dev)	Range (median)	
Height (cm)	170 (9)	150–192 (170)	174 (8)	156–188 (175)	0.007[c]
Weight (kg)	75 (14)	51–113 (72)	77 (16)	53–128 (73)	0.613[d]
BMI	25.9 (4.2)	19.4–36.8 (25.2)	25.4 (4.9)	17.7–40.0 (24.0)	0.470[d]

[a] RP-CT = Radiotherapy planning CT scans.
[b] DG-CT = Diagnostic CT-scans.
[c] T-test with independent samples.
[d] Mann Whitney U tests.