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

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 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-DG 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 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.

[INSERT TABLE 1 – HERE]

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 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 was 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.

[INSERT TABLE 2 – HERE]

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 Whitney U test was when comparing these parameters in the two samples. When using correlation coefficients values, $r>0.7$ the correlation is strong positive, when it is $0.3>r>-0.3$ it is a weak correlation and when it is $r<-0.7$ it is a strong negative correlation.[9] The linear regression trendlines are indicated by least squares fit. Findings with $p<0.05$ were considered statistically significant. Mean with SD and median with range were also reported using the study data.

Ethics

This retrospective study have only used anonymous data with no information that may identify an individual, neither directly nor indirectly. The data was collected by the staff at the hospital for quality assurance purposes. The Data Protection Official at Oslo University hospital have stated that the project is not subject to notification or need ethical approval.

Results

The overall scan length was not significantly different between groups (Table 3; $p=0.549$). CT dose data (CTDIvol and DLP) from the 110 CT-thorax from DG-CT and RP-CT were

analysed. CT dose data from the RP-CT scans showed a CTDIvol almost 4 times higher than in DG-CT (Table 3). CTDIvol for RP-CT varied from 24.6 to 51.3 mGy with mean/SD of 38.1/4.9 mGy compared to 2.17 to 31.8 mGy for the DG-CT scan, mean/SD 9.6/6.2 mGy. Table 3 also highlights that the DLP value is also nearly 4 times larger for RP-CT scans when compared to the DG-CT scans. The DLP for RP-CT scans ranges from 836.5 to 1472 mGy·cm with mean/SD of 1472/224 mGy·cm compared to 81.22 to 1414 mGy·cm in DG-CT, with a mean/SD of 376.5/251.7 mGy.

[INSERT TABLE 3 – HERE]

The correlation between height, weight, BMI, and CTDIvol for both DG-CT and RP-CT are demonstrated individually in Figures 1A-C. In the DG-CT scans the correlation coefficients(p-values) for weight and BMI against CTDIvol are r=0.778(p<0.001) and r=0.825(<0.001), respectively. RP-CT scans had r=0.340(0.011) and r=0.310(0.021), respectively. Correlation coefficients for weight and BMI against DLP are r=0.797(p<0.001) and r=0.827(0.001) for DG-CT and r=0.441(0.002) and r=0.185(0.176) for RP-CT, respectively. The correlation between height and scan length was r = 0.476(0.001) in DG-CT and r=0.451(0.001) in RP-CT.

Variation in CTDIvol against BMI is illustrated in Figure 1C. As seen, the DG-CT scans have a much lower CTDIvol values than the RP-CT scans. The distribution of DG-CT CTDIvol values demonstrate a strong linear relationship with the BMI of the patients (r=0.83). The linear correlation between the CTDIvol of the scans and the BMI of patients in the RP-CT case is much lower (r=0.31). In addition to linear correlation, the two trend lines in Figure 1C show that the CTDIvol values are much more dependent on BMI in DG-CT scans than in RP-CT scans, giving an even larger difference between CTDIvol in the low BMI patients scanned with RP-CT.

As reported in Table 3 and illustrated in Figure 1, the scan length for RP-CT and DG-CT are not significantly different (RP-CT: mean/SD 38.7/4.1 cm, range 31.2 to 50.2 cm; DG-CT mean/SD 39.1/3.2 cm, range 30.8 to 46.9 cm; p=0.549). However, the mean DLP value of RP-CT is approximately four times larger than the DLP value of DG-CT; while the average scan length is close to the same (Table 3).

[INSERT FIGURE 1 – HERE]

Table 4 shows the mean CTDIvol, DLP, scan length and patient size parameter at the 3 different NI used in the RP-CT scans and 4 different NI used in the DG-CT scans. As shown in the RP-CT scans, height and weight are higher in the patients where higher NI

were used. In the DG-CT scans, the individual optimization appears to relate to patient size, as the low BMI patients are scanned using a higher NI. In the RP-CT scans the CTDIvol are lower when a NI of 4 is used instead of 2.8. However, using a NI of 11.5 leads to increased CTDIvol as a result of the limitations in maximum mAs, which are higher in these. This can also explain why the CTDIvol values in the RP-CT scans are less dependent on BMI of the patients. Employing very low NI as done in RP-CT scans, has resulted in very high mAs causing high dose to the patients.

In RP-CT scans, CTDIvol values in patients with high BMI (≥25) were 1.1 higher than in patients with low BMI (<25) (39.6 mGy vs 36.4 mGy, respectively). In DG-CT scans, the high BMI group had 2.7 higher CTDIvol values than the low BMI group (15.8 mGy vs 5.8 mGy, respectively). For patients with low BMI, the CTDIvol in the RP-CT scan is 6.3 times higher than the one in the DG-CT scans. For high BMI, the CTDIvol in the RP-CT is 2.5 times higher than the one in the DG-CT scans.

[INSERT TABLE 4 – HERE]

Discussion

The mean CTDIvol with BMI in two groups of patients scanned for CT thorax with DG-CT and RP-CT protocols differ significantly. The CTDIvol and DLP values in RP-CT are almost four times larger than in DG-CT. The CTDIvol in both RP-CT and DG-CT CTDIvol increase with larger BMI values, but the dependence is much stronger in the DG-CT scans than in the RP-CT. This results in more pronounced dose difference in low BMI subgroups, with our data showing an increase to above 6 times larger dose in BMI <25. The variations in CTDIvol with BMI indicate the ability to modulate the mA to the patient size. Furthermore, the DG-CT scans are better able to optimize the mA to the patient size than the RP-CT. Our data also shows an almost identical scan length in both RP-CT and DG-CT. For the DG-CT scans a correlation between NI and CTDIvol is also observed; the higher NI, the lower CTDIvol. This is not the case in the RP-DG scans.

The Norwegian national reference values for thoracic CT in adults are 15 mGy (CTDIvol) and 400 mGy·cm (DLP).[10] These reference values describe the 75% percentiles of the reported dose values at different CT-scanners in Norway.[10] Our results show that the average CTDIvol at the RP-CT is 2.5 times higher than the reference value compared to the reported CT dose data for DG-CT at 60% of the Norwegian reference values. The RP-CT DLP is nearly four times higher than the Norwegian reference value, while the DG-CT dose value is just below. Based on normalised effective dose per DLP for adults in CT of the chest the average effective dose given to the RP-CT patients are 30.0 mSv while the DG-CT scans

gives an effective dose of 7.7 mSv.[11,12] This is an estimation based on a standard patient size and a more accurate need to take e into account patient size and sex.[13] The CTDIvol and DLP are affected by the difference in collimation and pitch. Dose inefficiency at narrow beam collimations will increase when a narrow 10 mm collimation is used in the RP-CT scans compared to 40 mm in the DG-CT scans, but at the same time the z-overscanning effect is smaller in the RP-CT scans due to a lower pitch.[13] DLP is directly dependent of scan length. As seen in Figure 1 and the correlation coefficients, scan length does not depend on BMI and the variation in DLP is due to difference in CTDIvol only.

Our data shows that RP-CT scans are very much less depended on BMI and/or weight. In the study carried out by Goo[14] the effect of body size-adopted protocol is mentioned as a fundamental part of CT dose optimization. In Goo's study,[14] the optimal tube voltage and current should be determined for the adapted radiation dose. This is not being prioritized for RP-CT plans and should be the focus of future research. The choice of very low NI in RP-CT has put some limitations on mAs regulation and has caused a higher CT dose.

The image quality is of high concern in RP-CT as using new radiotherapy techniques demands optimal delineation accuracy. One of the fundamental elements determining CT image quality is image noise.[14] As our results show the RP-CT scans are performed with very low NI, this results in very high mAs values and in turn a high radiation dose to the patients. One way to minimise increased noise is the use of noise-reducing image reconstruction algorithms with a potential to reduce the CT radiation dose.[14] However, the use of noise-reduction filters may decrease image contrast. One solution can be through use of iterative reconstruction as suggested and discussed in earlier studies performed by Mieville et al.[15] and Winklehner et al..[16] There is a direct relationship between CTDIvol and NI.[1] CTDIvol of the DG-CT scans is reduced when higher NI is used, as shown in Table 4. In RP-CT data shown in our study, a considerably smaller CTDIvol reduction is seen for low BMI patients. Because of this BMI independency of the dose in RP-CT scans, the difference between doses in DG-CT and RP-CT is even higher for low BMI patients. A study by Oderdra et al.[17] shows that a patient size and a NI based protocol are both able to reduce the CTDIvol in a coronary angiography examination. The thoracic CT protocol in the DG-CT site of the current study is a combination of adjusted to patient size and NI. The large correlation between CTDIvol patients size is observed to lead to lower CT dose in the DG-CT scans for patients with low BMI. This is also confirmed by our data as described earlier. We have already shown that there is a 10% difference in CTDIvol between patients with low BMI and high BMI in RP-CT. This difference is 170% higher in CTDIvol for patients with low and high BMI indicating a higher BMI CT dose dependence in DG-CT. In the case of the RP-CT, the

CTDIvol are lower when a NI of 4 is used instead of 2.8. However, when a NI of 11.5 is used, the dose increases. The increased dose here is the result of limitations in maximum mAs which are higher in the scans performed with NI = 11.5. This can also explain why the CTDIvol values in the RP-CT scans are less dependent on the BMI of the patients. Although NI is used to regulate the mAs providing a constant noise in images, the NI may be set so low that it seems as the limitations in mAs determine the final tube current and not the NI. Therefore, the noise in the images is not as low as NI indicates.

The high observed CTDIvol values in RP-CT scans indicates that the employed RP-CT protocols are not optimized according to the patient's size.[18] In a study carried out by Larson,[19] it is pointed out that the principle of ALARA calls for optimal CT radiation dose, not simply dose reduction. The optimal radiation dose will depend on patient size and a large correlation between patient size and absorbed radiation dose, also achievable in a thoracic CT examination.[20] We cannot see that this has been initiated in the RP-CT scans.

We accept that there are some limitations with our work. The patient parameters in the two CT groups in our current study are not fully matched, especially for the height ($p=0.009$). This mismatch may have some impact on our results. However, in a study carried out by Jan Menke,[20] they concluded that body weight alone enables suitable estimates for individual CT dose adaptation. Furthermore, Jan Menke[20] claims that the use of weight and height as independent variables is only slightly more exact than using only weight. Therefore, we consider our analysis to be reasonable. The impact of the detailed CT parameters for RP- and DG-CT protocols on image quality are not investigated in this study. The main goal of our study was to explore the CT-dose differences between the two CT-protocols. The CT parameters' effect on the image quality are under investigation in another ongoing study and will be presented in near future.

Conclusion

Our study found that radiation doses given to patients in thoracic RP-CT scans are four times higher, on average, than the doses given in DG-CT scans. The differences are largest between patients with low BMI. The lack of using patient size modified CT protocols in RT planning is the main reason for higher patient dose in RP-CT thorax scans. It is important to emphasize the use of patient size modified CT protocols even when high quality images are required. More research to understand and evaluate image quality in RP-CT scans should be a priority.

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KEYWORDS:

Computed tomography; Radiotherapy planning; Thorax; Absorbed dose; CTDIvol; DLP

LEGENDS FOR FIGURE

Figure 1: CTDIvol as function of a) Height, b) Weight and c) BMI in CT-thorax and d) DLP as function of BMI from radiation treatment RP-CT scans (orange) and DG-CT examinations (blue)

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