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Original Research Article

Palliative radiotherapy of soft tissue tumoral masses based on diagnostic instead of planning computed tomography scans

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ABSTRACT

Background and purpose: Radiotherapy (RT) treatment planning is based on a planning computed tomography scan (pCT), while the decision to treat is often already established on a diagnostic CT scan (dCT). The objective of this study was to evaluate the usage of dCT for palliative radiation planning of soft tissue tumoral masses (STTMs), removing the need for a pCT scan and associated attendances.

Materials and methods: RT planning was performed retrospectively to 38 STTMs of 7 anatomical sites using volumetric modulated arc therapy techniques in dCT and transferred to pCT. The dose of clinical target volumes (CTV), D(95 %,50 %), were compared between the plans. The patient setup was assessed in cone-beam CT scans.

Results: The differences of D(95 %,50 %) between dCT and pCT plans were the lowest in the STTMs of the thoracic cage (0.9 %,0.9 %), STTMs in the inguinal area (0.8 %,1.3 %) and in mediastinal masses associated with superior vena cava syndrome (SVCS) (1.1 %,1.3 %), while the differences increased for other sites. The patient setup was acceptable for 88 % of mediastinal masses associated with SVCS and $\leq$ 60 % of cases in other sites comparing pCT and CBCT images with a strict margin of 6 mm, but all cases fitted to increased 2 cm margin.

Conclusions: This study demonstrated the possibility of using dCT scans for palliative RT planning of STTMs for mediastinal masses associated with SVCS and for STTMs in the thoracic cage and in the inguinal area, indicating the potential feasibility of this procedure for clinical use.

1. Introduction

Radiotherapy (RT) is one of the most effective ways of providing palliation of cancer symptoms. The intention of RT is palliative in 40–70 % of all RT courses [1]. The main objective of palliation is at its simplest to increase patients quality of life. RT treatment pathway should be kept most straightforward to ensure patient's comfort, and this implies to the entire pathway including simulation and RT techniques [1].

Soft tissue tumoral masses (STTMs) may cause intense pain due to the mass pressing on bones and nerves. STTMs may cause bleeding, ulceration of the skin and organ obstruction, including critical situations of airway obstruction and an acute emergency of superior vena cava syndrome (SVCS).

The objective of the study was to evaluate if diagnostic computed tomography (dCT), instead of a planning CT (pCT), could be used in the palliative RT treatment of STTMs to fasten the RT pathway. This idea is justified as dCT images are generally available when deciding on a patient's applicability for RT.

The past few years this topic has attracted interest [2–9], as fast and efficient workflows are increasingly important with cancer patients surviving longer with their disease and thus palliative interventions during the course of their illness required more excessively.

Earlier in 2023 we carried out a study to investigate if we can treat bone metastases (BMs) without a pCT based on a dCT [10]. We found out that it is possible to treat BMs accurately in some specific locations (e.g. thoracic and lumbar vertebrae and pelvic area), whereas it was challenging in other locations (e.g. cervical vertebrae, costae).

In this study we tried to find out if omitting pCT from the RT pathway was equally feasible for STTMs, especially considering as the group of STTMs is more heterogenic. The definition of STTMs being arbitrary, in this study we included soft tumor metastases adhering to pelvic bones and thoracic cage, mediastinal masses (more specifically those causing SVCS), tumors of the urinary bladder, subcutaneous metastases and finally lymph node metastases in two areas known to contain lymph nodes abundantly and rather superficially (clavicular fossa, inguinal area).

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Our particular goal was to evaluate if STTMs could be treated with equal accuracy dosimetrically without a pCT. We also investigated which STTMs would be able to be treated this way. The objective of the study was to investigate the potential of using dCTs in palliative RT of STTMs.

2. Materials and methods

2.1. Patient selection

This retrospective study was approved by the ethical committee of the Comprehensive Cancer Center of the Helsinki University Hospital. A total of 38 STTMs were treated with palliative RT. The average age of the patients was 77 years (ranging from 55-89 years).

We included soft tumor metastases adhering to thoracic cage (N = 5) and pelvic bones (N = 5). Subcutaneous metastases (N = 5) and lymph node metastases in two areas known to contain lymph nodes abundantly (inguinal area (N = 5), clavicular fossa (N = 5)) were included as well as soft tissue mediastinal masses related to superior vena cava syndrome (SVCS) (N = 8) and urinary bladder (N = 5). We did not include any central nervous system tumors.

2.2. Data analysis

Analyzed palliative STTM patients were collected from oncologists' patient lists starting from January 2020, and at least five targets per site were included. The inclusion criteria constituted of a documentation of STTM with a diagnosis of cancer and RT treatment plan with palliative intent, an actual RT treatment planned to pCT images, a dCT available with a sufficient field of view (FOV) with a maximum of 30 days prior to pCT, and a cone beam computed tomography (CBCT) imaging for patient positioning before treatment. We excluded patients with implants in the treatment area to avoid calculation errors produced by image artefacts.

Data of dCT and pCT imaging, RT planning and the actual RT treatment CBCT, was used in the analyses. Imaging parameters of dCT images varied as images were acquired from multiple manufacturers' CT scanners, these changes to treatment planning were previously investigated [10].

dCT and pCT images were fused using rigid translation and rotation movements employing treatment planning software (Eclipse, 16.1.10, Varian Medical System Inc., Palo Alto, USA). Clinical target volume (CTV) was contoured to both images separately. To avoid dose changes in calculations caused by couch absorption, straight couch was contoured to both pCT and dCT images despite the change in patient positioning due to a curved couch in dCT images [11].

Instead of conventional palliative RT techniques, volumetric modulated arc therapy (VMAT) technique was used in RT planning (Acuros External Beam, version 16.1.0, Varian Medical System Inc., Palo Alto, USA) to spare healthy tissues and achieve more conformal dose distributions with better target volume coverage [12]. ICRU 95 criteria [13] were used to normalize the treatment dose to cover 50 % of planning target volume (PTV). The treatment plan was made to dCT images with 6 mm margins to CTV for creating PTV and transferred with fixed monitor units to fused pCT images.

Investigated values of organs at risk (OAR) were mean dose differences of ipsilateral and contralateral lung, heart and maximum dose difference of spinal cord. OARs were contoured and these values were calculated if OARs were closer than 5 cm from the CTV. The mean values were investigated if the whole OARs were imaged in both dCT and pCT images.

Dose volume histogram (DVH) of treatment plans made for dCT and fused to pCT images were compared, and the dose differences of CTV in 50 %, (D50%), 95 %, (D95%), and in OARs were calculated.

2.3. Treatment

Dose fractionation of treated patients varied from 1 × 8 Gy (5 patients) to 5 × 4 Gy (22 patients), 5 × 5 Gy (1 patient) and 10 × 3 Gy (10 patients). A CBCT image was taken for each fraction before treatment and matched to dCT images with translation directions as in treatment protocol with Halcyon 2.0 (Varian Medical System Inc., Palo Alto, USA). The match was considered acceptable if the target volume in CBCT image fitted to the PTV of the dCT. If the target failed to fit in any of the fractions, the margin from CTV to PTV was increased and matched again until the target fit. Depending on how well the target matched to CBCT images, an arbitrary margin (from 6 mm to 20 mm) was added to CTV. The margins (CTV to PTV) were consistently set in all three directions.

2.4. Statistics

Statistical analyses were performed using SPSS 25.0 (IBM SPSS Statistics 25 software, Armonk, NY, IBM Corporation). Wilcoxon signed rank test was used to test significances, and the significant value adopted was 0.05.

3. Results

The median image acquisition delay between dCT scan and pCT scan ranged from 0 to 30 days and varied by the STTM's site (Table 1). When using the strictest margin (6 mm) the match of the target in dCT image and CBCT image was found to be 88 % acceptable for mediastinal mass causing SCVS, 60 % for subcutaneous metastases, pelvic bone and thoracic cage, only 40 % for lymph nodes in clavicular fossa, urinary bladder and lymph nodes in the inguinal area. However, all CTVs fitted into 2 cm margin (Table 1).

Fig. 1 shows the results of the differences in D50% and D95% for CTV between dCT and pCT plans. The median dose difference of thoracic cage, inguinal and mediastinal STTMs remained moderate. For thoracic cage differences in D50% was 0.9 % (range 0.5–2.6 %) [p = 0.7] and in D95% was 0.9 % (0.3–3.5 %) [p = 0.3], for lymph node metastases in the inguinal area 0.8 % (0.2–2.4 %) [p = 0.5] and 1.3 % (0.4–4.3 %) [p = 0.1], and for mediastinal masses causing SCVS 1.1 % (0.5–1.9 %) [p = 0.3] and 1.3 % (0.3–8.2 %) [p = 0.3], respectively. None of these differences were significant.

Dose differences for the rest of the STTMs were higher with wider

Table 1
Anatomical sites, quantity of analyzed patients (n), median value of days between dCT and pCT image acquisition, dose volume histogram (DVH) criteria of treatment plan for clinical target volumes (CTV) and matching of CTV with added margin in dCT images and treated CBCT images.

CTV site	n	Median days between dCT and pCT (and range)	Acceptable matching of CTV to margin in CBCT images (%)					
			6 mm	8 mm	10 mm	12 mm	14 mm	20 mm
Thoracic cage	5	26 (18–28)	60	60	80	80	100	100
Pelvic bone	5	23 (14–27)	60	60	80	80	80	100
Subcutaneous	5	18 (13–24)	60	100	100	100	100	100
Lymph node inguinal area	5	27 (18–28)	40	60	80	80	100	100
Lymph node clavicular fossa	5	25 (4–30)	40	60	60	80	80	100
Mediastinal mass SVCS	8	3 (1–15)	88	88	88	88	88	100
Bladder	5	15 (0–21)	40	100	100	100	100	100
Total	**38**	**19 (0–30)**						

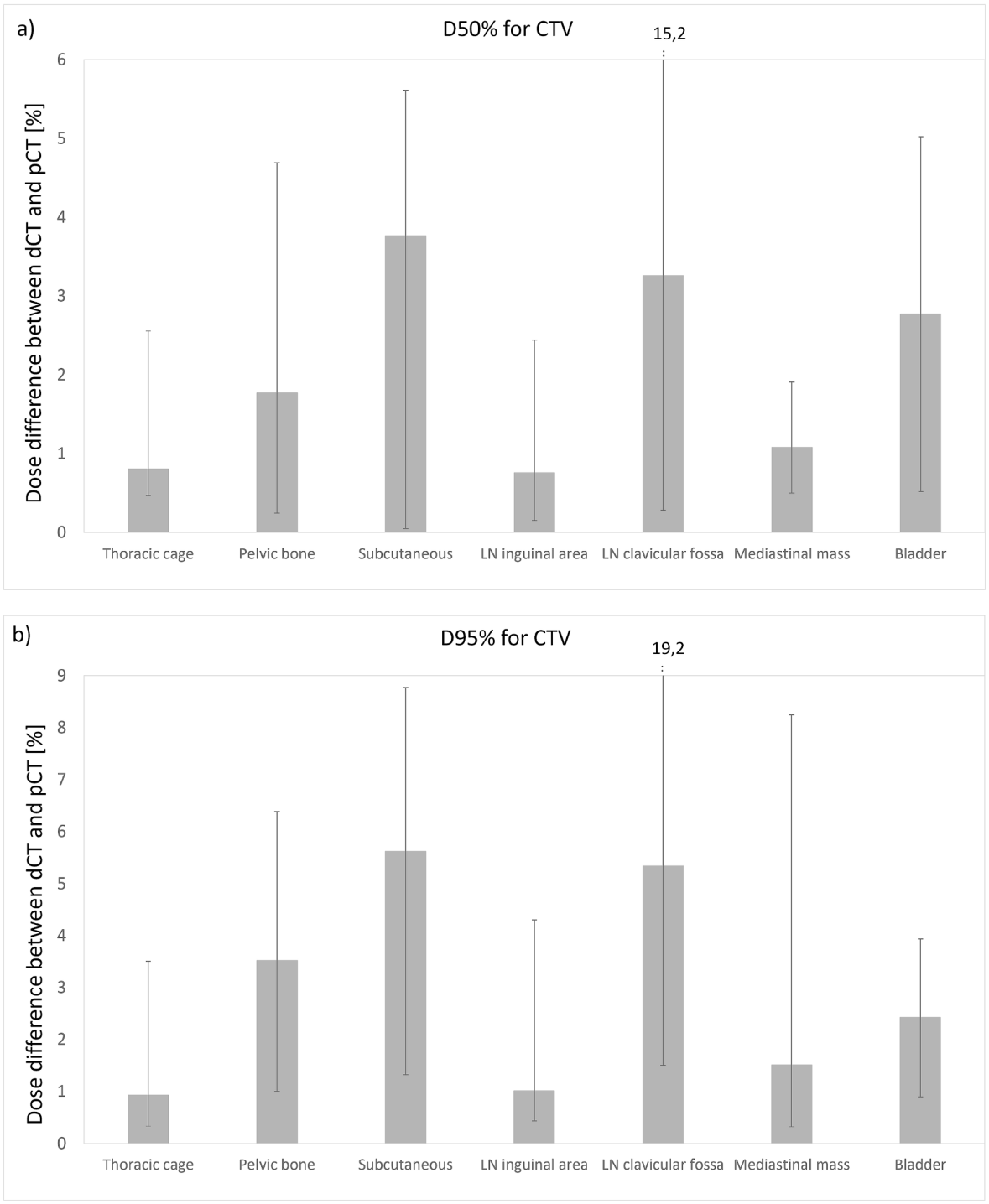

Fig. 1. Median dose difference with ranges between plans calculated for diagnostic CT (dCT) images and planning CT (pCT) images shown as *a)* 50% and *b)* 95% of CTV.

ranges. For STTMs related to the pelvic bone difference in D50% was still relatively modest, 1.8 % (range 0.2–4.7 %) [p = 0.08], however D95% difference raised significantly to 5.5 % (1.0–6.4 %) [p = 0.04].

The differences were even more remarkable, yet with no statistical significance, for subcutaneous metastases (D50%=3.3 % (0.1–5.6 %) [p = 0.5], D95%=3.5 % (1.3–8.8 %) [p = 0.3]) and for lymph node metastases in the clavicular fossa (D50%=3.3 % (0.3–15.2 %) [p = 0.08], D95%=4.6 % (1.5–19.2 %) [p = 0.7]), and for urinary bladder (D50%= 2.9 % (0.5–5.0 %) [p = 0.2], D95%=2.5 % (0.9–3.9 %) [p = 0.2]).

Fig. 2 shows the differences in OAR doses between pCT and dCT plans for lymph node metastases in the clavicular fossa, STTMs related to thoracic cage and mediastinal masses causing SVCS. Small and non-significant differences were observed in lymph nodes in the clavicular fossa where difference for the ipsilateral lung was 0.4 % [p = 0.1]. In the lymph nodes of the thoracic cage, heart showed high 11.7 % [p = 0.3] dose difference while the difference was only 0.3 % [p = 0.2] for spinal cord, 1.3 % [p = 0.7] for ipsilateral and 0.1 % [p = 0.3] for contralateral lung.

The significant difference in OAR doses was observed in mediastinal mass (associated with SVCS) for spinal cord 12.4 % [p = 0.01]. Also,

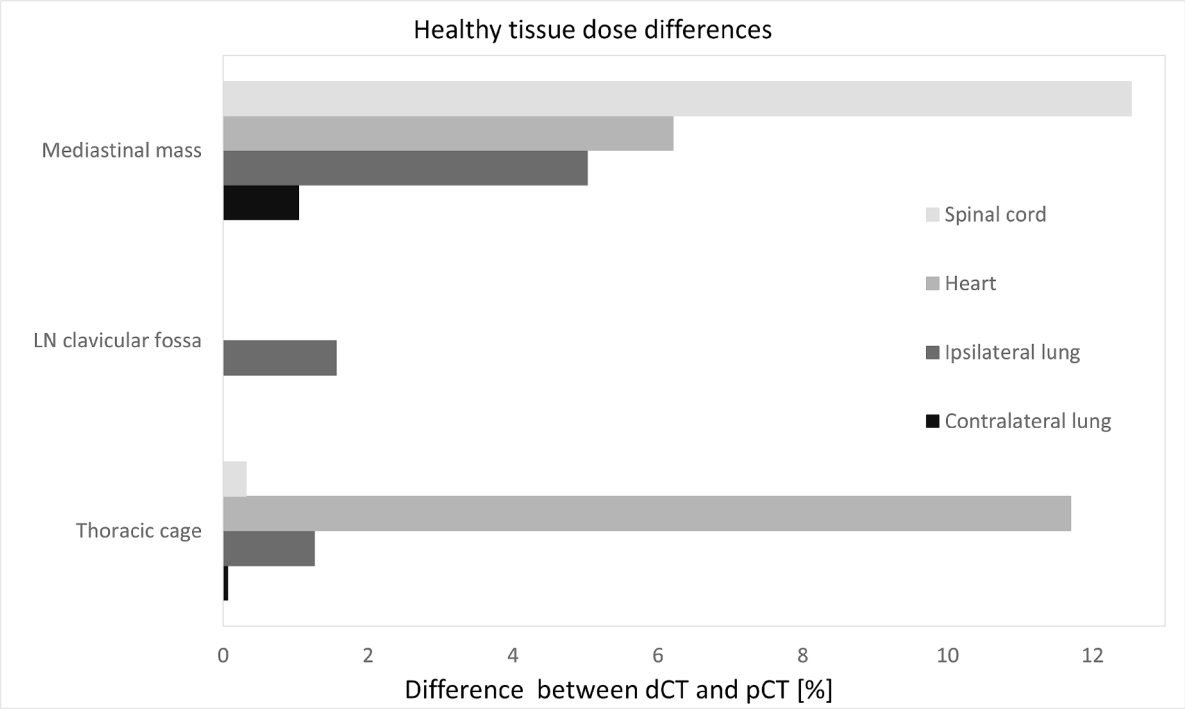

Fig. 2. Median dose difference between plans calculated for diagnostic CT (dCT) images and planning CT (pCT) images shown by mean volume of healthy tissue.

differences in heart 3.4 % [p = 0.03] and contralateral lung 0.6 % [p = 0.01] were still significant, but in ipsilateral lung 2.7 % [p = 0.07] the difference was not significant.

Dose differences D50% and D95% between pCT and dCT plans as a function of time delay are shown in Fig. 3 with trendlines and boxplot graphs. Average time delay between dCT and pCT was 19 days and the dose difference varied from 0.05 % to 15.2 % for D50%, and 0.3 % to 19.2 % for D95%.

4. Discussion

Our study indicated that STTMs located in the mediastinum leading to SVCS, and also those located in the thoracic cage and inguinal area, could be safely and accurately treated, with some reservation and carefully considered planning techniques, using volumetric modulated arc therapy (VMAT) planning based only on a dCT image.

The study included a limited sample of several potentially clinically relevant sites, yet the variety of STTMs is in general large and heterogenic. Obtaining systematic information on RT given to STTMs is therefore challenging. Nevertheless, deriving information from our investigation we could conclude that well defined subgroups of STTMs could be reliably treated based on a dCT scan. The study design was informed by bucket trials, where choosing a variety of different sites to test, which one – if any – of the locations could be treated omitting a pCT potentially in the future. Also, to note, this study was a preliminary study and further research with adequate statistical sample size is required.

As discussed, this item of omitting pCT from the RT planning has drawn a lot of interest during the last few years, studies focusing mainly on time saved [3], but also possibilities from a dosimetric perspective [2,5,9] or both [4,6–8]. Currently, an ongoing clinical trial is comparing the workflow of palliative RT based on dCT to standard of care, the primary outcome measure being time spent at the cancer center [14]. In that clinical trial, soft tissue, and also bone and lung malignancies are included, and the treatment will be given with an optical surface guidance-equipment and thus differs from our study, as our study relies on CBCT imaging.

Previous studies most similar to ours, comparing CBCT images and dCT images in the actual RT treatment, attempted to obtain similar patient position as during diagnostic imaging but were unable to correct for anatomical changes such as tumor growth. We did not try to replicate the original position, as we wanted to keep the treatment path most simple and reproducible, but we shared the challenge of potential tumor growth to deal with. Therefore we calculated plans with a varying increasing margin (from 6 mm to 2 cm, as in Table 1). In a previous study by Ho et al. [5], where a small number of soft tissue masses was also included, the daily median growth of the masses was reported to be 1.8 %. This is in line with our observations. In our retrospective study the dCT images were 0–30 days old (median 19 days), and the relatively long time delay caused the mismatches in the target fitting, as seen in Fig. 3. However, the median time lapse between dCT and pCT for mediastinal masses was only 3 days.

The fact of tumor growth was taken into consideration in a study using an online adaptive radiotherapy, however one of the limitations was the long calculation time for adaptive VMAT in patients with pain [6]. In a similar fashion, the potential increase in tumor size could be considered by magnetic resonance (MR) guided linear accelerator, but MR-guided linear accelerator cannot be consistently used in a palliative setting due to the lack of resources and lengthy treatment time. As this increase in treatment time is not acceptable in palliative circumstances, the time spent in treatment is shorter than in a standard linear accelerator by using novel ring style gantries such as in Halcyon, as used in our study [15].

The time difference between pCT and dCT is an artefact of the method. If no pCT was taken, this difference would not exist, and as such parts of the results (time delay issues, last paragraph) and Fig. 3 are only thought-provoking, but not a result to the study question, and rather a confounder of the study. This situation would not exist in a real-life clinical situation.

Despite the fact, that according to our study, all STTM sites could not be treated based on solely a dCT, we encountered a few very promising locations for clinical use. Especially mediastinal masses causing SVCS are a most excellent example of a situation when using dCTs is useful, as the treatment is usually planned to begin urgently. We had concerns

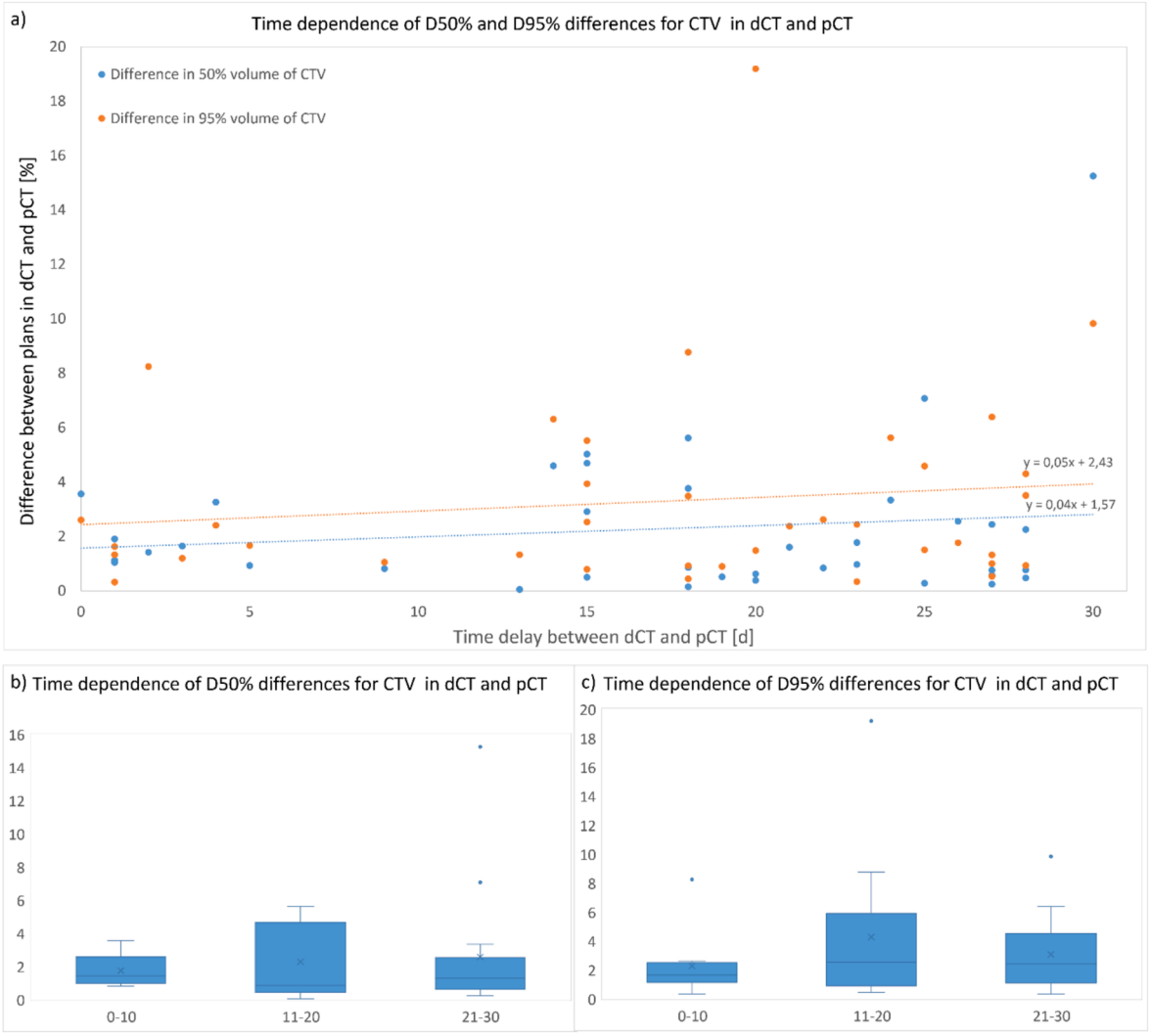

Fig. 3. Time dependence of median dose difference between plans calculated for diagnostic CT (dCT) images and planning CT (pCT) images shown as *a)* 50% and 95% of CTV with linear trendlines, *b)* a boxplot of 50% of CTV and *c)* a boxplot of 95% of CTV.

about the ability to fuse dCT and pCT as they differ with their means of free-breathing and breath-hold, and often differ with arms up (pCT) and arms down (dCT), yet this did not cause problems. However, in clinical use, the planning technique could be even more improved to avoid inaccuracy or the high OAR dose differences. In a palliative setting the treatment doses are in any case very moderate and not clinically relevant to OARs, except in re-irradiation cases that were not included.

In this study there was one outlier among the mediastinal masses with the patient scanned with arms down in the dCT and with arms up in the pCT that generated the match of the target in dCT and CBCT to decrease to 88 %, if this patient had not been included, the accuracy would have been 100 % with only 6 mm margin to CTV. In a clinical situation, however, the treatment would be planned in the available image (dCT with arms down), and this would not be a challenge.

STTMs in the thoracic cage and inguinal STTMs also showed good accuracy in dose difference studies of CTVs. However, 60 % of the thoracic cage and only 40 % of the inguinal area planning targets fitted in the dCTs' strict 6 mm margin of CTV. Both of these STTMs had long delay between dCT and pCT, which may have caused anatomical changes and tumor growth and therefore problems in matching. For thoracic cage high OAR dose difference in heart may be due to variation in breathing.

A single fraction RT to urinary bladder, when a malignancy of the bladder causes severe and continuous bleeding, is a quite common indication of palliative RT. We hoped omitting pCT would have eased the RT pathway in this case, however the diagnostic CT is usually taken with a full bladder, whereas the pCT would be taken with an empty bladder. This may have caused bladder's high dose differences in CTVs. However, with a margin of only 8 mm the acceptance of CTV with added margin in dCT and treated CBCT images was 100 % (Table 1).

It was anticipated, and then confirmed, in our small but representative sample of STTMs that many of the sites differ too much in the positions of the patient in dCT and pCT. This does not, however, represent completely the actual clinical situation, as the positioning of the patient could be further modified based on the pCT in most cases. This was not studied further in our investigation. Also, occasionally patients are referred to palliative RT with no prior dCT, but with a different type of imaging (MR or X-ray) or even with no previous imaging if only based on symptoms.

When implementing in use, the important question remains how many patients can be treated this way, as this was not assessed in our study. In previous studies with similar patient inclusion criteria, even if study settings were not equal, the proportions of patients meeting the eligibility criteria were approximately 1/3 to 2/3 of the potential patients [3,6].

Using intravenous contrast enhancement in the dCT did not affect the dosimetric calculations, and on the contrary, its presence may be useful to the clinician contouring the volumes [16,17].

The biggest limitation of the study was its small size and retrospective approach. In respect of the small size of the study, the diversity of the tumor sites led to small subgroups that caused difficulties to distinguish any potential importance. Also, time delay was an important factor affecting the treatment procedure and the results (as seen in Fig. 3). However, we assume that most of the fact that mediastinal masses related to SVCS were well matched in this retrospective study, was the urgency of the clinical situation and thus the median time in between the dCT and pCT was only three days. Expecting a substantial daily growth in the volume of the STTMs, the number of days is relevant. Also, in respect to daily growth, different histologies may lead to varying patterns of growth, but the histology of the tumors was not recorded in our study.

When the RT treatment planning based on dCT will be taken in to be practiced clinically, particular consideration on how the clinical flow will benefit from this, will be made. To conclude, the potential of planning palliative RT of STTMs using only dCT images in thoracic cage, mediastinal mass and inguinal region was demonstrated by this study.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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