



A Method to Correct Cone Beam CT (CBCT) Images Using Planning CT for Derivation of Plan of the Day in STEREOTACTIC Body Radiotherapy (SBRT)

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Abstract: A robust method for voxel by voxel enhancement of Cone-beam CT (CBCT) images using a priori knowledge from the planning Computed Tomography (pCT) scan has been developed and used to evaluate the dosimetric accuracy of pCT based CBCT correction method for SBRT dose verification in lung metastasis. This is a retrospective study under which SBRT is carried out in 10 patients presented with lung metastasis. pCT images of patients were acquired and treatment planning was carried out on Varian Eclipse (V11) for 30 Gy in 5 fractions. Daily imaging using CBCT has been done for each patient with an On-Board Imaging system. CBCT is corrected using Matlab function considering CT as fixed and CBCT as moving, the images are registered. Planning target volume (PTV), lung, heart and spine were recontoured on uncorrected CBCT and corrected CBCT separately and the calculated plan on CT is recalculated on both the CBCTs. The dose distribution between the pCT and both the CBCT images were compared. A paired sample test was performed to test the variations. The distribution of pixel intensity of corrected CBCT is closer to the pCT than the uncorrected CBCT. The maximum percentage difference between the corrected CBCT and pCT is 1% in PTV evaluation, which is 3.5% between uncorrected CBCT and pCT. The method increases the accuracy of CBCT density values and enabling the use of CBCT images for dose calculation in radiotherapy.

Keywords: CBCT Image Correction, SBRT, MATLAB, Lung

1. Introduction

In the age of progressive external beam radiation therapy, image guidance has become important to reduce the random as well as systematic errors in the patient setups. CBCT is a major component in the treatment planning process of image-guided radiation therapy (IGRT) [1]. CBCT images for each treatment fraction can provide sufficient anatomical information for correcting setup errors and can also be used for adaptive radiotherapy where the treatment plan is

modified based on regular imaging throughout the treatment course. Numbers of studies have investigated the utilization of CBCT for dose calculation [2, 3] as CBCT images are easy to acquire before treatment whereas repeat CT during the course of radiotherapy is difficult for patients. Therefore, the importance of CBCT is not only limited to image guidance it can be utilized for treatment planning and dose verification for patients during their course of radiotherapy. CBCT images are composed of voxels (or volume elements) that are assigned a specific CBCT number per tissue attenuation (in Hounsfield Units or HU). CBCT thorax

images are subject to artifacts (or apparent flaws in CT numbers) such as cupping (dark artificially hypo-dense image regions) and streaking (lines of hyper/hypo-dense image regions), which are due to the broad-beam scanning geometry [3], and patient respiration during slow scan time. Thus, CBCT number data within patient lung tissue can be misleading, and electron density information derived from CBCT numbers used directly for dose calculations can be inaccurate. Also, these artifacts create challenges in accurately identifying tissue abnormalities and reduce their usefulness for clinical applications [4, 5]. The shading in CBCT images with larger motion artifacts (e.g. respiratory motions) is more challenging to correct and it requires modern approaches to avoid reconstruction errors by supplementing either missing information or incorrect information in the projection images. We utilized the planning CT information and projection scatter correction method to correct the CBCT images. The planning CT-based correction and projection scatter correction require complex image processing algorithm. In simple words, a correction algorithm is constructed to correct the CBCT image scatter by considering planning CT as a reference.

2. Objective

The purpose of this work is to assess the magnitude of errors in CBCT numbers (HU), and determine the resultant effects on derived tissue density and computed dose accuracy for stereotactic body radiation therapy (SBRT) of lung cancer. The work performed and presented here explores the efficacy of using planning Computed Tomography (CT) images as prior knowledge to improve quantitative cone-beam CT (CBCT) image quality in radiation therapy. A planning CT based correction was performed to reduce the scatter effect and complete the CBCT with full anatomy using Matlab R2017b (The MathWorks Inc., Natick, MA) image processing toolbox.

A robust method for voxel by voxel enhancement of Cone beam CT (CBCT) images using a priori knowledge from the planning Computed Tomography (pCT) scan has been developed and used to evaluate the dosimetric accuracy of pCT based CBCT correction method for SBRT dose verification in lung metastasis.

3. Materials and Method

This is a retrospective study under which SBRT is carried out in 10 patients presented with lung mets. Planning CT (pCT) with 4DCTscan of all patients were acquired and treatment planning was carried out on Eclipse (Aria 11) for 30 Gy in 5 fractions on Planning target volume (PTV) which was generated based on 4DCT scan. Daily imaging using CBCT has been done for each patient with a Varian On-Board Imaging system which means 5 CBCTs for each patient and altogether, a total of 50 CBCT images to be corrected. CBCT is corrected using the following method.

1. CT and CBCT images are registered rigidly using

Matlab function considering CT as fixed and CBCT as moving [Figure 1].

2. The registered CBCT is segmented for bone, soft tissue, and lung and masked for pixels greater than 0.6.
3. The segmented images are filtered to reduce the high spatial frequency information.
4. The enhanced CBCT images are generated for bone, soft tissue and lung by merging the filtered image to its corresponding CBCT image.
5. Each segmented region is hence used in adjusting the intensity of the pixels in CBCT to obtain corrected CBCT.

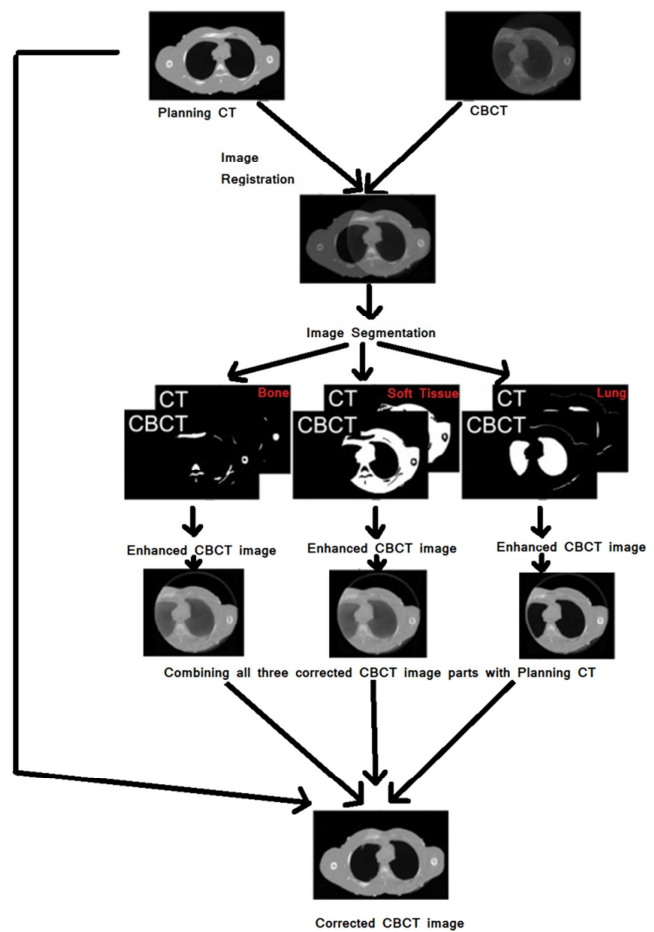


Figure 1. Detailed diagram with description of the CBCT correction algorithm.

The small field of view (FOV) of corrected CBCT is completed using the pCT to avoid the uncertainty in dose calculation due to calculation volume. This corrected CBCT for each patient is imported in the Eclipse treatment planning system (TPS). pCT is registered with uncorrected and corrected CBCTs with the help of rigid registration and areas of similar tissue type were outlined on the pCT and both the CBCTs. The mean and standard deviation of the Hounsfield Unit (HU values) were compared [6]. Planning target volume (PTV) and Organs at risks (OARs) like lung, heart, and spine were copied from pCT and adjusted manually (if required) on uncorrected CBCT and corrected

CBCT separately. The calculated plan using Analytical Anisotropic Algorithm (AAA) on pCT is recalculated on both the CBCTs using HU to RED (Relative Electron Density) calibration curve which was generated for CBCT and already fed in the TPS for dose calculations on CBCT

images [7]. The dose distribution between the pCT and both the CBCT images were compared. A single factor ANOVA test is carried out to determine if the difference in CT number in all three datasets are statistically significant for bone, soft tissue, and lung (Table 1).

Table 1. Mean value of CT numbers in three different regions for pCT, uncorrected CBCT and corrected CBCT.

| ROI | Mean CT number | | |
|-------------|----------------|------------------|----------------|
| | pCT | Uncorrected CBCT | Corrected CBCT |
| Bone | 318 | 431 | 300 |
| Soft tissue | -98 | -132 | -105 |
| Lung | -883 | -991 | -908 |

4. Results

The bone, soft tissue, and lung uncorrected HU values were 35%, 34% and 12% higher respectively than similar regions in pCT. CBCT image correction significantly ($p < 0.05$) improved the agreement for bone, soft tissue, and lung by 6%, 7% and 3% respectively (Table 1).

The whole dosimetric data were obtained from all the corrected CBCT images for evaluation. Table 2 shows the comparison of dose to the PTV, combined lung and heart for

the CT and both CBCTs. The reference prescription dose was set such that 99% of the PTV received at least 30 Gy (i.e. D99). The distribution of pixel intensity of corrected CBCT is closer to the pCT than the uncorrected CBCT. The maximum percentage difference between the corrected CBCT and pCT is 1% in PTV evaluation, which is 3.5% between uncorrected CBCT and pCT. Therefore, accurate determination of lung density, especially for very low lung density is essential, but difficult to achieve using the CBCT data. Plans comparison amongst pCT, uncorrected CBCT, and corrected CBCT has been clearly explained from Figure 2.

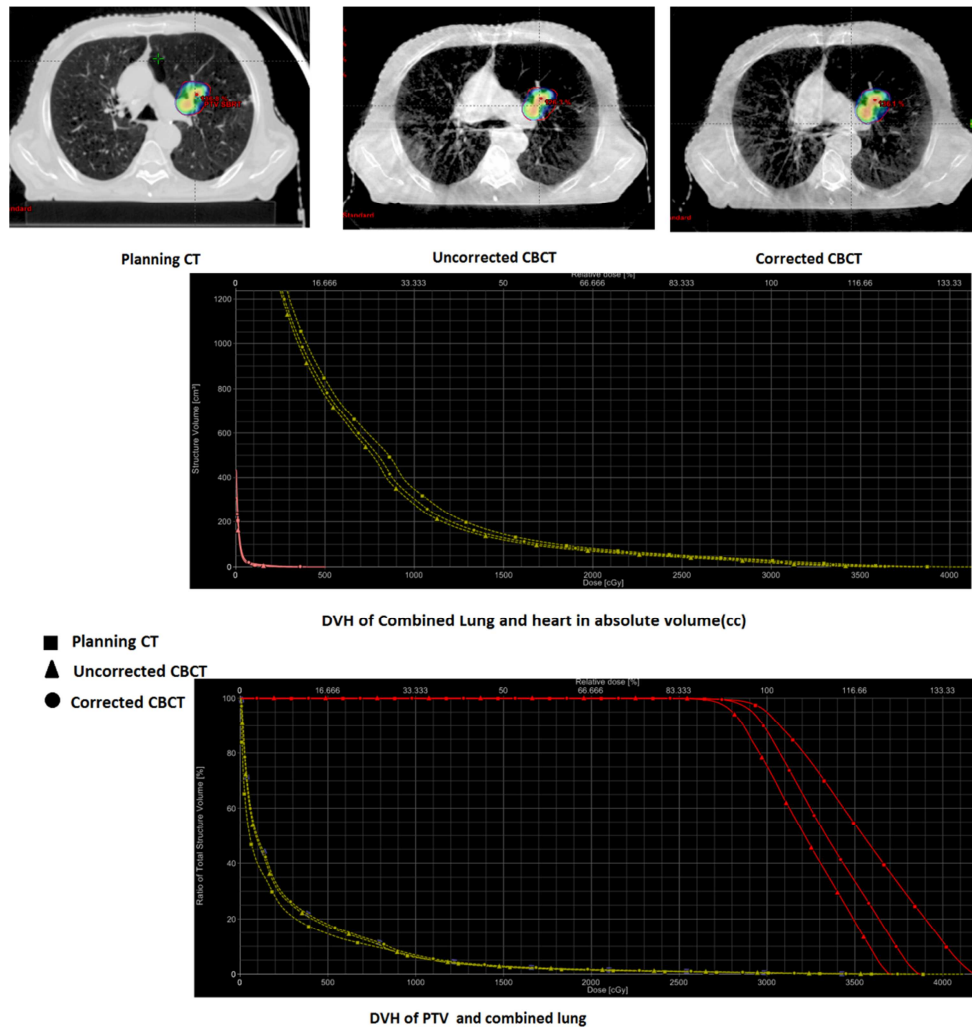


Figure 2. Plan evaluation on pCT, uncorrected CBCT and corrected CBCT datasets including DVH analysis.

For the normal tissue doses, the dose calculated on uncorrected CBCT data set was lower than the pCT whereas the corrected CBCT dataset showed almost similar doses as the pCT. (Table 2).

Table 2. Dose delivery obtained from uncorrected CBCT and corrected CBCT in reference to the planning CT. Doses are in Gy.

| Target and OARs | Dose indices | Planning CT (pCT) (Gy) | Uncorrected CBCT (Gy) | Corrected CBCT (Gy) |
|-----------------|----------------------|------------------------|-----------------------|---------------------|
| PTV evaluation | D99 | 29.0±1.3 | 27.8±2.6 | 28.7±2.1 |
| | D50 | 35.6±2.8 | 33.6±3.5 | 35.2±3.9 |
| | Dmax | 40.1±6.3 | 37.0±4.6 | 39.7±8.1 |
| Combined Lung | Dose to Min critical | 1000 cc | 4.5±7.8 | 4.7±14.8 |
| | volume below | 1500 cc | 10.2±11.6 | 9.7±20 |
| Heart | Dmax | 15.4±25.8 | 14.8±22.1 | 15.6±30.3 |

5. Discussion

In IGRT, a planning CT is always available for treatment planning purposes. Using the planning CT to help scatter estimation has its advantage as the planning CT image has superior image quality to the CBCT, ensuring more accurate algorithm modeling and therefore improved calculation accuracy. The second advantage of using a planning CT is to avoid calculation error caused by the problem of image truncation in CBCT due to relatively small FOV. The proposed method of correction with prior knowledge of CT improves the quality of CBCT image, which further enhances the appearance of structural and tissue details in the CBCT image [8]. The shading in CBCT images with larger motion artifacts (e.g. respiratory motions) is more challenging to correct than the shading in CBCT images containing more high contrast bony structures [9]. Marchant et al. described a post-processing algorithm that uses a corresponding radiotherapy planning CT image to derive a low spatial frequency greyscale shading map that is used to correct CBCT images [8, 10]. We here proposed a similar method for shading correction which was evaluated and validated through patient studies, the algorithm used in our study was also tested and validated extensively on 50 clinical images of SBRT patients [11]. The dosimetric data obtained from corrected CBCT, confirms the efficacy of the proposed correction method and its utilization for adaptive treatment planning in lung radiotherapy [12]. In the first place, the proposed strategy significantly improves the bone, soft tissue and lung contrast of CBCT, which empowers clinicians to settle on better clinical choices [13]. Second, the increased HU accuracy can enormously improve the precision of dose calculation using CBCT image sets. With all considerations, the improved image quality utilizing the proposed scatter correction method ought to be alluring in clinical applications [14, 15].

For lung cancer patients where there is a probability of tumour movement in between fractions, it is important to track the tumor motion with respect to patient anatomy and its dosimetric effects on the daily SBRT treatment. The plan of the day might be done using repeat CT imaging, which is a cumbersome and time consuming process. Dose calculation and systemetic dose tracking for all patients is more readily

achievable using CBCT images by registering daily CBCT image with the initial CT.

Furthermore, the proposed methodology allows retrospective analysis of the dose delivered to patients who have already completed treatment since the CBCT images were reconstructed from the existing clinical projection images.

This study confirmed that the image quality of chest CBCT images can be improved to allow highly accurate CBCT based dose calculations. Dose of the day calculation or plan of the day studies are now well set in the clinical environment. CBCT based dose calculations are getting accustomed in the clinics and facilitate accurate prediction of geometric and dosimetric consequences within the planned course of treatment.

6. Conclusion

An automated method has been developed for improving the quality of CBCT images which enhances its utility in dose calculation for adaptive treatment planning. The results confirm that the corrected CBCT images are of better quality than the unprocessed versions, and that the correction algorithm is robust and effective. The method increases the accuracy of CBCT density values, allowing soft tissue details to be more easily visualized and enabling the use of CBCT images for dose calculation in radiotherapy. Comprehensive scatter corrected CBCT images allow highly accurate dose calculation as compared to uncorrected CBCT images for lung cancer patients, following the standard CT-based workflow in a treatment planning system.

Disclosures

No conflicts of interest, financial or otherwise, are declared by the authors.

Ethical Statement

This is a prospective study, therefore, no testing on humans and animals. All the patients were treated as per protocol for which written informed consent has been obtained from all patients. This dosimetric study was done on the images obtained during treatment.

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