The influence of the patient size and geometry on cone beam-computed tomography hounsfield unit

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ABSTRACT

The objective of this work is to study the influence of the patient size and geometry on CBCT Hounsfield Unit and the accuracy of calibration Hounsfield Unit to electron density (HU-ED) using patient specific HU-ED mapping method for dose calculation. Two clinical cases, namely nasopharyngeal carcinoma (NPC) case and prostate case for 4 patients with different size and geometry were enrolled to assess the impact of size and geometry on CBCT Hounsfield Unit. The accuracy of the patient specific HU-ED mapping method was validated by comparing dose distributions based on planning CT and CBCT, dose-volume based indices and the digitally reconstructed radiograph (DRR) by analyzing their line profile plots. Significant differences in Hounsfield unit and line profile plots were found for NPC and prostate cases. The doses computed based on planning CT data sets and CBCT datasets for both clinical cases agree to within 1% for planning target volumes and 3% for organs at risk. The data shows that there are high dependence of HU on patient size and geometry; thus, the use of one CBCT HU-ED calibration curve made of one size and geometry will not be accurate for use with a patient of different size and geometry.

Key words: Cone beam computed tomography, electron density, Hounsfield Unit

Introduction

Kilo-voltage cone beam computed tomography (kV-CBCT) has been widely studied for dose calculation in an adaptive radiotherapy to monitor the dosimetric impact of geometric changes for intensity-modulated radiotherapy (IMRT) patients. The accuracy of kV-CBCT based dose calculation is highly dependent on the accurate calibration of Hounsfield Unit to electron density (HU-ED). However, due to its large field of CBCT acquisition, the original CBCT Hounsfield unit calculated in the reconstruction varies significantly with patient size and geometry. Thus, the use of one CBCT HU-ED calibration curve made of one size and geometry will not be accurate for use with a patient with different size and geometry.[1]

This technical note describes our study on the influence of patient size and geometry to CBCT HU numbers and the CBCT dose calculation accuracy by using the patient-specific HU-ED mapping method to establish the relationship between the electron density of various tissue and their corresponding CBCT number (in Hounsfield Units, HU) instead of the HU-ED calibration curve from a electron density phantom.

Materials and Methods

In this study, two head and neck cases represent 12-year-old kid (Patient A) and 37-year-old adult (Patient B) nasopharyngeal carcinoma (NPC) patients were scanned with Elekta XVI system to acquire CT_{Head} and $CBCT_{Head}$; and two prostate cases were selected with respect pelvis thickness. Patient C had thickness less than 20 cm whilst patient D had thickness more than 20 cm and they were scanned to acquire CT_{Pelvis} and $CBCT_{Pelvis}$. All data were collected from routine clinical applications.

Electron density-image sampling on the CMS XiO was used for HU-ED mapping,[2] known as patient specific HU-ED mapping method. This method involves various steps: first the CBCT images were imported as secondary studyset

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to the planning CT in the CMS XiO treatment planning system then the CBCT images were fused to the planning CT and the region of interests (ROIs) from planning CT were copied to CBCT images. A total of seven ROIs were used in generating the calibration curve, which included bone, soft tissue, muscle, air, cord, bladder, and skin. Then the image sampling was used to map the ROIs from planning CT to CBCT images and recorded the average CBCT HU numbers of these seven ROIs, image sampling tool reports HU numbers and relative electron density at the ROIs. Finally, the HU numbers from the CBCT scan were then calibrated as those from a planning CT scan so that electron densities are equivalent in both systems. The planning CT-based electron density on CBCT images allows more accurate dose calculations on an individualized patient basis.[3]

The accuracy of the patient specific HU-ED method was validated by comparing dose distributions based on planning CT and CBCT, dose-volume based indices for PTVs and OARs and the image quality of digitally reconstructed radiograph (DRR). This can be done by placing MLC shape, MU, and gantry angle of each beam from the original treatment plan generated with the planning CT data sets to the CBCT data sets for dose computation.[4] Assuming that only minor changes in the patient geometry occurred between first acquisition of the CBCT and planning CT, the observed dose distribution should be closely identical and the line profile plots should match well if the electron density mapping method is valid.

Results and Discussion

The HU-ED curves in Figures 1 and 2 illustrate the relationship between HU numbers and relative electron density for these four patients with different size and geometry, large discrepancies were noted from these calibration curves. NPC cases show higher HU numbers in CBCT than in planning CT. The planning CT data sets show HU numbers ranging from 809 to 1300 HU, whereas the CBCT NPC data sets offer HU numbers ranging from 100 to 2612 HU. For the same scanning parameters, patient A had a slightly larger range in HU numbers compared to the patient B. The increase was by 850 HU in patient A whose diameter of the head was 135mm compared to that of 152 mm in the adult patient.

In the pelvis CBCT, HU numbers ranged from 142 to 1303 HU and the HU-ED calibration curves were similar for both pelvis even though their pelvis thickness were different. It is because our current CBCT configuration for pelvis uses 120 kVp, which is similar to our CT scanner whereas CBCT configuration for head region uses 100kVp. Pelvis region also showed higher HU numbers in CBCT than in CT apart from the posterior area between the spine and the external air showed reduced HU because of the streak artifact.

Figures 3 and 4 show the comparisons of the image quality of DRRs reconstructed from CBCT data sets with those from planning CT data sets for Patient A and Patient B, respectively, by analyzing the line profile plot of the grey level values using ImageJ software (National Institutes of

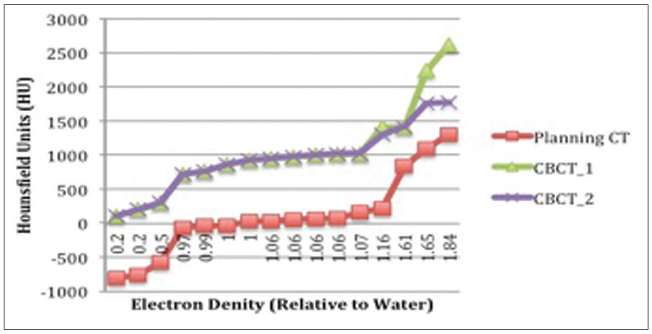

Figure 1: The HU-ED calibration curves for planning CT and head CBCT for Patient A (CBCT_1) and Patient B (CBCT_2)

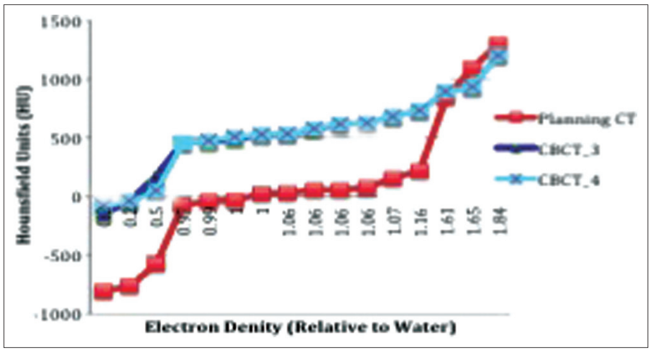

Figure 2: The HU-ED calibration curves for planning CT and pelvis CBCT for Patient C (CBCT_3) and Patient D (CBCT_4)

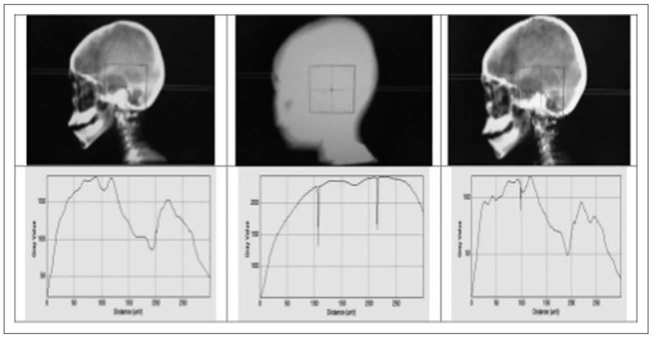

Figure 3: Comparison of the DRRs and line profile plots from the planning CT, original CBCT, and corrected CBCT data sets for Patient A

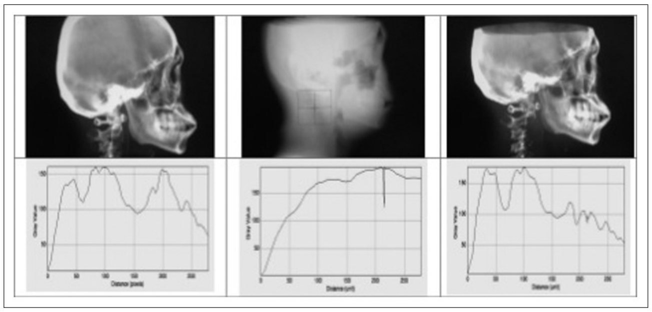

Figure 4: Comparison of the DRRs and line profile plots from the planning CT, original CBCT, and corrected CBCT data sets for Patient B

Health, USA). The DRRs reconstructed from the original CBCT data sets results in an inferior image quality compared to the DRRs reconstructed from the planning CT data sets. Due to reduced number of projections (400-700) for image reconstruction, the CBCT offered a limited image quality compared to the planning CT (2000-4000 projections). After applying patient-specific HU-ED calibration curve to the CBCT data sets (corrected CBCT data sets), the head CBCT shows identical DRRs compared with DRR reconstructed from the planning CT. By using the planning CT line profile plots as reference, there are significant improvements in line profile plots.

Figures 5 and 6 show the DRRs and the line profile plots in the planning CT and the corresponding CBCT for pelvis patients. In Figure 5, the original line profile plot for the CBCT DRR has much lower range in grey value as reflected by the blurred image. Once the CBCT date sets were collected with patient specific HU-ED calibration curve, a much better line profile plot was obtained.

Figure 6 shows the DRR and the line profile plot across the horizontal axis for patient D. Patient D has superior DRR image quality compared with patient C and visually, the line profile plot approaches identically in shape with small variations. We proved that the DRRs are highly depends on patient size, despite using the same scanning parameters.

Figures 7 and 8 show the comparisons of the IMRT isodose distributions for the patient B and patient C respectively. Almost similar isodose distributions were attained by applying the patient specific HU-ED calibration curves to CBCT data sets. This result showed good accuracy in CBCT based dose calculation with the patient specific HU-ED calibration curves created.

Table 1: Comparison of the IMRT plans for nasopharyngeal patient using planning CT data sets (pCT) and corrected CBCT data sets acquired on the first day of treatment

Dosimetric end point, cGy	*Patient B*		
	pCT	*CBCT*	*Percentage difference (%)*
PTV70, D95	6998	6987	-0.16
PTV60, D95	5941	5936	-0.08
Chiasm, Dmax	4727	4824	+2.05
Brain stem PRV, 1%	5883	6057	+2.96
Spinal cord, Dmax	4276	4301	+0.58
Right optic nerve, Dmax	4663	4578	-1.82
Left optic nerve, Dmax	4988	4965	-0.46
TM joint, Dmax	6584	6516	-1.03
Oral vavity, Dmean	3873	3875	+0.05
Right eye, Dmax	2510	2537	+1.08
Left eye, Dmax	2723	2746	+0.85
Right parotid, Dmean	3058	3062	+0.13
Left parotid, Dmean	3062	2983	-2.58

IMRT: Intensity-modulated radiotherapy, CBCT: Cone beam computed tomography

Table 1 shows the dose-volume-based indices to the PTVs and some normal organ at risk of the nasopharyngeal cancer patient (Patient B) in the planning CT data sets and their first CBCT data sets. For the PTV70 and PTV60, D95 showed agreement within 1% between pCT- and CBCT-based plans. The differences in the dosimetric endpoints of the critical organs for the pCT and CBCT could be as high as 3% when the organs are in extreme proximity with the PTV, especially for the optic track, brain stem and parotid glands. The discrepancy might due to the steep dose gradients of IMRT and variations in the patient setup.

A detailed comparison of dosimetric parameters for patient C, a prostate cancer patient was showed in [Table 2]. The similar excellent agreements are observed in dose volume based indices calculated using the planning CT data sets and CBCT data sets for the PTV74 (prostate and seminal vesicles).

CBCT HU numbers were highly influenced by the patient size and geometry. This suggests that a single CBCT HU-ED calibration curve will not be applicable to different patient size and geometry (the magnitude of scatter varies with patient-dependent factors such as size and location of the patient body)[5] as used for head and pelvis CBCT imaging for example. As a consequence, patient specific HU-ED calibration curves were created for the two CBCT imaging acquisition presets which are used in Pantai Hospital's clinical practice and four different geometries.

Conclusion

Our data show there is high dependence of Hounsfield Unit on patient geometry and less on size hence dose calculation on cone beam CT should be based on patient specific HU-ED. Since there are still have small differences between planning CT dose calculation and CBCT dose calculation, the first day of CBCT data sets rather than

Table 2: Comparison of the IMRT plans for prostate patient using planning CT data sets (pCT) and CBCT data sets acquired on the first day of treatment

Dosimetric End Point, cGy	*Patient C*		
	pCT	*CBCT*	*Percentage difference* (%)
PTV74, D95	7481	7500	+0.25
Bladder, Dmean	3324	3390	+2.0
Rectum, Dmean	3231	3134	-3.0
R Femoral Head, Dmax	4201	4157	-1.05
L Femoral Head, Dmax	5030	5081	+1.0

IMRT: Intensity-modulated radiotherapy, CBCT: Cone beam computed tomography

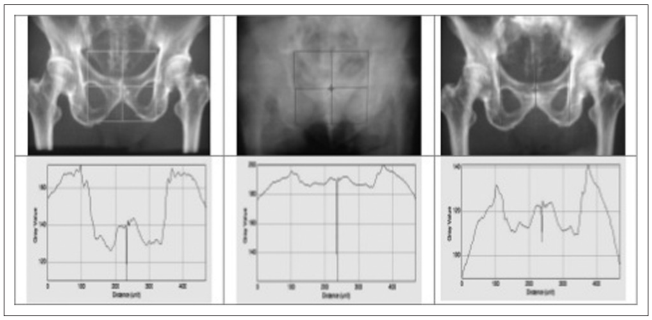

Figure 5: Comparison of the DRRs and line profile plots from the planning CT, original CBCT, and corrected CBCT data sets for Patient C

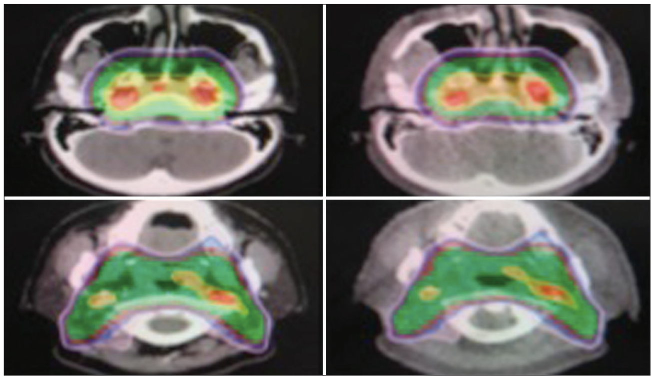

Figure 7: Comparison of isodose distributions (7350 cGy, 6994 cGy, 5940 cGy, 5400 cGy, 5000 cGy, and 4500 cGy) with the first CBCT plan and the original planning CT plan in axial slices for an IMRT technique of a Nasopharyngeal carcinoma patient (Patient B)

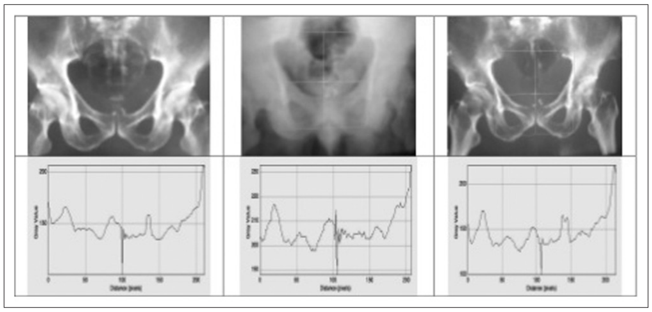

Figure 6: Comparison of the DRRs and line profile plots from planning CT, original CBCT, and corrected CBCT data sets for Patient D

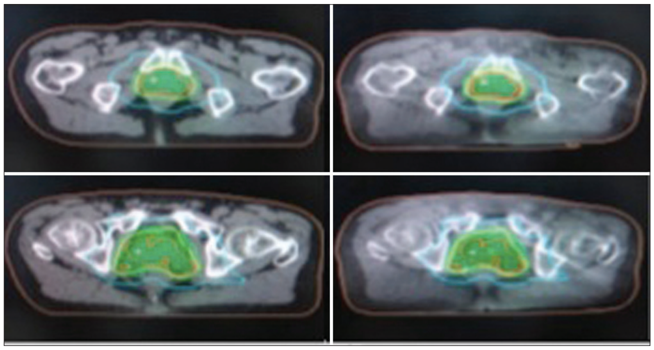

Figure 8: Comparison of isodose distributions (7770 cGy, 7400 cGy, 6800 cGy, and 5500 cGy) with the first CBCT plan and the original CT plan in axial slices for the IMRT technique of a prostate patient (Patient C)

planning CT should be used as reference for the dose tracking. This ensures that calculated dose distributions and DVHs using CBCT images provide reliable dosimetric parameters comparisons. The patient specific HU-ED calibration curves created can be used to study the dosimetric impact of weight loss for head and neck IMRT and to assess daily bladder and rectum DVH variations during radiotherapy of prostate cancer.

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