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Site Specific Calibration Curve and Its Implication in the Treatment Planning of Head and Neck Cancer.

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Abstract

Purpose: In this study, we created site specific Hounsfield Unit (HU) and Relative electron density (RED) calibration curves for computed tomography (CT) and cone beam computed tomography (CBCT) for head and neck radiotherapy dose calculation and compared them with standard calibration curves.

Methods: The calibration curves between HU and RED were generated using RANDO phantom for CT and CBCT and fed in the treatment planning system for dose calculation for head and neck patients. The treatment plans for 10 head and neck cancer patients were calculated using the standard calibration curves generated with CATPHAN and head and neck calibration curves generated with RANDO phantom for both CT and CBCT. Dose accuracy of head and neck calibration curves (H/N CC) were compared to the standard calibration curves (SCC) using dose volume metrics and 3D gamma analysis.

Results: The results show that slightly better dosimetric agreement from the SCC can be obtained when using this H/N CC.

Conclusions: A site specific calibration curves have been proposed and tested for the head-and-neck patients and the results explain the dosimetric benefits.

Introduction

Radiotherapy treatment planning is the process of determining the most appropriate way to treat the tumour by avoiding normal structures. One of the most important step of the planning process is the patient data acquisition required to define the target volume and normal structures and to perform accurate dose calculation [1]. These data are predominantly obtained from the patient's radiological images, primarily computed tomography (CT), which contain all the necessary information. The CT images not only provide important information about the anatomy, but also allow obtaining the distribution density of the organs and tissues. This density information is very important for accurate dose calculation, particularly in head and neck region where attenuation is very different from the attenuation in a homogeneous soft tissue volume due to tissue inhomogeneities such air and bone [2, 3]. Normally, tissue density information is obtained by Hounsfield Unit(HU) and electron density calibration curve, which is generated by scanning a phantom (CATPHAN) containing various inserts of known electron density. This calibration curve is CT scanner specific and uses as standand calibration curve(SCC) for dose calculation in the treatment planning system for all radiotherapy sites.[4]

For CT scans, the HU of an image set is highly dependent on many factors, including the size and material of the phantom, the materials placed in the phantom, and the imaging protocol used.[4,5]. Due to this variability, HU-to-density calibration curves obtained with phantoms for CT, lack sufficient robustness to be applicable to all patients of particular site.[6]

To potentially resolve this, we developed an alternative site-specific calibration curve for head and neck patients to achieve higher dose accuracy for its possible application to adaptive radiotherapy.

A promising solution for adaptive radiotherapy is to use cone-beam computed tomography (CBCT) image sets to dosimetrically assess plan quality, since these image sets are already routinely acquired prior to treatment for patient setup and monitoring. However, to perform dose calculations, accurate tissue density information must be extracted from the CBCT voxel values. [7,8]

To evaluate whether this calibration curve improves the dosimetric accuracy, we performed a retrospective patient study of 10 head and- neck clinical cases, and a phantom study for both CT and CBCT.

Materials and methods

In order to validate the data, a site specific calibration curve was created using RANDO phantom (The Phantom Laboratory, NY). It is an anthropomorphic phantom made of tissue-equivalent materials. For this, Rando head phantom was scanned in the CT scanner (Gemini Philips) using same parameters as used for head and neck patient scanning. To study the HU consistency of CBCT in the heterogeneous medium, CBCT images were acquired using On Board Imager (OBI) system integrated with Varian Trilogy linear accelerator (Varian Medical Systems, Palo Alto, CA) with the same setup and acquisition parameters, Both the CT and CBCT image sets of the phantom were registered using rigid automatic registration. The HU values of both CT and CBCT images (same locations) at different density of head and neck area, were obtained.The phantom HU (pHU) values were compared in both CT and CBCT sets at different regions of head and neck (Table 1). The site specific head and neck (H/N) calibration curves between relative electron density (RED) and pHU values were generated for both CT and CBCT (Figure 1). Both the curves were generated separately and stored within the TPS for dose calculation.

Tissue	**RED**	**pHU_{CT}**	**pHU_{CBCT}**
Teeth	2.67	2987	3800
Mandible	1.9	1620	1820
Skull	1.86	1480	1648
Clavicle	1.65	1020	1085
Vertebrae	1.56	902	935
Muscle(head)	1.02	55	75
Brain	1.02	40	65
Spinal cord	1.02	30	57
Eye	1.02	30	68
Oral mucosa, Tongue, Lips, Cheeks	1	25	42
Parotids	1	15	37
Nasal Passage	1	2	10

Esophagus	1	3	15
Air	0	-982	-1015

Table 1: Head and neck phantom HU values with their RED values for both CT and CBCT

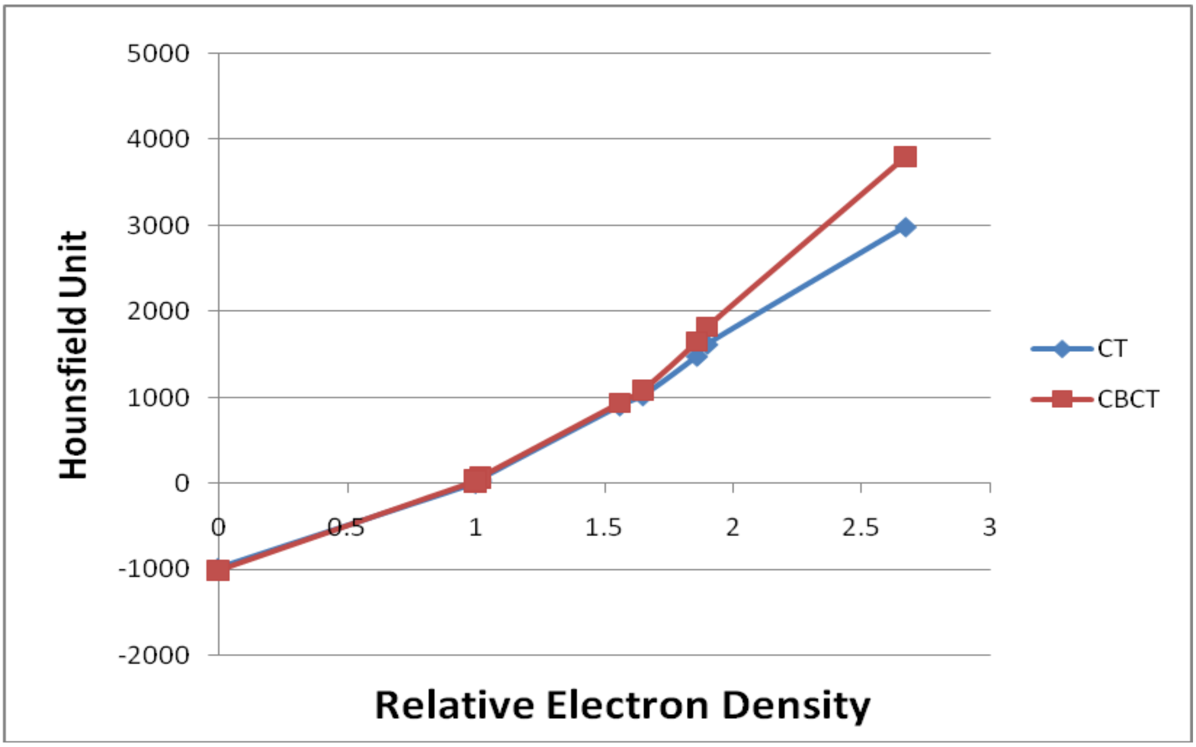

Figure 1: HU and RED calibration curve for CT and CBCT using Rando head and neck phantom

Ten head and neck cancer patients were selected at random from our institution database, all of whom had completed their treatment course .All CT and CBCT scans were acquired as a part of our routine clinical work. A nine-field 6 MV photon IMRT plan was optimized on CT scan of each patient for 70Gy in 35 fractions and calculated using Analytical Anisotropic Algorithm(AAA) with both standard calibration curve(SCC) and head and neck calibration curve (H/N CC). To run the optimization, structure set : clinical target volume (CTV) expanded with margin to a planning target volume (PTV), spinal cord, parotid glands, and mandible were delineated. CT and CBCT image sets were rigidly registered and the structure set was copied from CT to CBCT with a small manual adjustments in targets volumes (CTV,PTV) and Organs at Risk (OARs). Subsequently, the IMRT plan with fluence maps and monitor units was copied from CT to the CBCT and calculated using CBCT SCC and CBCT H/N CC.

The treatment plans with SCC and H/N CC for both CT and CBCT were evaluated by comparing dose-volume histogram (DVH) of PTV and OARs (Spine, mandible, parotids). To evaluate the dose distributions the minimum, maximum and mean dose from DVH parameters of the structures were recorded. Finally, the complete three-dimensional dose distributions were compared using gamma-index pass/fail analysis using 3% dose difference and 3 mm distance-to-agreement criteria.

Results

The results exhibit improved target coverage using H/N CC for both CT and CBCT. Doses for spine, and parotids were significantly less whereas mandible dose was significantly higher in plans using H/N CC as compared to SCC(Table 2). The results of the 3D gamma analysis were found to be similar for both the curves

(P value = 0.15), with the average (standard deviation) gamma pass rates of 96.7% (3.0%) and 96.1% (3.3%) for the H/N CC and SCC respectively.

Treatment plans	PTV doses (Gy)			OAR doses (Gy)			
	Dmax	Dmean	Dmin	Spine Dmax	Mandible Dmax	Rt Parotid Dmean	Lt Parotid Dmean
CT Plan using SCC	74.3±2.3	70.9±1.4	66.8±1.1	42.3±1.9	71.4±0.8	23.9±16.2	32.3±20.5
CT Plan using H/N CC	76.2 ±3.5	71.3±0.8	68.1±0.9	42.0±0.8	72.5±1.3	22.7±19.3	31.0±18.1
CBCT Plan using SCC	75.4±2.8	71.1±1.6	67.0±1.1	44.4±1.7	72.8±1.2	28.9±18.2	30.7±18.7
CBCT Plan using H/N CC	76.7± 1.9	71.5±1.2	67.7±2.1	43.3±2.1	74.5±0.3	27.4±16.6	28.8±17.6

Table 2: Dosimetric data from treatment plans calculated on CT and CBCT using SCC and H/N CC

Discussion

The calibration for HU to RED conversion in a treatment planning system (TPS) is typically based on measurements in CT scans of tissue equivalent materials of known electron densities in a phantom. *Yang et al.* investigated the stability of this tissue substitute HU-RED calibration for CBCT-based dose calculation. Based on CBCT scans of the Catphan 504 phantom (The Phantom Laboratory, Salem, NY, USA), supplied by the vendor for linear attenuation to HU calibration and image quality assessment, the HU-RED curve has been found to be stable both over time and across different scan settings[10] . However, the phantom uses Teflon composed of carbon and fluorine as the high electron density substitute for dense bone. In real bone the presence of calcium and phosphor with higher effective atomic number results in higher HU values for the same electron density as Teflon due to more photoelectric interactions leading to dose calculation inaccuracies[11,12]. More importantly for the variation in HU-RED relation for CBCT is the amount of scatter present during calibration which should resemble the clinical treatment situation. *Hatton et al.* shown a large impact on HU numbers due to the phantom length and especially the radial diameter for the head and neck region[8]. Also a reduction in scan length or cone angle will reduce the scatter contribution and change the HU-RED curve[13]. To minimize the influence on dose calculation accuracy site-specific HU-RED calibrations has been implemented .This has aimed to avoid the use of tissue equivalent materials by creating patient specific HU-RED curves. The average CBCT HU values for clinical tissue types were determined and subsequently mapped to average CT electron density for the same tissues.

Unlike the CT-based planning that uses only a single CT to electron density calibration curve(SCC) in the treatment planning system, a site-specific HU-to-density curve was created for each head and neck patient and compared it with SCC. HU to RED standard calibration curves for CT and CBCT were generated using CATPHAN and are using in our centre for all routine cases for treatment planning. James et al showed a variation of ±14% of the pCT-based dose using CATPhan phantom and the CT calibration curve[14]. The RANDO phantom is reliable for HU to RED for performing daily plans because it is made with three different materials (skeleton of normal human,soft tissue,lung) in an effort to overcome the disadvantages of non-uniformity of materials, size and shape. Dosimetric calculations on CT/CBCT images show doses with variations within ±5% of the CT-based plans, using the RANDO phantom. This concludes that while the CATPhan phantom produces linear responses and produces highly accurate and consistent HU values on CT/ CBCT, it does not provide accurate dosimetric values as compared to RANDO Phantom.

We found that CT number deviations are minimal for low-density materials but become significant for high-density materials , therefore, high-density materials may have a large effect on the accuracy of CT number and dose calculation. Recently Zurl et al [15] compared CT parameters and showed HU variation upto 20% with the impact on dose to 1.5% .

The results show that slightly better dosimetric agreement with the SCC can be obtained when using this H/N CC, for plan re-assessment during radiotherapy.

Conclusion

A site specific CT and CBCT calibration curves have been proposed and tested for the head-and-neck site.It is recommended to implement site specific curves for sites other than head and neck especially in lung cases to look upon the dosimetric accuracy.

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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