Quantification of the HU Variation on kV CBCT for Direct Dose Calculation in Adaptive Radiotherapy

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Introduction

In the most current application of adaptive radiotherapy (ART), the dose is calculated on the synthetic CT. The synthetic CT is the result of the deformable image registration (DIR) between CBCT of the day and the simulation CT. DIR has its own limitations in case of large anatomical changes such as bowel gas and missing or appearing tissues and other intrinsic uncertainties. Direct dose calculation on the CBCT of the day can bypass these limitations and speed up the workflow in ART. The accuracy of the Hounsfield Units (HU) is an important factor for accurate dose calculation on CBCT. This work quantifies the variation of the HU values of kV iCBCT in different test setups using both iCBCT reconstruction algorithm on Halcyon™ 3.0, Ethos, (Varian Medical Systems, Palo Alto, USA) and a currently under development improved prototype version. Results of this work will help to demonstrate potential usage of improved iCBCT for direct dose calculation.

Disclaimer:

- The iCBCT reconstruction algorithm referred here as Halcyon 3.0 is not the exact same version as the one used in the Halcyon 3.0 product. Though the differences have no significant impact on the final results presented in this study.
- The iCBCT reconstruction algorithm referred here as improved prototype version is a work in progress and does not represent the quality of the planned product version.

Aim

To quantify the HU variation of kV iCBCT caused by different image acquisition setups and different image reconstruction pipelines for application of direct dose calculation in adaptive radiotherapy.

Method

- **Radiotherapy machine for the measurements**: Halcyon™ 3.0 linear accelerator, Ethos, (Varian Medical Systems, Palo Alto, USA) (Figure 1) using the default pelvis protocol (125 kV).
- **Phantom**: CIRS Model 062MA CBCT Electron Density (CIRS Tissue Simulation & Phantom Technology, Norfolk, USA). The phantom consists of 9 different tissue equivalent electron/mass density plugs that can be positioned in 17 different locations (Figure 2).
- **Tests to assess the variation of the HU values:**
  - **Consistency:** HU difference between two plugs of the same tissue equivalent material positioned in outer and inner ring within the phantom.
  - **Scan length dependency:** changing the field size from 28 to 8 cm by changing kV collimator position longitudinally (±14 cm and ± 4 cm respectively around the isocenter) and comparing the HU values
  - **Object size dependency**: increasing the phantom lateral extent with additional bolus material from 33 to 45 cm (6 cm each side) and comparing the HU values
  - **Repeatability**: Comparing the HU values of the same phantom using the same protocol for 10 consecutive measurements.
- **Reconstruction method**: Scans were reconstructed using 2 mm slice thickness once with the iterative reconstruction algorithm (iCBCT Halcyon™ 3.0) and once with a currently under development improved prototype version. The improved version uses Acuros® CTS scatter correction and a spectrum-based HU assignment.
- **Analysis**: The measured HU values were calculated in a cylindrical Region Of Interest (ROI) for every plug and were compared for both algorithms.

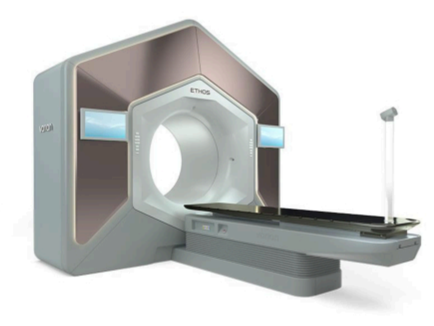

Figure 1: Varian Halcyon™ 3.0 linear accelerator, Ethos.

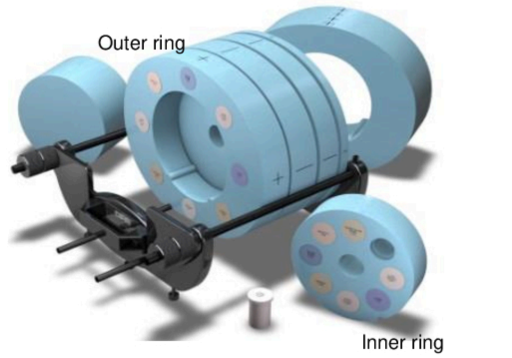

Figure 2: CIRS model 062MA CBCT Electron Density phantom.

Results

Consistency

The results of the consistency test for both sets of the reconstructed scans are shown in Figure 3. The center plug is filled with distilled water. The highest absolute inconsistency of 41 HU for soft tissue materials decreased to 10 HU using the improved prototype version of iCBCT. Nevertheless, the absolute HU inconsistency of bone-200 and lung-inhale increased by 10 HU.

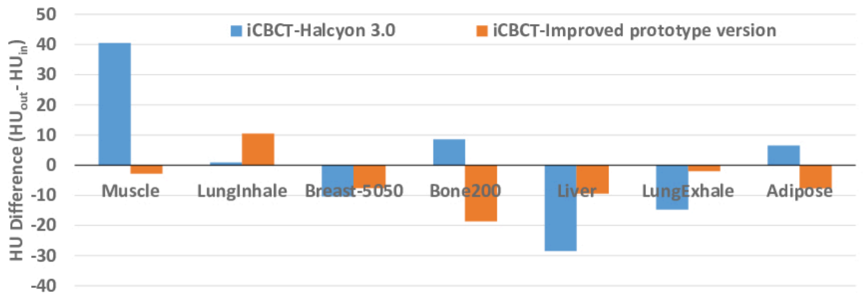

Figure 3: HU difference between two equal tissue equivalent plugs positioned in two different locations in outer and inner ring.

Scan Length Dependency

The results of the HU variations caused by changing the scan length (sl) is shown in Figure 4. The plugs located in the inner and outer part of the phantom are noted with "In" and "Out" extension respectively in the graphs below. The HU variation, caused by a 20 cm reduction in scan length, decreased by 75% in average using the improved prototype version of iCBCT.

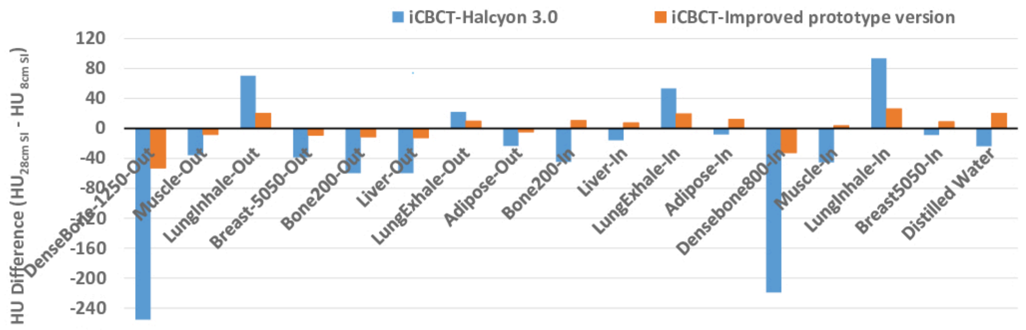

Figure 4: HU difference caused by changing the scan length (field size) from 28 to 8 cm.

Object Size Dependency

The results of the HU variations caused by changing the object size is shown in Figure 5. The overall HU variation caused by a 12 cm increase in the phantom total lateral extent decreased in average by 38% using the improved prototype version of iCBCT.

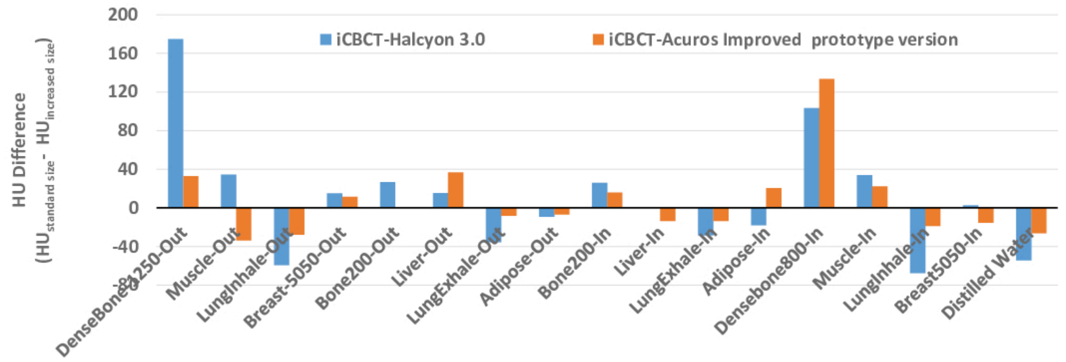

Figure 5: HU difference caused by increasing the phantom lateral extent with additional bolus material from 33 to 45 cm (6 cm each side).

Repeatability

The variation of HU values between 10 consecutive scans was at maximum 4 HU independent of the reconstruction algorithm.

Two examples of kV CBCT images reconstructed using iCBCT Halcyon 3.0 and the improved prototype version of iCBCT are shown in Figure 6.

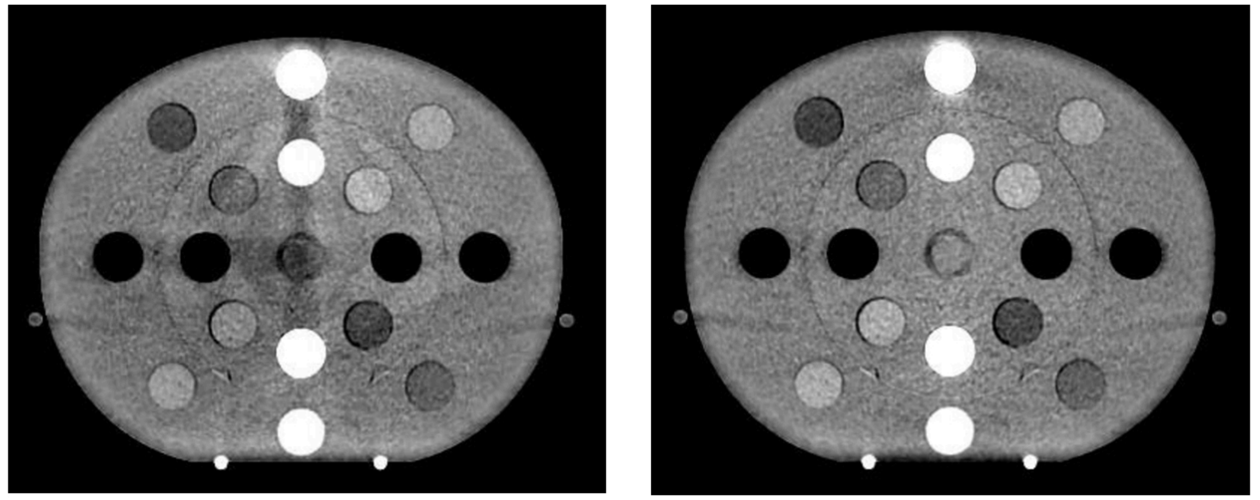

Figure 6: kV CBCT image (W/L=300/0) of CIRS phantom using Halcyon™ iCBCT default pelvis protocol (125 kV), acquired with a fully open collimation of 28 cm, reconstructed with iCBCT Halcyon 3.0 (left) and improved prototype version of iCBCT (right).

Discussion and Conclusions

Using Acuros® CTS for improved scatter correction and a spectrum-based HU assignment in iCBCT image reconstruction, improves overall HU consistency and reduces overall HU variation caused by different scan lengths and object sizes. It is expected that this helps to improve the accuracy of the direct dose calculation using iCBCT in adaptive radiotherapy.

To put these results in relation to simulation CT specifications, we measured in addition HU uniformity using the CT ACR 464 phantom (Gammex, Sun Nuclear corporation, Melbourne, USA). The maximum nonuniformity using iCBCT improved prototype version was found to be 17 HU while the recommendation for CT simulation is ±5 HU [1].

In order to investigate the accuracy of the calculated dose on iCBCT an additional investigation has been done [2] to proof our hypothesis if the demonstrated improvements in HU accuracy enable direct dose calculations using our improved iCBCT reconstruction framework. Further improvements in the image reconstruction pipeline and further investigations considering different test cases and their impact on the direct dose calculation are planned for the future.

References

1 Mutic S et al. Quality assurance for computed-tomography simulators and the computed-tomography-simulation process: Report of the AAPM Radiation Therapy Committee Task Group No. 66

2 Wessels C et al. Direct dose calculation on CBCTs for various treatment sites in adaptive radiotherapy . Joint AAPM COMP meeting, July 12-17, 2020, Poster Number PO-GeP-M-159

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