2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

Stability of CT numbers for advanced cone-beam computed tomography imaging – across scanners and time

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INTRODUCTION

Advanced cone-beam computed tomography (**CBCT**) has become available on standard C-arm linacs, making it widely applicable in photon-based radiotherapy.

AIM

Evaluate **CT number stability** of advanced CBCT detectors installed on **seven C-arm linacs** within a single institution, across CBCT systems and over time, and assess the **CBCT-based dose calculation** accuracy in head-and-neck, lung, and pelvic cancer patients.

METHODS AND MATERIALS

A Gammex Advanced Electron Density phantom (Sun Nuclear) was scanned at installation of eleven CBCT detector plates (including detector plate replacements) at seven TrueBeam C-arm linacs (Varian Medical Systems, A Siemens Healthineers Company), and **after three and six months**. Three CBCT protocols were evaluated; a head protocol with tube voltage of 100 kVp and iterative reconstruction (denoted iCBCT), a thorax protocol with tube voltage of 125 kVp and filtered back projection reconstruction using the Feldkamp-Davis-Kress (FDK) algorithm, and a pelvis protocol with tube voltage of 125 kVp and iCBCT.

Fifteen tissue-equivalent phantom inserts were scanned individually, placed at the center of the phantom. The mean CT number was extracted, and **CT number stability** was assessed across CBCT detectors and timepoints. CT number stability across detectors was compared to a previous CBCT detector model. Moreover, routine measurements using four inserts were performed until 18 months after installation. Additionally, **CT conversion curves** from CT numbers to mass density were generated, following a consensus guide. The spread of the curves due to CT number variation across detectors was assessed.

Treatment plans created on planning CT scans (pCT) **of 10 head-and-neck, 22 lung, and 15 pelvic cancer patients** were recalculated on CBCT scans, selected to match the anatomy seen on the pCT. Dose-volume parameters for targets and organs-at-risk were compared between pCT and CBCT.

ACKNOWLEDGEMENT

This research was paid for by Varian Medical Systems, a Siemens Healthineers company.

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RESULTS

The **CT numbers were consistent across the detectors and over time** for the iCBCT reconstruction algorithm, but to a lesser degree for the FDK reconstruction algorithm. The CT number variation increased with the density of the phantom inserts. For the high-density HE Cortical Bone insert, the interquartile range of the CT numbers across detectors was 29 HU (head protocol), 41 HU (thorax protocol), and 16 HU (pelvis protocol). For the longitudinal measurements, the median differences were 4 HU, -9 HU, and -8 HU after three months and -8 HU, -32 HU, and -26 HU after six months, for the head, thorax, and pelvis protocol, respectively.

For routine measurements, no clear time dependence was seen for CT number differences. It was found that **a single conversion curve per protocol** could be used for all CBCT systems. For iCBCT, median dose differences between pCT and CBCT were within 0.5% for head-and-neck and pelvis and 1.5% for lung, while FDK lung was within 2.5%. The largest deviations with iCBCT were -1.3% for head-and-neck, -1.1% for pelvis, and -3.8% for thorax, but -18.0% for thorax FDK.

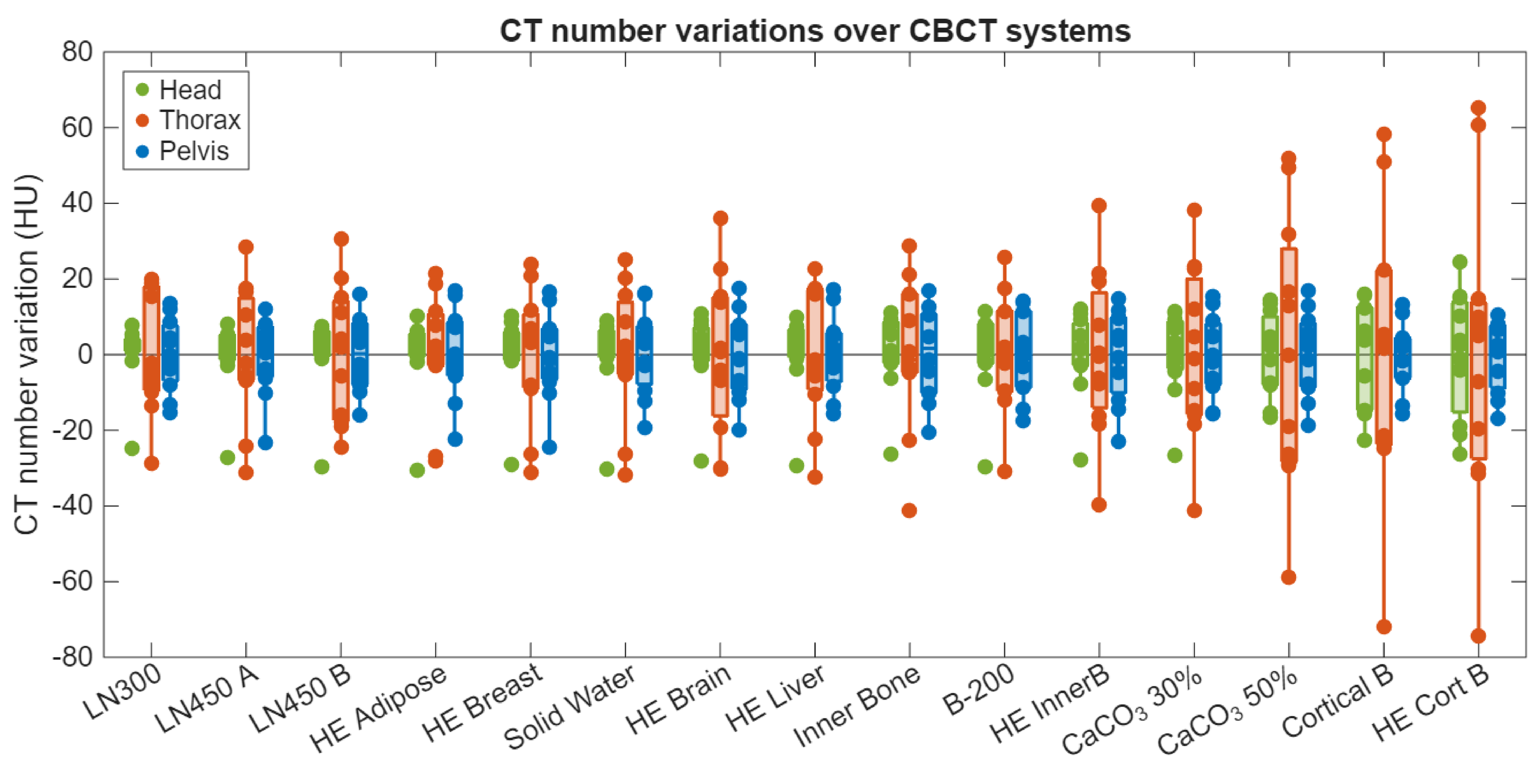


Figure 1: CT number variation across the CBCT systems measured at installation. The data is shown as the mean over all detectors minus the actual CT number for the specific detector plate for each of the 15 inserts. The data is plotted for each of the three CBCT protocols (Head, Thorax, and Pelvis).

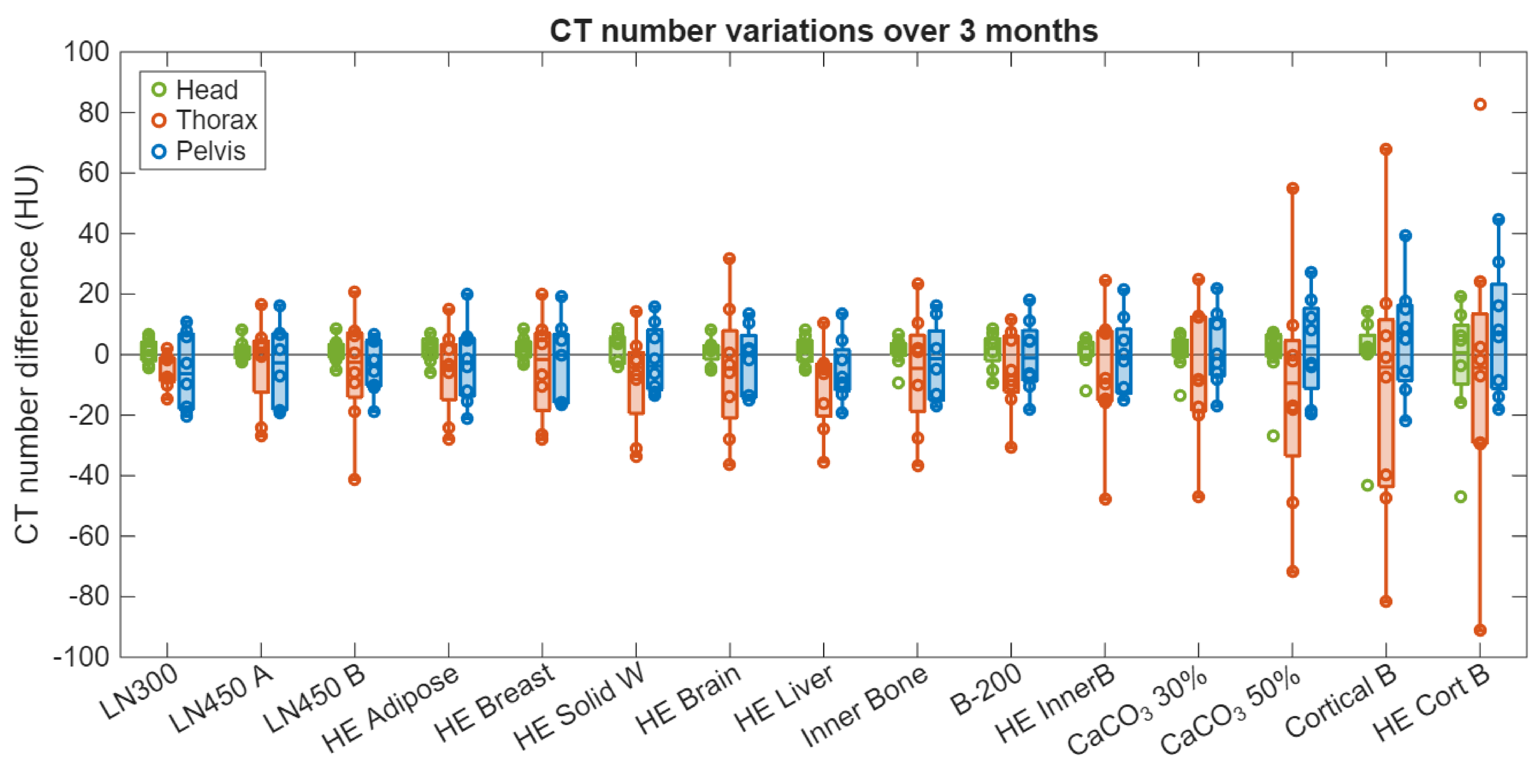
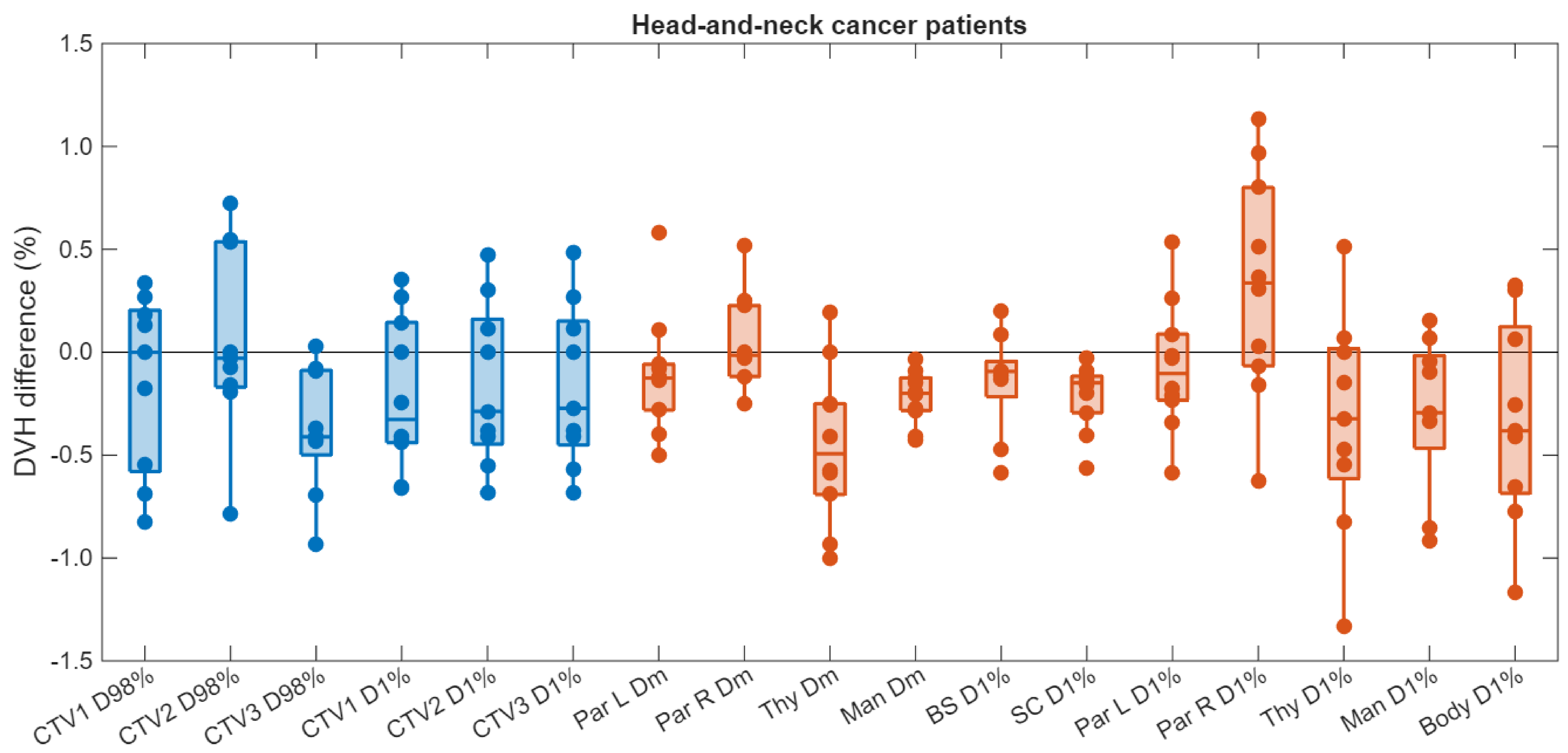
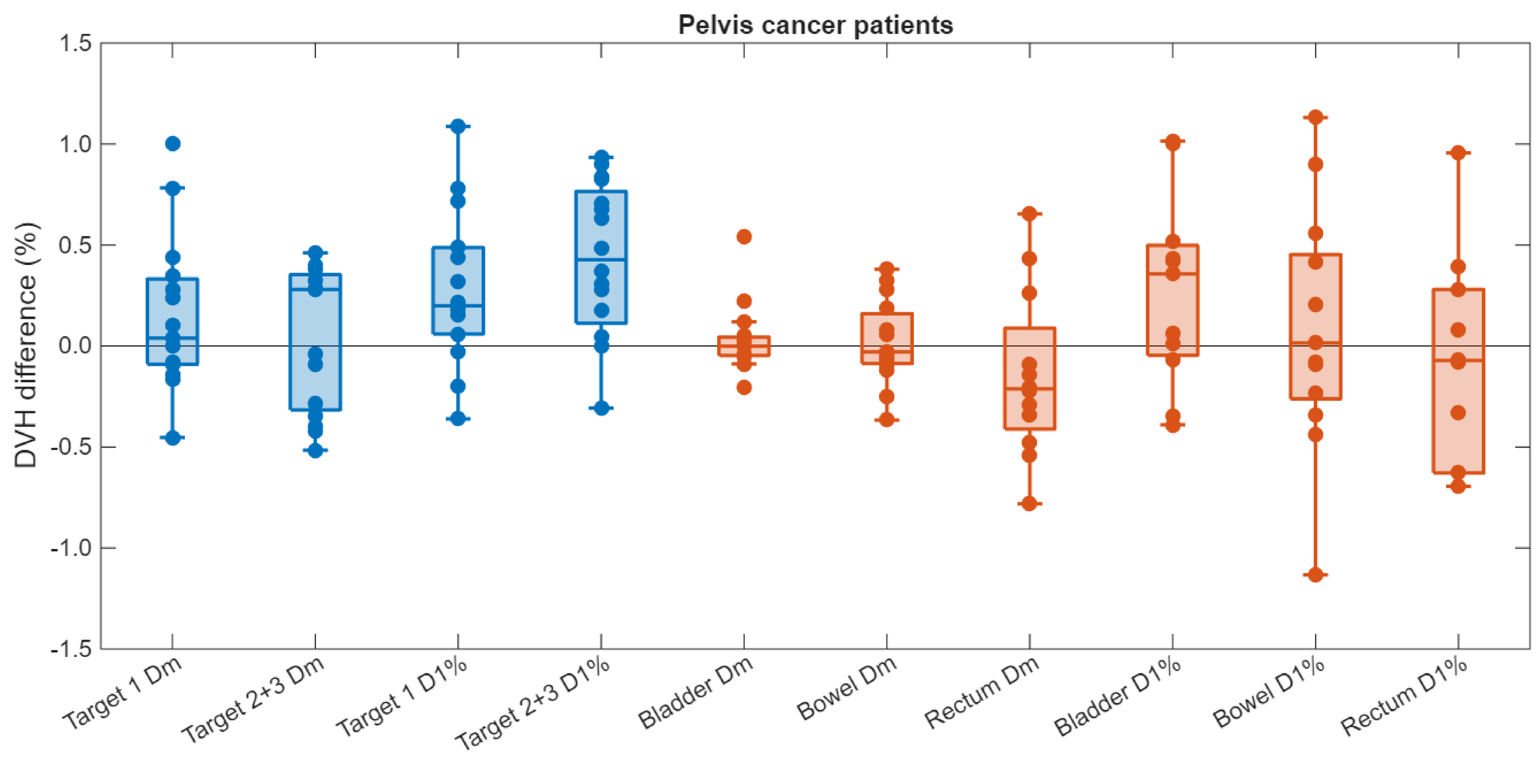


Figure 2: CT number difference for each specific CBCT system measured three months after installation. The CT number difference is defined as the measured CT number at 3 months minus the measured CT number at installation.





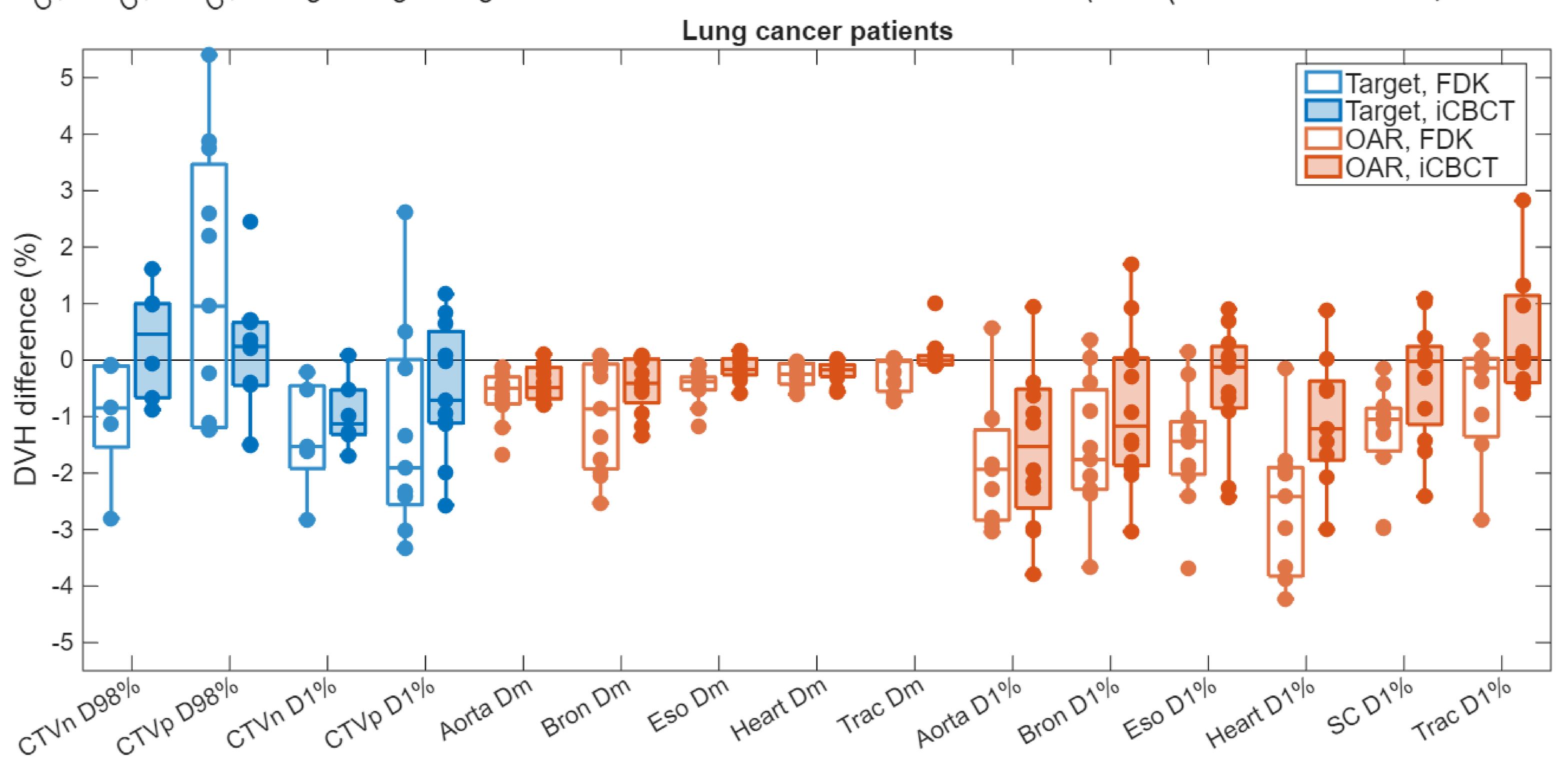


Figure 3: DVH differences between the treatment plan calculated on the planning CT and the CBCT, relative to the prescription dose, with target metrics shown in blue and OAR metrics shown in orange. For the lung cancer patients, results for both FDK (non-filled boxes) and iCBCT (filled boxes).
Outliers not shown for lung patients and FDK reconstruction: CTVp D98% = -18.0%, Heart D1% = 7.1%, and Trachea D1% = 6.8%.

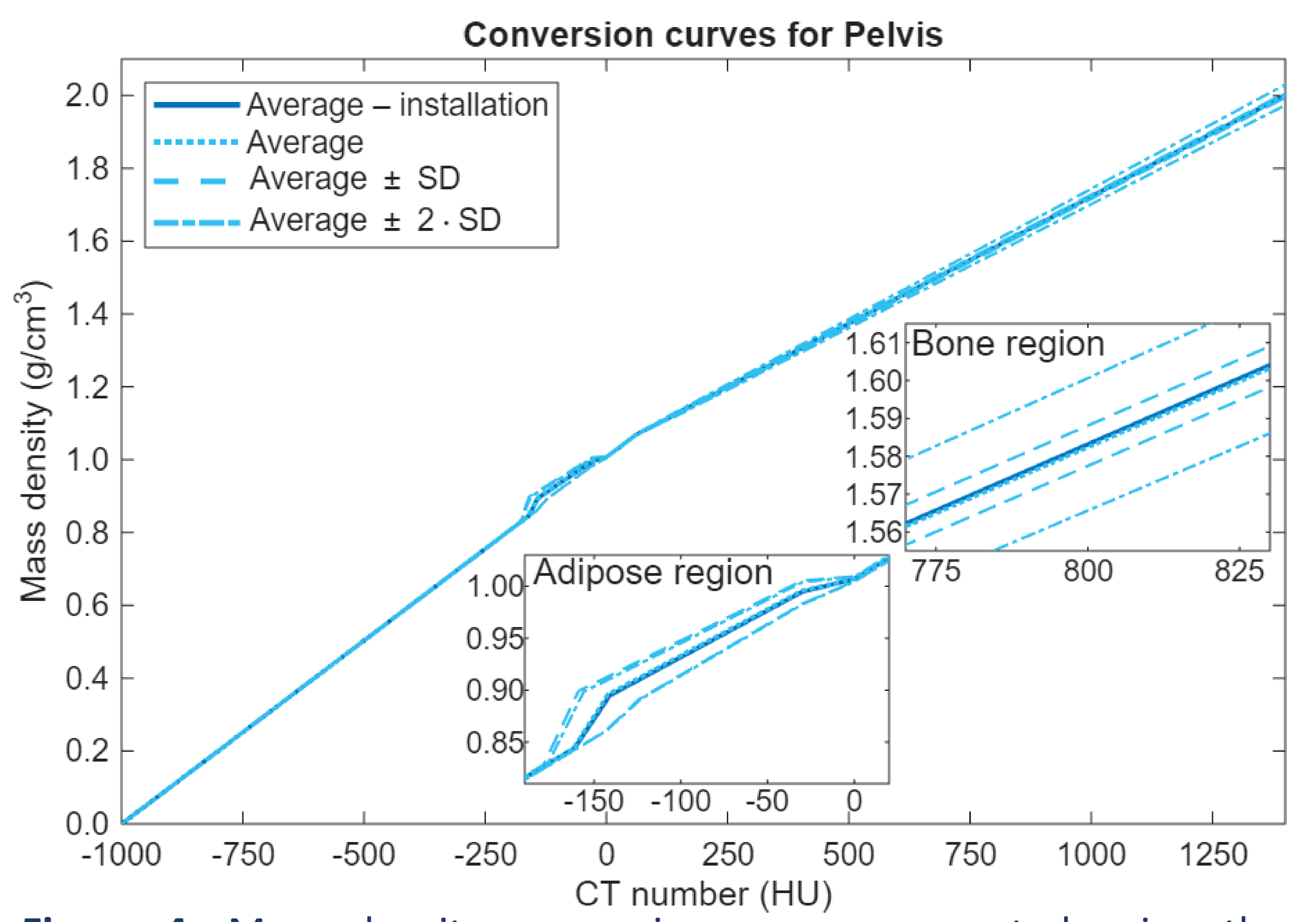


Figure 4: Mass density conversion curves generated using the average CT numbers across all CBCT systems acquired only at installation (full line), or at installation and after three and six months (dotted line), as well as the average ±1 or 2 standard deviations (SD) for all three time points and all CBCT systems.

CONCLUSIONS

The CT number stability was sufficient to allow for a single conversion curve per CBCT protocol to be applied across all CBCT scanners. A **high dose calculation accuracy** was found for 36 patients with iCBCT scans, while larger deviations were seen for eleven thorax FDK scans.