A Novel Method for Correcting CBCT Intensity Values and FOV Truncation

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INTRODUCTION

Adaptive radiotherapy (ART) is increasingly becoming a critical tool for high quality individualized patient care in radiation oncology. It allows a radiotherapy plan to be modified to adapt to the patient's changing anatomy during the treatment course.

Cone-beam computed tomography scans (CBCTs) acquired during treatment can be used to assess the extent of anatomical changes, but the effect of these changes on the planned dose distribution cannot be determined directly. CBCTs often exhibit artifacts, have incorrect Hounsfield unit (HU) values, and have a narrow field of view which may not cover the entirety of the anatomy of interest.

Therefore, a strategy is required to solve these problems before CBCTs can be used to perform dose-of-the-day calculations and determine if ART is needed.

AIM

To provide a deformable image registration (DIR) method which corrects HU values and addresses CBCT field of view (FOV) truncation to improve adaptive RT strategies.

METHOD

The DIR method presented here uses a combination of MATLAB and `elastix`[1], an open-source DIR toolbox . The steps [and associated software] were as follows:

1. **Resample the CBCT** image to the same resolution as the planning CT (pCT) [MATLAB]
2. **Pad the CBCT** with air to generate a CBCT approximately the same array size as the pCT. [MATLAB]
3. **Create a mask** for the cylindrical FOV of the CBCT to ignore ringing artifacts and truncated anatomy, [MATLAB]
4. **Perform initial rigid alignment** [`elastix`]
5. **Perform deformable registration** [`elastix`]
6. **Convert the deformed CT (dCT)** from the MHD format used for `elastix` **back to the DICOM** format to be imported into the treatment planning system (TPS) for dose calculation. [MATLAB]

For rigid and deformable registrations, the fixed image was the CBCT, the moving image was the pCT, and a mask was used to indicate the registration area.

Mutual information was used for the similarity metric, and a bending energy penalty term was used to constrain the deformation. In the case of spotlight CBCTs, an initial rigid registration was determined manually. Registrations were assessed visually and via the determinant of the Jacobian of the resulting transformation.

RESULTS

21 patients with 5 different treatment sites (Head&Neck (HN), liver, lung, breast, and spotlight breast) were assessed.

CBCTs had a voxel size of 0.511x0.511x1.99 mm^3 and an array size of 512x512, resulting in an FOV of 26.17x26.17x20.7 cm^3. The pCTs had a typical voxel size of 1.17x1.17x3.00 mm^3 and an array size of 512x512, resulting in an axial FOV of 60x60 cm^2.

The entire method (from exporting the pCT and CBCT from the TPS to importing the dCT back into the TPS) takes **under 30 minutes** to implement with a performance desktop. It is able to generate **deformed images with acceptable matching** between the CBCT and the dCT, **even in the case of very large anatomical changes**. See Figure 1 below.

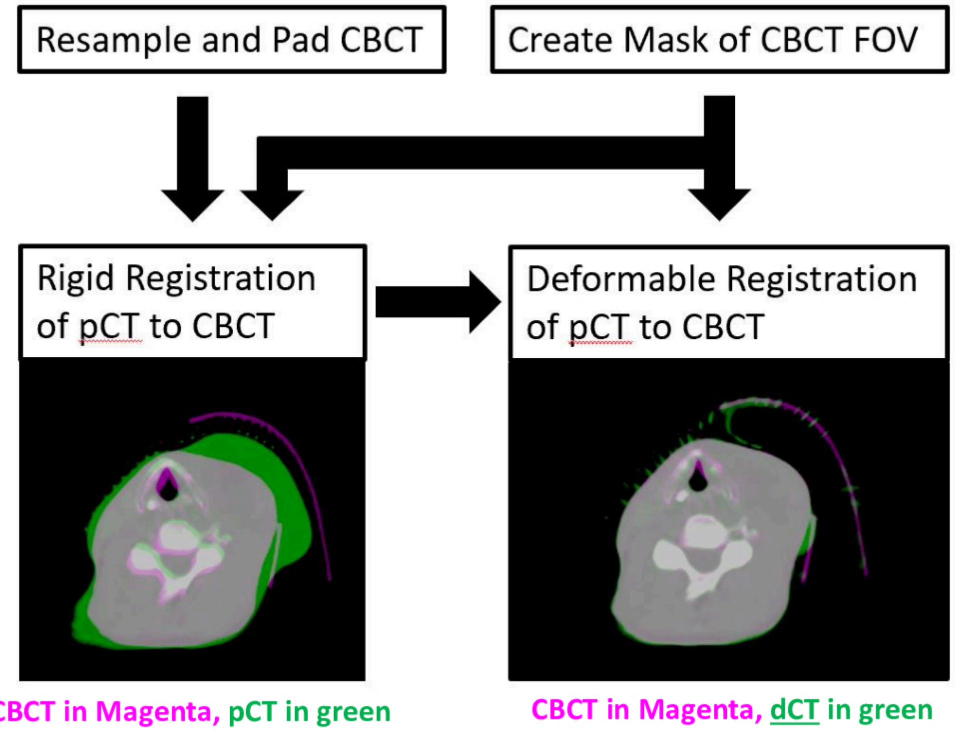
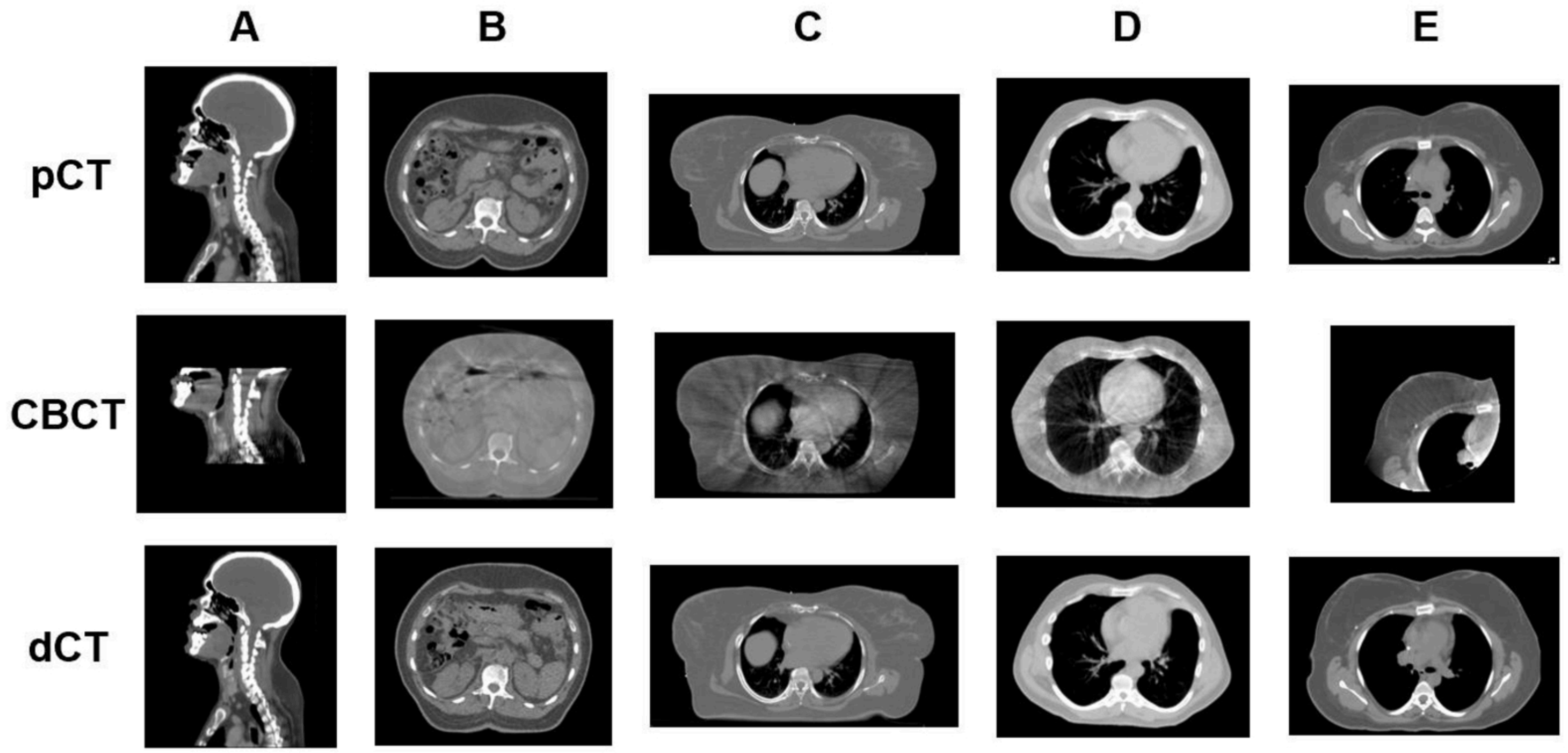


Figure 1. Diagram showing the workflow for dCT creation with a head and neck example exhibiting significant anatomical change over the course of treatment

Additionally, **the procedure corrected for artifacts and expanded the FOV** beyond that of the CBCT. This method presented usable images for dose reconstruction for a variety of sites presenting different challenges, such as artifacts and highly cropped images, without any manual tuning of parameters or state-of-the-art equipment.

Figure 2. Examples of dCT results for different treatment sites.



A	B	C	D	E
The dCT resolves the superior-inferior truncation of the HN CBCT.	The liver dCT reduced the artifact from gas buildup seen in the CBCT.	The dCT removed the artifact from the CBCT while still closely resembling the anatomy represented in the CBCT and incorporating the truncated anatomy.*	The dCT did not perfectly capture the expanded lung volume of the CBCT, but it generated a closer match than the pCT.	The dCT incorporated the truncated tissue to generate a full image with anatomy representative of the CBCT.*

*Minor artifact is visible at the boundary of the skin and air where the mask intersects.

CONCLUSIONS

A simple DIR method which used no commercial medical software was able to be implemented to generate CT-like images representing the anatomy of the day using just the pCT and the CBCT. The resulting dCTs exhibit little artifact, encompass approximately the same anatomy as the pCT, and have the correct HU values. This method does not require software licensing and is robust to different treatment sites and to large anatomical changes.

Previous methods have not been able to or have not attempted to incorporate anatomy omitted from the CBCT. Depending on beam arrangement, the truncated anatomy may be crucial for accurate dose calculation. The method presented here incorporates those capabilities and can provide acceptable images in less than 30 minutes.

REFERENCES

1 **S. Klein et al.** elastix: A Toolbox for Intensity-Based Medical Image Registration, IEEE Trans. Med. Imaging 29(1), 196–205 (2010).

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