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A Multichannel Feature-Based Approach for Longitudinal Lung CT Registration in the Presence of Radiation Induced Lung Damage

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INTRODUCTION

Understanding the relationship between planned radiotherapy (RT) dose and parenchymal tissue evolution is imperative in furthering the study of radiation-induced lung damage (RILD). Accurate tracking and quantification of local parenchymal tissue changes in the lungs is necessary for this purpose, but traditional intensity-based registration approaches fail in this task due to dramatic geometric changes between timepoints.

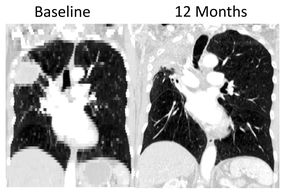

Figure 1: Baseline (left) and 12-month follow-up (right) scan of RILD patient. The tumour is in the upper right lobe in the baseline and in the follow up the upper right lobe has completely collapsed.

AIMS

To successfully register longitudinal pre- and post-RT lung CT scans with considerable anatomical changes due to RILD by extracting and registering only consistent anatomical features (lung boundaries, main airways, vessels).

METHODS

Fifteen pre-RT and 12-month post-RT CT pairs from lung cancer patients treated under a chemoradiation clinical trial were available, all with varying degrees of RILD, ranging from mild parenchymal change to extensive consolidation and collapse. Each patient dataset was placed into one of four categories of increasing expected difficulty of registration between the baseline and 12-month follow up scan.

For each CT, signed distance transforms from delineations of the lungs and main airways were generated and the Frangi vesselness was calculated. These feature maps were concatenated into multi-channel images and diffeomorphic multichannel registration was performed for each image pair.

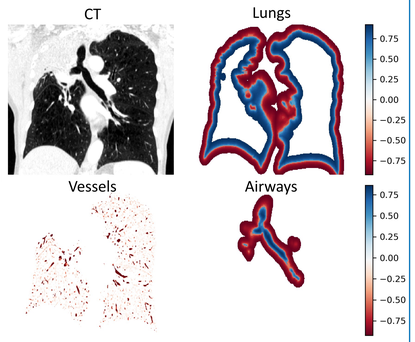

Figure 2: Feature images of patient dataset extracted from the CT.

For the evaluation, the pre- and post- registration landmark distance was calculated for all patients at a mean (range) of 44 (38-65) landmark pairs manually placed on vessel and airway bifurcations. Traditional intensity-based registrations were also performed for all patient datasets and evaluated in the same way as a comparison.

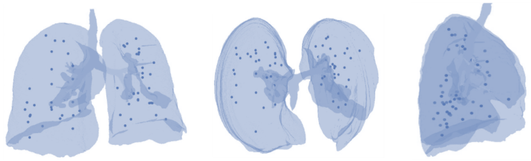

Figure 3: 3D rendering of the baseline lungs and main airways of patient dataset with landmark points

RESULTS

The mean (std) distance for all datasets and all categories decreased from 15.95 (8.09) mm pre-registration (D_{pre}) to 4.56 (5.70) mm post-registration (D_{reg}).

Qualitative improvements in image alignment were observed for patient datasets in all categories. The lung boundaries and main airways were remarkably well aligned even in the most difficult cases, but small-scale vessels and deeper airways could be misaligned in patients demonstrating extreme deformations.

In comparison, the D_{reg} of the traditional intensity-based registrations was higher, at 7.90 (8.97) mm. Registrations of patients with presence of atelectasis and extensive consolidation failed, producing highly implausible deformations such as the example presented in figure 6.

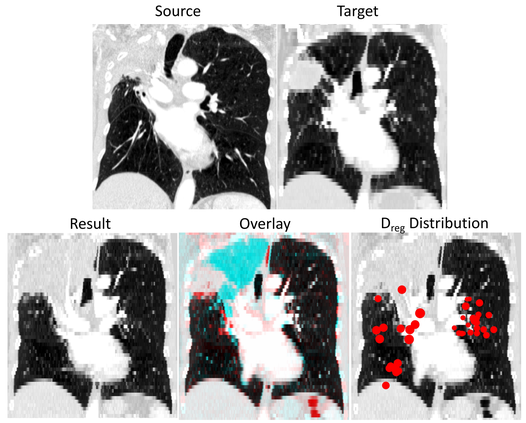

Figure 5: Coronal slices from source CT (12 month follow up), target CT (baseline), result CT, colour overlay of target (red) and result CT (cyan), landmark points displayed over the result CT (size of the landmark ∝ point magnitude of Dreg at that point).

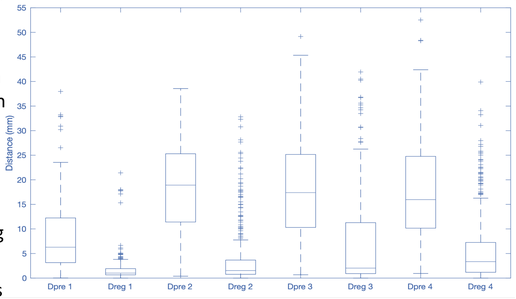

Figure 4: The distribution of pre- and post-registration landmark distance for each category presented in box plots.

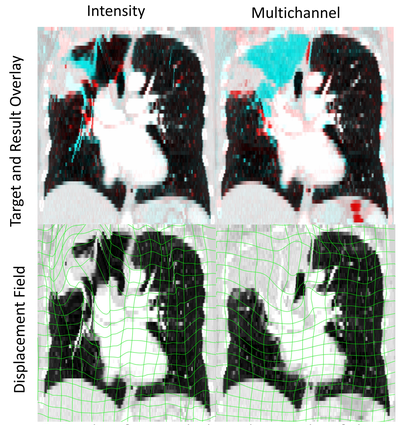

Figure 6: Results of our multichannel vs results of the intensity-based algorithm. The intensity algorithm has erroneously stretched the airway into the shape of the upper right lobe. In comparison, our multichannel algorithm has fully recovered the shape of the collapsed lobe with smooth and plausible deformations.

CONCLUSIONS

We have demonstrated that our registration method can successfully align 12-month follow up scans from RILD patients in the presence of large anatomical changes such as consolidation and atelectasis, outperforming the classical intensity-based registration approach both quantitatively and through thorough visual inspection. This is the first time that such registration accuracy has been achieved in baseline and 12-month follow-up pairs that exhibit extensive RILD-induced changes. The results are considered suitable for longitudinal tracking of parenchymal tissue changes post-radiotherapy.

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