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The impact of a Dixon sequence in creating a pseudo CT scan from MR images using a Gaussian mixture regression model

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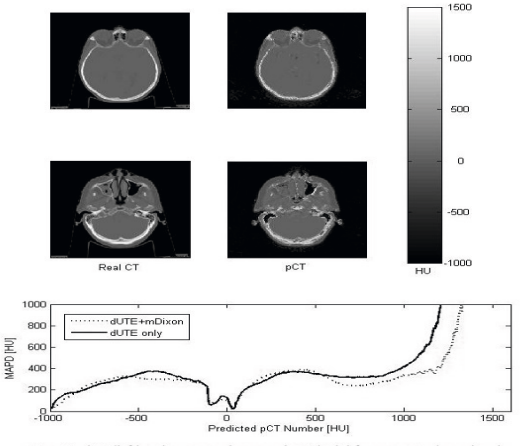
Purpose/Objective: For RT based on MRI only, a promising approach is to obtain a substitute CT scan from the MR images (a so-called pseudo CT, pCT) using a Gaussian mixture regression (GMR) model. The GMR model has previously been investigated on 3T MR images using a dual ultra-short echo time (dUTE) sequence and was shown to give sufficient information for training the GMR model. The dUTE sequence provides contrast between bone and tissue using dual echo times but at 1 T, chemical shift artifacts at the second echo time may cause voxels containing water and fat to behave like bone. The multiecho-Dixon (mDixon) MR sequence provides contrast between water and fat which could potentially remove this problem and provide valuable information for the GMR model. In this study, we investigate the robustness of the GMR model on predicting pCT scans from dUTE MR images of a 1 T scanner and how adding an mDixon sequence affects the generated pCT.

Materials and Methods: Head scans of 2 patients fixated for whole brain RT were acquired on a 1 T open MR scanner with flex coils. dUTE sequences were obtained at flip angles 10 and 25 degrees, respectively. Echo- and repetition times TE1/TE2/TR were 0.09/3.5 /7.1 ms with a voxel resolution of 1x1x1 mm and a 256 mm FOV. The mDixon was acquired with TE1/dTE/TR equal to 6.9/3.5/16 ms, a voxel resolution of 1x1x1.5 mm and a 250.5 mm FOV. CT head scans were acquired with a voxel resolution of 0.6x0.6x2 mm and a 220 mm FOV. The CT was registered to the high angle TE1 UTE using a mutual information algorithm and all MR scans were internally registered. All scans were resliced to the dUTE resolution and cropped to the smallest FOV. The MR images were low- and high-pass filtered creating two new images per filtered image. The MR images, their filtered counterparts and the CT image were considered as random variables and the voxel intensities a sample from their underlying distribution. A GMR model was initialized with 20 centers using k-means clustering and an EM algorithm was used to train the model on the data from one of the patients.The model was then applied on the other patient to generate the pCT. A model using only the dUTE images and one adding the mDixon images were trained.A comparison using the real CT to calculate the mean absolute prediction error (MAPD) of the pCT in bins of 20 HU was carried out.

Results: The pCTs of one patient using the extended model is shown in the figure. Qualitatively (upper images) and quantitatively (lower graph), the results are similar to those previously reported for 3T using dUTE only. A reduction in MAPD can be observed in the bone region(>500 HU) by adding mDixon to the model.



Top: Real CT (left) and corresponding pseudo CT (right) for a superior (upper) and inferior (lower) axial slice of the head. A HU grayscale is indicated on the far right. **Bottom:** The MAPD vs. pseudo CT in bins of 20 HU for the dUTE (solid) and the dUTE+mDixon (dotted) model.

Conclusions: The robustness of a GMR model on 1T MR images was demonstrated. The model was further expanded with an mDixon sequence which reduced the prediction error of predicted CT values >500 HU. Although a study based on larger amounts of data should be carried out, there is an indication that the mDixon sequence improves CT prediction from dUTE MR images.

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The introduction of simultaneous PET/MRI to radiotherapy planning

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Purpose/Objective: PET/CT aids target volume definition for many tumour sites including meningiomas. Recently simultaneous PET/MR (mMR) imaging has become available, but applications in radiotherapy planning are undefined. We performed a feasibility study using a Siemens Biograph 3T mMR for radiotherapy planning in meningiomas using ^{68}Ga-DOTATATE as PET tracer (binds to somatostatin receptors) and gadolinium (Gd) enhanced MRI.

Materials and Methods: Two phantoms (bespoke and Lucy) were scanned to assess image distortion and accuracy of mMR co-registration to planning CT. A customised flat acrylic baseboard compatible for mMR and CT was designed and manufactured in-house. Body surface coils were used in conjunction with the patient's thermoplastic (TP) radiotherapy head shell. A TP bridge was fitted over the shell to support the body surface coil. A healthy volunteer underwent mMR scan in the TP shell to establish tolerability (60cm bore scanner), shell durability(3T MRI) and anatomic clarity.

4 patients with meningiomas in different regions underwent mMR followed by PET/CT for radiotherapy planning.

mMR imaging protocol: Part 1 without TP shell (non-contrast T2 & diffusion = 35 mins), attenuation correction, immediately followed by Part 2 with TP shell (T1 -/+ Gd), DCEMRI, simultaneous PET images = 15 minutes). ^{68}Ga-DOTA (100MBq median) was injected prior to Part 1 to allow 40 minutes uptake before PET imaging in Part 2 (approx 50mins total in scanner). Patients had PET/CT scan approx 20 mins after mMR.

We assessed patient tolerability, software compatibility, biological target volume(BTV) on mMR and PET/CT, co-registration and PET SUV with and without the shell.

Results: Phantom work showed that co-registration and image distortion resulted in <1mm uncertainties in all regions assessed. The shell and baseboard were compatible with mMR, but attenuated PET signal 2.5-19% (increasing attenuation from anterior to posterior location). However, the shell increased co-registration accuracy (and would permit co-registration in the neck) and did not affect BTV delineation. Patients tolerated the protocol.

mMR images were incompatible with current planning software used for PET/CT BTV delineation. A complex solution involving a number of different software was developed. BTV was largely the same on mMR and PET/CT, but distinguishing tumour from the pituitary was clearer on mMR. In PET negative regions where standard MRI/ CT was suspicious for tumour, more complex MR sequences (e.g. diffusion) can be evaluated on the same slice on mMR, which may increase certainty about volume definition.

Conclusions: It is feasible to use mMR with ^{68}Ga-DOTA and Gd contrast for radiotherapy planning, although our current software pathway is complex and a simpler solution should be developed. Further study is required to establish if mMR permits more accurate BTV delineation. Use of mMR may reduce the overall numbers of scans as separate MRI is not required and there is potential for post-RT PET research. Scanning in shell improves co-registration but attenuates PET SUV.

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Impact of PET reconstruction algorithm on dose painting strategies

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Purpose/Objective: High FDG-uptake within a lung tumor is hypothesized to be an indicator of treatment resistance. Current treatment planning techniques are able to design dose distributions according to the FDG intensity within tumors, i.e. dose-painting strategies. Since the apparent FDG distribution in the PET image is dependent on PET reconstruction parameters, these parameters also