The Performance of Deep U-Net Pre-Clinical Organ-wise Segmentation in the Presence of Low Counting Statistics.

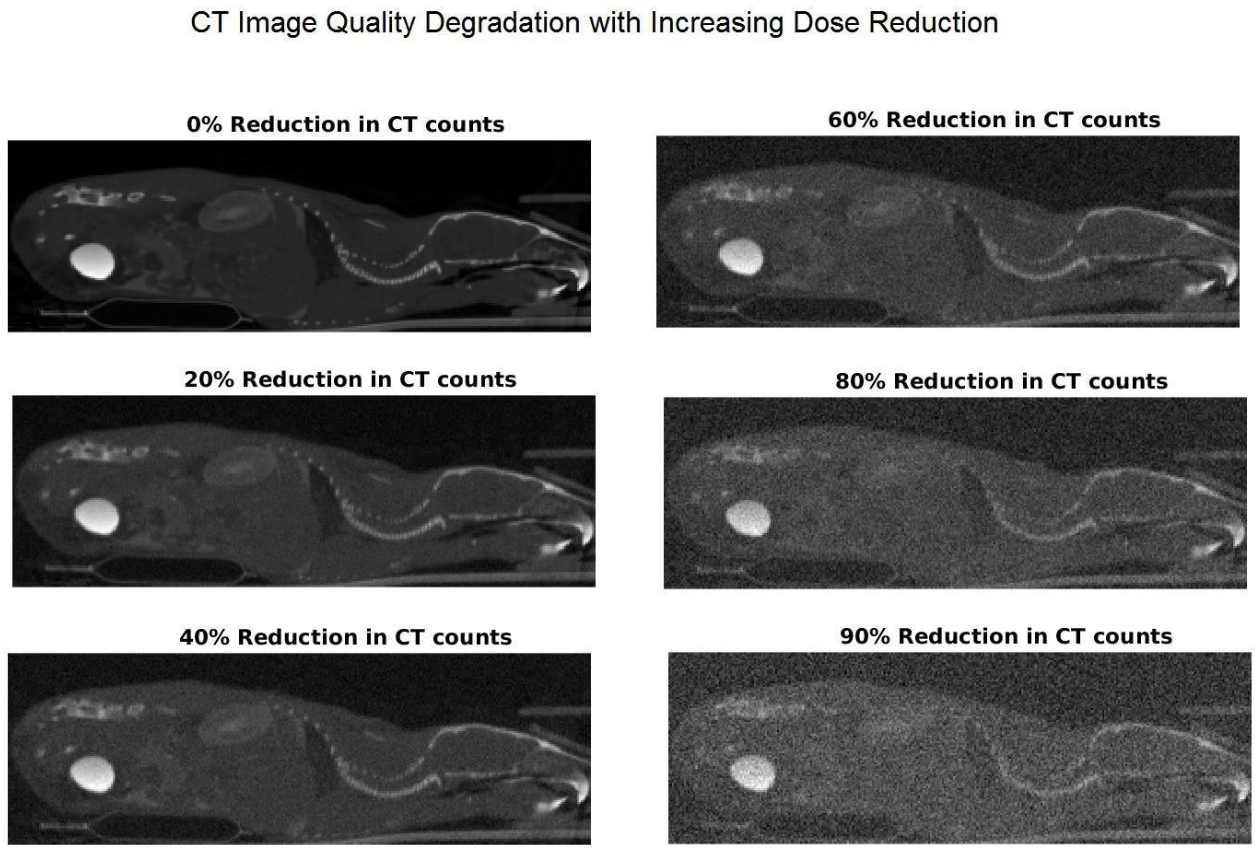
Aim

Micro-PET-CT allows non-invasive monitoring of biological processes, disease progression and therapy response. Morphological information provided by the CT allows organ / tissue delineation for subsequent quantification of the physiological information depicted by the PET. Deep learning with convolutional neural networks (CNNs) has achieved state-of-the-art performance for automated medical image segmentation and utilized successfully by our group in Micro-PET-CT (figure 1). The robustness of such approaches in the presence of noise addition / dose reduction of the CT data has not been explored. We thus simulate dose reduction of pre-clinical CT images using a Poisson noise model and evaluate the effect of segmentation performance with increasingly lower dose for 7 regions (skeleton, kidney, bladder, brain, lung, muscle and fat).

Materials and methods

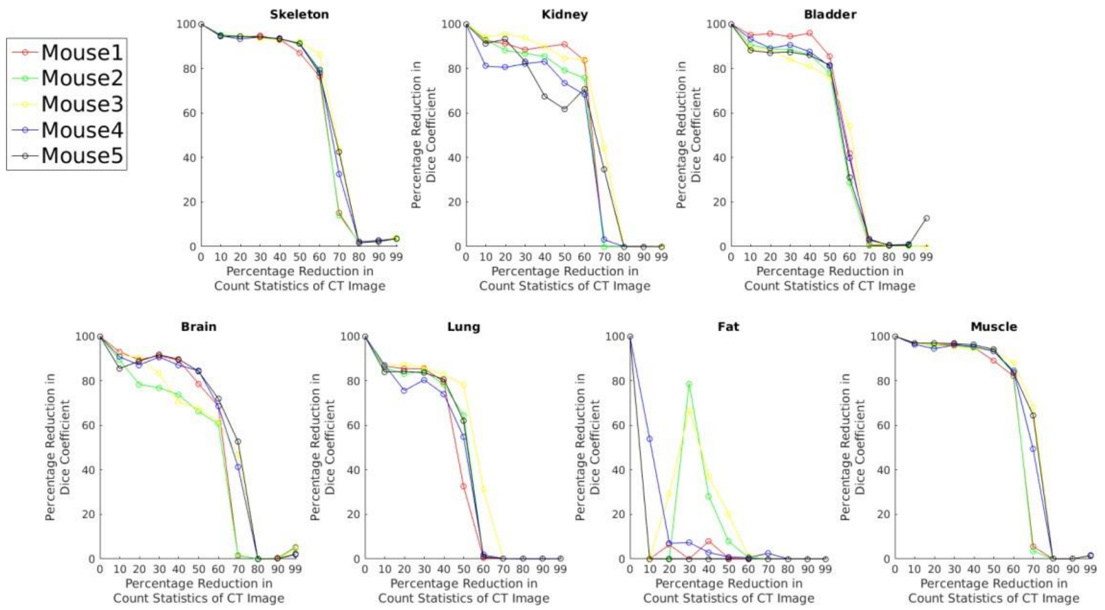
To investigate the performance of deep learning for organwise preclinical CT segmentation with incrementally reduced CT dose a CT dose reduction model was developed. Negating electronic noise and subject anatomy, variance in x-ray images may be asserted to quantum noise allowing a model for simulated image noise versus dose (mA) to be constructed. With a mono-energetic x-ray source the mean number of photons (N) incident on the detector is $N=N_o \exp(\text{-projections})$; N_o represents x-ray intensities. N is modelled as a Poisson process (λ=N) a term for the projection noise is thus $\log(N/N_o)$. Modulating No serves as a variable to control noise levels ($\sim 1/N_o$) in projections.

A linear relationship between image variance in a centralized region of an example image and $1/N_o$ was found. As image variance ~ 1/mA, systematically reducing N_o has the effect of simulating a percentage dose reduction in mA. Simulated dose reduction of 5 test cases (50kVp, 300mA, 0.25x0.25x0.25mm) was performed in the sinogram domain before reconstructing the noisy simulated CT images. Dose reduction was performed from 10% - 100 % in increments of 10%. Presented in Figure 2 is an example sagittal slice of a pre-clinical subject with increase dose reduction; this highlights clearly the effect on image quality when reducing CT dose. Test images using the incrementally reduced dose were segmented using our previously trained model for whole body preclinical image segmentation. The Dice coefficient of the six segmented regions (skeleton, kidney, bladder, brain, lung, fat, muscle) for each test case and each dose reduction was assessed allowing the performance of the segmentation model to be evaluated with reduced CT counting statistics.



Results

The percentage reduction in DICE from the ground truth serves as a measure of the reduction in performance of the segmentation with increasing noise. A 50% dose reduction was observed for all 5 test subjects to result in a mean (across all 7 organs) percentage reduction in DICE <25%. The pattern in reduction in performance of segmentation as dose was reduced was similar for each tissue (figure3). This may have implications for utilizing reduced dose CT coupled with a deep CNN for segmentation if the CT component is used to anatomically locate physiology on PET data.



Conclusion

This work evaluates the performance of a pre-trained deep model for organwise segmentation using CT data in the preclinical model with increase dose reduction. It can be observed that the accuracy of the segmentation measured by the DICE coefficient falls off as we simulate the reduction of CT dose. A 50% dose reduction was observed for all 5 test subjects to result in a mean (across all 7 organs) percentage reduction in DICE <25%. Adequate performance however is still observed in the DICE coefficient with a dose reduction of 30%, only an average of ~10% reduction in DICE is observed. This may have implications for utilizing reduced dose CT coupled with a deep CNN for segmentation if the CT component is used to anatomically locate physiology on PET data.