# Cross-validation log-likelihood regularization strength optimization in penalized likelihood reconstructions for total-body and conventional PET

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## Introduction

The penalized likelihood (PL) reconstruction algorithm is capable of suppressing image noise by its regularization term and hence can be used in low-dose and short scan time imaging. The regularization strength in the PL reconstruction is typically determined empirically. A cross-validation log-likelihood (CVLL) method was proposed to select the optimal regularization strength [1]. This study focuses on realizing the UC Davis in-house image reconstruction [2] and validating and comparing the CVLL method for total-body imaging with the uEXPLORER (United Imaging Healthcare), and conventional imaging with the Biograph mCT (Siemens Healthineers).

## Methods

**CVLL method**

- Step 1: reconstruct PET images using PL reconstruction and different regularization strength $\beta$ values;
- Step 2: select a $\beta$ by maximizing a CVLL function, the likelihood function of the images reconstructed using one subset of a list-mode dataset, based on another subset of the same dataset.

**In-house PET image reconstruction**

- Time-of-flight ordered subset expectation maximization reconstruction algorithm;
- CT-based attenuation, component-based normalization, singles-based random correction [3];
- Single scatter simulation scatter correction for the mCT, and Monte Carlo scatter correction for the uEXPLORER;
- 200×200×220 4.054-mm voxels for mCT images 239×239×679 2.85-mm voxels for uEXPLORER images.

**Method implementation**

- A lung cancer patient underwent a uEXPLORER scan at 60 min and then an mCT scan at 90min, after an intravenous injection of 213 MBq FDG;
- The method was tested on 150 s to 20 min mCT scans, and 19 s to 10 min uEXPLORER scans, using 2 min long data irreplaceably resampled out of the 22 min scan dataset for cross-validation.

## Results

- The optimal $\beta$ values were found to be 1000, 10, 0 and 0 for 75, 150 s, 5 and 10 min uEXPLORER scans, and were 300, 100, 30 and 0 for 150 s, 5, 10 and 20 min mCT scans.
- Optimal $\beta$ values for the 19 and 38 s uEXPLORER scans were not found in the range investigated.
- The contrast-to-noise ratio (CNR) between lesion and liver was estimated for different scan durations and $\beta$ values. The optimal $\beta$ values that maximize the CNRs are not perfectly consistent with those found by CVLL method.

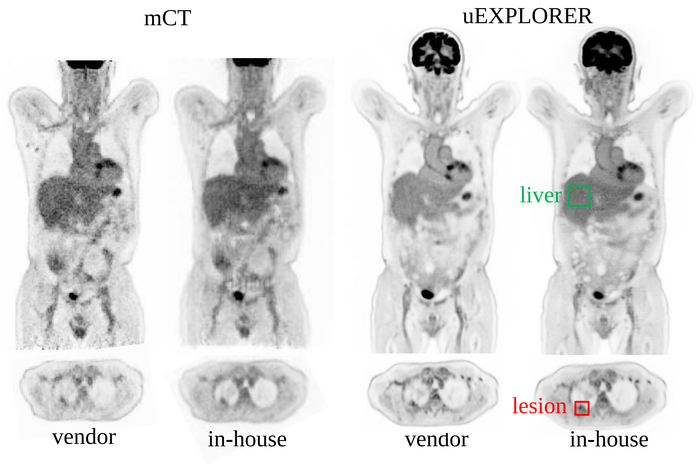


Fig. 1. Comparison of in-house with vendors' reconstructed images for conventional PET (mCT) and total-body PET (uEXPLORER) .

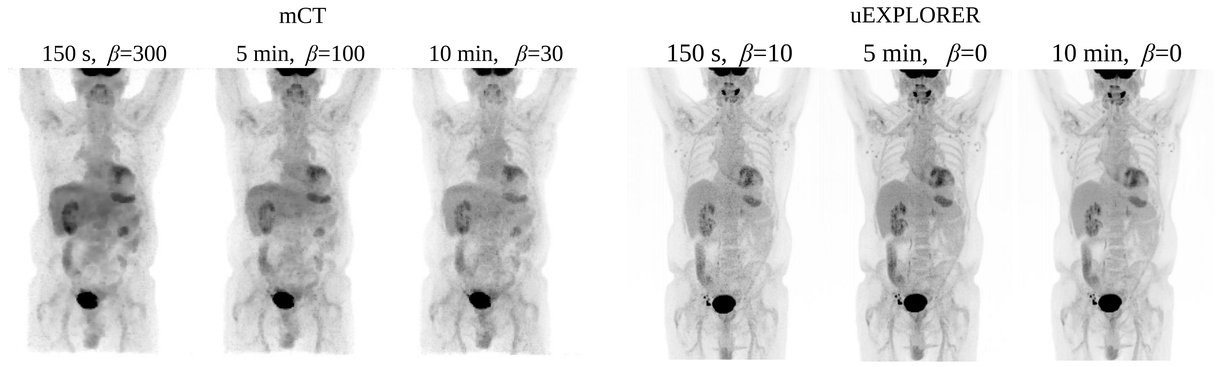


Fig. 2. Maximum intensity projections of the in-house reconstructed human (lung cancer patient) images of different scan durations using the optimal regularization strengths $\beta$ for the mCT and uEXPLORER, respectively.

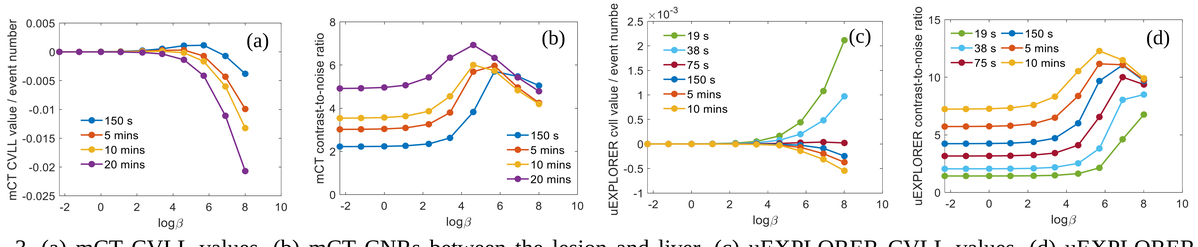


Fig. 3. (a) mCT CVLL values, (b) mCT CNRs between the lesion and liver, (c) uEXPLORER CVLL values, (d) uEXPLORER CNRs between the lesion and liver for different scan durations and $\beta$ values.

## Summary

- The in-house human images of conventional and total-body PET were reconstructed.
- The optimal regularization strength $\beta$ values were found for different scan durations using the CVLL method for both PETs.
- The CVLL value and CNR as the functions of $\beta$ values for different scan durations were compared for both PETs.

## Conclusions/Further Study

We implemented the CVLL method to optimize the regularization strength $\beta$ for total-body and conventional human PET imaging. The optimal $\beta$ were selected for short scans with different durations. This method will allow us to explore the limits of PET imaging in terms of the scan duration, delayed scan times and administered radioactivity, and broaden the clinical and research applications of PET. Specific applications of this knowledge include optimizing image quality for very short scans for pediatric patients who would otherwise need anesthesia, and very low dose scans for vulnerable populations and longitudinal studies. The proposed method will be further validated in total-body and conventional PET imaging of different cancer patients.

## Acknowledgements

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## References

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