Abstract

Cerebral Blood Flow Measurements Using Carotid Artery Image-Derived Input Functions in Positron Emission Tomography

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2013

Positron emission tomography (PET) can be used to image the distribution and kinetics of radioactive compounds of interest in the tissues of the body. In order to fully characterize the time-activity curves (TACs) of these tissues using kinetic modeling techniques, the blood radioactivity curve or input function is necessary. Such data are normally acquired by arterial sampling through catheterization with corrections for delay and dispersion to account for the distant sampling site. The internal carotid arteries that supply the brain are often visible in brain PET images when using the High Resolution Research Tomograph (HRRT). To avoid arterial blood sampling, it is desirable to develop a method involving an image-derived input function (IDIF) using such a blood pool visible in the PET images.

Our objective was to first devise a method for extracting an IDIF from the carotid arteries in images reconstructed from data collected on the HRRT utilizing anatomical information available from co-registered magnetic resonance (MR) images. We specifically sought to segment the carotid arteries in T1-weighted MR images and then transfer this information to the PET images to extract carotid TACs. Finally, we sought to calculate absolute cerebral blood flow (CBF) values from [^{15}O]water PET images using the IDIF. We have devised a method of delineating the internal carotids in co-registered MR images using the level-set method and applying the segmentations to PET images using a novel centerline approach. Centerlines of the segmented carotids were modeled as cubic splines and re-registered in PET images summed over the early portion of the scan. Using information from the anatomical center of the vessel minimizes partial volume and spillover effects. A scale factor correction was derived for calculation of cerebral blood flow (CBF) using gold standard arterial blood measurements. We

have applied the method to human subject data from multiple injections of [^{15}O]water on the HRRT. We demonstrated that re-registration resulted in higher and more consistent recovery measured by the ratio of the area under the curve to the arterial input function. We have also demonstrated the feasibility of both subject-specific and global population-based scale factors when computing CBF with IDIF. Between-subject variability decreased in the case of the global scale factor, whereas within-subject variability was increased in all cases.

This dissertation then addressed the issue of reducing within-subject variability introduced by use of the IDIF. The estimation of activity in small PET regions of interest (ROI) is complicated by the partial volume effect (PVE) and noise. This is particularly relevant for applications such as IDIF for brain PET using the internal carotid arteries. We specifically sought to develop a method to introduce anatomical information into PET reconstruction to compensate for both noise and PVE. We relied on the assumption that the carotid region is homogeneous in activity and that enforcing this homogeneity in reconstruction should reduce noise. We have developed a method for incorporating anatomical information about the carotid arteries, in the form of modeled centerlines, into a maximum likelihood expectation-maximization (MLEM) reconstruction algorithm for PET. Carotid centerline and annular regions were defined in PET images and single activity values for each ROI estimated. Areas outside these targeted regions were reconstructed in the typical fashion of a uniform voxel grid. Three variants of the ROIs were tested with both simulated list-mode data and real human subject data from [^{15}O]water PET studies. The variants employed different combinations of pre-defined uniform regions. IDIFs were extracted from the carotids in images generated using the region-based reconstruction methods. These IDIFs were scaled as before using CBF values calculated from arterial blood measurements. Region-based reconstruction methods generally showed lower within-subject variability in CBF estimates when compared with reconstruction using a standard uniform grid of voxels.

Finally, we sought to address the issue of characterizing the apparent recovery coefficient of our centerline model. We specifically examined the relationship between recovery coefficient and diameter at different contrast levels relevant to IDIF estimation. A phantom was designed with multiple hollow tubes of different diameters suspended in a background region. The phantom was tested on the HRRT with varied foreground and background radioactivity concentrations to assess different contrast levels.

This dissertation demonstrates a novel IDIF method for brain PET CBF studies based on MR-defined carotid artery centerlines. We have also introduced a partial volume correction in the reconstruction to improve within-subject variability for our method compared to application of the method to images reconstructed with our standard EM algorithm. We finally assessed the relationship between measured diameter and the apparent recovery coefficient of centerlines in carotid-like structures.