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Initial experence in small animal imaging with clinical PET/CT scanner

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Molecular Imaging is an emerging discipline that seeks to exploit our increased understanding of the molecular basis of disease through the design of novel imaging probes to specific molecular targets. Small animal PET offers the unique opportunity to in vivo image small animal models of human diseases noninvasively, repeatedly, and quantitatively in the same animal. Unfortunately, small animal PET scanner is not widespread and needs to additionally acquire anatomical image data (CT or MRI) to facilitate the precise target definition, which yields the need to seek for the alternative methods to deal with the problem. With the unique ability to acquire registered CT and PET images in the same scanner and provide clinical use and basic research, combined PET/CT scanner might be the potential option for small animal study. In addition, the CT-based attenuation correction can improve the overall visual quality and the quantitative accuracy of the radionuclide image data. Moreover, PET/CT images using a large-bore clinical scanner enables high-throughput studies to evaluate the performance of PET tracers in a timely and cost-effective manner by imaging multiple animals simultaneously. Dual-modality PET/CT imaging has had its great impact; however, the feasibility of PET/CT scanner which is developed for human imaging still needs to be concerned. Because of insignificant outcome and even producing much more noise, attenuation correction (AC) is not usually performed in microPET. In clinical PET/CT, it always adopts CT-based AC maps to improve image quality. However, the effect of AC technique on small animal imaging is still unknown. The main objective of this study is to investigate the effect of CT-based attenuation correction on performance of clinical PET/CT. We also proposed several CT imaging protocols in PET/CT system to investigate image quality of PET images and explore the performance difference between clinical PET/CT and microPET.

The feasibility tests are taken on PET/CT scanner (Discovery LS; GE Medical Systems) and small animal PET (microPET R4) with costumed cylindrical and uniform phantom. Regarding the demand for single mouse and multiple mice image applications, different FOV settings were selected. Three different CT protocols, CT high resolution model (CT-H-RES), CT auto fusion model (CT-auto) and CT attenuation correction model (CT-AC) were employed. The scanning parameters for CT-H-RES were: field of view 15×15 cm2 for single rat scan 25×25 cm2 for multiple rat high throughput scan, matrix size 512×512, slice thickness/interval =0.625/0.625 mm, number of slice = 2, helical pitch = 1. For CT-auto, the parameters were: field of view 50×50cm2, matrix size 256×256, slice thickness/interval =5/4.25 mm, number of slice =4, helical pitch = 0.75. For CT-AC, the parameters were: field of view 15×15 cm2 for single rat scan; 25×25 cm2 for multiple rat high throughput scan; 50×50 cm2 for CT-auto model, matrix size 512×512, slice thickness/interval =5/4.25 mm, number of slice = 4, helical pitch = 0.75, and coverage = 150 mm covering the whole phantom or rat. We use 80 kV and 300 mA for all scanning protocols. A cylindrical and uniform phantom was used to evaluate the performance of PET/CT including resolution, uniformity, and signal to noise ratio. The cylindrical hot spot phantom contains 4 by 4 cylindrical matrix in different bore size: 3, 2.5, 2, 1.75, 1.5, 1 mm to validate clinical PET/CT resolution level. Another cylindrical hot spot phantom containing various bore size from 2.6 to 1.2mm was used to investigate the resolution characteristics of microPET. To evaluate uniformity and signal to noise ratio of clinical PET/CT and microPET scanner, we constructed a homogeneous phantom at small animal size consisting of a hollow acrylic cylinder, 5.8 cm in inner diameter and 2.2 cm in height. In this study, we also inspect the intrinsic spatial resolution based on NEMA NU-2001 standard (National Electrical Manufacturers Association). The full width at half maximum (FWHM) and full width at tenth maximum (FWTM) are used to characterize the spatial resolution.

The PET images in resolution, uniformity, and signal to noise ratio under our protocol are evaluated. In single animal scan with CT-based attenuation correction: the spatial resolution = 2.5mm, signal to noise ratio = 27, Uniformity = ±8.5%; compared to without attenuation correction: the spatial resolution = 2.5mm, signal to noise ratio = 13, Uniformity = ±15.6%. In multiple animals scan with CT-based attenuation correction: the spatial resolution = 3mm, signal to noise ratio = 29, Uniformity = ±7.4%; compared to without attenuation correction: the spatial resolution = 3mm, signal to noise ratio = 15, Uniformity = ±14.3%. In the without CT-based AC protocol, we observed that resolution and signal to noise level did not reduce significantly, but image uniformity did reduce obviously. The resolution, uniformity and signal to noise ratio of microPET image is about 1.8mm, 8.5 %, and 27, respectively. Following NEMA NU-2001 in spatial resolution, the resolution is characterized by the FWHM and the FWTM levels of the reconstructed PSF in the 3 orthogonal directions (e.g., radial, tangential, and axial direction). This allows a best-case evaluation of scanners, taking into account the variation in resolution with radial distance which was chosen by different purpose with FOV. Here we summarized the transverse and axial resolution at various positions. Spatial resolution represented as FWHM at center of scanner: Axial resolution is 14.64mm, Transverse resolution is 5.49mm; and represented as FWTM: Axial resolution is 21.41mm, Transverse resolution is 8.95mm. At off center of scanner about 7.5cm which is to indicate side resolution at 15×15 FOV which represented as FWHM: Axial resolution is 15.14mm, Transverse-radial resolution is 5.91mm, Transverse-tangential resolution is 5.79mm; and represented as FWTM: Axial resolution is 21.93mm, Transverse-radial resolution is 9.31mm, Transverse-tangential resolution is 9.55mm. At off center of scanner about 12.5cm which is to indicate side resolution at 25×25 FOV which represented as FWHM: Axial resolution is 17.57mm, Transverse-radial resolution is 6.65mm, Transverse-tangential resolution is 5.80mm; and represented as FWTM: Axial resolution is 20.29mm, Transverse-radial resolution is 6.65mm, Transverse-tangential resolution is 9.27mm.

In this study, we have found that the overall image quality from the microPET scanner is superior to those from the PET component of PET/CT scanner due to smaller crystals and smaller detector ring diameters. Note that the difference is not quite significant. From the scanning protocol aspect, we observed that the image quality under the multi-mice scanning protocol was as well as those under single-mouse imaging protocol suggesting that high-throughput studies may be feasible with the reliability we demand. However, if high resolution images are vital, the multi-mice scanning protocol was not highly recommended to use because of the relatively lower resolution resulting from the off-center effect and relatively large FOV. Considering the effect of CT-based attenuation correction, we have found that corrections for photon attenuation are important to improve the image uniformity characteristics either in single-mouse or multi-mice protocol setting. In summary, although clinical PET/CT scanner can not compete with microPET scanner especially in spatial resolution due to the intrinsic geometry designs, the combined CT can bring about several possibilities in research application such as high-throughput studies. In addition, the precise fusion of molecular PET images with high-quality anatomical CT images facilitates anatomic localization of the PET findings, overcoming alignment problems due to internal organ movement, variations in scanner bed profile, and positing of the patient for the scan, which is often encountered with techniques that register images obtained from 2 separate systems. Furthermore, the CT-based attenuation correction can improve the recognition of radionuclide imaging and potentially the quantitative accuracy of the reconstructed image. Finally, considering all the advantages, clinical PET/CT imaging might be potential technique for small animal study.

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