

# Photon Attenuation Correction in Misregistered Cardiac PET/CT

A. Martinez-Möller<sup>1,2</sup>, N. Navab<sup>2</sup>, M. Schwaiger<sup>1</sup>, S. G. Nekolla<sup>1</sup>

<sup>1</sup>Nuklearmedizinische Klinik der TU München

<sup>2</sup>Computer Assisted Medical Procedures and Augmented Reality, TU München

Email: a.martinez-moller@lrz.tu-muenchen.de

**Abstract.** PET-CT misalignment has been reported as a source of artefacts in cardiac PET/CT due to a biased photon attenuation correction. Using the data from 28 cardiac PET/CT rest/stress examinations, PET-CT misalignment was corrected using three different methods: manual registration, automatic mutual information based image registration and an emission-driven correction algorithm. The clinical effects of the realignment were quantitatively assessed, and significant changes were observed in 6 out of 28 examinations (21.4%), in 5 of these studies resulting in the disappearance of large apparent perfusion defects. These results indicate that the excellent specificity of PET for the detection of perfusion defects could be compromised when CT-based attenuation correction is done without correction of PET-CT misalignment.

## 1 Introduction

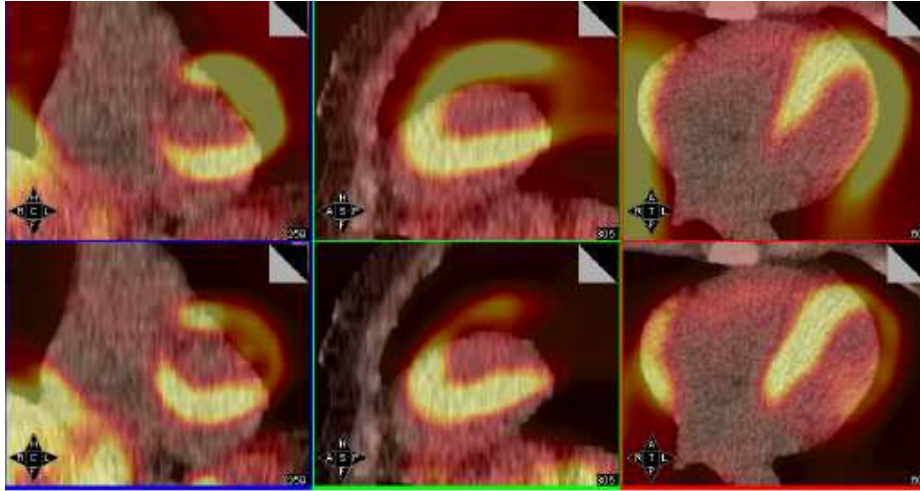
Positron emission tomography (PET) is a functional imaging technique which provides volumetric images of the distribution of a radiotracer in the body. This is achieved through the detection of 511 keV photons produced by the annihilation of positrons emitted by the radiotracer. However, only a fraction of the photons is being detected, as a significant part is being *attenuated* (either scattered or absorbed) through interactions within the body, according to the following formula:

$$A = A_0 \exp^{-\int \mu(x) dx} \quad (1)$$

where  $A_0$  is the flow of initial photons,  $A$  the flow of photons which go through the trajectory without suffering attenuation, and  $\mu$  the coefficient of attenuation for each of the body regions within each photon's trajectory. Therefore, a correction for photon attenuation is necessary for accurate quantification of PET images. This is done through the obtention of attenuation maps containing the coefficient  $\mu$  for each part of the body [1]. Since the introduction of combined PET/CT scanners, the attenuation map is usually computed by a bilinear scaling of X-ray tissue radiodensity as measured using CT [2].

One fundamental assumption of the attenuation correction is the accurate spatial registration of the PET emission data and the attenuation maps. However, even when using combined PET/CT scanners, a potential misregistration

**Fig. 1.** On the top row, fused PET/CT examination without attenuation correction showing a clear misregistration. On the bottom, the same examination after attenuation correction. A notable decrease of activity is observed in the misregistered areas of the myocardium due to a biased attenuation correction



can be found between both modalities as a result of non simultaneous acquisition and differences in temporal resolution between PET and CT. Such a misregistration can lead to artefacts in the attenuation corrected PET image, as can be seen in Fig. 1.

## 2 State of the art and new contribution

To our knowledge, no studies have reported on the effects of the misregistration for cardiac PET/CT yet. In contrast, the problem of emission-transmission misalignment in cardiac imaging -due to pharmacological stress, patient breathing or other patient motion- has been previously investigated using PET with rotating sources [3, 4], SPECT [5] and SPECT/CT [6].

This work provides new information regarding frequency and extent of cardiac PET-CT misregistration, evaluates the clinical impact of such a misregistration due to artefacts caused by biased photon attenuation correction, and proposes potential solutions to minimize these artefacts.

## 3 Methods

28 consecutive patients (20 men and 8 women, age  $63 \pm 12$ y) with suspected coronary artery disease (CAD) were enrolled in this study. All patients had been referred for a cardiac PET/CT rest/stress perfusion study to evaluate the functional impact of CAD. Imaging was performed on a Siemens Biograph 16 PET/CT (Siemens Medical Solutions, Erlangen, Germany).

Transmission data for the thorax were acquired with a low-dose CT scan (120 kV, 26 mA) performed in shallow breathing. After that, patients received a 300 to 500 MBq injection of  $^{13}\text{N}$ -labelled  $\text{NH}_3$  and the PET image was acquired for 10 minutes. Image data from 5 min p.i. to 10 min p.i. was summed and used for further analysis.

### 3.1 PET-CT registration

In order to investigate the clinical effects of PET-CT misalignment we sought to remove the misregistration by realigning the CT to the PET and repeating the PET reconstruction with the aligned CT-based attenuation map. For this purpose, a registration program was developed using IDL (Interactive Data Language, RSI Inc. Boulder, CO, USA), allowing three different possibilities to realign the PET and CT examinations: manual registration (only translational motion allowed), automatic mutual information based registration (exhaustive search within the translational space), and an “emission driven” correction method to modify the heart outline based on the PET data.

The emission driven correction is an in-house developed method based on the following assumption: if there is tracer uptake corresponding to the left ventricle (LV) in the PET image, the corresponding voxel in the CT should contain cardiac tissue. However, in case there is an inconsistency and the voxel contains lung tissue and therefore nearly no attenuation, the value of the voxel is modified to match that of cardiac tissue. As this operation was only to be applied in the LV, a fully automatic segmentation of the LV from the PET scan was required, and performed by means of a spatially localized thresholding, as the LV has always high  $\text{NH}_3$  uptake. The segmentation and modification of the attenuation map required less than one second runtime using a standard personal computer.

For each PET examination, all three realignment techniques mentioned above were separately applied, and the PET raw data was reconstructed again using each of the realigned CT. The tracer uptake was quantified before and after realignment by spatially sampling the left ventricle and projecting the measured activity on a polar map basis. The polar map was then divided in 17 segments according to the AHA17 model [7] and compared to a normal  $\text{NH}_3$  perfusion map. Segments where the uptake differed by more than 2.5 standard deviations were considered as perfusion defects.

## 4 Results

The average misalignment between the PET and CT datasets assessed by manual registration was  $6.1 \pm 6.3$  mm. The spatial distribution of the motion was as follows: left-right  $1.3 \pm 2.2$  mm (range: 0 - 5.1 mm), anterior-posterior  $1.6 \pm 2.9$  mm (range: 0 - 15.4 mm), head-feet  $4.7 \pm 6.1$  mm (range: 0 - 23.6 mm). Head-feet motion represented the major component of the misalignment, in agreement with the main direction of the breathing motion. The maximum value of the misalignment for an examination was 29 mm.

The defect size as quantified by comparison to a normal database changed by more than 10 %LV in 6 out of 28 patients (21.4%), all of them following a manual realignment greater than 10 mm. In 5 of the 6 patients, the perfusion defect - which ranged between 15 and 46 %LV- was fully artifactual and disappeared after reconstruction with the realigned CT-based attenuation map.

Automatic mutual information based image registration was not successful for the registration of PET and CT cardiac images. The effects of a misaligned heart in the were largely compensated by a reasonably well aligned thorax, so that the registration indicated that the original pose was always the best alignment. Subsequently, we tested a more regional approach by applying the registration to a manually defined volume of interest around the heart. Unfortunately, this technique did not produce better results, as the low correlation between the functional information provided by PET and the anatomical detail provided by CT made mutual information fail, being incapable of properly assessing the agreement between both poses when limited to the cardiac region only.

The emission-driven method had results equivalent to those obtained by manual registration. The correlation between the variation of measured uptake produced by both methods was high ( $R^2 = 0.74$ ,  $p < 0.001$ ) and good agreement was seen for large misregistration-induced defects.

## 5 Discussion

The results in this study indicate that PET-CT misregistration occurs frequently in cardiac perfusion studies and can have important clinical consequences. Changes of the defect size larger than 10% of the myocardium were observed in 6 out of 28 patients (21.4%), fact which which could compromise the otherwise excellent specificity of PET for the detection of perfusion defects.

Realignment of CT to PET and repetition of the PET reconstruction minimizes the artefacts induced by a biased photon attenuation correction. Although automatic registration would be the optimal approach, we obtained disappointing results for the cardiac region, indicating that manual registration is the only solid option. Alternatively to manual registration, the proposed emission-driven correction yielded equivalent results, having the advantages of being fast and fully automatic.

## References

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