Accuracy of CT-Based Attenuation Correction in Bone Imaging with PET/CT

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***Abstract*–PET/CT has become the most comprehensive diagnostic tool in oncology imaging providing improved lesion identification and localization. Bone is a common site of metastasis and the quantitative accuracy of PET images in bone tissue is important for assessing response to therapy. The use of CT images for attenuation correction is becoming a standard procedure in these scanners. However the impact of CT-based attenuation correction (CTAC) on the accuracy of PET tracer uptake values measured in bone has not been carefully evaluated, having only been carefully studied in soft tissue.**

We investigated the accuracy of CTAC on PET bone images by comparing the attenuation coefficients with PET transmission scans. For this, we imaged frozen bovine femur segments in a 20x20 cm cylindrical phantom. Different regions of the bones in both images were segmented by using thresholding and erosion methods to get equivalent volume masks. Differences in linear attenuation coefficients between the two images were then calculated. We repeated this analysis using patient images from the same patient imaged on the GE Advance PET scanner and the GE Discovery STE PET/CT scanner.

The impact of the errors in the linear attenuation coefficients on PET SUV measurements was evaluated by simulations using the patent images with known bone disease and elevated levels of FDG uptake in bone (e.g. SUV = 5) at disease sites. The impact of the errors in the linear attenuation coefficients was then estimated by forward projection and reconstruction, after including the effects of attenuation and attenuation correction.

I. Introduction

PET/CT has become the most comprehensive diagnostic tool in oncology imaging providing improved lesion identification and localization [1, 2]. An important synergy of PET/CT scanners is the use of the CT images for attenuation correction of the PET emission data [3-5]. The advantages of this approach are a less noisy image acquires in a shorter time than a standard PET transmission scan. However, the drawback of this technique is the potential bias due to the fact that CT data, which is acquired as a weighted average of photon energies ranging from approximately 30 to 120 KeV, has to be transformed to the estimate of attenuation coefficients at PET energies, that is 511 KeV [4, 5]. Several methods have been proposed to implement this conversion, being the simplest one a direct bi-linear or tri-linear scaling ([3-5] and Fig. 1).

Quantitative PET images of tracer uptake in bone tissue are potentially useful for oncologists, as bone is a common site of metastasis [6]. There are several works in the literature presenting results on the accuracy of the attenuation correction coefficients derived from CT images in soft tissue, with or without contrast agent (e.g. [5]) but the impact of CT-based attenuation correction (CTAC) on the accuracy of PET tracer uptake values measured in bone has not been carefully evaluated.

We investigated the accuracy of attenuation correction factors for bone derived from the CT image, comparing them with the ones obtained from the transmission PET, considered as a gold standard [5, 7]. For this we used a phantom made up with bovine femur segments and patient studies. The impact of the errors in the linear attenuation coefficients on PET SUV measurements was evaluated by simulations using patent images with known bone disease and elevated levels of FDG uptake in bone (e.g. SUV = 5) at disease sites. We also used simulation studies to evaluate the impact of variations of bone size, location, and composition.

II. Material and Methods

A. Conversion curves

The CT images were scaled to attenuation coefficients at 511 keV using the standard linear transform method [3-5]. The parameters used were based on the conversion curves supplied with the GE Discovery STE PET/CT scanner for contrast and without contrast. These curves are plotted in Fig. 1.

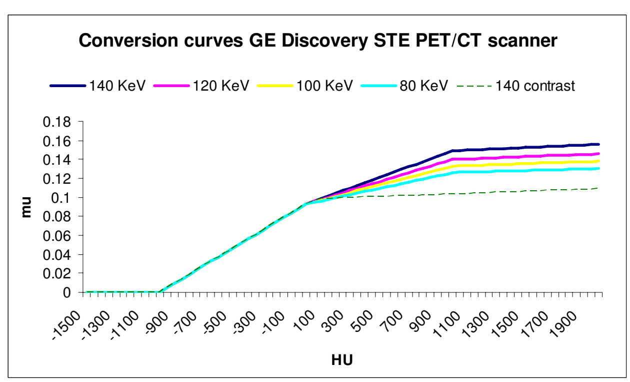

Fig. 1: Conversion curves used for scaling CT images to 511 KeV energy.

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B. Comparison of attenuation coefficients from CT and PET transmission scans

We investigated the accuracy of attenuation correction images derived from the CT image comparing the attenuation coefficients with the ones obtained from the transmission PET.

For this, we imaged frozen bovine femur segments in a 20x20 cm cylindrical phantom. The phantom contained three pieces of beef bone and a 5 cm diameter cylinder with dilute iodine-based contrast agent (Fig. 2). A 10 min PET transmission scan was obtained in the GE Advance PET scanner covering a FOV of 50 cm. Reconstruction was performed on a 30 mm FOV with an 2D-FBP algorithm applying a 5 mm Hanning window, obtaining a set of 65 4.25 mm-slices of 128x128 pixels of size 2.3 mm. A CT scan of the same phantom was obtained with a GE Discovery STE PET/CT scanner using 140 KeV and 200 mA. The attenuation coefficients from CT were extracted from a low pass filtered version of the CT image covering a FOV of 70cm, yielding a data set of 73 3.75 mm-slices with 512x512 pixels of size 1.37 mm.

The CT images were scaled to attenuation coefficients at 511 keV using the standard tri-linear transform method (using the same parameters as supplied with the GE Discovery STE PET/CT scanner) and interpolated to match the PET transmission resolution. The PET and scaled CT images were aligned manually as shown in Fig. 2.

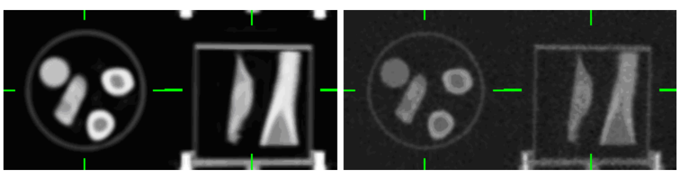


Fig. 2: Axial and sagittal views of frozen bovine femur segments bone in a 20x20 cm cylindrical phantom. Left: CT image (140 KeV and 200 mA) scan interpolated to match the PET transmission resolution after scaling attenuation coefficients to 511 keV using tri-linear transform. Right: 10 min PET transmission image at 511 keV used as a gold standard.

Different regions of the bones in both images were segmented by using thresholding and erosion methods to get equivalent volume masks (Fig. 3). Differences in linear attenuation coefficients between the two images were then calculated for each region.

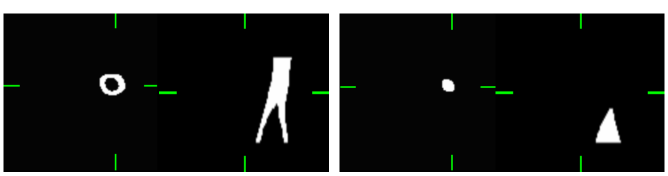


Fig. 3. Two of the six volume masks created using thresholding and erosion methods (left: hard bone tissue, right: marrow).

We repeated this analysis using images from the same patient imaged on the GE Advance PET scanner and the GE Discovery STE PET/CT scanner, using similar scan parameters to those listed above (Fig. 4).

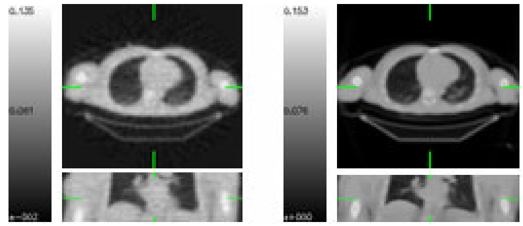


Fig. 4: Axial and coronal views of the 23 min PET transmission scan (left). Axial and coronal views of the CT image interpolated to match the PET transmission scan (right).

C. Evaluation of errors in simulated emission image propagated from CTAC

In a second experiment we used the same studies to evaluate the impact of error on the SUV values. For this, simulated images generated by thresholding in the CT image were forward projected and reconstructed including the effects of true attenuation, obtained from the PET transmission image (Fig. 5).

SUV values in emission images obtained when applying the true coefficients for attenuation correction were compared with those obtained when applying the coefficients with the errors found previously.

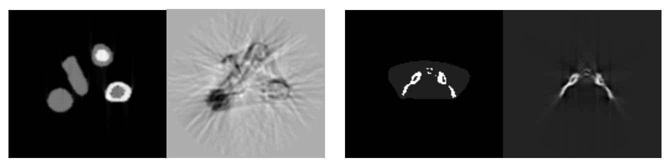


Fig. 5: Simulated emission object and difference between the emission image when applying the true coefficients for attenuation correction and the one obtained when applying the coefficients with the errors found previously for the bovine bone phantom corresponding to fig 2 (left) and patient data corresponding to fig 4 (right).

D. Real impact of errors in real emission image propagated from CTAC

The impact on PET SUV measurements of errors in the linear attenuation coefficients was evaluated by simulations using emission patient images with known bone disease and elevated levels of FDG uptake in bone (e.g. SUV > 5) at disease sites.

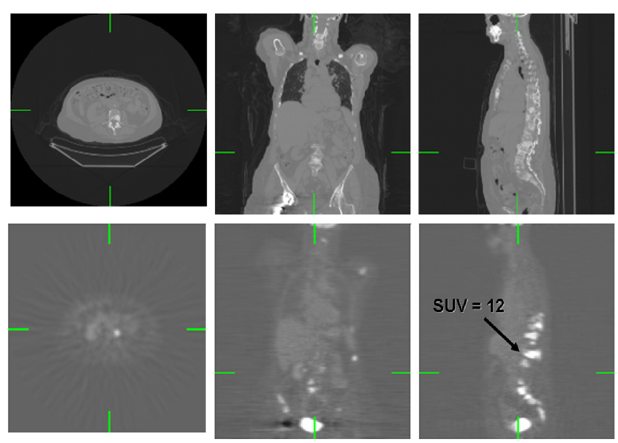


Fig. 5: Top: Axial, sagittal and coronal views of the 70 cm FOV - CT image. Bottom: PET images with elevated levels of FDG uptake in bone.

The impact of the errors in the linear attenuation coefficients was estimated by forward projection and reconstruction after including the effects of attenuation and attenuation correction.

Masks of the whole bone area and of different vertebrae were created by thresholding in the CT image (Fig. 6).

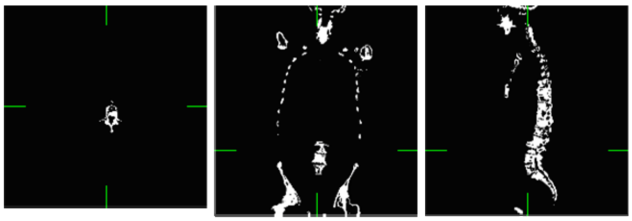


Fig. 6: Whole bone mask

III. Results

A. *Comparison of attenuation coefficients from CT and PET transmission scans*

Table I shows the results for the six 3D regions. Errors obtained for bone areas ranged from 1% to -4%. Values for regions with CT contrast agents present the highest errors as expected, since the conversion curves applied are intended for images without contrast. Results applying conversion curves for contrast lower these errors in contrast areas while increasing dramatically the error in hard bone areas. Therefore, for studies with contrast a different approach as dual energy methods or hybrid classification/scaling algorithm is advisable [3, 4, 8].

TABLE I
RESULTS WHEN GE DISCOVERY STE CONVERSION CURVES ('CTAC'= CT-BASED ATTENUANTIN CORRECTION, 'PET' = PET TRANSMISSION IMAGING AT 511 KEV).

	CTAC		PET		(CT-PET)/CT %
	mean	**sd**	**mean**	**sd**	
Hard bone top	0,149	0,003	0,155	0,011	**-3,74**
Hard bone bottom	0,148	0,004	0,153	0,013	**-3,11**
Marrow top	0,093	0,005	0,096	0,009	**-2,83**
Marrow bottom	0,094	0,005	0,097	0,010	**-3,58**
Left bone	0,114	0,011	0,113	0,014	**0,98**
Contrast	0,124	0,006	0,097	0,008	**21,69**

The same analysis using patient images showed differences between CTAC and PET transmission based measures on a linear attenuation coefficient values ranging from +2% to -2%.

B. *Evaluation of errors in simulated emission image propagated from CTAC*

The results indicated that the errors in PET emission SUV values (using the PET transmission image as a gold standard) ranged from +1 % to -4%, as shown in Table II.

TABLE II
IMPACT ON SUV VALUES OF THE ERROR IN THE ATTENUATION COEFFICIENTS 'ERROR SUV' = SUV WHEN CTAC IS USED RELATIVE TO PET TRANSMISSION SCANS)

	True SUV	Error SUV	Error %	Error PETAC – CTAC %
Hard bone top	7.770	0.349	4.488	-3.74
Hard bone bottom	6.376	0.283	4.444	-3.11
Marrow top	8.373	0.307	3.672	-2.83
Marrow bottom	10.355	0.344	3.320	-3.58
Left bone	6.650	0.266	4.006	0.98
Contrast	7.719	1.129	14.622	21.69

Simulation on the patient images showed 4% error in bone areas with SUV of 5.

C. *Real impact of errors in real emission image propagated from CTAC*

We studied the effect on the SUV values of an error in CTAC images of 3.84 and 1.9 corresponding to differences obtained in the previous experiments between the CTAC images and PET transmission scan. Table III shows the results.

Table III
IMPACT ON SUV VALUES OF THE ERROR IN CTAC

Region		SUV value	Error in AC 1.961		Error in AC 3.846	
			SUV err	**SUV err %**	**SUV err**	**SUV err %**
Vertebrae A	**Mean**	8.152	0.075	0.920	0.151	1.848
	Max	10.804	0.143	1.323	0.288	2.663
Vertebrae B	**Mean**	5.938	0.057	0.965	0.115	1.939
	Max	7.515	0.088	1.177	0.178	2.367
Vertebrae C	**Mean**	6.322	0.050	0.791	0.100	1.588
	Max	8.539	0.092	1.079	0.185	2.170
Hip	**Mean**	0.799	0.012	1.557	0.025	3.142
	Max	1.161	0.021	1.807	0.042	3.645
Whole	**Mean**	0.952	0.012	1.249	0.024	2.516
bone	**Max**	10.804	0.143	1.323	0.288	2.663

IV. Summary

We investigated the impact of inaccuracies in attenuation correction images derived from CT images on the PET emission values by comparing the results with the ones obtained using transmission PET data, traditionally used for attenuation correction. We used simulations with patent images with known bone disease and elevated levels of FDG uptake in bone (e.g. SUV > 5) at disease sites.

Differences in linear attenuation coefficients between the two methods ranged from +1% to -4% in the bovine bone phantom. The same analysis using patient images showed differences ranging from +2% to -2%.

For the error of ±2% in the patient bone alues, the corresponding errors in the FDG SUV values were ±1.5%. When the errors in the linear attenuation coefficients were changed to ±4%, corresponding to the bovine femur phantom study, the corresponding errors in the maximum FDG SUV values increased to only ±3 %. These results suggest that accurate PET tracer values in bone can be obtained with PET/CT studies using CT derived attenuation coefficients.

Small variations from tumour to background ratio (T/B), location and CTAC errors were also found based on simulation studies as shown in the Appendix A.

APPENDIX A: DEPENDENCE OF ERRORS WITH POSITION, CONTRAST AND TARGET SIZE

Bias introduced by incorrect estimation of linear attenuation coefficients dependent on position, contrast and target size was measured using computer simulations of an abdomen-sized object with a one circular test object as illustrated in the figure A.1. Results are shown in Fig. A.2, which indicate only small changes in SUV errors with position, contrast and target size:

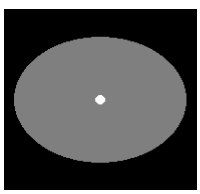
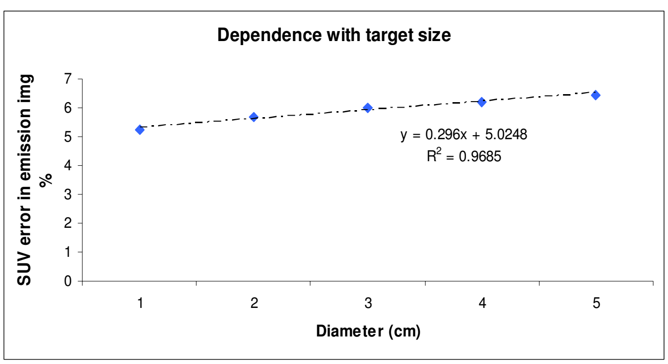
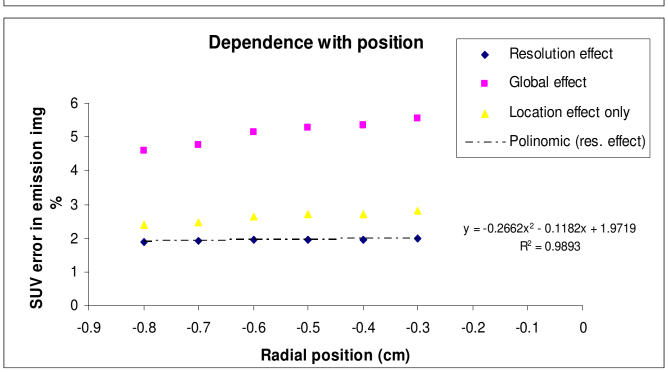
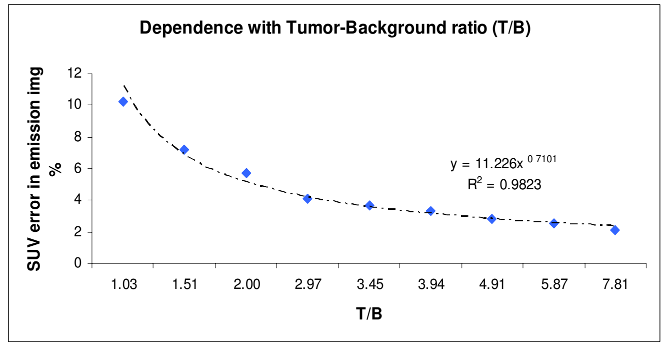
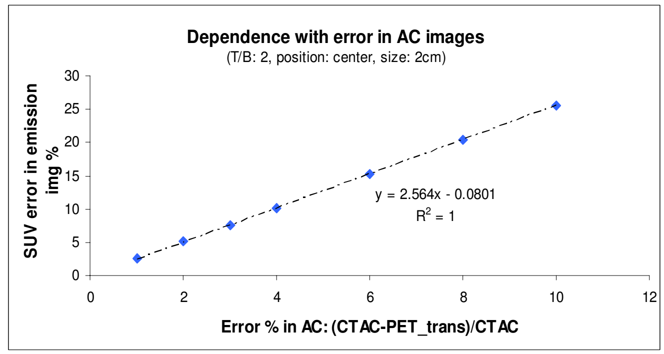


Fig. A.1: Abdomen-sized simulation test object.









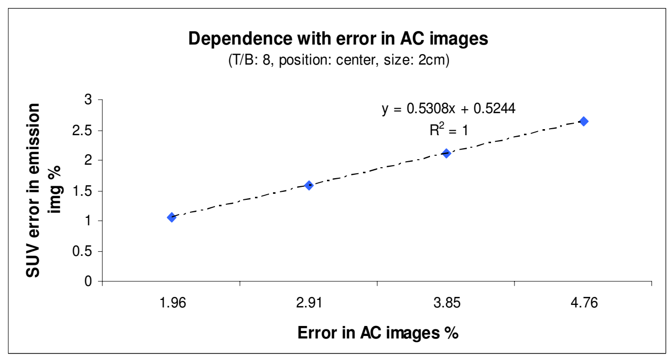


Fig. A.2: Variations on PET SUV values with changes in CTAC parameters.

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