Comparative Assessment of Different Energy Mapping Approaches in CT Based Attenuation Correction: a Patient Study

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Abstract — **Attenuation correction of PET emission data using spatially correlated CT images is fast and precise yielding a noise-free attenuation map (µmap) in comparison with radionuclide transmission scanning (TX). However, it is essential to convert the linear attenuation coefficients obtained from CT scans to those corresponding to 511 keV. Several conversion strategies have been developed including scaling, segmentation, hybrid and bilinear methods. The aim of this study is to compare the accuracy of different energy mapping methods for generation of 511 keV µmap using clinical studies. The procedure for generation of attenuation map from CT images using different energy mapping methods was assessed using clinical studies and the results compared to the TX image derived using Ga-68 rod sources acquired on the Discovery LS PET/CT scanner, were used as gold standard in this study. A region of interest analysis was performed at different locations of the µmaps. It was shown that for soft tissues, the relative difference of scaling, segmentation, hybrid and bilinear methods compared to TX technique were 11.3%, 9.2%, 11.3% and 10.8% respectively (no major difference). For bony structures, the quantitative analysis showed that the scaling method produces a substantial relative difference (31%). The relative difference of segmentation, hybrid and bilinear methods compared to TX were 29%, 14% and 18% respectively. However these results for lung tissue were 4%, 13%, 4% and 4% respectively for scaling, segmentation, hybrid and bilinear methods with a great difference for segmentation method. It can be concluded that for soft tissues all energy mapping methods give satisfactory results. For bone, the scaling and segmentation methods yield substantial relative differences but the other 2 methods give acceptable results. For lung tissue the results are approximately close to each other except for segmentation method.**

Keywords — **TX, Attenuation Correction, µmap, LAC**

I. Introduction

PET/CT scanners which combine anatomical and functional data are considered as a major advance in lesion detection in nuclear medicine imaging and treatment planning in radiotherapy [1]. Attenuation of photons in tissues degrades the visual quality of PET images therefore attenuation correction is one of the most important steps in PET image reconstruction. Attenuation correction of PET emission data using spatially correlated CT images is a fast and precise method which yields a noise-free µmap in comparison with radionuclide transmission imaging (TX) technique. It should be noted that CT images provide linear attenuation coefficients (LAC) of the tissues at effective CT energies (~ 60-80 keV) rather than 511 keV which is the energy of PET imaging, so it is necessary to convert the LAC at CT energies to those corresponding to 511 keV. Several energy mapping strategies have been proposed that convert the LACs of CT images to the LACs of 511 keV. These conversion methods include scaling [2], segmentation [2], hybrid segmentation/scaling [2] and bilinear. Bilinear method is the common utilized method in most commercial PET/CT scanners. The accuracy of the µmap has an important effect on the quality of the reconstructed PET image. Each of the energy mapping methods has their own drawbacks and so far no comprehensive assessment of all these methods has been performed: existing published studies [2], [3] merely involve the comparison of two or three of these methods and not all methods. In present study the accuracy of different 511 keV µmaps generated using different energy mapping methods from clinical CT image were evaluated through comparison with gold standard µmaps of the patients obtained by TX imaging. It should be noted that our previous publication was based on a phantom study [4] but here we try to evaluate our results on clinical images.

II. Materials And Methods

A. Energy Mapping Methods

For generating 511 keV µmaps for CT based attenuation correction of PET data a number of conventional energy mapping methods are used which include scaling, segmentation, hybrid (scaling/segmentation), and bilinear method. In all of the energy mapping methods attenuation correction requires accurate conversion from CT numbers to

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LACs at 511 keV. In the following, a short description of these methods is presented.

Scaling: In the scaling method, it is assumed that the ratio of LAC of a tissue at any two energies is a constant and hence 511 keV μmap is formed by multiplying the CT image by the ratio of LAC of water at CT and PET energies [2].

Segmentation: In this method, the 511 keV μmap is acquired by segmenting the reconstructed CT image into different regions. Then the CT numbers of each region are replaced with their corresponding LAC at 511 keV. The CT image can be segmented to soft, bone, lung, adipose, etc regions [2].

Hybrid: In the hybrid method, the aforementioned concepts of scaling and segmentation are combined together where the 511 keV μmap is formed by first setting a threshold to segment bones out of the CT image, and then using specific scaling factors for the bone and non-bone regions. The reason behind this is that for most materials (an exception being bone), the ratio of LAC at any two energies is almost a constant [2].

Bilinear: In this method a bilinear calibration curve is acquired from the LACs and measured CT numbers (HU) of three reference points (air, water, and cortical bone). The obtained bilinear curve has a break point at water point and yields the LACs of any material against its CT number. Bilinear method is the most commonly used method in commercially available PET/CT scanners [5].

B. Generation of μmaps Comparison Strategy

The mentioned energy mapping methods were performed on the clinical CT images of patients. This study was conducted on five whole body patient data. The data were acquired on a Discovery LS (DLS) PET/CT scanner (GE Healthcare Milwaukee, USA) with the resolution of 4.8 mm and tube voltage of 140 kVp. The DLS scanner has the potential to acquire the transmission scan both using CT and ^{68}Ge/Ga rod sources (TX). In order to derive the different μmaps and compare them with a gold standard, a reference μmap was needed for each patient. The best reference map would be a map obtained by the TX technique which was also performed on the studies patients. Therefore different μmaps were generated by the stated energy mapping methods and compared by their corresponding TX maps that were specific for each individual patient and were acquired by DLS PET/CT scanner.

Before performing the energy mapping methods, CT images (512×512 matrix size) of the patients were first down-sampled to 128×128 in order to match the matrix size of TX maps and then followed by 8 mm Gaussian smoothing to match the resolution of the PET images. In the last step, energy mapping methods were carried out on the down-sampled and smoothed images.

C. Comparison Strategy

For quantitative comparison of the different μmaps and the gold standard maps, a region of interest (ROI) analysis was employed, i.e. different ROIs were selected on different regions of the body in the four generated μmaps and also in the reference maps exactly in the same positions. Then the average LAC of each ROI was measured and the percent of relative difference of LAC for each ROI to the reference ROI was calculated. Overall, 100 different ROIs were selected on the 5 patient CT images. These ROIs were divided into soft, bone and lung groups. At last the average relative difference for each group to TX values for every method was calculated. The magnitude of the average relative difference for each group was considered as the accuracy criterion for each method.

III. RESULTS

Figure 1 shows an example, for one of the patients, of the TX μmap as well as the generated μmaps by different energy mapping methods.

The ROI analysis was done on the obtained μmaps and as stated, the average relative difference of each method compared to TX was computed. The results of the quantitative analysis showed that for soft tissues the relative differences for the scaling, segmentation, hybrid (scaling/ segmentation) and bilinear methods compared to TX were 11.3%, 9.2%, 11.3% and 10.8%, respectively.

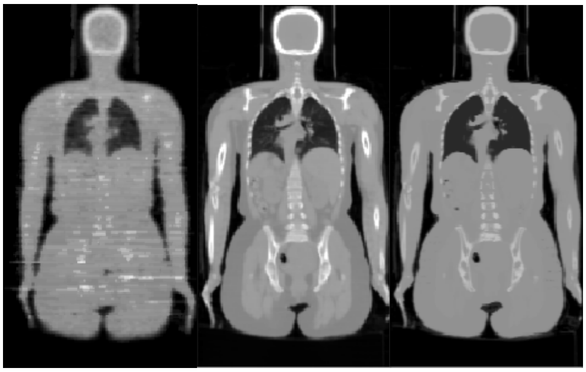
Figure 2 shows the analysis of different ROIs in soft tissue regions.

From figure 2, it is obvious that the relative differences of all energy mapping methods compared to TX are almost close to each other and less than 12%.

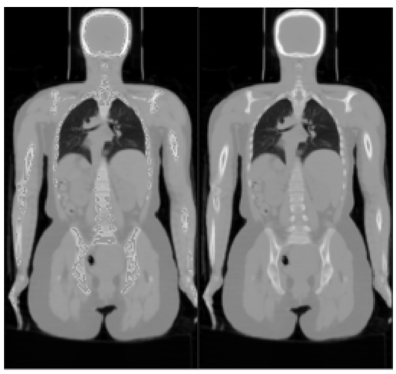
For bone tissues higher percent difference values were obtained: compared to TX these were 31%, 29%, 14% and 18% for the scaling, segmentation, hybrid (scaling/ segmentation) and bilinear method, respectively.

Figure 3 shows the relative difference of each method compared to TX for bone tissues.

As shown in figure 3, the scaling and segmentation methods have the greatest relative difference compared to other methods. However the relative difference of hybrid and bilinear techniques compared to TX are lower.



(a) (b) (c)



(d) (e)

Fig. 1. Generated μmaps obtained by different methods, (a) TX technique, (b) scaling, (c) segmentation, (d) hybrid scaling/segmentation and (e) bilinear methods.

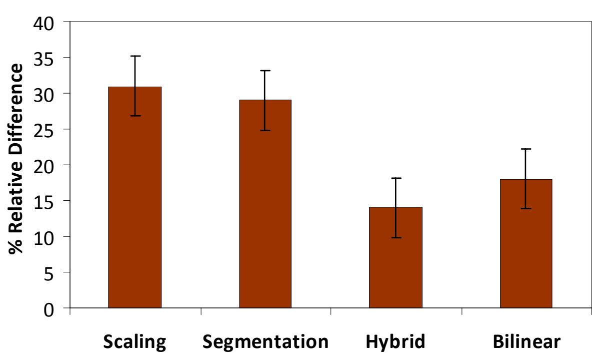


Fig. 2. Relative difference of energy mapping methods for bone tissues.

For Lung tissues the relative difference of energy mapping methods were approximately 4%, 13%, 4% and 4% for scaling, segmentation, hybrid and bilinear methods respectively. Figure 4 shows the percent of relative difference for lung tissue.

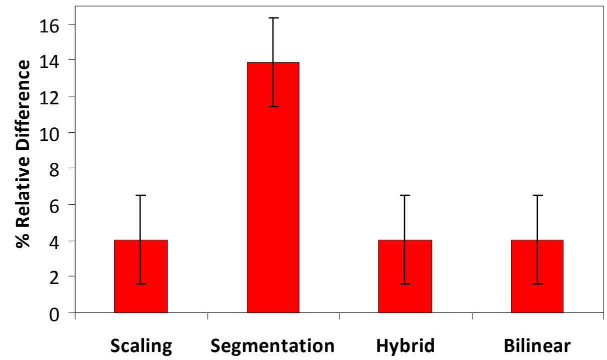


Fig. 3. Relative difference of energy mapping methods for Lung tissues.

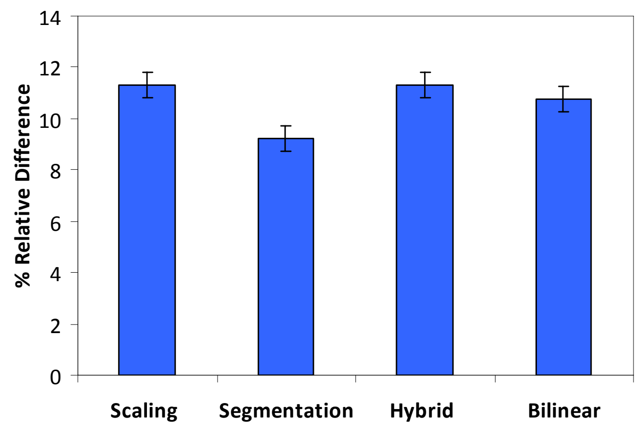


Fig. 4. Relative difference of energy mapping methods for soft tissues.

As it is shown in figure 4, except the segmentation method, the results of other three methods are more or less similar.

It is worth mentioning that the quality of the TX images was very poor in order to keep the patient dose as low as possible and they appeared to underestimate the LACs which we attribute to not correcting for the scattering effect during the reconstruction of TX images. This issue can be one of the factors that influence the results of the comparisons.

In table 1 a summary of all the results is presented.

Table 1. Percent of relative difference for different energy mapping methods regarding the type of tissue.

	Scaling	Segmentation	Hybrid	Bilinear
Soft	% 11.3	% 9.2	% 11.3	% 10.8
Bone	% 31	% 29	% 14	% 18
Lung	% 4	% 13	% 4	% 4

IV. DISCUSSION AND CONCLUSION

As demonstrated in figure 2, the results of all four energy mapping methods were similar to each other compared to TX maps. So it can be concluded that for soft tissues all the mentioned energy mapping methods produce acceptable 511 keV µmaps and there is not a major difference between them.

However for bones (fig. 3) scaling and segmentation methods produced the highest relative differences compared to TX maps and hence relative to the other two methods, they should be considered as sub-optimal techniques especially for bones. By contrast, the relative difference of hybrid and bilinear methods compared to TX were lower and they gave more accurate µmaps; therefore these methods can be considered as more robust methods of choice for CT based attenuation correction of PET images.

The high relative difference of scaling is attributed to the abundance of calcium and phosphor in bones which have a high photoelectric interaction cross section. It should be noted that the predominant interaction at 511 keV is Compton scattering but in bones due to the presence of calcium and phosphor the predominant interaction is photoelectric and this is the reason of high relative difference of scaling method in comparison with other methods.

The reason of the almost high relative difference of segmentation method for bones is that all types of bones are considered as cortical bone regardless of their densities and types and they are all replaced by a single LAC value of cortical bone. This relative difference shows itself especially in presence of less dense bones and spongia bones. Another drawback of the segmentation method is that in segmenting regions with variable densities such as lungs a high error can happen in these regions because of setting a strict threshold to separate these types of tissue. This problem was clear in Fig. 4 that the relative difference of segmentation method was well evident compared to other methods.

Generally it can be concluded that scaling and segmentation are not suitable methods for creating µmaps since they have high errors in bony regions. In regard to soft regions all the aforementioned methods can create more acceptable attenuation maps.

The hybrid method gave satisfactory results for soft, lung and bone tissues, particularly for bone tissues. Concerning Fig. 3, it is clear that for bones, the hybrid method gave the smallest amount of difference with TX values in comparison with other methods.

It should be pointed out that all these comparisons were performed on attenuation maps and the conclusions were based on the assessment of those attenuation maps. For a more comprehensive conclusion the quantitative comparisons of reconstructed PET images by different methods should be performed. Currently our group is working on comparative assessment of reconstructed PET images by different energy mapping methods and tries to evaluate the results through both different µmaps and reconstructed PET images.

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