Accuracy of CT-based Attenuation Correction in SPECT/CT Gamma camera images

Dalton Bermudez[1], Roberto Maass-Moreno PhD[2] , Ali Cahid Civelek MD[2]

[1]City College of New York, Grove School of Engineering, NYC, NY and [2]National Institutes of Health, Bethesda MD

INTRODUCTION

The Single-photon emission computer tomography (SPECT) has been widely used in diagnostic imaging since its introduction at the late 1970s [1]. One of the many advantages is that it provides images that reflect internal organ function through the detection the distribution of radiopharmaceuticals [2]. However, images provided by SPECT have limited spatial resolution (~7mm) and are significantly affected by tissue attenuation [3]. To correct for the effects of tissue attenuation, different methods have been developed, including: a) the Chang attenuation correction (Chang-AC) algorithm that assumes an identical attenuation coefficient for all tissues types in the body [4] b) CT-based attenuation correction (CT-AC) that uses attenuation coefficients calculated for each pixel based on the HU from the co-acquired CT images [5]. The main effects of uncorrected or poorly corrected attenuation on an image is the reduction in contrast, the introduction of artifacts and the reduction of the quantitative value of the image, which eventually compromise the diagnostic accuracy of the imaging study. In this study, we examined the effects of various AC methods on SPECT images of the parathyroid glands and of neuro-endocrine tumors imaged with ^{111}In-octreotide.

METHODS

The diagnostic quality of Non-AC images were compared to the same images after either CT-AC or Chang-AC. In the Chang-AC case the correction was done by limiting the correction to the tissue boundaries (the traditional way) or by 'enhancing' the correction by expanding the attenuating distance beyond the boundaries of the tissue (Chang$_{enhanced}$-AC). The Chang-AC images were done using a gamma camera proprietary program. An IDL (Harris Geospatial) based code written for this purpose (DHB), allowed comparing Chang-AC and Chang$_{enhanced}$-AC with the same method. Namely, the Chang attenuation factor (Eq 2) for each pixel within a region of interest (Eqs 1A and 1B). By applying the map of correction factors to the Non-AC images, the Chang-AC and AC-Chang $_{enhanced}$ images were obtained (Fig 1). To quantify for the quality between Non-AC, CT-AC, Chang-AC and Chang$_{enhanced}$-AC, we calculated the contrast-to-noise ratio (CNS) for each of them. To ensure that the differences in counts were independent on the type of filter used all images were treated with a Butterworth filter of order 10, with a cut-off of 0.48 (f_c/f_{Nyq}). To also ensure that the number of counts were independent on the depth various region of interest (ROI) within the image were sampled at different slice numbers.

Equation 1 Rectangular and Polar equation versions of the elliptical ROI used to determine the Chang mean attenuation distance for each pixel at location (*x*,*y*).

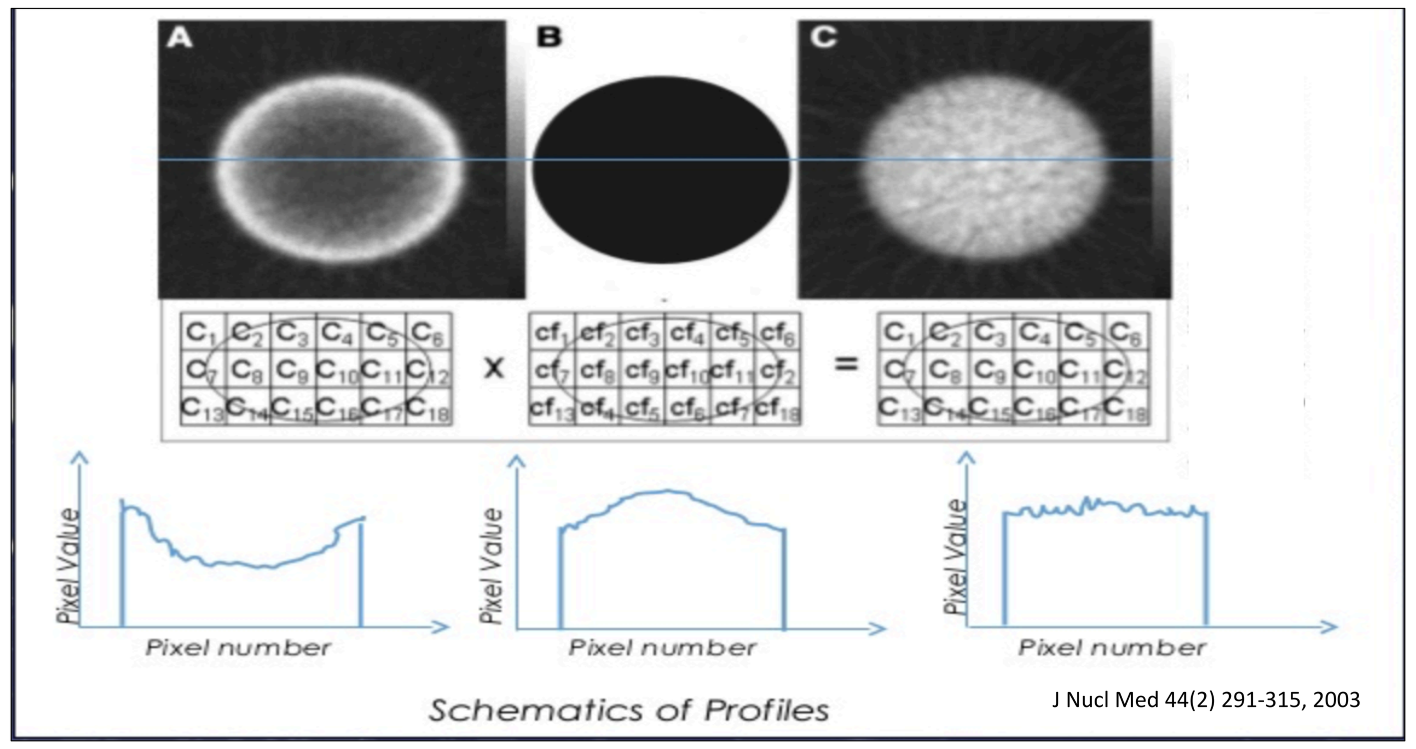
A
$$\frac{((x-h)\cos(A)+(y-k)\sin(A))^2}{(a^2)}+\frac{((x-h)\sin(A)-(y-k)\cos(A))^2}{(b^2)}=1$$

B
$$r(\theta)=\frac{ab}{\sqrt{(b\cos\theta)^2+(a\sin\theta)^2}}$$

Equation 2. Expression for the Chang attenuation correction factor at each pixel C(x,y) .

$$C(x,y)=\left[\frac{1}{M}\sum_{i=0}^{M}e^{-ul(x,y,\theta_i)}\right]^{-1}$$

Figure 1. Displaying the pixel intensity profiles (lower row) for **(A)** non-attenuation corrected image of a phantom, **(B)** Chang map, and **(C)** Attenuation corrected image of a phantom after Chang map is applied.



RESULTS

Table 1. Lesion$_{CNRs}$ of 10 patients for each of the attenuation correction methods used

Patient #	Case Type	Non-AC	CT-AC	Chang-AC	Chang-AC enhanced	Highest Lesion Contrast to Noise Ratio
1	Parathyroid	5.5	5.18	5.63	5.9	Chang-AC
2	Octreo	3.14	4.27	4.73	4.23	Chang-AC
3	Octreo	1.39	1.29	1.3	1.32	Non-AC
4	Parathyroid	1.9	1.97	2.12	2.44	Chang-AC enhanced
5	Parathyroid	1.43	1.59	1.47	1.44	CT-AC
6	Parathyroid	1.42	1.4	1.45	1.45	Chang-AC and Chang-AC enhanced
7	Octreo	3.48	2.68	2.96	2.9	Non-AC
8	Parathyroid	2.81	3.27	3.57	3.4	Chang-AC
9	Parathyroid	2.62	2.59	3.66	3.57	Chang-AC
10	Octreo	1.63	1.57	1.76	1.64	Chang-AC

Figure 2. Coronal image of patient-5 with corresponding parathyroid Lesion $_{\text{Contrast to Noise Ratio}}$ (LCNR)

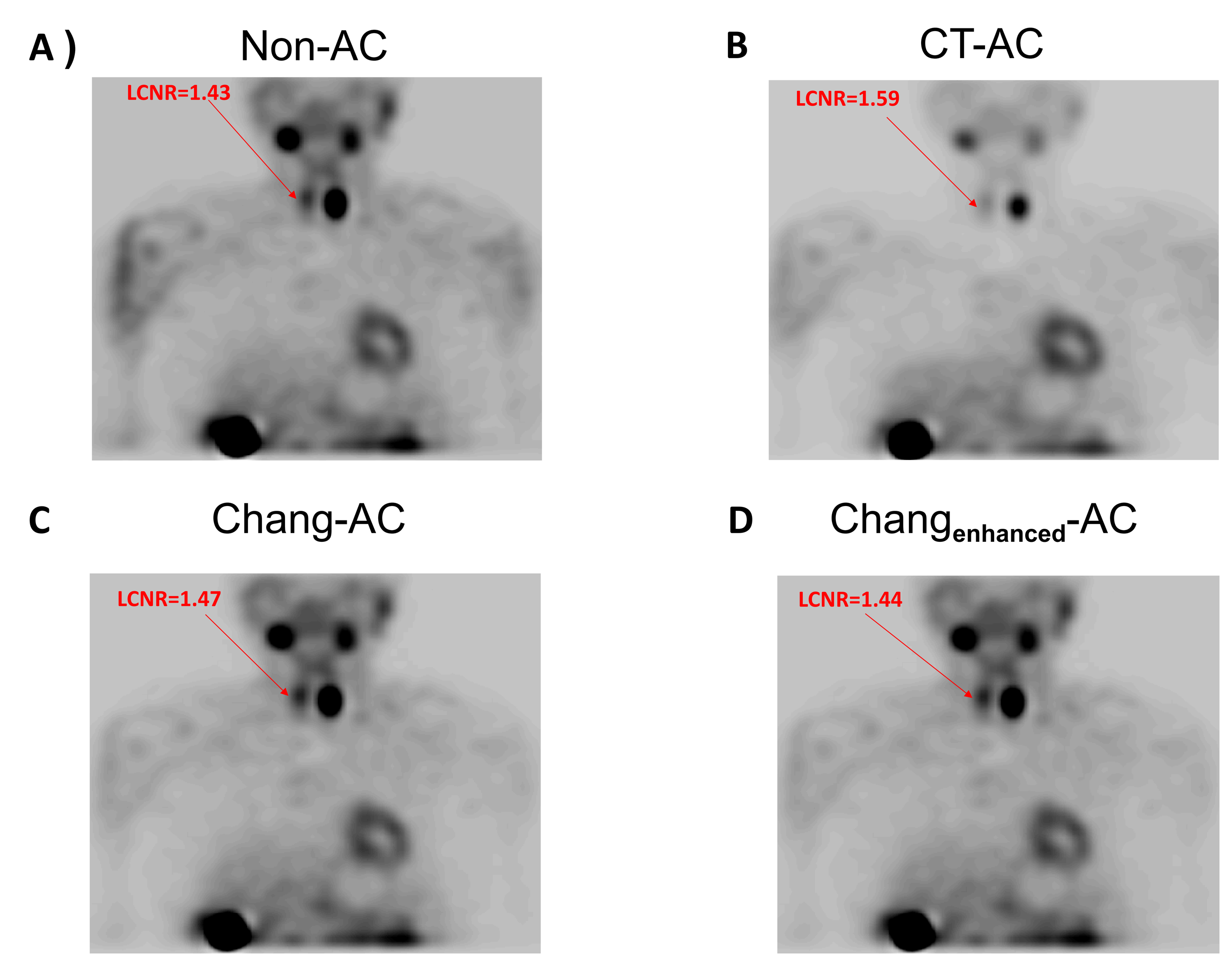


Figure 3. Coronal image of patient-9 with corresponding parathyroid Lesion$_{\text{Contrast to Noise Ratio}}$

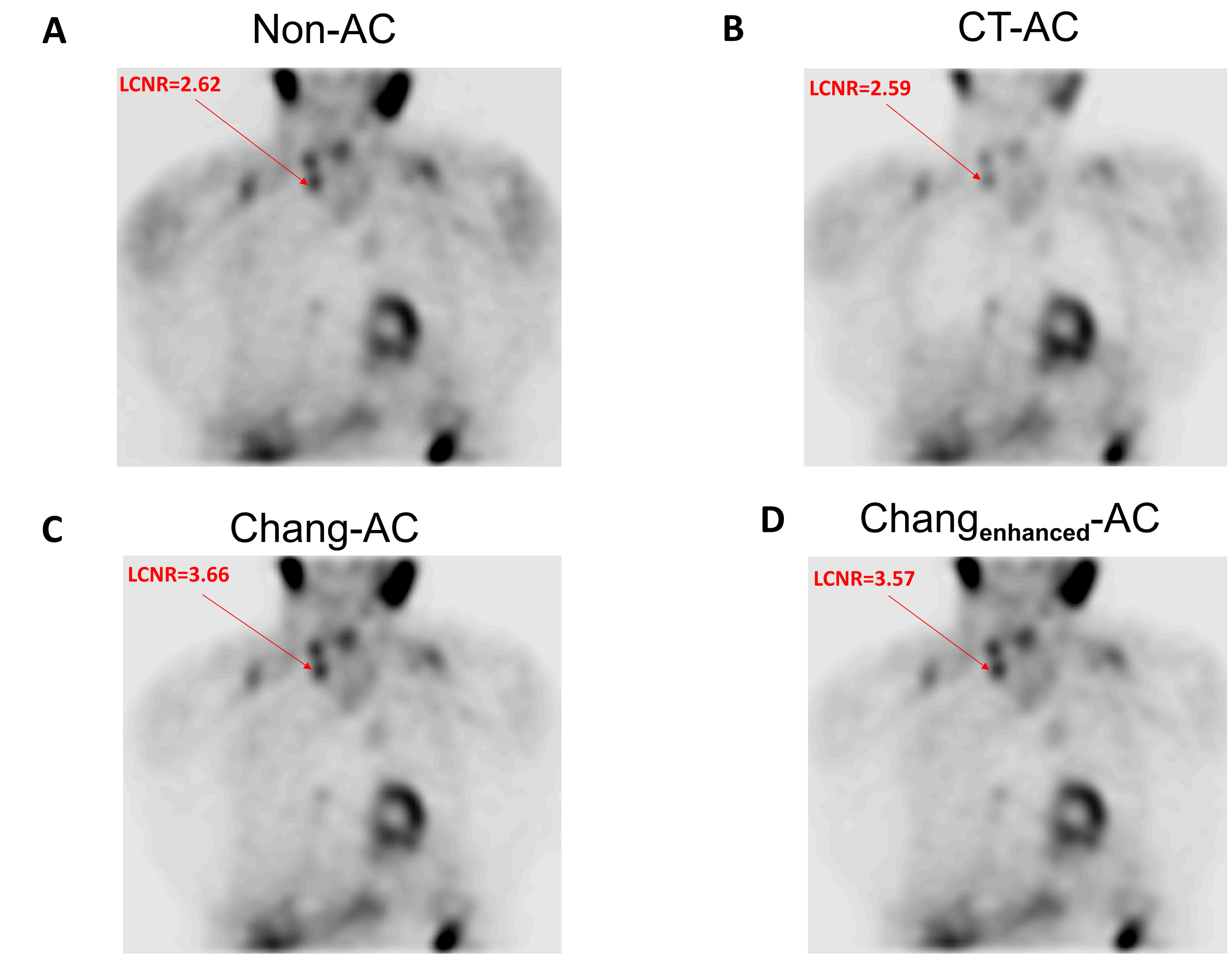
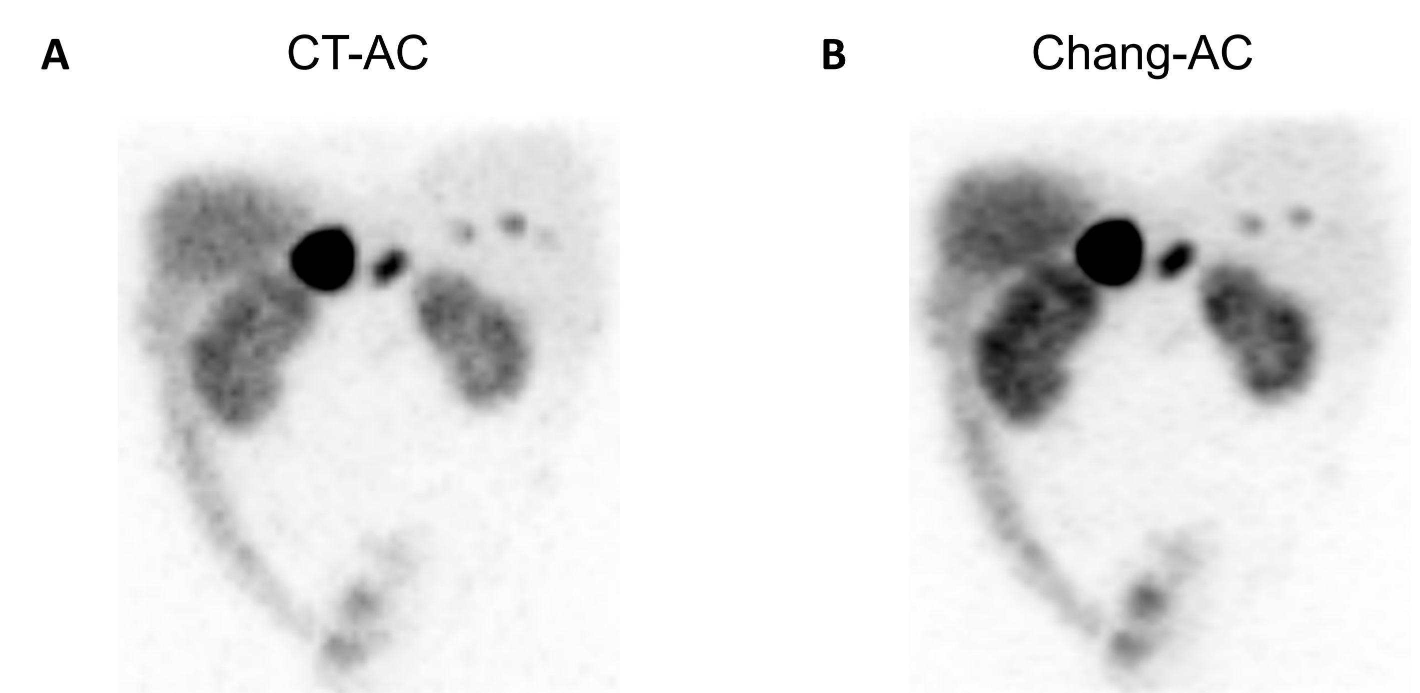


Figure 4. 24 hours ^{111}In-Octreo Posterior MIP image- filter with Hanning 1.5 for **(A)** CT-AC and **(B)** Chang-AC. **Lesions located at the periphery of a patient might not be improved in resolution**



CONCLUSION

The Chang-AC method seems to be more consistent at depicting small lesions than either Non-AC and CT-AC in SPECT images of the parathyroid adenomas and of neuroendocrine tumors. Although CT-AC should provide more accurate attenuation correction (AC) than Chang-AC, factors such as beam hardening artifacts and relative organ motions that occur in between the CT and the SPECT scan acquisitions may introduce errors that compromise the accuracy of CT-AC. Further studies may be performed to document the affect of Chang-AC method on the diagnostic power of parathyroid adenoma and/or other SPECT imaging methods.

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