Generation of hybrid SPECT bone scans and reconstruction using CT-derived anatomical priors

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***Abstract*—Anatomical priors derived from CT scans offer the promise of improved image quality in SPECT reconstruction. We describe reconstruction of clinical SPECT/CT bone scans of the spine using anatomical priors to enhance SPECT. We also generate hybrid images: lesion-absent backgrounds from a clinical scan with a synthetic lesion generated by Monte Carlo simulation. These hybrids can be used to assess the change in image quality due to anatomical priors.**

I. Introduction

With the increasing clinical availability of SPECT/CT and PET/CT systems, and ongoing research into PET/MRI and SPECT/MRI, there is interest in using high-resolution anatomical priors derived from CT or MRI to improve reconstruction in emission tomography. At past MIC conferences we have presented on the use of anatomical priors in gallium scintigraphy [1]–[3]. While ^{67}Ga is an interesting isotope due to its multiple-photopeak decay process, ^{67}Ga is no longer widely used in the United States for SPECT imaging, and thus not currently of clinical relevance. We have therefore switched our focus to ^{99m}Tc bone scans of the spine. Because bones are relatively easy to segment in CT images, it should be possible to produce high-quality anatomical priors. Therefore bone imaging provides a good test case to assess the extent of image quality improvements afforded by anatomical priors.

Use of SPECT/CT in spine imaging has been enthusiastically adopted by physicians because of the improved ability vs. CT to identify disease and vs. SPECT to localize lesions. For clinical intervention it is important to know precisely where increased radiotracer uptake occurs. A small difference in lesion location can lead to a huge difference in patient treatment. For example, a lesion located in the pedicle is likely to be treated with surgical bone fusion, while a lesion in the nearby facet joint would receive a steroid injection. (See figure 1). We believe that anatomical priors may improve the resolution of SPECT reconstructions. Thus anatomical priors may allow for more precise localization of lesions than the current clinical standard of fused SPECT/CT images.

Our past work has used the digital MCAT phantom to assess image quality. Although digital phantoms offer many advantages—for example precise knowledge about lesion location and uptake—they are of necessity somewhat stylized, and do not yet offer the same range of variability seen in our clinical population. In this paper we use clinical backgrounds with synthetically added lesions to gain clinical realism while maintaining precise knowledge about the lesions. We call the combination of a clinical background and a simulated lesion a hybrid scan. The goal of this work is to build up a collection of hybrid spine scans. This collection will then be used in future observer studies to measure the impact of anatomical priors on clinically-relevant image interpretation tasks.

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II. Methods

A. Clinical scans

We use clinical ^{99m}Tc-labelled methylene-diphosphonate (MDP) bone scans as negative (lesion absent) cases, and as the backgrounds for hybrid lesion-present cases. Scans were recorded using a Phillips Precedence SPECT/CT system. All patients were referred for a spine scan. Scans were read by a board-certified nuclear-medicine physician. Only cases in which no lesions were detected using SPECT were included this study. Identifying information was redacted, and use of the anonymized clinical scans was approved by the human-participant institutional review boards (IRB) at the University of Massachusetts and at the University of Vermont.

Note that these scans are *negative*, not *normal*. In all cases patients were referred because of a suspected spine problem. Use of normal volunteers without any history of severe back pain is not possible, due to the extra radiation dose from a CT scan. There is thus the possibility that false-negative scans will inadvertently be included in our collection of backgrounds and hybrids.

B. Hybrid images

We generated projection images of the simulated increased-uptake lesions. Our projector included the effects of depth-dependent resolution and attenuation but did not model Compton scatter. Lesions were located within one or more vertebrae, for example at the bottom of L1 and top of L2. The simulated lesions were then added to the clinical backgrounds described above to produce lesion-present hybrid data. The hybrid generation process is illustrated in fig. 2.

The hybrid projections were then reconstructed as if they were a clinical scan. The number of lesions per hybrid case varies, as occurs in lesion-present clinical scans. Synthetic lesions were added only to the emission data. Lesions were not added to the CT images nor CT-derived attenuation maps.

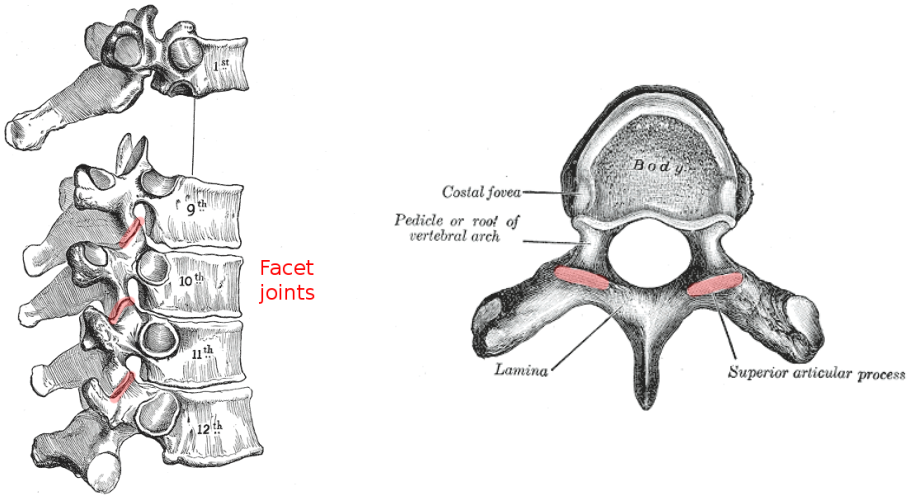

Fig. 1. A lesion in the facet joints would be treated with a steroid injection, while one in the nearby pedicle would be treated with bone fusion surgery. Illustrations are from the public-domain 1918 edition of *Gray's Anatomy*, downloaded from Wikimedia Commons.

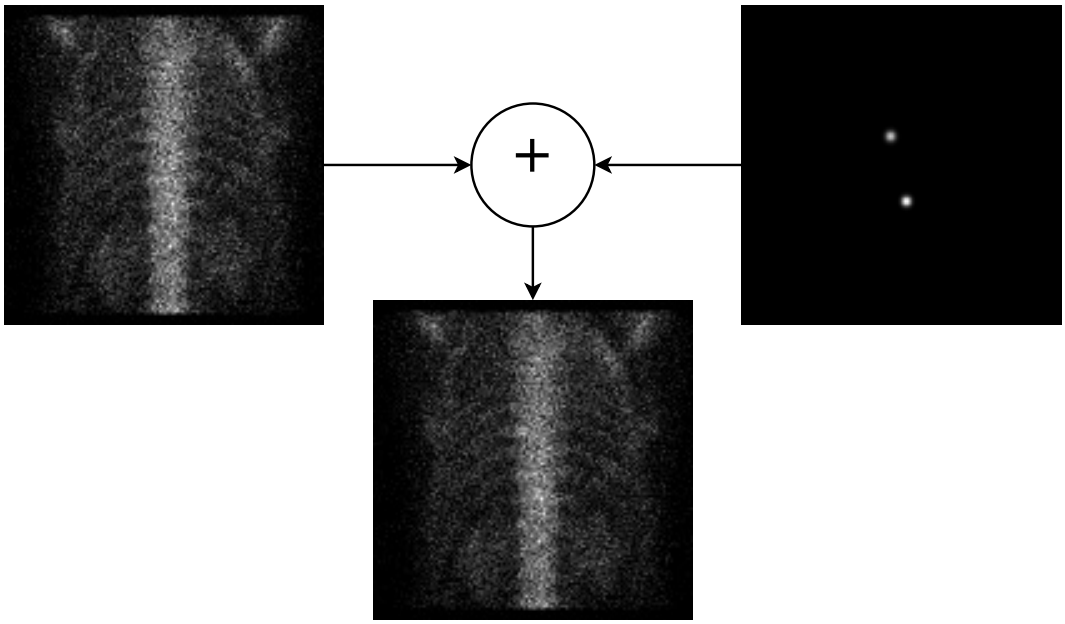

Fig. 2. To generate a lesion-present hybrid we use a lesion-absent patient scan as the background and add a simulated lesion.

C. Reconstruction using anatomical priors

Clinical backgrounds and the hybrid images were reconstructed using several 3D iterative algorithms. As a baseline control we reconstructed using the rescaled block iterative (RBI) algorithm [4] without any priors. As a second control, we ran the De Pierro algorithm [5] with a quadratic Gibbs prior with no knowledge of the boundary [1]. Finally we reconstructed using the De Pierro algorithm [5] with a quadratic anatomical prior [1], [6].

The anatomical prior does Gibbs quadratic smoothing within organs, but not across organ boundaries. Region boundaries were determined using the attenuation map derived from the CT scan. Neighboring voxels with attenuation values within 10% of each other were considered to be in the same region. Effectively this segments the CT scan into two categories: bone and not bone. Because we did not add lesions to the CT-derived attenuation maps, the prior had no access to lesion boundaries.

III. Results & Discussion

Fig. 3 shows SPECT images of a quality-control phantom reconstructed using the RBI control and using the CT-derived anatomical prior. The anatomical prior images show sharper edges and appear to have improved resolution. Note that this phantom scan has much higher counts than would be collected from a patient. Therefore this example may underestimate the effect of noise on final image appearance.

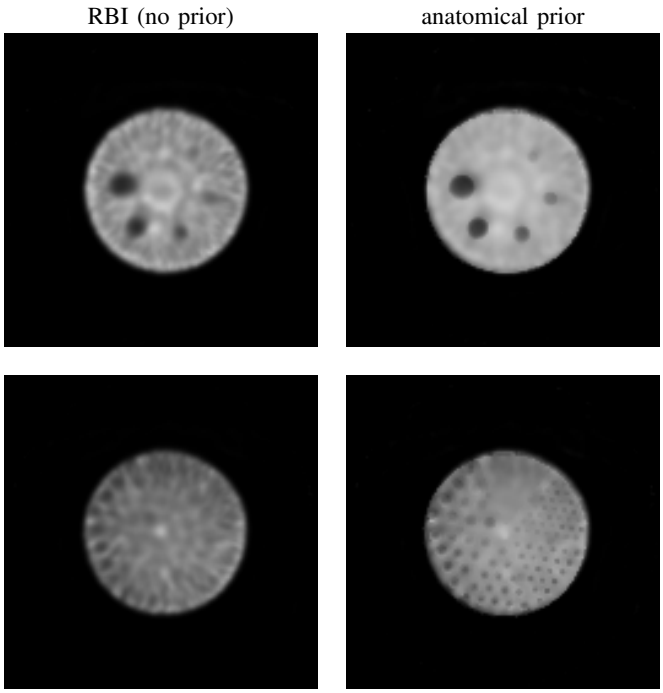

Fig. 3. Two slices of a quality control (QC) phantom, reconstructed using RBI and the anatomical prior. The prior sharpens edges and appears to improve resolution of the reconstruction.

Figs. 4 and 5 show two slices of a lesion-absent clinical scan and lesion-present hybrid scan. The anatomical prior appears to sharpen bone edges. However the prior also reduces lesion-to-background contrast.

The anatomical-prior reconstructions here all used quadratic smoothing, with no distinction between trabecular and cortical bone. In the future we plan to investigate other functional forms for the prior, as well as priors that distinguish between the two types of bone.

IV. Conclusion

Anatomical priors offer the promise of improved resolution reconstruction in SPECT/CT. The hybrid images described here will ultimately allow us to conduct a human-observer study to measure the impact of anatomical priors on bone-scan image quality.

References

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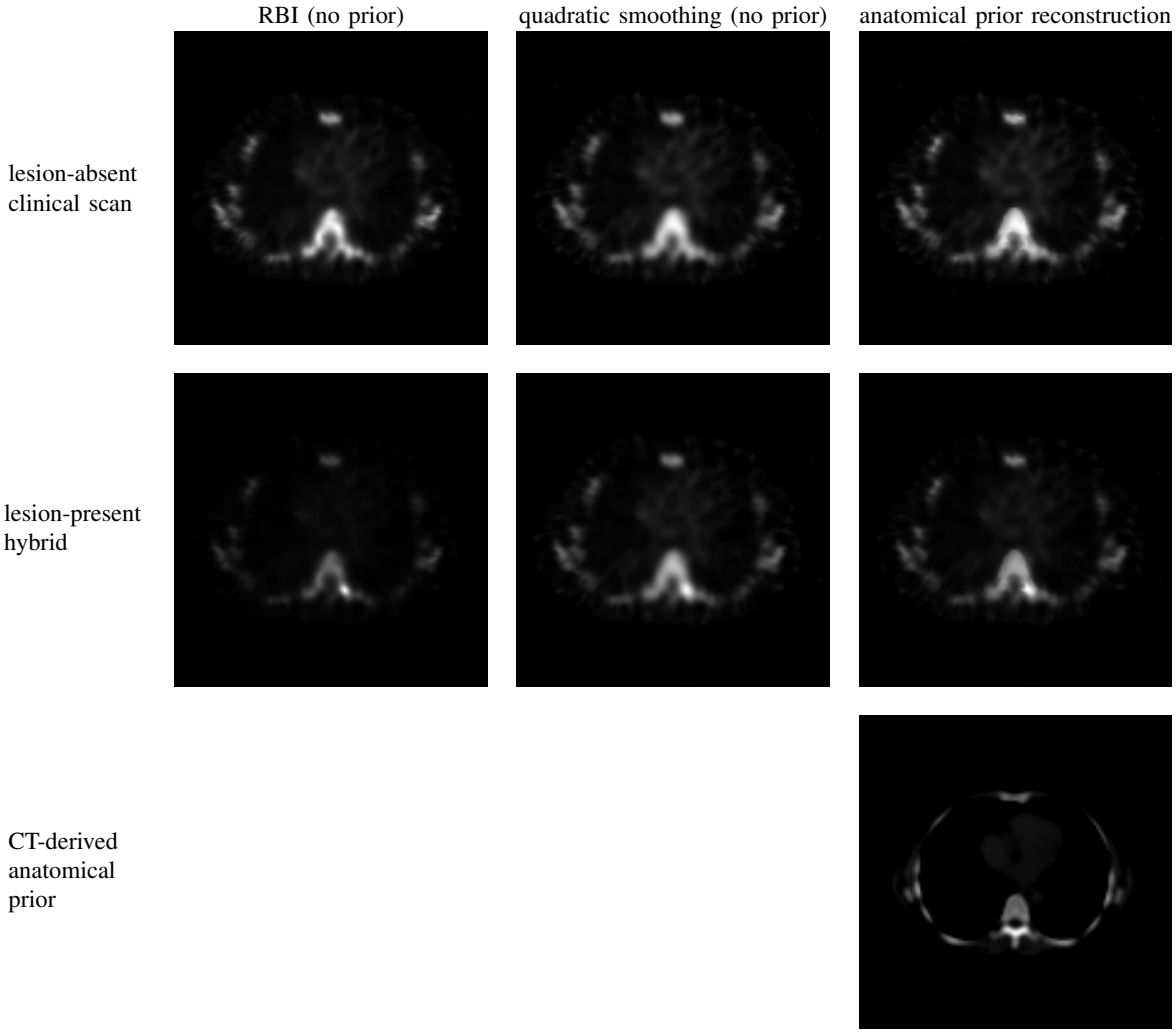

Fig. 4. Reconstructed transaxial slice through the center of a lesion, together with the CT-derived map used as an anatomical prior. This is the same clinical background and hybrid shown in figure 2.

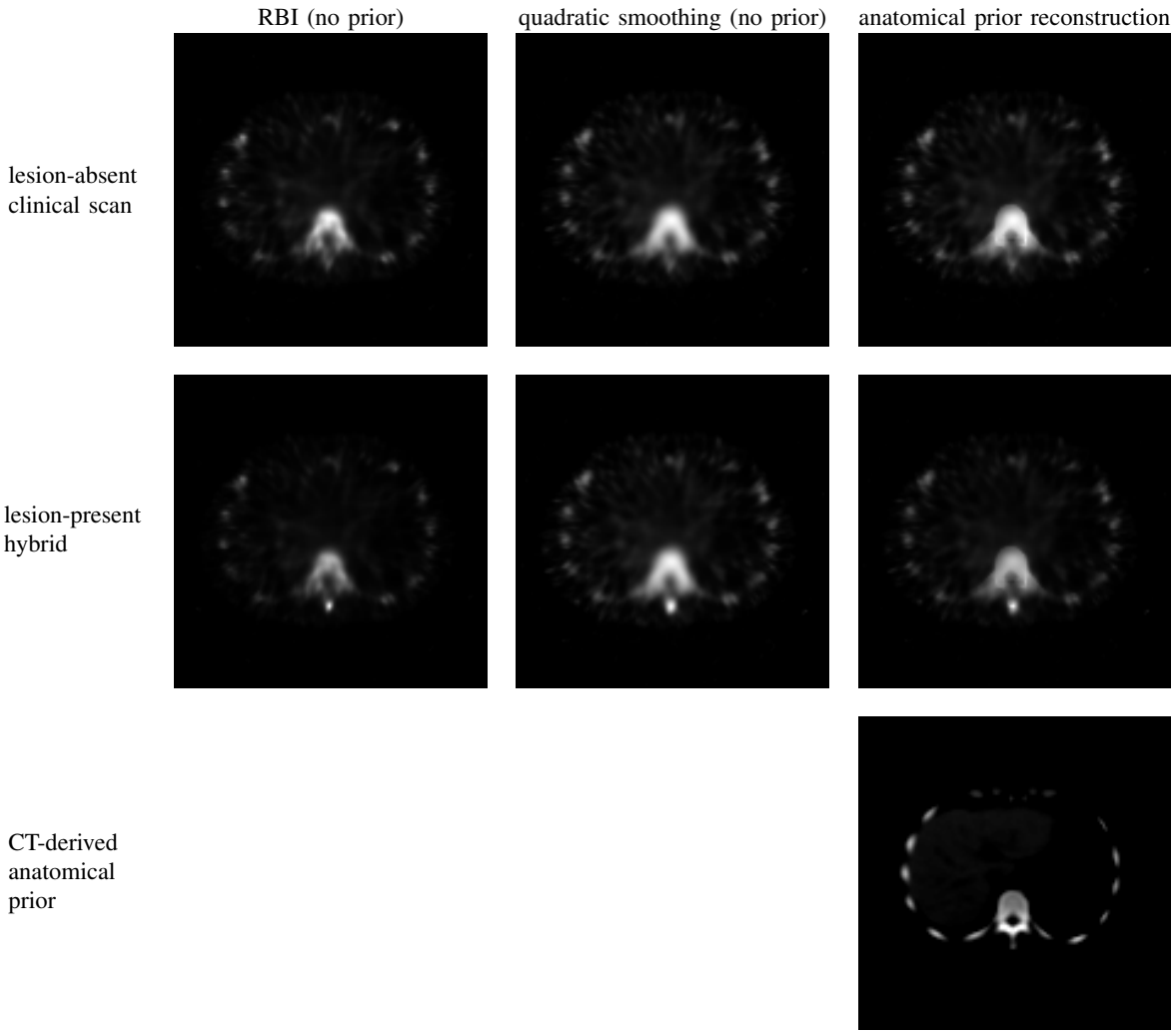

Fig. 5. Reconstructed transaxial slice through the center of the other lesion in the hybrid shown in figs. 2 & 4.