Hybrid Convolution Kernel: Optimized CT of the Head

Kenneth L Weiss MD*, Aaron L Greeley DO, Rebecca S Cornelius MD, Dongmei Sun PhD

Department of Radiology, University of Cincinnati, Cincinnati, Ohio

Introduction

Selection of a CT convolution kernel determines the tradeoff between image sharpness and pixel noise.(1) High pass filter algorithms utilized in commercially available “sharp” convolution kernels preserve higher spatial frequencies at the expense of greater noise and typically work best for tissues with inherently high CT contrast. Conversely, low pass algorithms utilized in “smooth” convolution kernels reduce the higher frequency contribution decreasing noise and spatial resolution; and work best for tissues with inherently lower contrast such as the brain or liver.(2, 3)

Consequently, as most clinical exams include tissues with both high and low inherent contrast, it is often desirable to create at least two separate data sets utilizing different convolution kernels. Unfortunately, this increases the number of images needed to be generated, transmitted, stored and reviewed by a corresponding factor of two or more.

To address this problem, Schaller et al. described a spatial domain filtering algorithm for fast modification of the image sharpness-pixel noise tradeoff. While providing the ad hoc ability to reduce the noise and spatial resolution of images generated with a high pass convolution kernel, tradeoffs exist and the resultant images only approximate those prospectively created with routine low pass convolution kernels.(1)

Rather than develop a distinct algorithm to approximate routine clinical convolution kernels, we chose to combine well established kernels in such a fashion as to directly duplicate within a single hybrid image the established tissue contrast that had been individually optimized for soft tissues or bone. In so doing, we hoped to halve the number of images to be archived and reviewed without compromising or altering clinically established CT tissue contrast; thereby obviating a learning curve and facilitating comparison with conventional single kernel images.

Materials and Methods

Subjects:
IRB approval with waived consent was obtained to retrospectively review de-identified shelf data and test the proposed investigational algorithm. Subjects were not stratified by ethnicity, age or gender. Selection was random, based on the presence of both bone and soft tissue convolution kernels obtained at similar slice location and plane thickness from retrospective, clinical CT studies performed from 9/14/06 to 12/13/06. A total of 21 CT examinations were reviewed using the hybrid technique, including ten head, five spine, and six head and neck (2 orbit, 2 paranasal sinus, and 2 temporal bone protocol) cases.

Image Acquisition:
CT examinations were performed on a 16 slice GE Lightspeed Pro or 8 slice GE Lightspeed Ultra scanner (GE Medical Systems, Milwaukee, WI) with standard non contrast enhanced clinical protocols. Clinical non-contrast axial CT images of the head, spine, or head and neck; and generated with separate bone and soft tissue kernels at the same slice thickness, were retrospectively combined so that soft tissue algorithm pixels less than -150 HU or greater than 150 HU are substituted with corresponding bone kernel reconstructed pixels. Hybrid images were generated in Matlab (Math Works, Inc, Natick MA) and subsequently re-imported into eFilm Workstation 2.0 (Merge Technologies Inc., Milwaukee WI) for viewing along with conventional images.

Analysis:
Three neuroradiologists independently reviewed all 21 hybrid cases and compared them to both standard soft tissue and bone kernel reconstructed images for characterization of anatomy and pathology. For each case, corresponding image sections were simultaneously viewed in the manufacturer preset window and level settings for bone (window 2500, level 480), head and neck (window 350, level 90), brain (window 80, level 40), and with independently adjusted window and level settings. An additional intermediate setting (window 800, level 200) for spine cases was reviewed. The conspicuity of bone, soft tissue, and brain anatomy and pathology were separately scored for each CT convolution technique.

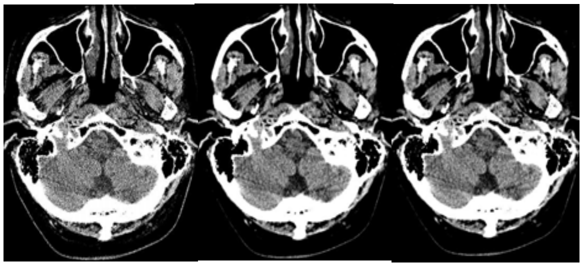

Figure 1a. Brain window settings (W 80 L 40).
Axial CT images obtained with bone (A), standard/soft tissue (B), and hybrid (C) convolution kernels.

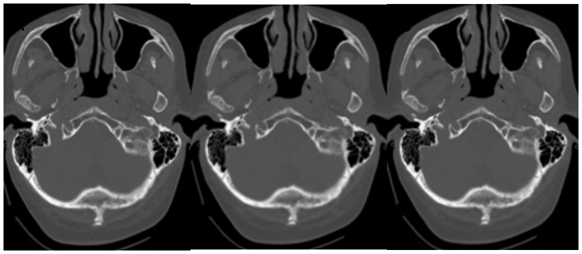

Figure 1b. Bone window settings (W 2500 L 480).
Axial CT images obtained with bone (A), standard/soft tissue (B), and hybrid (C) convolution kernels. Note the non-displaced fracture of the occipital bone without underlying intracranial hemorrhage.

Results

For the depiction of bone, in all 21 cases, the three neuroradiologists scored the hybrid images as being equivalent to bone kernel reconstructions but superior to the standard kernel. For depiction of extra-cranial soft tissues and brain, the hybrid kernel was rated equivalent to the standard kernel but superior to that of the bone kernel.

Figures 1a (brain W/L settings) and 1b (bone W/L settings)illustrate the dual optimized brain and bone detail afforded by the hybrid convolution kernel technique in CT of the head as opposed to the respective standard and bone algorithms.

Discussion

The aforementioned hybrid technique is easily implemented, requiring only a few lines of code and may have broader utility than demonstrated in this investigation. For example, substituting the high pass “lung” convolution kernel for the high pass “bone” kernel, the technique has recently shown promise for chest CT.(4) While performed retrospectively off-line for this investigation, if CT manufacturers desire and regulatory clearance is obtained, the algorithm could become an on-line processing option allowing routine, essentially real-time creation of such hybrid data sets without the need for single convolution kernel image generation. As such, radiologists would not have to choose between convolution kernels to limit image creation and storage.

The choice of convolution kernel can affect lesion conspicuity as well as measured Hounsefield units (HU).(2-7) With the technique described, hybrid kernel tissues containing HU measurements between -150 to 150 should behave similar to those generated with the “standard” algorithm and tissues above or below this range should behave similar to those generated with the bone algorithm. The conspicuity of lesions that overlap the boundaries of HU -150 or 150, so that both bone and soft tissue kernels will be applied to a single lesion, is less clear and may deserve further study. Additionally, more testing is required to assess the technique’s performance over a wider range of cases particularly those obtained with IV contrast administration or generated using other vendor’s proprietary convolution kernels. As iodine administration increases soft tissue attenuation, when contrast is given it might prove helpful to increase the algorithm’s 150 HU upper limit for the soft tissue (standard) low-pass convolution kernel.

Conclusion

Hybrid convolution kernel is a promising technique affording optimized bone and soft tissue evaluation while halving the number of images needed to be transmitted, stored, and reviewed.

References

1. Schaller S, Wildberger JE, Raupach R, Niethammer M, et al. Spatial domain filtering for fast modification of the tradeoff between image sharpness and pixel noise in computed tomography. IEEE Trans Med Imaging 2003; 22:846-853.
2. Boedeker KL, McNitt-Gray MF, Rogers SR, et al. Emphysema: effect of reconstruction algorithm on CT imaging measures. Radiology 2004; 232:295-301.
3. Birnbaum BA, Hindman N, Lee J, Babb JS. Multi-detector row CT attenuation measurements: assessment of intra- and interscanner variability with an anthropomorphic body CT phantom. Radiology 2007; 242:109-119.
4. Strub W, Weiss K, Sun D. Hybrid Reconstruction Kernel: Optimized Chest CT. AJNR 2007:accepted for publication.
5. Prevrhal S, Engelke K, Kalender WA. Accuracy limits for the determination of cortical width and density: the influence of object size and CT imaging parameters. Phys Med Biol 1999; 44:751-764.
6. Armato SG, 3rd, Altman MB, La Riviere PJ. Automated detection of lung nodules in CT scans: effect of image reconstruction algorithm. Med Phys 2003; 30:461-472.
7. Cademartiri F, Runza G, Mollet NR, et al. Influence of increasing convolution kernel filtering on plaque imaging with multislice CT using an ex-vivo model of coronary angiography. Radiol Med (Torino) 2005; 110:234-240

* KLW has proprietary interests in the Hybrid Convolution Kernel, US Patent Pending