Iterative Reconstruction in CT: What Does It Do? How Can I Use It?

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CT images have been reconstructed from raw data using filtered back projection (FBP) since the inception of the modality. The standard FBP algorithm operates on several fundamental assumptions about scanner geometry but is basically a compromise between reconstruction speed and image noise. One might make different assumptions about scanner geometry, scanner optics, and noise statistics which are computationally more complex and combine these with multiple iterations of reconstruction — termed *statistical iterative reconstruction*. Such statistical iterative reconstruction may result in slightly longer reconstruction time but also in substantially less image noise from the same raw data through more complex modeling of detector response and of the statistical behavior of measurements. An adaptive shortcut which starts iterative reconstruction after a first-pass FBP reconstruction, *adaptive statistical iterative reconstruction*, can help shorten the longer reconstruction time of pure iterative reconstruction while maintaining much lower image noise than if the same raw data were reconstructed with FBP alone. Adaptive iterative reconstruction substantially reduces image quantum noise with no impact on spatial or contrast resolution.[(1-4)] This degree of substantial noise reduction can be taken as either improved image quality or as a reduction of patient radiation dose, typically in the 25-40% range compared to FBP. There are now over 5,000 CT systems operating world-wide with this technology.

When 64-channel CT is performed with *automated tube current modulation* (ATCM), image noise is determined in part on some scanners by operator selection of a predicted image noise, noise index (NI), defined as the standard deviation of the image noise resulting from the range of mA employed by the

ATCM. By increasing the operator-selected noise index (lowering the center of the mA range), patient dose may be decreased at the expense of greater image noise. At this lower patient dose level, if the greater image noise is modulated downward by adaptive statistical iterative reconstruction (instead of using FBP), the lower dose CT scanning might have image noise comparable to the image noise from higher dose scanning that was reconstructed with FBP. This is the conceptual approach to using iterative reconstruction to lower patient radiation dose from CT.

More recently, a much more complex iterative reconstruction algorithm has become available called fully-model-based iterative reconstruction. From a raw dataset (without a first-pass FBP), model based reconstruction uses both backward and forward projections according to a statistical metric.[(5)] This algorithm includes mathematical recognition of the cone-shape of the x-ray beam in CT, as well as the real three-dimensional shape of the voxels. It also models the non-linear polychromatic nature of x-ray beams, and models shape considerations of the focal spot as well as the detectors (system optics). Forward-projected data is compared with the actual measured CT data according to statistical metrics, and the computed difference is itself used to create a new updated image with lower noise. This sequence is repeated until the difference between actual measured data and the new forward-projected data becomes minimal. By combining many more iterations with the much more complex mathematics, image noise can be reduced to a much greater degree – typically enabling 80-90% patient radiation dose reductions compared to FBP. But such complexity resulting in such huge noise/dose reductions comes at a cost: model based iterative reconstruction requires a bank of multiple server computers and 30-40 minutes to reconstruct a standard CT of the abdomen and pelvis. Even with today's processor speeds, a raw dataset reconstructed with FBP at 15 images per second or with adaptive statistical iteration at 10 images per second might be reconstructed with model based iteration at one image per second. Still, particularly for patients under the age of 45 or who will be getting multiple CT exams over a short period of time, the model based iterative approach may be compelling due to its ultra-low radiation. In our experience, ER referring physicians are very dose conscious and very time sensitive, yet they frequently request very low dose model based iterative CT scans on younger patients despite the 30 minute extra wait.[6] There are several hundred such CT systems operating worldwide equipped with fully-model-based iterative reconstruction technique.

Most recently, a compromise iterative reconstruction algorithm - called partial-model-based - has emerged which takes much less reconstruction time than full-model-based iterative but results in substantially greater noise reduction than adaptive statistical iteration (though not as great as model based). This partial-model-based iterative approach uses all of the methodology and mathematical features of full-model-based except for the system optics component. Since the system optics component is by far the most mathematically demanding, removing that component results in image reconstruction times which are comparable to adaptive statistical iterative (6-8 images per second). But the noise and patient radiation dose reduction for the partial-model-based iteration is in the 50-60% range compared to FBP. As such, it is a good compromise between image reconstruction speed and patient radiation dose reduction - especially for younger patients. Only a few of the newest models of CT scanners have this capability.

What about the fact that the "look" of images is different with all types of iterative reconstruction compared to the "look" of FBP? This different look is due to the marked decrease in overall noise plus a slightly different pattern of both noise and tissue depiction. There is no question but that each iterative method subtly changes the appearance of the images. But the important question is: does iterative reconstruction change spatial resolution, low contrast resolution, or diagnostic power? Phantom studies suggest that all iterative reconstruction slightly improves spatial resolution and low contrast resolution at any given dose level, especially the model based types.[5,7] Clinical studies note, in particular, marked reduction of streak and other artifacts with iterative reconstruction compared to FBP. Other clinical studies on the use of iterative reconstruction for CT exams of specific organ systems and disease processes have been reported.[8-11] A recent review of 1616 articles dealing with clinical use of iterative reconstruction concluded that both subjective and objective measures of image quality were the same or improved without reported diagnostic compromise compared to older techniques.[4] However, radiologists do need time working with iterative reconstruction images to become accustomed to the different look and to gain confidence in the diagnostic capability. Typically, after about 90 days, many radiologists hardly notice the difference in image appearance.

The implementation of iterative reconstruction can be an important component of overall CT radiation dose reduction – Imaging Wisely – without compromising diagnostic content in CT studies. Other CT radiation dose reduction factors may include weight-based selection of kVp; X, Y, and Z axis automated tube current modulation with noise indices selected in weight-based categories; organ dose modulation for the breast, eyes, and thyroid; very careful patient centering in the gantry; limitation of Z axis coverage; and limiting number of passes per CT exam. Considering that iterative reconstruction alone can result in patient dose reductions in the 30-80% range, it should be an important part of any overall CT radiation dose reduction program. Each facility and group practice needs to find by serial experimentation the appropriate tradeoff between image appearance, patient radiation dose, and CT exam diagnostic capability when incorporating iterative reconstruction over time. This process usually requires adapting the rate of change to your local culture.

In order to smooth the introduction of iterative reconstruction techniques, step-wise implementation might be considered. When adaptive statistical iterative reconstruction first arrived, we initially blended it 40% with FBP. But over time, as personnel became accustomed to the look of the images and gained confidence, we stepped the blend up to 70%, implementing serial radiation dose reductions. While full-model-based iterative reconstruction does not blend with any other technique (is always 100%), on the adaption of partial-model-based iterative reconstruction we also stepped up our blend over time up to the 60-70% range. Ideally, having a feedback mechanism in place to survey radiologists as these steps occur can help monitor the process constructively.

Each CT manufacturer offers several types of iterative reconstruction, usually depending on the model of scanner. A recent review article lists the various trade names employed by the several manufacturers for their iterative reconstruction techniques.[4] There are subtle differences in iterative reconstruction implementation methodology among the manufacturers, so time spent with operations manuals and applications personnel unique to a particular CT scanner is appropriate.

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