Image Reconstruction Techniques

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Image reconstruction in CT is a mathematical process that generates images from X-ray projection data acquired at many different angles around the patient. Image reconstruction has a fundamental impact on image quality and therefore on radiation dose. For a given radiation dose it is desirable to reconstruct images with the lowest possible noise without sacrificing image accuracy and spatial resolution. Reconstructions that improve image quality can be translated into a reduction of radiation dose because images of acceptable quality can be reconstructed at lower dose.

Two major categories of methods exist, analytical reconstruction and iterative reconstruction. Methods based on filtered backprojection (FBP) are one type of analytical reconstruction that is currently widely used on clinical CT scanners because of their computational efficiency and numerical stability. Many FBP-based methods have been developed for different generations of CT data-acquisition geometries, from axial parallel- and fan-beam CT in the 1970s and 1980s to current multi-slice helical CT and cone-beam CT with large area detectors. For a general introduction of the fundamental principles of CT image reconstruction, please refer to Chapter 3 in Kak and Slaney’s book (1). An introduction to reconstruction methods in helical and multi-slice CT can be found in Chapters 9 and 10 in Hsieh’s book (2). A review of CT image reconstruction methods used on clinical CT scanners can be found in the article by Flohr, et al (3).

Users of clinical CT scanners usually have very limited control over the inner workings of the reconstruction method and are confined principally to adjusting various parameters specific to different clinical applications. The reconstruction kernel, also referred to as “filter” or “algorithm” by some CT vendors, is one of the most important parameters that affect the image quality. Generally speaking, there is a tradeoff between spatial resolution and noise for each kernel. A smooth kernel generates images with lower noise but with reduced spatial resolution. A sharp kernel generates images with higher spatial resolution, but increases the image noise.

The selection of reconstruction kernel should be based on specific clinical applications. For example, smooth kernels are usually used in brain exams or liver tumor assessment to reduce image noise and enhance low contrast detectability. Radiation dose associated with these exams is usually higher than that for other exams due to the intrinsic lower contrast between tissues. On the other hand, sharper kernels are usually used in exams to assess bony structures due to the clinical requirement of better spatial resolution. Lower radiation dose can be used in these exams due to the inherent high contrast of the structures.
Another important reconstruction parameter is slice thickness, which controls the spatial resolution in the longitudinal direction, influencing the tradeoffs among resolution, noise, and radiation dose. It is the responsibility of CT users to select the most appropriate reconstruction kernel and slice thickness for each clinical application so that the radiation dose can be minimized consistent with the image quality needed for the examination.

In addition to the conventional reconstruction kernels applied during image reconstruction, many noise reduction techniques, operating on image or projection data, are also available on commercial scanners or as third-party products. Many of these methods involve non-linear de-noising filters, some of which have been combined into the reconstruction kernels for the users’ convenience. In some applications these methods perform quite well to reduce image noise while maintaining high-contrast resolution. If applied too aggressively, however, they tend to change the noise texture and sacrifice the low-contrast detectability in the image. Therefore, careful evaluation of these filters should be performed for each diagnostic task before they are deployed into wide-scale clinical usage.

Scanning techniques and image reconstructions in ECG-gated cardiac CT have a unique impact on image quality and radiation dose. Half-scan reconstruction is typically used to obtain better temporal resolution. For the most widely employed retrospectively ECG-gated helical scan mode, the helical pitch is very low (~0.2 to 0.3) in order to avoid anatomical discontinuities between contiguous heart cycles. A significant dose reduction technique in helical cardiac scanning is ECG tube-current pulsing, which involves modulating the tube current down to 4% to 20% of the full tube current for phases that are of minimal interest. Prospectively ECG-triggered sequential (or step-and-shoot) scans are a more dose-efficient scanning mode for cardiac CT, especially for single-phase studies. An overview of scanning and reconstruction techniques in cardiac CT can be found in an article by Flohr et al (4).

Iterative reconstruction has recently received much attention in CT because it has many advantages compared with conventional FBP techniques. Important physical factors including focal spot and detector geometry, photon statistics, X-ray beam spectrum, and scattering can be more accurately incorporated into iterative reconstruction, yielding lower image noise and higher spatial resolution compared with FBP (5). In addition, iterative reconstruction can reduce image artifacts such as beam hardening, windmill, and metal artifacts. A recent clinical study on an early version of iterative reconstruction demonstrated a potential dose reduction of up to 65% (6) compared with FBP-based reconstruction algorithms. Due to the intrinsic difference in data handling between FBP and iterative reconstruction, images from iterative reconstruction may have a different appearance (e.g., noise texture) from those using FBP reconstruction. Careful clinical evaluation and reconstruction parameter optimization will be required before iterative reconstruction can be accepted into mainstream clinical practice. High computation load has always been the greatest challenge for iterative reconstruction and has impeded its use in clinical CT imaging. Software and hardware methods are being investigated to accelerate iterative reconstruction. With further advances in computational technology, iterative reconstruction may be incorporated into routine clinical practice in the future.
References


