Introduction  Single-slab 3D T2-weighted TSE imaging\(^1,2\) provides high SNR and high resolution but does not fully utilize the scan time. As an alternative, multi-slab 3D TSE imaging has higher scan efficiency but is affected by ringing and venetian blind artifacts in the slice direction. Various techniques have been proposed to minimize the venetian blind artifacts\(^3,4\). Conventional 3D spiral TSE techniques\(^5,6\) have advantages such as high SNR efficiency, but mostly rely on a spiral-out only trajectory. In this work we propose a multi-slab 3D TSE imaging prototype, using a spiral-in/out trajectory\(^7\) to provide higher SNR efficiency, using sliding-slab\(^8\) to minimize the venetian blind artifacts, and using non-uniform slice phase encoding to reduce the ringing artifacts in the slice direction.

Methods  The TSE spiral readout proposed in the past usually uses a spiral-out trajectory (Fig. 1a) so it either does not align the spin echo with the center of k-space, or only acquires half of the echo (if the spiral starts from the spin echo point, not shown in the diagram). A spiral-in/out trajectory (Fig. 1b) collects the full echo with the spin echo point centered at the k-space origin and therefore has higher SNR efficiency. A rewinding or 1\(^{th}\) order moment compensating gradient could be added, as well as other spiral trajectory designs.

The basic sliding-slab method has been described\(^1\), which also acquires an additional echo to demodulate the signal variation among frames in a slice. In this work, to minimize the impact on the echo train length, an additional short period is inserted in the readout to acquire calibration data at the center of k-space (as shown in the insert of Fig. 1b). Calibration data can also be acquired at the beginning of the gradient waveform.

Due to the limited number of slice phase encoding steps, ringing artifacts arise from Fourier leakage. A non-uniform slice phase encoding scheme with oversampling (Fig 2a, Blue) is proposed against the conventional uniform sampling (Fig 2a, Red). For instance, if 8 slices are encoded, 12 encoding steps can be acquired to more densely sample the center of k-space (Fig 2a, Blue). The kz locations are optimized such that their sampling density coefficients are equal to the inverse of the weights from a typical anti-ringing filter. This reduces the ringing artifacts, as shown by the PSFs in Fig 2b. The SNR loss due to non-uniform signal weighting in the Discrete Fourier Transform (DFT) is also eliminated.

The sequence was implemented on a Philips 3T Ingenia scanner. Volunteer data were acquired with the following imaging parameters: FOV = 230x230x120 mm\(^3\), resolution = 0.9x0.9x3 mm\(^3\), 4 slices/slab, 40 arms/slice, ADC = 15.82 ms, TR = 3000 ms, ETL = 6, TE = 100 ms, scan time = 11:43. 2D Cartesian TSE data were also acquired as a reference with FOV = 230x190x120 mm\(^3\), the same resolution and TR, ETL =16, and TE = 80 ms. Reconstruction was performed in GIP using DFT, sliding-slab processing, data correction, gridding, and deblurring. Two images were reconstructed (one for the spiral-in and one for the spiral-out part) and then combined to form the final image.

Results and Discussion  Fig. 3 shows two axial images acquired with 2D Cartesian (a) and the proposed 3D spiral technique (b). The spiral images have comparable quality to the 2D Cartesian reference. Fig. 3c and 3d are the reformatted sagittal images for 2D Cartesian and 3D spiral TSE, respectively. No visible ringing or venetian blind artifact is observed in the spiral image.

Conclusion  In summary, a 3D TSE imaging prototype is implemented using sliding-slab acquisition, a spiral-in/out readout, and a non-uniform slice phase encoding scheme. The preliminary results demonstrate that its image quality is comparable to 2D Cartesian data without visible artifacts.


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