Eliminating Edge Errors in 3D Spiral Sampling Density Correction and Image Reconstruction

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INTRODUCTION: 3D sampling schemes that move outward in k-space like the spirals-on-cones schemes (1) require gridding or non-equi-spaced FT for image reconstruction. For this type of reconstruction it is necessary to calculate the sampling Density Correction Factors (DCF) for each k-space sample point. The sampling density distribution of the resulting waveforms can be analyzed by calculating the volumes of 3D Voronoi cells around each of the sample points (2). However, the method of ref (2) does not readily translate to 3D sampling schemes where memory size limits the number of sampling points that can be added to the analysis. By calculating spiral waveforms to a slightly longer readout time than desired, it was possible to calculate the sampling densities for the desired readout time accurately. The final gradient waveforms and DCF were obtained by subsequent truncation of the waveforms, the k-space data and DCF data at the desired readout time, or to desired maximum k-space radius. This mechanism is illustrated for a set of 40-projection 2D spiral trajectories. The erroneous and unbounded sampling points are simply discarded. To compensate for this loss the gradient waveforms can be calculated for a slightly higher maximum k-space radius (k_{max}) and longer readout time. The dots on the trajectories in the figure 1A show where the trajectories and DCF can be truncated after Voronoi analysis to avoid these errors. The method for 3D trajectories is entirely analogous.

METHODS: For the DCF calculation were performed on 3D projection waveform sets as described in ref. (3) with 1240 projections and 890k points total. The Voronoi analysis was performed on k-space trajectories for gradient waveforms designed for a slightly (2-10%) higher k_{max} and longer readout time. In this spiral on cone schemes a single projection along the kz axis was also added by translating the radial k-space position as a function of time to a Z-gradient waveform Trajectory data and sampling volumes were then truncated at the desired readout time and k_{max}. Voronoi volumes were calculated with the Qhull algorithm(4) in Matlab v7 (Mathworks, Natick, MA).

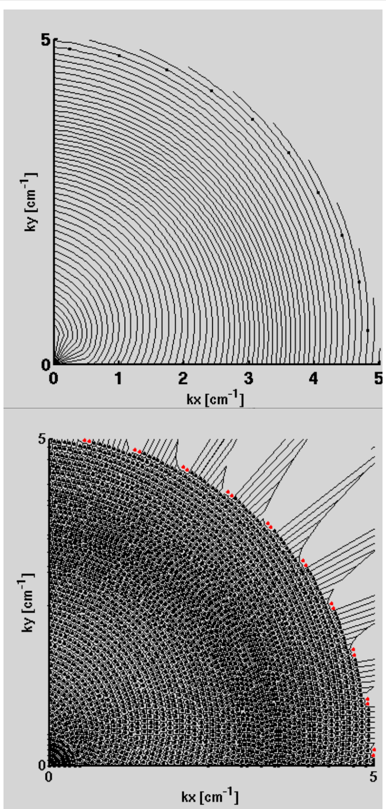

Figure 1 *Errors in sampling area for a 2D spiral. One quadrant of k-space is shown. Non-truncated spiral trajectories (A) yield sampling areas (B) at the edge of sampled k-space that are too large or infinite (red points).*

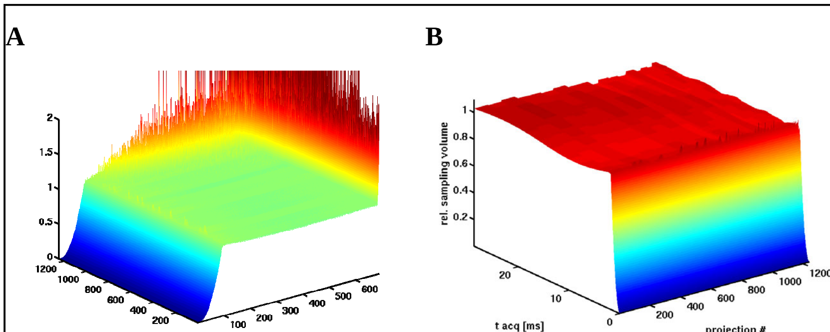

Figure2 *Voronoi volume errors for 3D spirals-on-cones trajectories with 1240 projections of 718 points,(Tread 28ms). Non-extrapolated (A) and after extrapolation-truncation. A pure k-z projection was added to remove volume errors in the last 10-12 projections*

RESULTS: On an Apple (Apple, Cupertino, CA) dual 2Ghz G5 the DCF calculation for almost a million sampling points took less than 15 min. Sampling volumes as calculated before and after truncation of the k-space position matrices (see fig. 2) show that without the adaptation the Voronoi analysis would lead to severe volume errors for the sampling points at the k-space boundaries. The excessively large sampling volumes calculated by Voronoi analysis of 3D spiral sampling schemes are completely eliminated by this strategy.

CONCLUSION: Presented is an accurate and practical method for calculating DCF for the 3D k-space sampling patterns that can be extrapolated in time or otherwise. The effects of the DCF errors on image reconstruction are generally not severe for projection type spirals that start at the center of k-space, but may be very severe for projections with minimal curvature, or trajectories that do not start at k-space center.

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