Independent Phase Modulation for Dual-Slab 3D Imaging

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Introduction: Applications of MRI such as contrast-enhanced breast MRI and bilateral extremity imaging demand rapid imaging of multiple 3D volumes. Simultaneous (rather than sequential) acquisition of volumes can significantly increase signal-to-noise ratio (SNR), but also increases scan time when regions between volumes must be phase-encoded. We show that independent slab phase modulation eliminates the need to encode extra space, resulting, for example, in a time savings of 20-30% for simultaneous bilateral breast imaging.

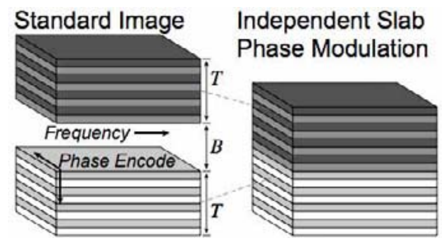

Figure 1: *Independent slab phase modulation shifts two phase-encoded slabs together in the image, reducing the encoded FOV from $2T+B$ to $2T$.*

Theory: In phase-encoded MRI, a linear phase ϕ per phase-encoded line applied to k-space data results in a shift of $(\phi/2\pi) \times$ FOV (where FOV is the phase-encode direction field-of-view). Consider two slabs of width T, separated by empty space B. If the slabs are excited *separately* in a time-multiplexed scheme [1], their excitation phases can be *independently* increased by $\phi = \pm\pi B/FOV$ on each slab-direction phase encode such that after normal imaging, the slabs appear to be shifted together, as shown in Fig. 1. This allows multiple slabs to be phase-encoded as if they were a single, contiguous volume. Slice locations can be labelled correctly after reconstruction. This is a 3D extension of phase-offset multi-planar imaging [2].

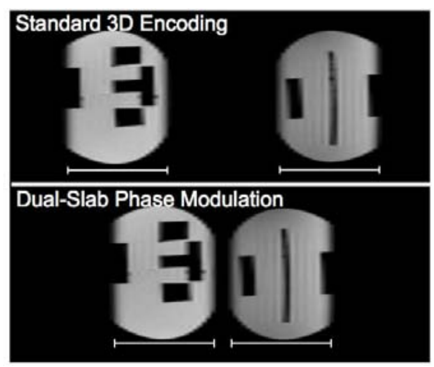

Figure 2: *Dual-cylinder phantom imaged with two excited slabs (width shown by marks) and a large FOV in the slab direction (Top). With independent slab phase modulation, the slabs shift together in the images (bottom), and the FOV could easily be reduced without aliasing.*

Methods and Results: We used a 1.5T GE Excite 12.0 scanner and VIBRANT 8-channel breast coil to scan a phantom and 7 human subjects (after informed consent). All scans use RF-spoiling and a 40°-flip, dual-band water-only excitation [1], which allows independent control of position, phase, center frequency and shim for two slabs. Note that independent phase modulation could also be achieved with two simple slab-selective pulses in rapid succession.

Our phantom consists of two cylinders placed in the breast coil, with axes in the A/P direction. We excited two 3D sagittal slabs and acquired an image using a large FOV and standard 3D Cartesian encoding. Next, we repeated the identical experiment, but modulated the phases of the excited slabs with phase-encode number in the right/left direction. The axial reformats of both images (Fig. 2) are identical, except that phase modulation shifts the slabs together in the bottom image, and the FOV could be reduced without aliasing.

In 7 human subjects we tested 3D Cartesian ($0.5 \times 1.0 \times 1.5$ mm^3 resolution, 8 minute scan time) and 3D stack-of-spiral [3] ($1.2 \times 1.2 \times 3.0$ mm^3 resolution, 10 second scan time) sequences with the slab-direction FOV (9.6 cm) in this direction equal to the total thickness of two sagittal slabs, one placed over each breast. Figure 3 shows the slab positioning, and the reconstructed images. The slabs are shifted together with no aliasing despite the reduced FOV.

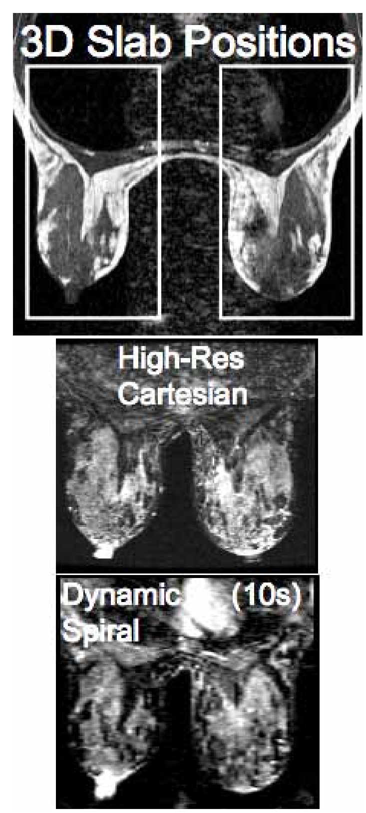

Figure 3: *Axial scan showing prescribed 3D slabs (top). Axial reformats from sagittal high-resolution 3D Cartesian (middle) and rapid 3D stack-of-spiral acquisitions (bottom), both with independent phase modulation, shown at the same scale. The slabs are shifted together without aliasing, decreasing the FOV (and scan time) by 20% in this example.*

Discussion: Independent phase modulation of 3D slabs is a simple and effective technique that can be applied to gradient echo, RF-spoiled, balanced SSFP and spin echo sequences. Care must be taken to avoid abrupt changes to the steady state for each slab, but for any linear phase-encode ordering, this is possible. Independent phase modulation allows simultaneous imaging of multiple 3D slabs with higher SNR, but the same scan time as sequential imaging. Alternatively, multiple 3D volumes may be encoded as if they were contiguous, reducing FOV and significantly reducing scan time.

References: [1] Pauly JM, et al. 11th ISMRM, p. 966., 2003.
[2] Glover GH. JMRI 1:457–461, 1991. [3] Irarrazabal P. et al. MRM 33:656–662, 1995.