Optimized refocusing flip angles for efficient single-shot fast spin echo imaging

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Target audience: MR physicists and clinicians interested in fast T2 imaging for body applications

Purpose: Single shot T_2-weighted imaging methods like SSFSE and HASTE are robust to patient motion but suffer from specific absorption rate (SAR) limitations, reducing their efficiency at 3T due to lengthened TRs. We investigated a variable refocusing flip angle scheme for SSFSE (vrfSSFE). The control parameters that determine the refocusing flip angle train were optimized for minimal SAR/TR and maximal SNR/contrast for imaging the biliary/pancreatic ducts and the female pelvis.

Methods: Rather than the goal of maintaining transverse magnetization over long echo trains[1], our strategy focused on minimizing TR/SAR whilst maintaining SNR and contrast. Following the scheme of [1], after an initial flip of 130°, flip angles were ramped down to f_{min} to slow the T_2 decay, ramped up to f_{cen} where the center of k-space is acquired and ramped down to f_{end} at the end of the train (Fig 1a). We searched the parameter space spanned by f_{min}, f_{cen} and f_{end} to maximize SNR and minimize SAR for two applications: (a) visualization of cysts and biliary/pancreatic ducts (b) female pelvis imaging. An Extended Phase Graph (EPG) algorithm implemented in MATLAB using T_1/T_2 values for 3T abdominal tissue[2] was used to simulate signal evolution. All subjects were scanned under IRB approval on a 3.0T MRI scanner (MR750, GE Healthcare, Waukesha WI) with conventional SSFSE (constant flip angle of 130°) and vrfSSFSE using a 32-channel torso array. Other parameters were 416x320 matrix, 5 mm thick, 20-30 slices, BW ±50 kHz, ARC parallel imaging 3X, half Fourier k-space with 8 extra lines, TE_{eff} 140/100 ms (biliary/pelvis), echo spacing 5ms.

Results/Discussion: Fig 1a. shows SSFSE and vrfSSFSE flip angle trains for TE_{eff}=140ms. The corresponding EPG signal curves are shown in Fig 1b. Lower f_{min} produced a flatter signal response but required longer echotrains to achieve the desired TE contrast at the center of k-space (dotted lines), increasing the waveform TR. Fig 2c shows EPG predicted waveform TR and measured TR (maximum of SAR-limited TR and waveform TR) vs. f_{min}. Optimum TR is achieved at f_{min}= 90°, where TR is limited only by waveform duration. Fig 2d shows normalized signal and SAR as a function of f_{cen} and f_{end}. The highest value of f_{cen} that still produced waveform-limited TR was chosen (100°) and f_{end} set to 45°. These parameters were similar using T_1/T_2 values of bile/liver as well as of endometrium/cervix, suggesting its tissue-type independence. Fig 3-4 show coronal slices from a male subject evaluated for biliary obstruction and from a female subject obtained using SSFSE and vrfSSFSE ($f_{min}/f_{cen}/f_{end}$ 90°/100°/45°). Note the comparable image quality achieved with 2X less TR using vrfSSFSE. The use of f_{min} lower than 60° results in refocusing flip angles lower than 90° near the center of k-space, which can cause signal voids from increased motion sensitivity.

Conclusions: By optimizing the refocusing flip angle trains, significant (2X) reduction in TR was achieved while maintaining similar SNR and contrast as SSFSE imaging in the body. The reduced TR can be used to increase spatial coverage or reduce the total breath-hold time.

References: 1. Busse RF et al. *MRM* 2008 2. De Balzaire et al. *Radiology* 2004

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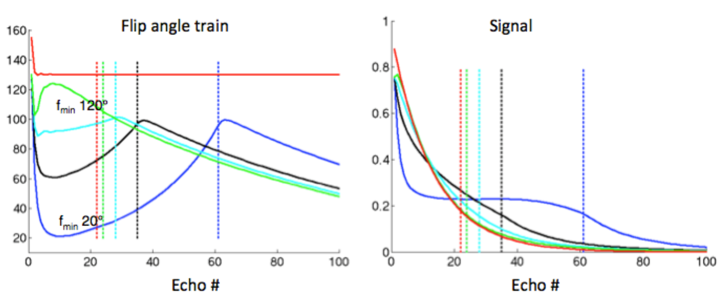

Fig 1. Flip angle trains for SSFSE (red) & vrfSSFSE with f_{min} = 20°, 60°, 90° & 120°. The signal curves are shown to the right.

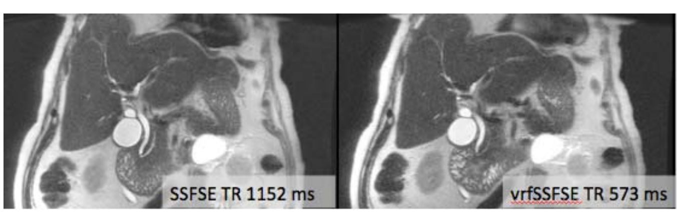

Fig 3. Conventional SSFSE (left) vs. vrfSSFSE (right) from a patient evaluated for biliary/pancreatic duct obstruction. Note the near identical image quality with ~2X reduction in TR using vrfSSFSE.

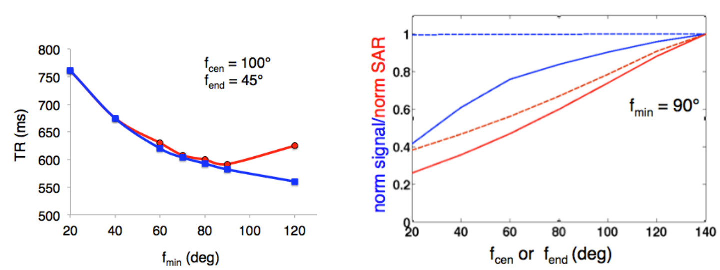

Fig 2c- TR vs. f_{min} from EPG simulations (blue) and measurements (red). Values greater than 90° are SAR-limiting. Fig 2d- Signal vs. f_{cen} (solid blue) and vs. f_{end} (dashed blue). SAR vs. f_{cen} (solid red) and f_{end} (dashed red). For f_{cen} <= 100°, TR was still not SAR limited. Note that signal is also insensitive to f_{end}

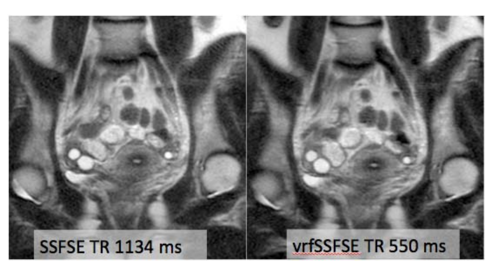

Fig4. SSFSE (left) vrfSSFSE (right) acquired on a female subject showing similar SNR & contrast in half the scan time.