MR Fluoroscopy Employing Interactive Pulse Sequence Switching

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Introduction Several commercial MRI systems provide an interactive MR "fluoroscopy" option that has been used for cardiac plane localisation, fetal imaging and MR guided interventions. Gradient echo based sequences are mainly used for acceptable frame rates. Slower spin echo sequences have been used for applications such as bowel, fetal and biliary imaging. In general all these techniques provide interactive control of scan plane orientation and geometry parameters such as FOV and slice thickness but the interactive manipulation of image contrast has been limited to features within a class of pulse sequence - such as the toggling of RF spoiling capabilities, selection of fat suppression and reversal of phase encode order. Few, if any, commercial systems provide the ability to switch in "real-time" between a gradient echo based and spin echo based sequence. This could be clinically useful in situations where anatomy or imaging information is changing rapidly. Examples include MR enteroclysis where during rapid filling of the bowel the ability to switch rapidly between a hydrographic spin echo based projection image (showing the bowel lumen) and a thin section balanced gradient echo image (showing the bowel wall) would be helpful for detecting subtle strictures. Another application would be during direct MR guided arthrography the ability to switch rapidly between a spin echo based sequence, minimising needle artefacts for positioning, and a fat suppressed spoiled gradient echo image for confirming the correct location of dilute gadolinium contrast medium during injection. Both these applications require relatively fast switching between the sequences, particularly for enteroclysis where given the speed of lumen filling, intestinal peristalsis and other physiological motion such as vascular pulsation and respiration the switching would ideally take place within a second or at worst within a breath-hold (15 seconds) allowing the location to be maintained. Improved computer performance on most MRI systems has reduced the time to switch between sequence classes but this is still relatively slow. This work aimed at developing a comprehensive MR fluoroscopy sequence, integrated into a commercial MR system, that allows interactive switching between a single-shot fast spin echo (SSFSE) sequence and the three types of gradient echo imaging (RF spoiled [SPGR], phase rewound [GRE] and fully balanced [FIESTA]).

Fig. 1: Real-time control application

Method A research real-time SSFSE sequence within a proprietary real-time imaging interface on a 1.5T whole body MR system (i/Drive Pro Plus & Excite HD, GE Healthcare, Waukesha, WI) (1) was modified to support an additional gradient echo scan "core" creating a real-time gradient/spin echo (RTGS) sequence. To overcome the limitations of the i/Drive GUI a separate control tool was developed that communicated directly with the RTGS sequence and provided a mechanism for modifying sequence parameters in real-time. This control application was developed in Java using the JBuilder™ 2005 Foundation IDE (Borland, Cupertino, CA) and the GUI constructed using the Java Swing API (Fig. 1). Interprocess communication between the application (client) and the pulse sequence (server) was achieved using non-blocking UDP datagram sockets. The underlying pulse sequence development environment (EPIC) was modified to incorporate the necessary BSD socket library header files in the compilation. The real-time pulse sequence was modified to create and bind a socket to the address of the computer running the tool, in this case the scanner host computer. Once initiated the Java client program connects to the scanner Applications Gateway Processor (AGP) and then makes the desired sequence parameters updates available. This application can also provide interactive geometry control, orthogonal plane selection and control over field-of-view, slice thickness, flip angle, fat saturation, dynamic/on-demand imaging (2), hydrographic mode (2), and repetition time (TR) as well as sequence switching.

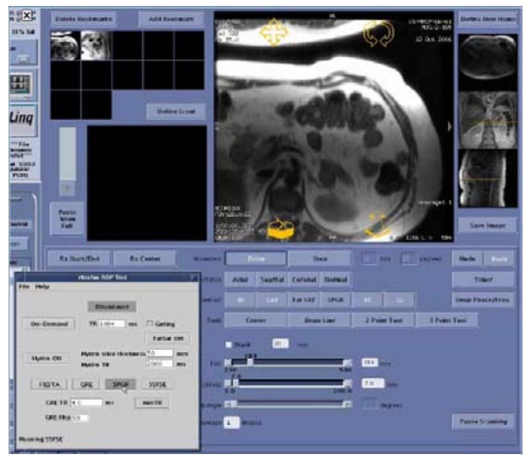

Fig. 2: The RTGS controller interfaced to i/Drive and running an SSFSE sequence axially in the mid- abdomen of a volunteer.

The real-time RTGS sequence and controller interfaces with the i/Drive GUI and standard scanner reconstruction (Fig. 2) or alternatively can operate standalone using an in-house image reconstruction and display application. This is a multi-threaded Java application that reads data from the scanner real-time data server (RDS, GE Healthcare, Waukesha, WI) over TCP/IP, supports multi-coils and performs image reconstruction using FFTW. The raw data routing can be interactively switched between i/Drive and RDS as required. Currently the i/Drive interface requires the acquisition matrices, bandwidth and NEX for the SSFSE and gradient echo scans be identical as real-time control of the host reconstruction process is not currently possible. These factors currently limit the RTGS - FIESTA implementation in particular to a TR of 6msec and 0.5NEX reconstruction when compared with the standalone real-time FIESTA version that achieves a TR of 3msec.The standalone reconstruction software allows more flexibility through interactive modification of the y-resolution acquisition matrix and therefore control of partial Fourier methods and it also permits additional interactive image processing. The sequence switching capability was evaluated by comparing the time taken to change imaging sequences using the fastest routinely available method using the standard scanner and i/Drive interface (with book marking, and prepared protocol parameters and no prescanning) and the RTGS sequence and controller application interfaced to the i/Drive display and scanner reconstruction. Using an imaging phantom in an 8 channel cardiac array the times taken to switch between sequences and parameters (simulating their use in clinical applications) outlined in Table1 was compared. After initial training and practice a single operator familiar with both systems switched as quickly as possible between the sequences and the mean of three timed attempts for both systems and both simulated examinations obtained.

Results The initial evaluation demonstrated that a marked reduction in switching time was achievable using the dedicated RTGS sequence and control application (lower 2 rows of Table1), even without preloading all the parameters which could further reduce the switching time. The improvement is largely for two reasons, firstly because it avoids the scan interface software delays during the manipulations to select a new sequence, download and prepare it. Secondly it also avoids the need to collect the reference image locations acquired when starting the i/Drive interface after a new sequence type has been selected.

Conclusion This work demonstrates that rapid sequence switching within a breath-hold is feasible on current commercial systems and with improvements sub-second sequence type switching may be possible. Most vendors have yet to fully appreciate the clinical applications potential for real-time MRI but fast switching and improving the ease of use of real-time interfaces are likely to be important to facilitate new real-time clinical examinations. Future work will address optimising further the implementation of the sequence versions through control provided by the standalone reconstruction process.

TABLE	MR Enteroclysis		MR Arthrography	
1	*(a) SSFSE*	*(b)FIESTA*	*(c)SSFSE*	*(d)FSPGR*
TE	700msec	0.9msec	60msec	2.1msec
TR	4000msec	3-6msec	1400msec	6.5msec
Matrix	256x256	256x256	256x256	256x256
FOV	34cm	34cm	20cm	20cm
Thick	100mm	10mm	10mm	40mm
Flip		50^o		60^o
Fatsat	Y	N	N	Y
iDrive	23.7 secs		28 secs	
RTGS	4.3 secs		6.4 secs	

References

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Acknowledgements

FFA, MRIS Unit Radiographers, Addenbrooke's Hospital. Jeff Stainsby (RDS, GE Healthcare)