Real Time Interactive Spiral Imaging in a Reduced FOV for Cardiac Applications

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Introduction:
Ultra-fast MR data acquisition, instantaneous image reconstruction and fast changes of sequence parameters constitute the essential basis for real-time interactive MR imaging [1,2]. To implement such a system in practice is an especially challenging task for cardiac applications due to the fast motion of the heart. Among all currently used MRI sampling patterns, the spiral trajectory approach is one of the most efficient schemes to sample the data in k-space. Fast changes in anatomy or contrast can be captured due to the frequent update of the central portion of k-space and the robustness of this scheme against motion and flow effects. In cardiac applications the dynamic processes take place in one part of the field of view. The restriction to this reduced field of view (rFOV) can be used either to increase the spatial or the temporal resolution. MR imaging of the rFOV involves suppression techniques to avoid backfolding artefacts. In spin-warp imaging magnetization outside the rFOV has to be suppressed in the phase encoding direction only, whereas in spiral imaging all magnetization outside the rFOV has to be cancelled. In this work effective suppression schemes are presented to support spiral MR fluoroscopy in a rFOV. The position and size of the rFOV can be controlled interactively.

Method:
In spiral imaging all signal outside the rFOV can be suppressed by a regional suppression technique (REST) [3], e.g. by four thick saturation slabs to leave a rectangular region untouched. Two different suppression schemes are tested. 1.) After applying four REST slabs a given number of interleaves can be acquired. 2.) Under the assumption that the saturation of the magnetization is sufficient for a while, two subsequent RESTs with perpendicular orientation are applied after each one or more spiral interleaves are acquired (Fig. 1).

Figure 1: Schematic sequence of rFOV spiral imaging. The orientation of two parallel REST slabs are toggled perpendicularly between subsequent acquisition windows. The sequence has been implemented in the interactive scan mode of our scanner [4] that allows to control several MR parameters such as slice position and angulation, excitation flip-angle, etc. during continuous scanning with a short latency of 100 ms. The position and orientation of the actual FOV formed by the REST slabs can be moved interactively. In addition the flip angle of the REST RF-pulses can be changed interactively to improve the outer volume suppression.

Experimental:
The real-time system is basically a conventional 1.5 T MR scanner (Gyroscan, ACS-NT15, Philips Medical Systems, gradients 23 mT/m in 0.2 ms) to which a general-purpose real-time reconstruction hardware is added to reconstruct data sampled at high speed along arbitrary k-space trajectories [5]. Parallel acquisition and reconstruction of data from six phased-array coils are supported in real time. K-space is traversed using interleaved spiral trajectories with variable angular speed. Continuous real-time sliding window [1] image reconstruction is performed, with update of the image after acquisition of each or each second spiral interleave. The images of the individual coils are combined using the sum of squares approach. A spectral spatial pulse is used for RF excitation. For cardiac real-time imaging the FOV was set to 180° mm². The acquisition window was 16 ms, the number of spiral interleaves 2/3/5 each with an TR/TE=32/5ms (incl. REST) results in an in-plane resolution of 2.8/2.0/1.5 mm.

Results and Discussion:
In-vivo experiments to study the performance of this approach were performed on healthy volunteers. The short latency and the high update rate of 20 frames per second of the reconstructed images allows to monitor cardiac motion with a good temporal resolution. With the additional tool of the interactive scanning mode, scouting and/or positioning procedures are supported. With rFOV spiral imaging a higher spatial and/or temporal resolution can be achieved. Therefore it is possible to visualise cardiac wall motion during the entire R-R interval (Fig. 2).

Figure 2: Extracted spiral real-time frames without (a) and with rFOV imaging (b). (1.5 mm resolution, 2 elem. array coil).

The use of REST slabs predominately reduces the effect of backfolding artefacts (alasing rings) as shown in Fig. 2. Different suppression schemes have been tested. Phantom experiments show that with rFOV imaging the outer volume magnetization is suppressed by a factor larger than 100. If a higher number of interleaves are acquired after the suppression all REST slabs should be applied at once (first scheme). If only few interleaves (n<2) are acquired, the second scheme provides a more frequent suppression. The quality of the outer volume suppression depends strongly on the relaxation times of the tissues and thus on how often the magnetization is saturated.

Conclusion:
We demonstrate that rFOV imaging improves real-time spiral imaging of the cardiac function. The restriction to a rFOV can be used to increase the spatial or the temporal resolution. The application of this method allows rapid in-vivo localisation and offers the opportunity to study transient in-vivo phenomena with high temporal resolution. The conventional MR system, upgraded with an ultra-fast real-time general-purpose reconstruction unit and a real-time user interface, may be useful in cardiac diagnostics to study motion or contrast media uptake or to guide future interventional procedures.

References: