Flexible and Retrospective Trade-off Between Temporal and Spatial Resolution in Dynamic MR Imaging

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Introduction

MR Imaging of dynamic processes is of increasing interest in a wide field of applications, for example in cardiac and interventional imaging, orthopedics and angiography. Dynamic processes are typically hardly reproducible, seldom strictly periodic and difficult to predict. This demands careful planning of a scan, especially to well define the trade-off between temporal and spatial resolution of a time frame. The parameters cannot be modified retrospectively, so that misplanning of a scan or variable kinetics result in waste data and false depiction of highly dynamic events (Fig.1a). Consequently, prerequisites of real-time imaging are first, the ability to reconstruct any arbitrary moment from a dynamic readout train, and second, to reconstruct this time point with arbitrary temporal resolution. It has been shown that increased image update rates and a limited choice of temporal resolutions per frame can be achieved with imaging approaches based on radial scanning and segmented data acquisition [1]-[4]. Then the selection of a time point and its temporal resolution is limited by the segmentation precept, and the planning still requires a-priori knowledge about the contrast or the motion kinetics. In this work, it is shown that a *retrospective and fully arbitrary* selection of a time point and its temporal/spatial resolution from a dynamic readout train (Fig. 1b) can be achieved when spacing succeeding radial acquisitions (views) by a constant azimuthal increment of ϕ_{GR}=111.246°, which is related to the Golden Ratio.

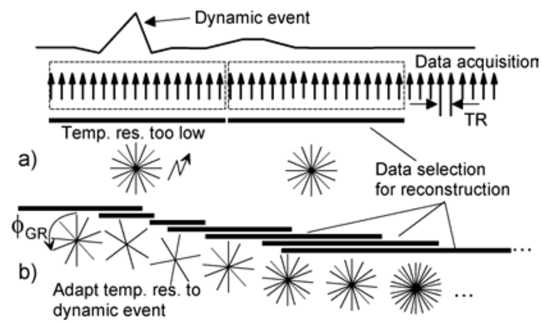

Fig. 1. a) Conventional imaging. The trade-off between temporal and spatial resolution must be carefully balanced to appropriately depict highly dynamic events. b) The acquisition scheme based on the Golden Ratio permits the retrospective adaptation of the reconsruction parameters to variable kinetics.

Methods

The Golden Angle increment is obtained by dividing 180° according to the Golden Ratio $\phi_{GR}=180°/\gamma$ (γ=1.618) and causes radial lines to be very evenly spaced in time independent from the number of acquisitions (Fig.1) [5]. It can further be shown, that the most uniform sample distribution is reached, if the number of radial views represents a Fibonacci number, which also results in a maximum SNR (99.5% with respect to the uniform radial trajectory) and a minimum artifact level. The decrease of uniformity reduces the SNR at most by only 2.5% with respect to the traditional uniform radial sampling pattern [6]. The method was applied to cardiac imaging, where the exact moments of maximum and minimum contraction are of special importance for cardiac function examination. These time points can now be selected retrospectively and be depicted with arbitrary temporal resolution (SSFP, FOV=340x340x10mm^3, matrix=128x128, TR/TE=2.6/1.3ms, flip angle=60°). In a second experiment, the technique was employed in a joint function imaging experiment in comparison with a uniform and segmented (sliding window) radial acquisition (FFE, FOV=300x300x8mm^3, matrix=224x224, TR/TE=4/2ms, flip angle=50°, 56 views per segment). The segments are arranged according to the reversed bit order, which allows the user to choose between at most 3 different and distinct temporal resolutions (1 segment: 224ms, 2: 448ms, 4: 896ms) [3]. All imaging was conducted on 1.5T clinical scanners (Philips Achieva, The Netherlands) on healthy volunteers.

Results

Cardiac imaging: The Golden Angle acquisition permits the accurate, fully flexible, and retrospective selection of the moment of maximum and minimum cardiac contraction as well as the arbitrary adjustment of the temporal resolution of a time frame (Fig. 2). Joint function imaging: Fig. 3 depicts two frames (t_n, t_{n+1}) of both series (conventional segmented acquisition versus Golden Angle) of a continuously moving knee with the same temporal resolution (ΔT=448ms). The segmented acquisition provides the choice between 3 distinct temporal resolutions per frame, whereas the proposed acquisition scheme enables the user to fully flexibly adjust the temporal resolution per frame to the kinetics occurring during scanning. Furthermore, the image quality of the segmented acquisition suffers jump discontinuities from frame to frame (see Fig. 3) for certain segment combinations (2 segments in this example), whereas the Golden Angle acquisition yields a constant artifact/quality level for all frames and resolutions selected. In addition, the level of motion (streak) artifacts is slightly lower in the image obtained by the Golden Angle (Fig. 3, arrow).

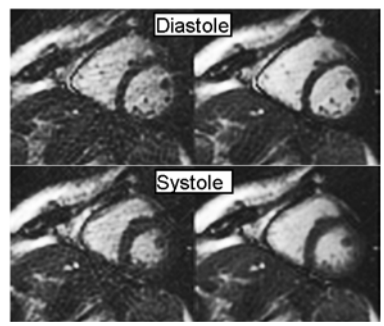

Fig. 2. Cardiac imaging with fully arbitrary temporal resolution at arbitrary time points. Diastole: ΔT=230ms (89 views/frame), systole: ΔT=88ms (34 views/frame).

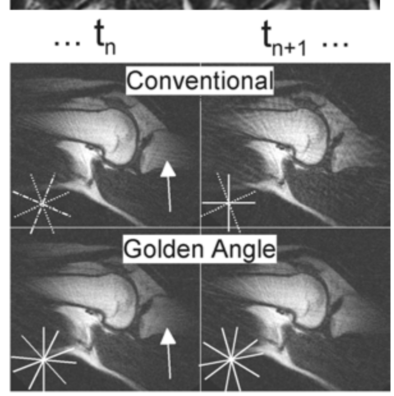

Fig. 3. Two consecutive time frames during joint function imaging of a knee. The motion artifact level is slightly lower for the Golden Angle acq. (arrows). The Golden Angle acq. always provides a constant level of image quality from frame to frame in contrast to the reversed bit segmented acquisition.

Discussion and Conclusion

Spacing successive views in k-space by the Golden Angle ensures that, given a view set fully arbitrary in size, views are nearly uniformly distributed over the radial space. This results in two major advantages compared with the standard radial trajectory. First, data inconsistencies like motion are likewise always uniformly distributed over the entire radial space. And second, the acquisition becomes very insensitive to the temporal length of the reconstruction window, allowing the user to flexibly optimize the trade-off between the temporal and spatial resolution of a frame as well as to arbitrarily select its temporal position from a dynamic readout train. Since those parameters can as well be set retrospectively, the acquisition scheme obviates any a priori planning and knowledge about the expected kinetics occurring during scanning. E.g. cardiac function or blood flow studies in the presence of arrhythmia as well as joint function studies that can hardly be externally controlled could be improved, since the reconstruction window can inherently be adapted to shorter or shifted periods of low motion instead of rejecting the entire shot on account of some corrupted views. According to these findings, we expect the acquisition scheme to significantly facilitate dynamic imaging, as it permits the fully flexible and retrospective reconstruction of dynamic processes.

References:

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