Declaration of Conflict of Interest or Relationship

Speaker Name: Davide Piccini

I have the following conflict of interest to disclose with regard to the subject matter of this presentation:

Company name: Siemens AG, Erlangen, Germany
Type of relationship: Grant/Research Support

Spiral Phyllotaxis: A Better Way to Construct a 3D Radial Trajectory in MRI

Joint Annual Meeting ISMRM-ESMRMB 2010

SIEMENS

Davide Piccini, M.Sc.

Pattern Recognition Lab. (CS 5)

Friedrich-Alexander-University Erlangen-Nuremberg, Erlangen, Germany

E-mail:davide.piccini@informatik.uni-erlangen.de

Arne Littmann, Ph.D.

Peter Schmitt, M.Sc.

Michael O. Zenge, Ph.D.

Siemens AG, MR Applications Development, Erlangen, Germany

Synopsis

In order to exploit the self-navigating properties of 3D radial MRI, the trajectory has to be interleaved so that the first readout of each interleave is oriented in superior-inferior direction. If this is done sub-optimally, image quality is degraded. Hence, an innovative trajectory based on spiral phyllotaxis featuring optimized interleaving properties is presented. The trajectory was compared to an Archimedean spiral in phantom experiments and in-vivo. The smooth gradient waveforms of the novel trajectory avoided eddy current effects and, thus, allowed for whole-heart coronary imaging with high image quality. Moreover, the presented method is intrinsically prepared for self-navigated cardiac MRI.

Motivation

Coronary MRI has to deal with the complex anatomy and motion of the heart

Interleaved radial 3D acquisition provides:

- Extended 3D volume coverage
- Possibility of off-line reformats
- Low sensitivity to radial undersampling
- Intrinsic robustness to motion artifacts

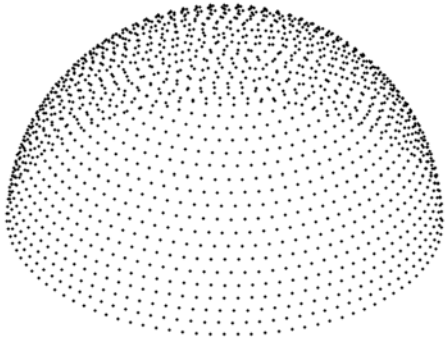
Current 3D radial trajectories trade-off between an overall uniformity of readouts and a minimization of eddy currents effects

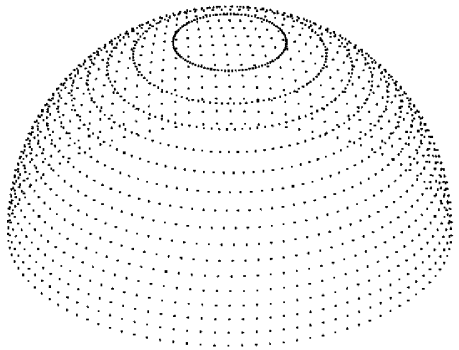
3D Archimedean spiral trajectory

Type A: S. Nielles-Vallespin, Pr. 14th ISMRM: 366 (2006)

Type B: C. Stehning, et al, MRM 52: 197-203 (2004)

Overall distribution of readouts:



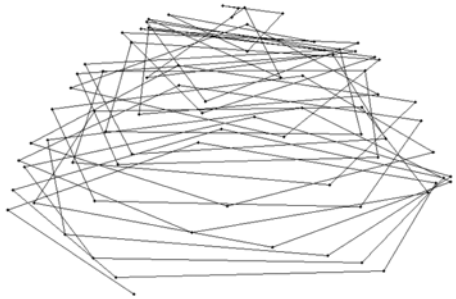


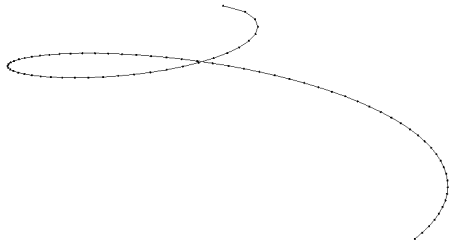
Dots represent the origins of readouts

Overall uniformity preserved

Non-uniform distribution of readouts requires advanced density compensation

Distribution of readouts of a single interleave:





Lines represent change of the gradient moment between successive readouts

Rapidly changing gradient moments induce eddy currents effects

Eddy current effects are avoided

3D spiral phyllotaxis trajectory

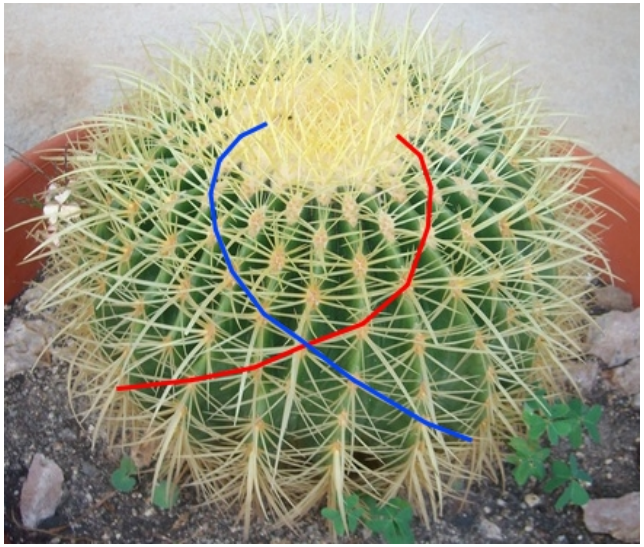
The formula was derived from a 2D implementation[1] and expressed in spherical coordinates:

Radius: $R = const$

Polar angles: $\theta_n = \pi / 2 \cdot \sqrt{n / N}$

Azimuthal angles: $\varphi_n = \left(\frac{2\pi}{360^\circ} \right) \cdot n \cdot \varphi_g$

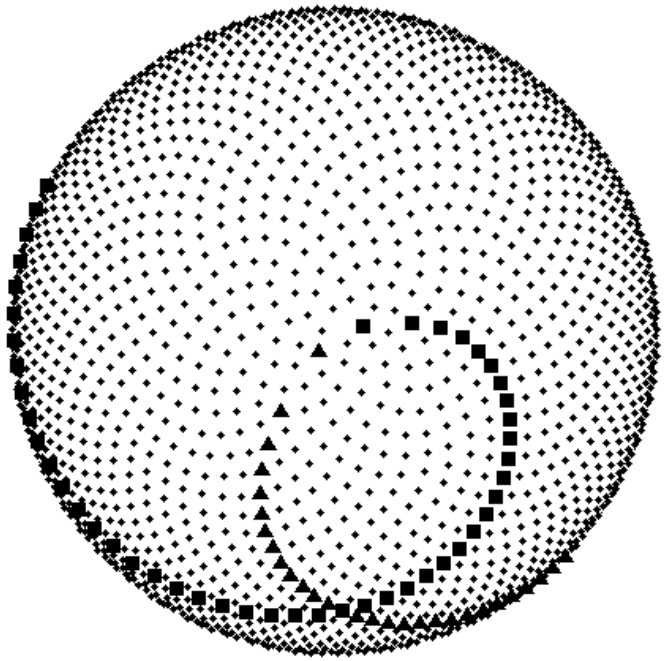
Golden angle: $\varphi_g \cong 137.51^\circ$

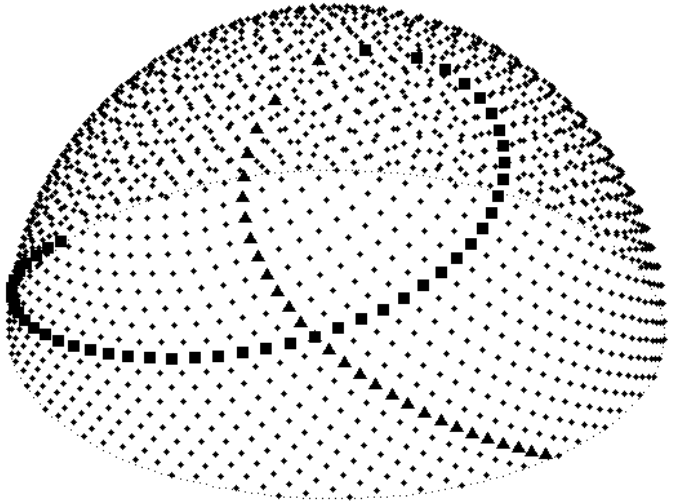


N = tot number of readouts

[1]H. Vogel, Math Biosci 44: 179-189 (1979)

Overall distribution of readouts

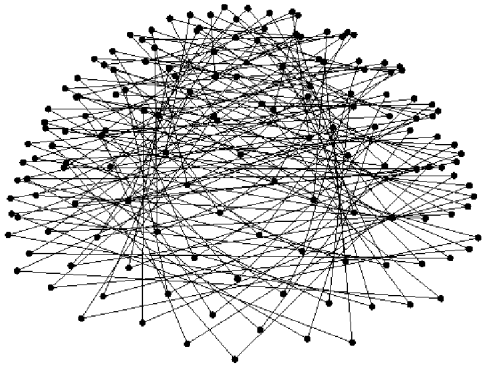




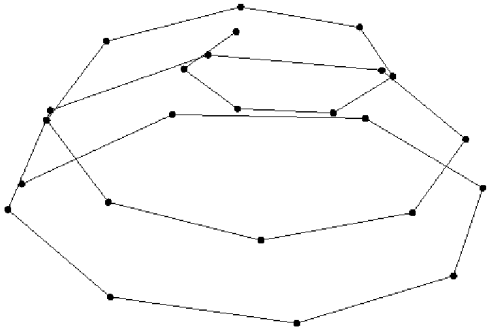
The 3D spiral phyllotaxis trajectory features an overall uniform distribution of the readouts.

Interleaving properties

Non Fibonacci

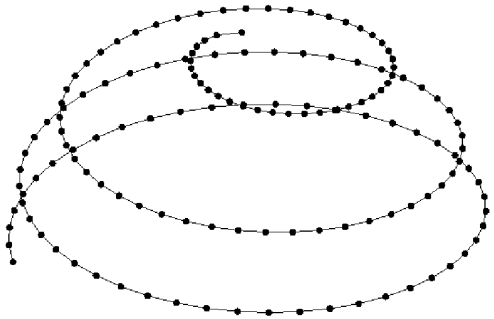


M=24 P=126

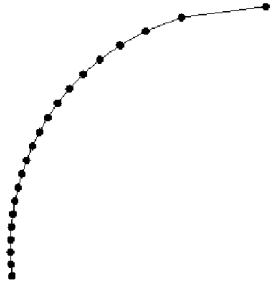


M=126 P=24

Fibonacci



M=21 P=144



M=144 P=21

Robustness against eddy current is intrinsically obtained when a Fibonacci number of interleaves (M) is selected

M = number of interleaves

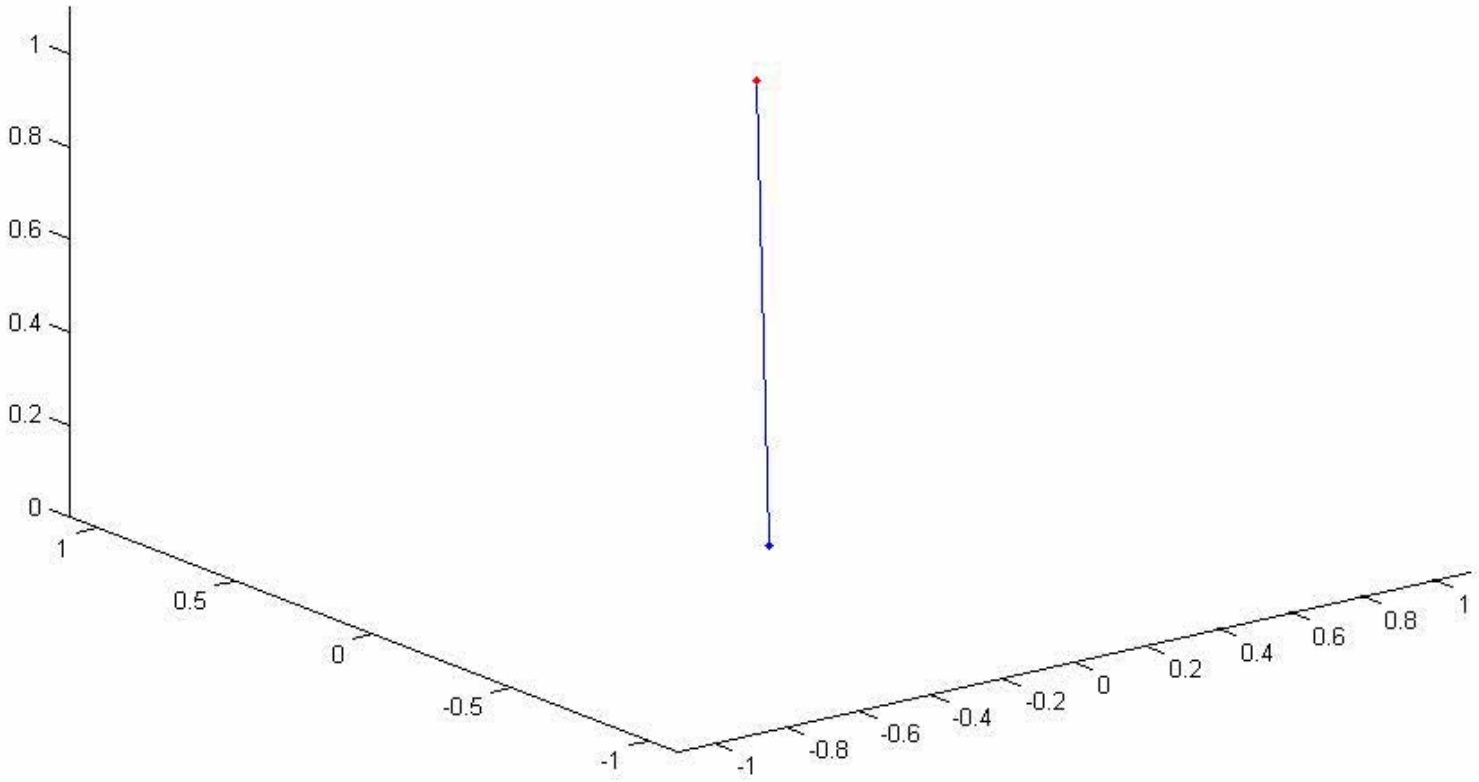
P = number of readouts per interleave

N = M x P = total number of readouts

Davide Piccini

06.05.2010

Simulation of data acquisition scheme



Notice: The rotation angle between successive interleaves equals the golden angle.

MR experiments

The 3D spiral phyllotaxis trajectory was compared to the Type A Archimedean spiral with identical density compensation, as for:

- The overall image quality with interleaved acquisitions in phantom
- The overall image quality in whole-heart coronary imaging for 6 healthy volunteers
- The quantitative image quality in-vivo in off-line reformats of the RCA: SNR, CNR and vessel sharpness

MR data acquisition Protocol

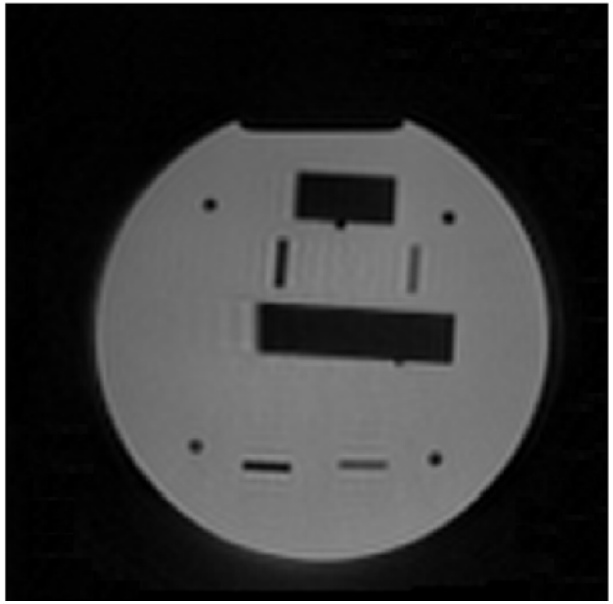
All experiments were performed on a 1.5T Magnetom Avanto (Siemens AG, Erlangen, Germany):

- Non-selective, T2 prep., Fat Sat., TrueFISP
- 12818 Readouts: 377 interleaves x 34 projections → U.sampl: 22%
- FOV 220 x 220 x 220 mm^3 - Base Resolution 192 px
- Voxel size 1.1 x 1.1 x 1.1 mm^3
- TR / TE = 3.0 ms / 1.52 ms
- Flip Angle 90º - Bandwidth 898 Hz/Px

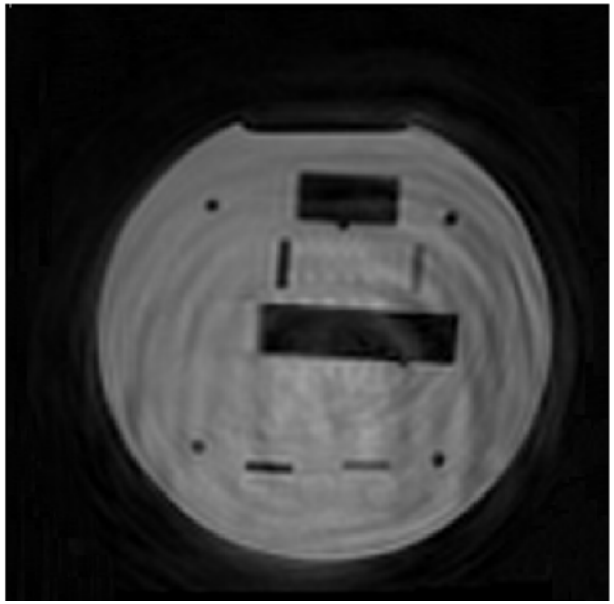
IN VIVO

- ECG trigger – 12el Body + Spine matrix coils
- Crossed-slice spin-echo navigator on right hemidiaphragm: tol. 5mm
- TA = ~ 15 min in free breathing

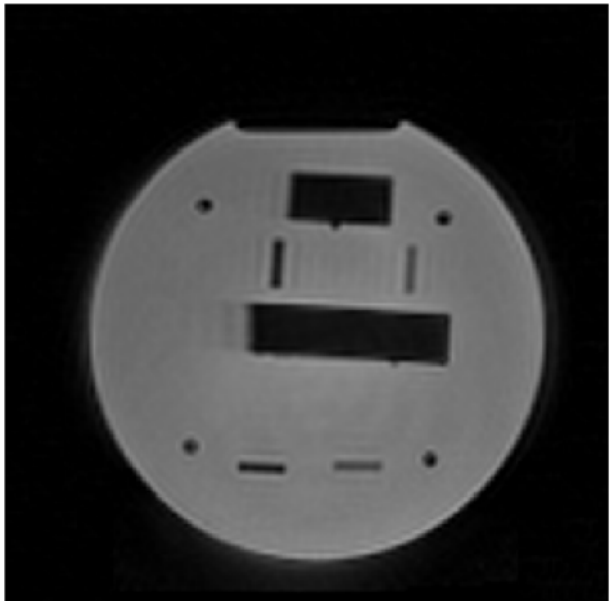
Overall image quality restored



Type A Archimedean spiral trajectory, non-interleaved



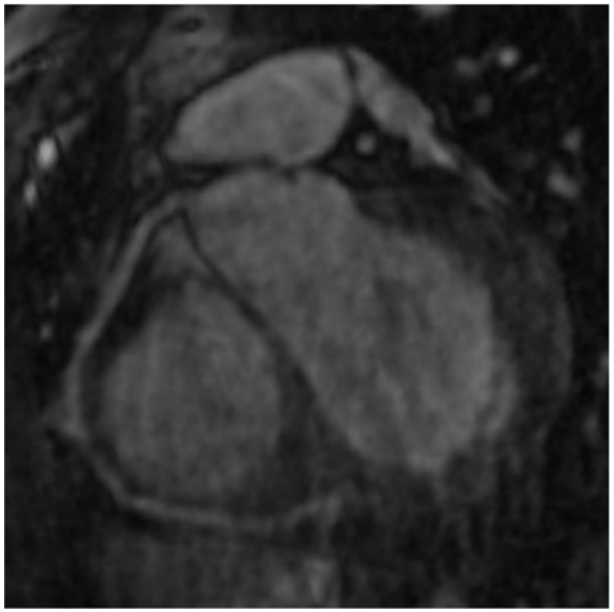
Type A Archimedean spiral trajectory, interleaved



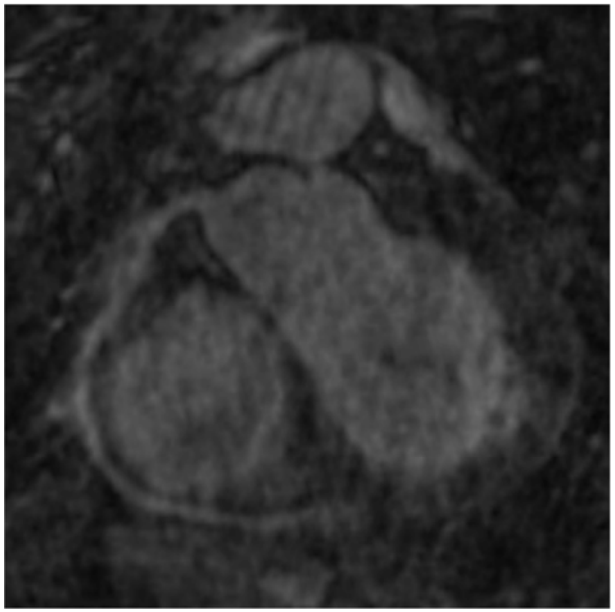
Spiral phyllotaxis trajectory, interleaved

Eddy currents which degrade the image quality in case of the interleaved Archimedean spiral trajectory are avoided with the 3D spiral phyllotaxis trajectory.

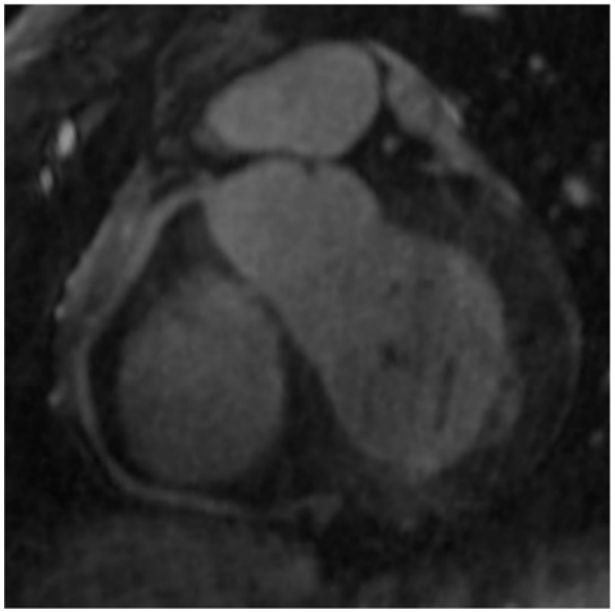
Image quality better than Reference



Type A Archimedean spiral trajectory, non-interleaved



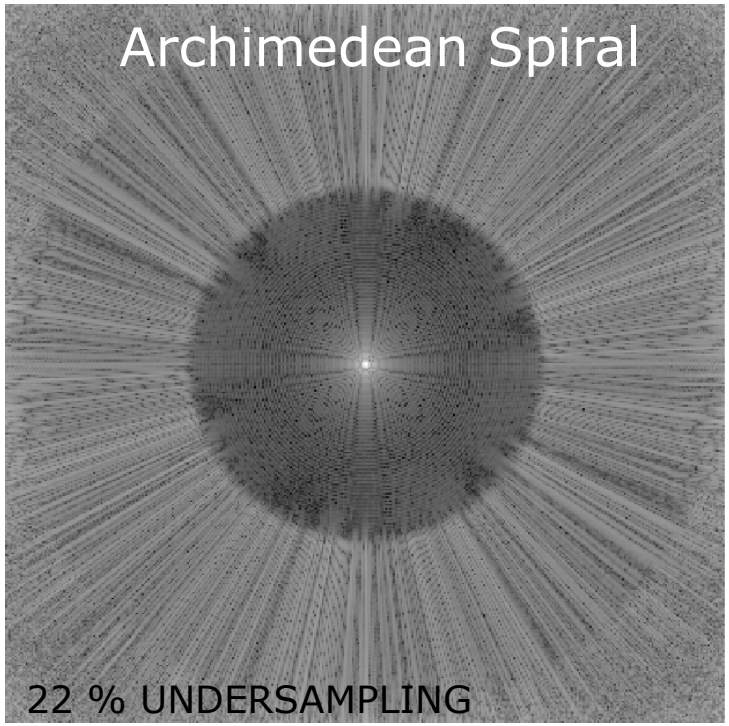
Type A Archimedean spiral trajectory, interleaved

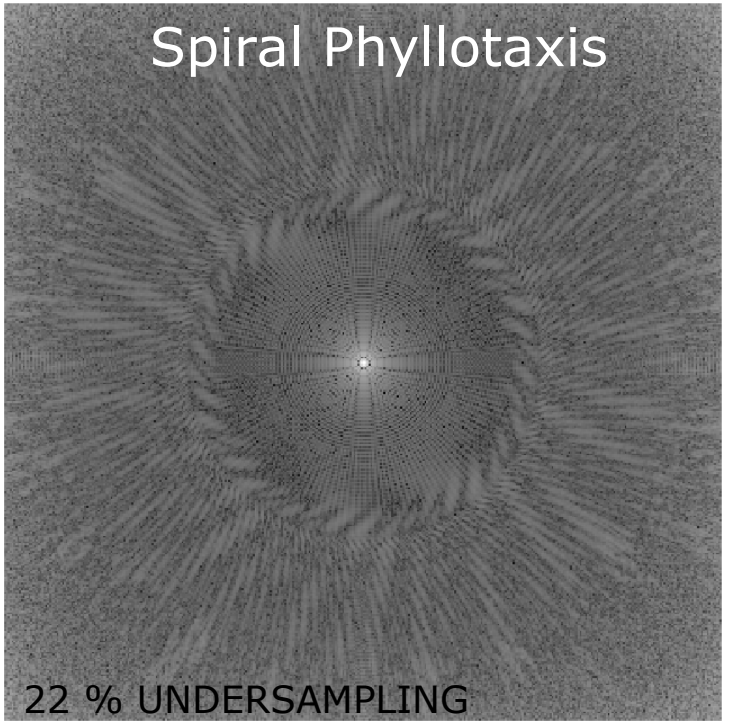


Spiral phyllotaxis trajectory, interleaved

Not only that eddy currents effects are avoided, but in-vivo the image quality of the 3D spiral phyllotaxis trajectory is even superior to the Archimedean spiral reference.
This can be explained by comparing of the point spread functions.

Comparison of Point Spread Functions





Undersampling artifacts are reduced with the spiral phyllotaxis trajectory because the mean signal intensity of the PSF is:

- significantly reduced in the peripheral region,
- only slightly increased in the central region.

Quantitative results confirm superiority

	Archimedean Non Interleaved	Archimedean Interleaved	Spiral Phyllotaxis
SNR	5.71 ± 1.41	4.17 ± 1.05	6.42 ± 1.71
CNR	2.46 ± 0.94	1.81 ± 0.83	2.96 ± 1.16
Vessel Sharpness	0.68 ± 0.12	0.64 ± 0.14	0.74 ± 0.13

Summary and Conclusions

- The spiral phyllotaxis trajectory resolves the trade-off between an overall uniform distribution of the readouts and a minimization of eddy current effects.
- It allows for interleaved respiratory gated whole-heart coronary MRI with high undersampling ratio.
- The image quality achieved is superior to the image quality of the Archimedean spiral trajectory.
- Last but not least, the novel trajectory is intrinsically prepared for self-navigated cardiac MRI.