# Golden Angle PROPELLER MRI

**K. Nehrke[1], P. Börnert[1], G. H. van Yperen[2], and H. Eggers[1]**
[1]Philips Research Europe, Hamburg, Germany, [2]Philips Medical Systems, Best, Netherlands

## Introduction

In PROPELLER MRI [1] rigid in-plane motion may be corrected as a post-processing step in image reconstruction. In addition, more complex (i.e. non-rigid or through-plane) motion may be partially suppressed by correlation weighting, exploiting the high degree of oversampling in central k-space. However, complete rejection of motion-corrupted blades results in undersampling of the peripheral k-space, and hence, potentially degrades image quality. On the other hand, it has been shown that regular angular undersampling produces only minimal image artefacts [2]. Hence, the least artefacts may be expected, if corrupted blades are distributed uniformly over the unit circle. The *Golden Angle* principle, also known from biology (phyllotaxis), is noted for such an isotropic coverage and has been investigated for radial real-time MRI recently [3].
In the present study, the *Golden Angle* principle has been applied to PROPELLER MRI to generate a shuffled spatiotemporal blade order.

## Methods

*The Golden Angle principle:* The golden angle $b \approx 137.51°$ is the angle created by dividing the circumference $c$ of a unit circle into two sections $a$ and $b$ such that $c=a+b$ and $c/a=a/b$. If the golden angle is used as successive increment $\varphi(i) = i \cdot b$, an isotropic, increasingly dense angular coverage of the circle is achieved, which is used by nature for e.g. the arrangement of leaves.
For the diametric PROPELLER blades, only a semicircle has to be considered, which results in a golden angle increment of $b \approx 68{,}75°$. In Fig. 1a, an example for such an alignment is shown. As a result of the infinite sequence period, the blade arrangement is slightly asymmetric. However, in a typical PROPELLER acquisition the number of blades is fixed, making a symmetrical arrangement more preferable. This can be achieved by assigning the Golden Angle blade order to a symmetric arrangement (Fig. 1b), referred to as shuffled π-order in the following. Here, the angle of the i-th acquired blade may be written as $\varphi(i)= f(i)\cdot\pi/N$, where N and $f$ denote the total number of blades and the discrete shuffle function for mapping from temporal to spatial order, respectively.

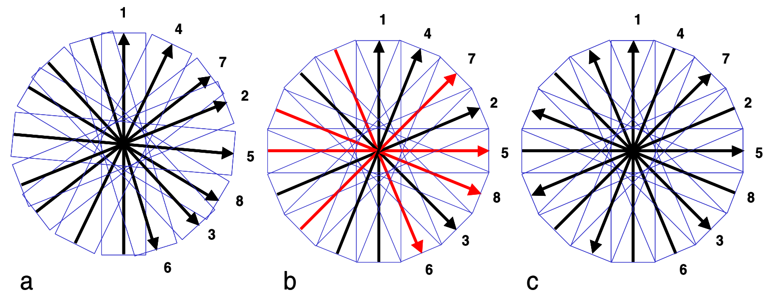


**Figure 1: PROPELLER blade arrangements:** Golden angle increment (a) and slightly adapted, equidistant alignments (b: shuffled π-order, c: shuffled 2π-order). The numbers indicate the acquisition order of the respective blades. In (b) the second halftime is indicated by red arrows to illustrate the nearly isotropic coverage. The arrows indicate the direction of k-space traversal.

Furthermore, a shuffled 2π-order (Fig. 1c) may be achieved by slightly modifying the above expression to $\varphi(i)= f(i)\cdot\pi(1+1/N)$. In this mode, the readout-gradients rotate by 2π, facilitating e.g. a correction of gradient delay imperfections.
*Experiments:* PROPELLER MRI has been implemented on a clinical scanner platform (Achieva, Philips Medical Systems). A head coil quality phantom was scanned in transversal orientation using a TSE PROPELLER sequence (TR/TE = 1000/40 ms, matrix/TSE factor/blades = 256/16/16, FOV = 256mm, slice thickness =10 mm). To mimic through-plane patient motion, the table was moved a few centimetres just after half of the acquisition to shift a different phantom section into the image slice (Fig. 2a,d). The experiment was performed for both linear and shuffled π-orders as described above. Reconstruction was performed with and without correlation weighting. In the first case, a blade from the first halftime of the acquisition was chosen as reference.

## Results and Discussion

The shuffled π-order order resulted in much better image quality than the linear order (Fig. 2b,c), which can be explained with the undersampling properties of the PROPELLER trajectory [2]. As a result of the low correlation between target slice and polluting slice, correlation weighting resulted effectively in nearly 50% k-space undersampling. For the employed motion pattern, the shuffled order results in nearly regular angular undersampling, which is more robust for image reconstruction than the omission of several adjacent blades characteristic for the linear order.
Of course, these findings cannot simply be generalized for arbitrary motion pattern, but it may be expected that the inherently isotropic sampling characteristic for the Golden Angle principle will be beneficial for improving the motion robustness of PROPELLER MRI in general. The presented shuffled orders could also be advantageous in case of dynamic PROPELLER imaging to update potential contrast changes also for higher spatial frequencies in a uniform manner.

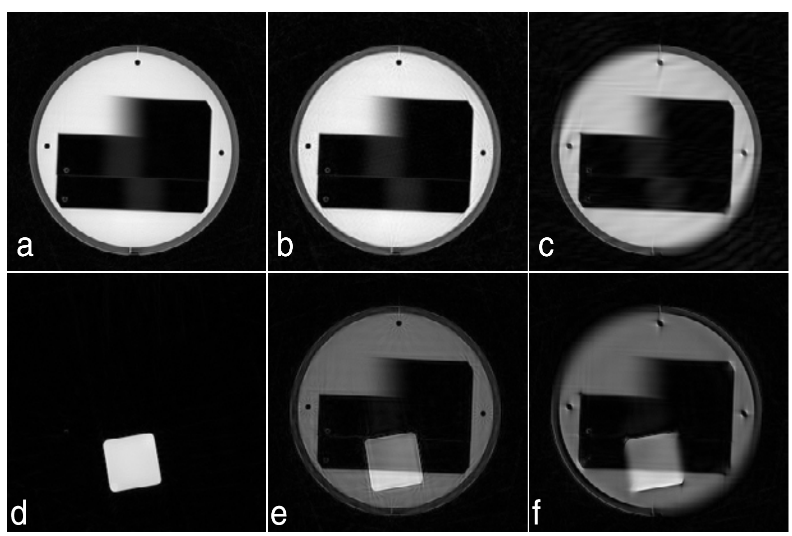


**Figure 2: Through-plane motion:** Images reconstructed from motion-corrupted data are shown for different blade orders and weighting schemes (b: shuffled π-order, correlation weighting; c: linear π-order, correlation weighting, e: shuffled π-order, no weighting; f: linear π-order, no weighting), demonstrating the superiority of the shuffled order. For comparison, the target slice (a) and the polluting slice (d) are shown.

## References

1. Pipe JG. MRM 1999;42:963-9.
2. Arfanakis K. MRM 2005;53:675–683
3. Winkelmann S. IEEE TMI 2006; in press.