# FAST ISOTROPIC BANDING-FREE BSSFP IMAGING USING 3D DYNAMICALLY PHASE-CYCLED RADIAL BSSFP (3D DYPR-SSFP)

Thomas Benkert[1], Philipp Ehses[2,3], Martin Blaimer[1], Peter Jakob[1,4], and Felix Breuer[1]

[1]*Research Center Magnetic Resonance Bavaria, Würzburg, Bavaria, Germany,* [2]*Department for Neuroimaging, University of Tübingen, Tübingen, Baden-Württemberg, Germany,* [3]*High-Field MR Center, Max Planck Institute for Biological Cybernetics, Tübingen, Baden-Württemberg, Germany,* [4]*Experimental Physics 5, University of Würzburg, Bavaria, Germany*

**Target audience:** Clinicians and physicists who are interested in fast imaging, steady-state imaging or radial imaging as well as in the depiction of cranial nerves or musculoskeletal imaging.

**Purpose:** Balanced steady-state free precession (bSSFP) combines short acquisition time, high signal-to-noise ratio and excellent fluid-tissue contrast. Due to these properties, it is an ideal candidate both for musculoskeletal imaging and depiction of cranial nerves. However, a major drawback is its high sensitivity to inhomogeneities of the main magnetic field, which may appear as signal voids (banding artifacts) and can render images non-diagnostic.

While the acquisition and subsequent combination of several bSSFP images with different RF phase-increments (phase-cycles) [1-2] may reliably remove these artifacts, scan time is several fold increased.

Recently, a conceptually different approach has been proposed, termed dynamically phase-cycled radial bSSFP (DYPR-SSFP) [3]. Here, a dynamically varying phase-cycle is combined with a (quasi-) randomly sampled radial trajectory. Thus, each projection is acquired with a different RF phase-increment. Applying a conventional radial reconstruction allows one to obtain an image without banding artifacts from one single acquisition, thereby enabling banding-free bSSFP imaging in short scan times

Up to now, the DYPR-SSFP concept has been combined with a 2D radial trajectory. However, the change of the phase-increment from projection to projection is indirectly proportional to the acquired number of projections and is therefore rather high, yielding corresponding artifacts. Here, the combination with a 3D radial trajectory is proposed, effectively mitigating this drawback and allowing the generation of 3D banding-free bSSFP images with high isotropic resolution.

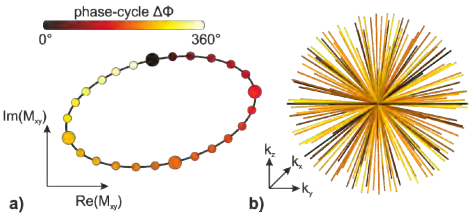


**Fig. 1: (a)** Using conventional phase-cycled bSSFP, the complex frequency response ellipse is sampled with entire images (e.g. four, large circles). With DYPR-SSFP, the complete ellipse is sampled with radial projections (small circles). **(b)** 3D DYPR-SSFP k-space sampling scheme.

**Methods:** bSSFP images with one fixed phase-cycle correspond to single points on the complex bSSFP frequency response ellipse. For conventional phase-cycled bSSFP, this ellipse is sampled with a limited number of complete images (Fig. 1a, large circles). However, with DYPR-SSFP, the entire ellipse is sampled with radial projections (small circles). Because all projections overlap in the k-space center and are therefore intrinsically averaged, banding artifacts are cancelled out. To minimize coherent artifacts due to the varying signal level and phase of the dynamically phase-cycled projections, a quasi-random reordering has to be applied. Nevertheless, noise-like artifacts may remain, at least when the number of acquired projections lies below an empirical limit (≈ 1000 projections). Therefore, the combination of DYPR-SSFP with a 3D radial trajectory, where a large number of projections are required a priori, seems promising and synergetic.

Fig. 1b shows the k-space sampling scheme of the proposed 3D DYPR-SSFP technique. Niederreiter random numbers [4] were used to obtain quasi-random reordering.

In vivo measurements of the brain of healthy volunteers were performed on a clinical 3T scanner. Both 3D bSSFP and 3D DYPR-SSFP were applied with the following parameters: matrix size = $256^3$, isotropic resolution = 0.9mm, TR = 4.2ms, flip angle = 40°, 65536 acquired projections, total scan time = 4min and 39s per acquisition. Furthermore, the knee of a volunteer with prior anterior cruciate ligament (ACL) reconstruction surgery was examined. In this case, 76000 projections were acquired with an increased matrix size of $320^3$ and a TR of 5.8ms, yielding an isotropic resolution of 0.56mm and a scan time of 7min and 26s.

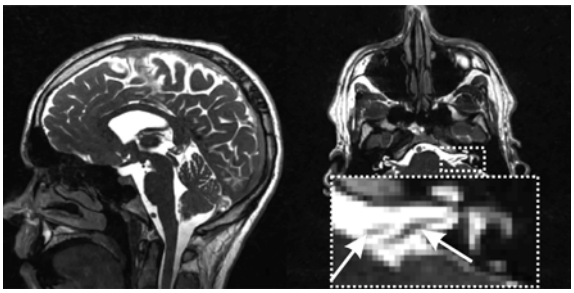

**Fig. 2:** 3D DYPR-SSFP brain measurement, showing complete absence of banding artifacts and depicting even small structures such as the facial and vestibulocochlear nerves (arrows).

**Results:** Fig. 2 shows results of a 3D DYPR-SSFP brain measurement. No signal cancellations due to banding artifacts occur. While small, banding-like structures such as cranial nerves (arrows) could be misinterpreted as artifacts in a conventional bSSFP measurement, they can be unambiguously classified with the proposed technique.

Results from the knee measurement of the patient with ACL reconstruction are shown in Fig. 3. Due to the fixation screws, severe banding artifacts (arrows) can be seen in the 3D bSSFP measurement (a). These artifacts are completely removed with the proposed technique (b) and cartilage as well as synovial fluid is clearly depicted.

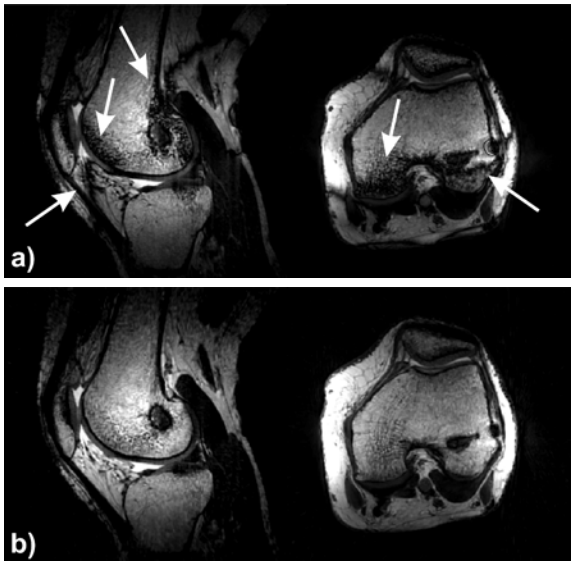


**Fig. 3:** Measurement of the volunteer with ACL reconstruction. With 3D bSSFP **(a)**, severe banding artifacts occur, while banding-free images are obtained with 3D DYPR-SSFP **(b)**.

**Discussion and Conclusion:** 3D DYPR-SSFP enables banding-free bSSFP imaging with high isotropic resolution, while scan time is not prolonged compared with a conventional bSSFP acquisition. Due to its high fluid-tissue contrast, promising clinical applications are cartilage imaging or imaging of the cranial nerves. This hold true especially for high field strengths, where conventional bSSFP is hindered by banding artifacts.

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