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# PROPELLER (periodically rotated overlapping parallel lines) Comparable Image Quality to the Conventional Cartesian Magnetic Resonance Images: A Phantom Study

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**To the best of our knowledge, studies comparing PROPELLER and the conventional Cartesian MRI have mostly been reported on motion sensitivity, and there has been no focused study on the standard phantom imaging to compare them. The purpose of this study was to investigate the effect of PROPELLER method on ACR guideline QA protocol compared to Cartesian method. In this study, we compared the ACR phantom image quality of T2WI acquired on PROPELLER and conventional Cartesian method. In addition, we performed comparisons using different AFs (acceleration factors). For quantitative analysis SNR, geometric accuracy, high-contrast spatial resolution, slice thickness accuracy, slice position accuracy and low-contrast object detectability were measured on the acquired images. There were no statistically significant differences in the 6 quantification values for both methods ($p > 0.05$). In conclusion, we found that PROPELLER method provided a comparable SNR to Cartesian method, regardless of the various Afs**

**Keywords :** non Cartesian, quality assurance, parallel technique, PROPELLER, ACR phantom

## 1. Introduction

Conventional magnetic resonance imaging (MRI) based on Cartesian technique has been widely used as a routine diagnostic image in brain for decades [1, 2]. MR is very sensitivity to artifacts, such as motions artifacts from uncooperative or pediatric patients [1-3]. In the past years different approaches were introduced to address these difficulties [4, 5]. Recently, it has been reported that periodically rotated overlapping parallel lines with enhanced reconstruction (PROPELLER) sequences have been used to reduce motion artifacts, pulsation artifacts and $B_0$-related artifacts [6].

PROPELLER is based on a Turbo spin echo (TSE) sequence with non-Cartesian radial k-space coverage. The echo trains cover the k-space in a rotating and partially overlapping way. While parallel k-space lines are acquired in a rectilinear way in a conventional Cartesian sequence [3, 6].

However, the disadvantage of PROPELLER is the presence of streak artifacts on MR images. Streak artifacts attributable to under sampling appear in the gridding process, which adjusts the position of acquired data by complementary processing from oblique trajectory to the accurate grid of k-space [7]. In addition, a data acquisition time in PROPELLER is longer than that of conventional TSE. Alternatively, the improved PROPELLER techniques have been developed using the free adjustment of relative bandwidth to improve the signal to ratio (SNR) and reduce artifacts enabling a parallel technique. Also works in multiple orientations and for various contrasts providing high resolution and short scan time [8, 9].

However, to the best of our knowledge, studies comparing PROPELLER and the conventional Cartesian MRI have mostly been reported on motion sensitivity [10-12], and there has been no focused study on the standard phantom imaging to compare them. Therefore, the purpose of this study was to investigate the effect of PROPELLER method on ACR guideline QA protocol compared to Cartesian method.

## 2. Materials and Methods

### 2.1. Phantom experiment study

As in a previous study [7], an MR phantom accredited by the American College of Radiology (ACR; JM, Specialty Parts, San Diego, CA, USA) was used for the phantom measurements. The internal measurements of the ACR

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phantom are a length of 148 mm and diameter of 190 mm. The phantom was filled with a solution of nickel chloride and sodium chloride (10 mM $NiCl_2$ and 75 mM NaCl) [8], and was carefully aligned and positioned in the center of each head coil with the spatial orientation defined according to its nose and chin marks. The phantom was then scanned at room temperature (21.0 °C) to nullify the quantitative measurements showing temperature dependence. The phantoms were kept in the same MRI room with a temperature logger, and using consistent coil and phantom support arrangements, with the identical sequence version and parameters each.

### 2.2. Image acquisition

All scans were performed on a clinical 3 Tesla MR Scanner (Ingenia CX, Philips Healthcare, The Nethelands) using 32-channel head coils. We used both PROPELLER sequence and conventional Cartesian sequence at ACR standard T2 weighted image (T2WI) for phantom experiment. The standard T2WI scanning parameters were as follows : field of view (FOV), 256 × 256 × 110 mm; voxel size, 0.9 × 0.9; acquisition matrix, 256 × 256; reconstruction matrix, 512 × 512; flip angle (FA) 90°; time of repetition (TR), 3000-5000 ms (shortest); time of echo (TE), 80 ms (shortest); slice thickness, 5 mm; slice gap, 5 mm; number of slice, and echo train length (ETL), 16. In addition, we performed comparisons using various sensitivity encoding (SENSE) acceleration factors (AFs) 1, 1.5, 2.0, 2.5, and 3.0; except for TR, TE, and SENSE AFs, all parameters is identical (Table 1).

### 2.3. Image analysis

The location of the ACR phantom slice 7, where the phantom was uniform, was used for measuring the signal to noise ratio (SNR) analysis. All acquired images were calculated SNR values. SNR was calculated using equation (1) according to the subtraction method related to two images obtained with identical parameters [15, 16]: a subtraction of one image from the other was performed to produce a noise only image.

$$\mathrm{SNR} = \frac{S}{\sigma/\sqrt{2}} \qquad (1)$$

**Table 1.** Quantitative results of SNR in two groups.

| Category | | Cartesian | PROPELLER | P value |
|---|---|---|---|---|
| SNR | AF 1.0 | 312.75 ± 9.37 | 297.56 ±8.65 | .248 |
| | AF 1.5 | 296.60 ± 8.48 | 280.87 ± 9.14 | .562 |
| | AF 2.0 | 263.45 ± 10.23 | 259.53 ± 9.88 | .478 |
| | AF 2.5 | 229.82 ± 12.86 | 215.46 ± 9.32 | .425 |
| | AF 3.0 | 191.65 ± 9.28 | 188.79 ± 8.72 | .378 |

Where S was the mean signal value of two images and σ is the standard deviation of the subtracted images. S and σ were derived from corresponding ROIs on the two images and the subtracted image. The √2 factor was required because noise with a propagation of error is derived from the difference image [7, 15]. The image analysis was performed using Image J (Image J v. 1.45; National Institutes of Health, Bethesda, MD, USA).

Additionally, there were five quantitative tests made using measurements on the acquired images. They were geometric accuracy, slice position accuracy, slice thickness accuracy, high-contrast spatial resolution, and low-contrast object detectability. No image signal intensity correction was applied for coils. For these reasons, we excluded signal uniformity correction and percent signal ghosting test. Five important parameters for the assessments of MR quality were included with recommended acceptance criteria: geometric accuracy (148 ± 3 mm and 190 ± 3 mm), high-contrast spatial resolution, slice thickness accuracy (5.0 ± 0.7 mm), slice position accuracy (< 5 mm) with reference limits in parenthesis.

### 2.4. Statistical Analysis

Both of PROPELLER and Cartesian sequences obtained with standard T2WI according to the ACR guideline quality assurance (QA) protocol. The effect of changing various assessments between the Cartesian sampling and varying parameters using paired-T test to investigate. Statistical analyses were performed using IBM SPSS Statistics analyses for Windows/Macintosh, Version 21.0 (IBM Corp, Armonk, NY, USA). For all statistical analyses, a two-sided p value less than 0.05 was considered to indicate a statistically significant difference.

## 3. Results

The quantitative results showing the relationship between profile methods and AFs in both PROPELLER and Cartesian are presented in Table 1. Table 1 compares the SNR values of images obtained using the PROPELLER and Cartesian methods for various AFs. There were no statistically significant differences in the SNR values for both methods ($p > 0.05$).

For geometric accuracy, all measured values were within the ACR criterion (± 2 mm) for the true values. There were no statistically significant differences between PROPELLER and Cartesian in any direction ($P > 0.05$) (Table 2).

The slice position accuracy of both slice 11 images of T2WI in two group passed the ACR criterion of 5 mm or less of the absolute value. There was no significant

**Table 2.** Quantitative results of geometric accuracy in two groups.

| Category | | Cartesian(mm) | PROPELLER (mm) | P value |
|---|---|---|---|---|
| AF 1.0 | #1 RL | 189.46 ± 0.13 | 189.55 ± 0.15 | .212 |
| | #1 AP | 189.71 ± 0.11 | 189.63 ± 0.21 | .186 |
| | #5 RL | 189.51 ± 0.17 | 189.46 ± 0.19 | .736 |
| | #5 AP | 189.32 ± 0.21 | 189.78 ± 0.22 | .135 |
| | #5 RD | 189.74 ± 0.16 | 189.81 ± 0.18 | .425 |
| | #5 LD | 189.56 ± 0.15 | 189.69 ± 0.13 | .568 |
| AF 1.5 | #1 RL | 189.61 ± 0.14 | 189.61 ± 0.17 | .158 |
| | #1 AP | 189.54 ± 0.17 | 189.82 ± 0.20 | .363 |
| | #5 RL | 189.82 ± 0.15 | 189.86 ± 0.15 | .340 |
| | #5 AP | 189.75 ± 0.19 | 189.52 ± 0.17 | .111 |
| | #5 RD | 189.41 ± 0.22 | 189.63 ± 0.19 | .576 |
| | #5 LD | 189.52 ± 0.17 | 189.42 ± 0.16 | .129 |
| AF 2.0 | #1 RL | 189.63 ± 0.21 | 189.58 ± 0.16 | .052 |
| | #1 AP | 189.58 ± 0.17 | 189.81 ± 0.13 | .145 |
| | #5 RL | 189.82 ± 0.18 | 189.85 ± 0.19 | .108 |
| | #5 AP | 189.76 ± 0.19 | 189.73 ± 0.22 | .358 |
| | #5RD | 189.60 ± 0.17 | 189.59 ± 0.16 | .242 |
| | #5 LD | 189.91 ± 0.25 | 189.62 ± 0.15 | .662 |
| AF 2.5 | #1 RL | 189.35 ± 0.15 | 189.65 ± 0.12 | .268 |
| | #1 AP | 189.66 ± 0.13 | 189.33 ± 0.15 | .125 |
| | #5 RL | 189.54 ± 0.18 | 189.51 ± 0.11 | .356 |
| | #5 AP | 189.75 ± 0.17 | 189.59 ± 0.17 | .515 |
| | #5 RD | 189.69 ± 0.20 | 189.81 ± 0.16 | .228 |
| | #5 LD | 189.72 ± 0.18 | 189.69 ± 0.17 | .102 |
| AF 3.0 | #1 RL | 189.51 ± 0.13 | 189.33 ± 0.12 | .148 |
| | #1 AP | 189.67 ± 0.14 | 189.54 ± 0.17 | .192 |
| | #5 RL | 189.74 ± 0.15 | 189.71 ± 0.15 | .788 |
| | #5 AP | 189.59 ± 0.12 | 189.64 ± 0.20 | .205 |
| | #5 RD | 189.48 ± 0.17 | 189.75 ± 0.21 | .085 |
| | #5 LD | 189.81 ± 0.22 | 189.82 ± 0.23 | .825 |

TB = top to bottom, LR = left to right, RD = right diagonal, LD = left diagonal. Length values are expressed as mean ± standard deviation.

difference between PROPELLER and Cartesian for slice 11 of T2WI. (P > 0.05) (Table 3).

The slice thickness accuracy of both slice 1 images of T2WI in two group passed the ACR criterion of 5.0 ± 0.7 mm. There were no significant differences in slice 1 of T2WI between PROPELLER and Cartesian (P > 0.05) (Table 4).

The high contrast spatial resolution of both slice 1 images of T2WI in both directions passed the ACR criterion of 1.0 mm in two groups. No statistically significant differences in slice 1 of T2WI in either direction were found between the groups (P > 0.05) (Table 5).

The low-contrast object detectability, the total number of measured spokes in all three groups passed the ACR criterion of greater than 37 spokes for 3.0 T. There were no statistically significant differences between PROPELLER and Cartesian for T2WI (P > 0.05). However, the total

**Table 3.** Quantitative results of slice position accuracy in two groups.

| Category | | Cartesian(mm) | PROPELLER (mm) | P value |
|---|---|---|---|---|
| AF 1.0 | # 1 | -0.92 ± 0.16 | -0.81 ± 0.21 | 0.012 |
| | # 11 | -5.09 ± 0.23 | -5.20 ± 0.35 | 0.385 |
| AF 1.5 | # 1 | -0.78 ± 0.15 | -0.68 ± 0.21 | 0.188 |
| | # 11 | -5.23 ± 0.27 | -5.20 ± 0.35 | 0.232 |
| AF 2.0 | # 1 | -0.82 ± 0.19 | -0.85 ± 0.21 | 0.342 |
| | # 11 | -5.09 ± 0.23 | -5.20 ± 0.35 | 0.415 |
| AF 2.5 | # 1 | -0.92 ± 0.06 | -0.68 ± 0.21 | 0.156 |
| | # 11 | -5.09 ± 0.23 | -5.20 ± 0.35 | 0.215 |
| AF 3.0 | # 1 | -0.92 ± 0.06 | -0.68 ± 0.21 | 0.412 |
| | # 11 | -5.09 ± 0.23 | -5.20 ± 0.35 | 0.225 |

**Table 4.** Quantitative results of slice thickness accuracy in two groups.

| Category | Cartesian (mm) | PROPELLER (mm) | P value |
|---|---|---|---|
| AF 1.0 | 4.96 ± 0.05 | 4.97 ± 0.03 | 0.568 |
| AF 1.5 | 4.98 ± 0.05 | 4.92 ± 0.03 | 0.614 |
| AF 2.0 | 4.91 ± 0.05 | 4.91 ± 0.03 | 0.488 |
| AF 2.5 | 4.81 ± 0.05 | 4.78 ± 0.03 | 0.645 |
| AF 3.0 | 4.55 ± 0.05 | 5.04 ± 0.03 | 0.512 |

**Table 5.** Quantitative results of high contrast spatial resolution in two groups.

| Category | | Cartesian (mm) | PROPELLER (mm) | P value |
|---|---|---|---|---|
| AF 1.0 | UL | 0.9 | 0.9 | NA |
| | LR | 0.9 | 0.9 | NA |
| AF 1.5 | UL | 0.9 | 0.9 | NA |
| | LR | 0.9 | 0.9 | NA |
| AF 2.0 | UL | 0.9 | 0.9 | NA |
| | LR | 0.9 | 0.9 | NA |
| AF 2.5 | UL | 0.9 | 0.9 | NA |
| | LR | 0.9 | 0.9 | NA |
| AF 3.0 | UL | 0.9 | 0.9 | NA |
| | LR | 0.9 | 0.9 | NA |

NA, not applicable. UL, upper left; LR. lower right.

**Table 6.** Quantitative results of low contrast object detectability in two groups.

| Category | Cartesian | PROPELLER | P value |
|---|---|---|---|
| AF 1.0 | 40 | 40 | NA |
| AF 1.5 | 40 | 40 | NA |
| AF 2.0 | 40 | 40 | NA |
| AF 2.5 | 40 | 40 | NA |
| AF 3.0 | 40 | 40 | NA |

NA, not applicable.

number of measured spokes tended to decrease as AFs increased (Table 6).

## 4. Discussion

In this study, we compared the ACR phantom image quality of T2WI acquired on PROPELLER and conventional Cartesian method. In addition, we performed comparisons using different AFs. We found that PROPELLER method provided a comparable SNR to Cartesian method, regardless of the various AF. Despite similar image quality, increased noise and aliasing artifacts were observed at AFs of overall, for both methods using T2WI. However, our findings are not consistent with previous results that showed the SNR values of a PROPELLER method to be equal to a Cartesian. This is not the first study to show a difference between PROPELLER and Cartesian. Compared with previous similar study may be explained by differences in the acquisition k-space reconstruction, which may exclude from the image quality assurance. In addition, round image reconstruction was observed at the peripheral of the ROI when using the PROPELLER method. This can be explained by degradation of phase encoding directions at the peripheral of ROI, which causes homogeneity differences towards the peripheral [19].

Our experiments demonstrated that ACR QA protocol comparable to both methods as the AFs increased in T2WI. In terms of ACR QA results, some studies demonstrated that PROPELLER method passed ACR QA results [13]. However, we did not find such as a pattern, with our methods showing that the various AFs showed no significant difference in ACR QA results between PROPELLER and Cartesian. With respect to PROPELLER, most studies only state the motion correction. A number of studies have shown these sequences to be associated with reduced motion artifact [9, 11, 13, 14] and improved structure depiction in the brain [10, 11, 13]. Abdominal imaging applications of PROPELLER, such as hepatic [16-21] and renal [22] MRI, have also been reported to yield reduced artifacts and improved lesion detection.

To our knowledge, no studies investigating the utility of these sequences in the clinical application have been

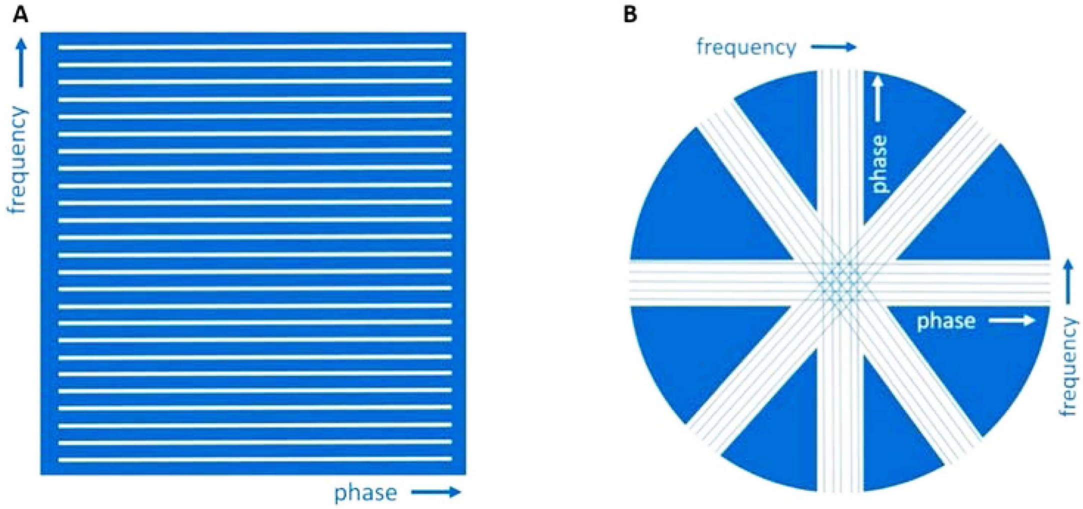

**Fig. 1.** (Color online) Cartesian (A) and PROPELLER (B) k-space filling techniques. In PROPELLER technique, blades are obtained along the phase and frequency encoding direction in a rotating fashion.

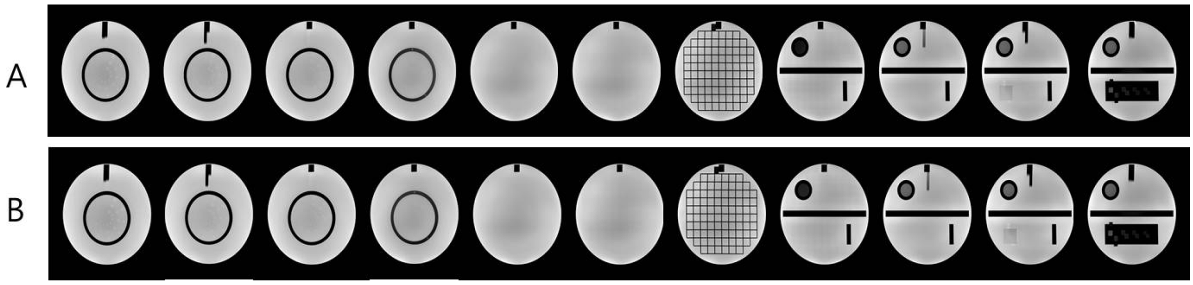

**Fig. 2.** The T2WI obtained with a Cartesian AF=1.0 (A) and a PROPELLER AF=1.0 (B) according to ascending slice number to ACR phantom. Representative images acquired with the head coil, displayed using their default contrast level and window.

reported. Our results indicate anatomic depiction and overall image quality were improved with the PROPELLER sequence when compared with the standard T2WI. It is essential to use standard phantoms in MR quality assurance to enable uniform measurement of the systems. Generally, the ACR protocol was easy to perform and clearly instructed. The results showed that most of the systems operated at the level fulfilling the ACR QA recommended acceptance criteria. The results of our ACR QA protocol that use of the PROPELLER method can improve image quality and reduce scan time applied parallel technique.

There are some limitations to this study. First, because of profile method constraints associated with the two methods in the T2WI, there were differences in parameters the two methods. However, the shortest TR and TE settings used should be the most efficient in terms of the sequence condition. Second, we used ACR phantom that did not express the diversity of soft tissues and organs present in the real human body. In the parallel techniques, it is common to compare g-factor values, but in the propeller technique, which is the technique of this study, there are differences in image reconstruction techniques, so the comparison between the two techniques has many limitations. Therefore, a further study needs to be performed with a relatively inhomogeneity body area containing diverse anatomical structures, to demonstrate the exact effects the two profile methods have on image quality. Despite the above-mentioned limitations, this is the first comparison experiment focusing on the image quality assurance MR with a various AFs on both PROPELLER and Cartesian.

## 5. Conclusion

This study compared the ACR phantom image quality of T2WI acquired on PROPELLER and conventional Cartesian method. The improved PROPELLER techniques have been developed using the free adjustment of relative bandwidth to improve the SNR and reduce artifacts enabling a parallel technique. PROPELLER can provide comparable image quality on ACR QA protocol to Cartesian when using parallel methods with various AFs in T2WI.

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