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# Evaluation of Motion-Corrected Multishot Echo-Planar Imaging as an Alternative to Gradient Recalled-Echo for Blood-Sensitive Imaging

J.A. Murchison, D. Shoshan, M.B. Ooi, Z. Li, and J.P. Karis



## ABSTRACT

**SUMMARY:** We evaluated motion-corrected multishot EPI compared with gradient recalled-echo imaging to determine whether it can be used as a faster technique for blood-sensitive imaging in the emergency department setting. Multishot EPI was found to be superior to gradient recalled-echo ( $P < .05$ ) in motion artifacts, overall image quality, and lesion detection. These results and reduced scan time make motion-corrected multishot EPI a viable alternative for blood-sensitive imaging in the emergency department setting.

**ABBREVIATIONS:** GRE = gradient recalled-echo; msEPI = multishot echo-planar imaging

MR imaging of the brain performed in the emergency department requires time-efficient acquisition protocols to provide timely patient care and maintain patient throughput.<sup>1</sup> In addition, a T2\*-sensitive series that demonstrates pathologic hemorrhage is critically important when performing emergency department MR imaging examinations. Gradient recalled-echo (GRE) imaging is favored over SWI at our institution as a more time-efficient technique for obtaining T2\*-weighted images. The GRE sequence at our institution uses approximately 30% of the total examination time (approximately 2 minutes of an 8-minute examination). We previously attempted to implement a T2\* sequence using a multishot EPI (msEPI) technique, which permits more rapid image acquisition (~50% faster compared with GRE); however, the sequence was particularly vulnerable to patient motion (unpublished data). Recently developed motion-correction techniques for msEPI use a navigator echo that can reduce motion and phase errors, which are common in patients with acute medical conditions (Fig 1).<sup>2-4</sup> In this study, we evaluated a novel 2D interleaved motion-corrected msEPI sequence to determine whether it can be used as a faster technique for blood-sensitive imaging in the emergency department.

## MATERIALS AND METHODS

### Patient Population

This prospective study was performed at a single clinical site, was approved by the institutional review board, and was compliant with

the Health Insurance Portability and Accountability Act. Patients in the emergency department undergoing nonemergent imaging for stroke were eligible for inclusion. Informed consent was waived for this minimum-risk study, and motion-corrected msEPI sequences were obtained in addition to the standard GRE sequences.

### Imaging Methods

The msEPI sequence and reconstruction algorithm were developed by Li et al.<sup>5</sup> The study was performed on a single Ingenia MR imaging scanner (Philips Healthcare) with a standard hardware configuration. A standard-of-care GRE sequence with compressed sensing was obtained, with a  $230 \times 230$  mm<sup>2</sup> FOV,  $1.0 \times 1.1$  mm<sup>2</sup> resolution, 5-mm section thickness, 1-mm section gap, 18° flip angle, 18-ms TE, ~25–32 slices, compressed sensing factor of 2, and ~105 Hz/pixel frequency-direction receiver bandwidth. The TR and total scan time varied with the number of prescribed slices. The typical TR used was ~860 ms, and the typical scan time was ~2 minutes 15 seconds. The proposed motion-corrected msEPI with a navigator echo scan was then obtained with matched geometric parameters. The image echo was acquired with an echo-train length of 27, eight shots, 24-ms TE, ~945 Hz/pixel frequency direction, and ~27 Hz/pixel phase-direction receiver bandwidths. The navigator echo was collected with an echo-train length of 23, sensitivity encoding acceleration factor of two, 72-ms TE, 2 signal averages, and ~1-minute scan time. Because the radiofrequency pulse must be refocused, T1-related tissue signal recovery is interrupted, resulting in altered tissue contrast compared with msEPI without a navigator echo. A 120° flip angle and ~3500-ms TR were chosen to match tissue contrast.

### Radiologic Assessment

Two radiologists (1 staff neuroradiologist and 1 neuroradiology fellow) reviewed all subjects, and consensus scoring was obtained.

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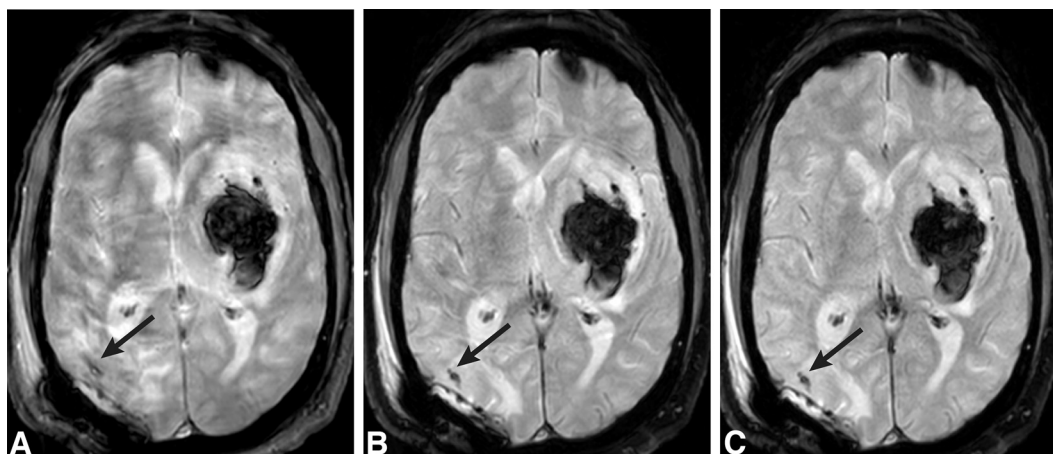
From the Department of Neuroradiology (J.A.M., D.S., Z.L., J.P.K.), Barrow Neurological Institute, St. Joseph's Hospital and Medical Center, Phoenix, Arizona; and Philips Healthcare (M.B.O.), Houston, Texas.

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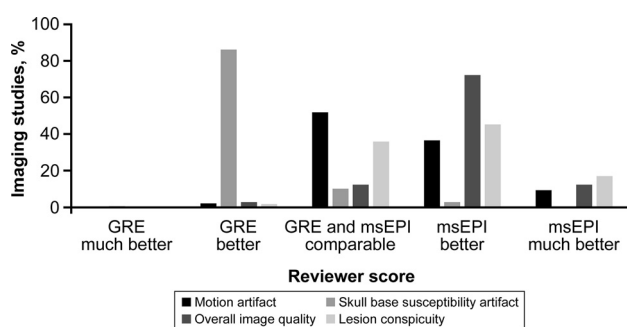
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**FIG 1.** Axial MR images in a patient with a large left thalamic hemorrhage showing the effects of motion artifacts on standard GRE imaging (A) compared with non-motion-corrected (B) and motion-corrected (C) msEPI. Also note the increased conspicuity of a small parenchymal hemorrhage (arrow) in the right parietal region on msEPI compared with standard GRE. Reprinted with permission from the Barrow Neurological Institute, Phoenix, Arizona.



**FIG 2.** Results of scoring between GRE and msEPI for a total of 137 subjects with 53 subjects having T2\* lesions. Motion-corrected msEPI was superior to GRE imaging in motion artifacts ( $P < .001$ ), image quality ( $P < .001$ ), and lesion conspicuity ( $P < .001$ ). However, GRE was superior to motion-corrected msEPI in skull base artifacts ( $P < .001$ ). Reprinted with permission from the Barrow Neurological Institute, Phoenix, Arizona.

For each subject, the matching pairs of GRE and motion-corrected msEPI were compared and scored relative to one another on motion artifacts, skull base susceptibility artifacts, overall image quality, and lesion conspicuity (marked NA if no lesion was visible). Each metric was scored on a 5-point Likert scale, in which 1 indicated that GRE was much better than msEPI, 2 indicated that GRE was better than msEPI, 3 indicated that the 2 modes were comparable, 4 indicated that msEPI was better than GRE, and 5 indicated that msEPI was much better than GRE. The position in which GRE and motion-corrected msEPI scans were presented was randomized (left versus right) and anonymized for review. Additional sequences were made available when requested to confirm the presence of a lesion. Susceptibility artifacts associated with adjustable shunt valves and postoperative pneumocephalus were also included in the evaluation of skull base susceptibility artifacts because they degrade image quality. Lesions bright on T2-weighted imaging (eg, arachnoid cysts and cystic encephalomalacia without hemosiderin staining) and lesions originating from the skull base were not considered for scoring lesion conspicuity

because these lesions do not show susceptibility and thus were not considered a T2\* imaging lesion.

### Statistical Analysis

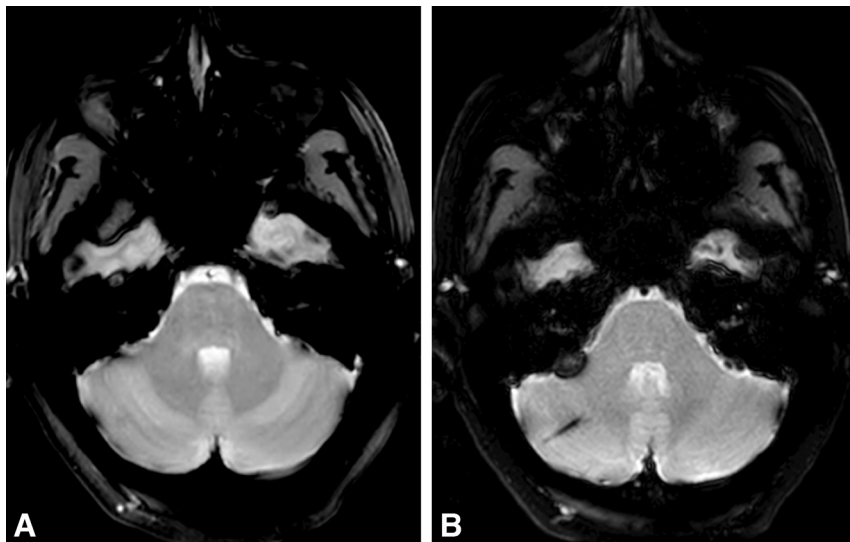
Statistical analysis was performed using R statistical and computing software (Version 4.1.3; <http://www.r-project.org>). Nonparametric statistics were used because of the use of ordinal data. A 1-sample Wilcoxon signed-rank test was used to compare GRE versus motion-corrected msEPI. We tested the null hypothesis,  $H_0: \Delta = 3$ , where  $\Delta$  is the average of the 2 scores over the subject population for a given metric because a score of 3 means that msEPI is comparable with GRE. Rejection of the null hypothesis suggests that the scoring distribution is not symmetric around 3 but in favor of either GRE  $\Delta < 3$  or msEPI  $\Delta > 3$ . Significance was set at  $P < .05$ .

### RESULTS

Imaging was performed and analyzed for a total of 137 subjects with 53 subjects having T2\* lesions. The cohort included 57 male patients and 80 female patients (mean age, 50.9 years; range, 9–90 years). Motion-corrected msEPI was superior to GRE in motion artifacts ( $P < .001$ ), image quality ( $P < .001$ ), and lesion conspicuity ( $P < .001$ ). However, GRE was superior to motion-corrected msEPI in skull base artifacts ( $P < .001$ ) (Fig 2). Detailed assessment scores are included in the Online Supplemental Data.

### DISCUSSION

Although the reduced overall signal due to the decreased scan time of the motion-corrected msEPI could have resulted in suboptimal imaging, we found that motion-corrected msEPI demonstrated improved overall image quality compared with GRE. Both reviewers noted that although overall signal intensity was less for motion-corrected msEPI compared with GRE, contrast resolution and sharpness were better with msEPI. Contrast between the lesions and the surrounding tissues was measured, and the mean values were 0.675 (range, 0.183–0.987) for GRE and 0.800 (range, 0.367–0.994) for msEPI. The results from 18



**FIG 3.** Axial standard GRE (A) and motion-corrected msEPI (B) in a subject with a developmental venous anomaly showing improved identification of tubular lesions in motion-corrected msEPI versus standard GRE imaging. Reprinted with permission from the Barrow Neurological Institute, Phoenix, Arizona.

measurable lesions showed that the msEPI had a greater difference between lesions and surrounding tissue compared with GRE, though this difference was not statistically significant. The lack of statistical significance might be partially due to the limited sample size.

Motion-corrected msEPI was rated as superior to GRE for motion artifacts. When significant motion artifacts were present, some GRE images were nondiagnostic and were repeated according to the protocol. This repeat sequence resulted in longer overall examination times for those patients. Only 3 subjects had worse motion artifacts associated with msEPI compared with GRE, possibly because of randomly increased patient motion during msEPI acquisition compared with during the GRE acquisition. Additional images of GRE and msEPI with and without motion correction are presented in the Online Supplemental Data.

Motion-corrected msEPI was also rated as superior to GRE for lesion detection. Every lesion identified on GRE was also identified on msEPI, but msEPI identified some lesions that were not identified on GRE (Fig 3).

As expected, GRE was found to have less susceptibility at the skull base compared with motion-corrected msEPI due to a designed longer effective TE resulting in increased susceptibility-induced signal loss. Skull base susceptibility artifact assessment also served as an internal control to ensure appropriate T2\* weighting of msEPI. Note that increased skull base susceptibility artifacts did not negatively affect image quality or lesion detection. Although 3D msEPI provides fine section coverage and a high signal-to-noise ratio, it is still prone to motion artifacts, which are of great concern in the emergency department setting.

Motion-corrected 2D msEPI can potentially alleviate this concern through the use of a navigator echo.

Motion-corrected msEPI performed better than GRE in motion artifacts, overall image quality, and lesion detection. Skull base susceptibility artifacts were more prominent on msEPI than on GRE, consistent with the longer effective TE of msEPI, resulting in increased susceptibility-induced signal loss.

## CONCLUSIONS

For institutions that have attempted implementation of non-motion-corrected msEPI but have been unsuccessful due to image degradation from patient motion, the improved image quality and reduced scan time achieved by replacing GRE with motion-corrected msEPI makes this new technique a viable

alternative for blood-sensitive imaging in the emergency department.

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Disclosure forms provided by the authors are available with the full text and PDF of this article at [www.ajnr.org](http://www.ajnr.org).

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