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# Readout-segmented echo-planar imaging in the evaluation of sinonasal lesions: A comprehensive comparison of image quality in single-shot echo-planar imaging

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ABSTRACT

*Purpose:* To investigate the role of readout-segmented echo-planar imaging using parallel imaging and a two-dimensional (2D) navigator (RESOLVE) in the evaluation of sinonasal lesions and to qualitatively and quantitatively compare the image qualities of single-shot echo-planar imaging (SS-EPI) and RESOLVE.
*Materials and methods:* Both sinonasal SS-EPI and RESOLVE images were acquired from 32 patients on a 3-T MR scanner. Image quality, lesion conspicuity and the distortions of the SS-EPI and RESOLVE images were qualitatively evaluated by two radiologists. Distortion was also quantitatively evaluated by comparing the distances between the same anatomic points on TSE-T1WI, TSE-T2WI, SS-EPI and RESOLVE images. The apparent diffusion coefficient (ADC) values, signal-to-noise ratios (SNRs), and contrast-to-noise ratios (CNRs) of the two DWIs were compared.
*Results:* The comparisons of the qualitative scores indicated that RESOLVE significantly improved the image quality and lesion conspicuity and reduced the distortion of the sinonasal diseases. The orbit, skull base, temporal bone and upper neck were also better displayed on RESOLVE. Quantitative evaluations revealed that RESOLVE greatly reduced but did not completely remove the distortion. The ADC values of the sinonasal lesions on RESOLVE were lower than those on SS-EPI, whereas no differences were found in the brainstem. The SNR of RESOLVE was lower than that of SS-EPI. There were no differences in the CNRs of the two diffusion-weighted imaging (DWI) techniques.
*Conclusion:* RESOLVE significantly improved the image quality for evaluations of sinonasal lesions by reducing the susceptibility artifacts, distortion and blurring compared with SS-EPI. RESOVLE offers more accurate ADC values of sinonasal lesions than SS-EPI.



## 1. Introduction

In recent years, the applications of DWI for the evaluation of lesions in different locations in the body have been extensively reported. It has been verified that DWI is important for the evaluations of lesions and that this technology can offer information about lesions of the head and neck in addition to that supplied by conventional MRI [1–4]. However, there are still many questions that require resolution regarding the application of this technology to sinonasal lesions. There are few reports of evaluations of sinonasal lesions by DWI [1,2,5] primarily due to the magnetic susceptibility artifacts that result from susceptibility changes at tissue–air and tissue–bone interfaces (particularly at higher field strengths, such as 3 tesla (3 T)), T2* blurring and the low resolution of images acquired with single-shot echo-planner imaging (SS-EPI), which seriously affect evaluations. Although the introduction of parallel imaging techniques, such as GeneRalized Autocalibrating Partially Parallel Acquisition (GRAPPA), has reduced these effects, there are still significant residual problems. Small lesions and lesion with irregular shapes are also difficult to evaluate [2,5].

Multishot and readout-segmented echo-planar Imaging (RS-EPI) is used to sample subsets of k-space points in the readout direction in each shot and allows for substantial reductions in echo spacing and associated reductions in the time required to traverse the k-space in the phase-encoding direction; these effects lead to effective reductions in magnetic susceptibility artifacts and T2* blurring and enable the acquisition of high-resolution DW images. RESOLVE is the newest RS-EPI technique and integrates this method with two-dimensional navigator correction to robustly correct motion-induced linear and

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non-linear phase errors [6–12]. GRAPPA can also be implemented to save time. This technique was recently used to evaluate pediatric brains, head and neck regions, pelvises and breasts and exhibited advantages relative to SS-EPI [6,7,13–18]. We hypothesized that sinonasal lesions could be accurately evaluated with this DWI technique [15,19]. However, thus far, there have been no studies that have focused on the usage of RESOLVE in the sinonasal cavity, which is one of the regions that are most difficult to resolve with DWI.

The present study initially sought to explore the feasibility of the application of RESOLVE to the sinonasal cavity on a 3-T scanner. Specifically, a relatively comprehensive comparison of sinonasal SS-EPI and RESOLVE images was performed to qualitatively and quantitatively compare the image qualities of these techniques.

## 2. Materials and methods

### 2.1. Patients

Between September 2014 and December 2014, 32 patients (20 men and 12 women, aged 12–79 years, mean 50.2 years) with sinonasal lesions who underwent sinonasal MRI via both the SS-EPI and RESOLVE techniques were enrolled in this study. This study was approved by the Institutional Review Board of our hospital, and written informed consent was obtained from all patients.

### 2.2. MR imaging

Imaging was performed with a 3.0-T MRI scanner (Magnetom Verio, Siemens Healthcare, Erlangen, Germany) with a 12-channel head coil. The MR images were acquired using the following sequences: 1) precontrast, axial, turbo spin-echo (TSE) T1-weighted imaging (T1WI) (repetition time/echo time (TR/TE) = 450/9.1 ms; slice thickness = 4 mm; gap = 0.6 mm; field of view (FOV) = 240 × 240 mm; matrix = 480 × 640 or 512 × 640); 2) coronal and axial TSE T2-weighted imaging (T2WI; TR/TE = 4530/101 ms; slice thickness = 4 mm; gap = 0.6 mm; FOV = 222 × 240 or 240 × 240 mm; matrix, 474 × 640 or 512 × 640); 3) post-contrast, T1-weighted images were acquired in the axial and coronal planes using the same parameters; and 4) prior to the injection of contrast agent, SS-EPI and RESOLVE were performed. To match the acquisition time of the RESOLVE, the average SS-EPI was increased to 4, and the average RESOLVE was 1. The acquisition times were 2 min 34 s for the SS-EPI and 2 min 55 s for the RESOLVE. GRAPPA was also used in both of the DWI sequences with an acceleration factor of 2. The imaging parameters were as follows: RESOLVE (TR/TE = 4700/66 or 4700/70 ms; slice thickness = 4 mm; gap = 0.6 mm; FOV = 240 × 240 or 220 × 220 mm; matrix = 154 × 192 or 192 × 192; average = 1; readout segments = 7; echo spacing = 0.34 ms; b value = 0 and 1000 s/mm$^2$); SS-EPI (TR/TE = 8000/88 or 7900/87 ms; slice thickness = 4 mm; gap = 0.6 mm; FOV = 240 × 240 or 220 × 220 mm; matrix = 154 × 192 or 164 × 164; average = 4; echo spacing = 1.08 ms; b value = 0 and 1000 s/mm$^2$).

For the 25 patients, the axial TSE-T1WI, TSE-T2WI, SS-EPI and RESOLVE sequences were designed with the same FOV of 240 × 240 mm, slice thickness of 4 mm and gap of 0.6-mm, and the same proportional matrix (80% phase resolution) was utilized.

### 2.3. Image assessment

#### 2.3.1. Qualitative evaluation

Two trained head and neck radiologists evaluated the DWIs and apparent diffusion coefficient (ADC) maps of the sinonasal cavities that were acquired from the 32 patients using RESOLVE or SS-EPI. Decisions were made based on consensus when there were divergences of opinion between the two radiologists. All images were rated according to a scale that ranged from 1 (unacceptable image quality) to 5 (artifact-free image without distortions and with high-level anatomic detail). Similarly, lesion conspicuity was rated according to a scale that ranged from 1 (unable to evaluate) to 5 (excellent visibility) with respect to the lesion border, internal structure and distortion. Image distortion was also rated according to a scale that ranged from 0 (no distortion) to 4 (severe distortion). Image fusions between the two DWI sequences and the TSE-T2WI images were performed as the references (Fig. 1).

#### 2.3.2. Quantitative evaluations

Quantitative evaluation of the geometric distortion: For the patients with the same FOVs, slice thicknesses, gaps and the same or proportional TSE-T2WI, TSE-T1WI, RESOLVE and SS-EPI matrices (25 patients), the pixel lenses (a function of the Siemens workstation that can locate the points drawn on an MR image and generate the coordinates of those points) were placed on the same anatomic points in the TSE-T2WI, TSE-T1WI, and b0 maps from the SS-EPI and RESOLVE images at the same levels, including the bilateral frontal–internal points, lateral points and back points of the maxillary sinus, bilateral back points of the inferior nasal concha, and bilateral frontal–lateral points of the sphenoid sinus that were not completely destructed or unrecognizable. The coordinates of these pixel lenses were then recorded. The lengths between each pair of matched pixel lenses from the TSE-T2WI and TSE-T1WI and the TSE-T2WI and b0 maps from the EPI, TSE-T2WI and b0 maps from the RESOLVE images were calculated and compared (Fig. 2).

ROI definition: For the patients with acceptable lesion conspicuity (20 patients), freehand ROIs were carefully matched to the lesion shape on the ADC maps from the SS-EPI and RESOLVE images and copied to the corresponding b1000 maps. For all patients, matching circular ROIs on the ADC SS-EPI and RESOLVE maps of approximately 1 cm$^2$ were fixed on the brainstem images that were well displayed and artifact-free and copied to the corresponding b1000 maps. The mean ADC values, signal intensities and standard deviations of the ROIs were generated automatically and recorded. Circular ROIs were fixed on the backgrounds on the b1000 maps of all of the patients, and the standard deviation of each ROI was also generated automatically and recorded.

Comparisons of the ADC values, signal-to-noise ratios (SNRs) and contrast-to-noise ratios (CNRs) of the two DWI techniques: The mean ADC values for the lesions and the brainstems were generated automatically at the time at which the ROIs were defined and then compared. The SNR of the lesions (or brainstems) and the backgrounds on the b1000 maps were defined as the ratios between the mean signal intensities of the lesions ($S_{ROI}$) or the brainstems ($S_B$) and the standard deviations of the background noise. The contrast-to-noise ratio (CNR) was defined as the difference between the signal intensity of the lesion ROI and the signal intensity of the brainstem divided by the standard deviation of the lesion ROI ($\sigma_{ROI}$) and brainstem ROI ($\sigma_B$) according to the following formula:

$$CNR = \frac{|S_{ROI} - S_B|}{\sqrt{{\sigma_{ROI}}^2 + {\sigma_B}^2}}$$

### 2.4. Statistical analysis

The statistical analyses were performed using the SPSS software package (v. 16.0.1, Chicago, IL) and Medcalc (Mariakerke, Belgium). P values < 0.05 were considered statistically significant. Paired Wilcoxon signed rank tests were used to assess the two radiologists' ratings of the two DWIs. Paired t tests were used to compare the differences between the lengths of the pixel lenses on the T1WI,