Performance of TGSE BLADE DWI in the diagnosis of cholesteatoma compared with RESOLVE DWI

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Abstract

Background: Based on the high resolution of soft tissue, MRI has gained increasing importance in the evaluation of cholesteatoma, especially diffusion-weighted imaging (DWI). The purpose of this study was to evaluate the role of 2D turbo gradient- and spin-echo (TGSE) diffusion-weighted (DW) pulse sequence with BLADE trajectory technique in the diagnosis of cholesteatoma at 3T and to qualitatively and quantitatively compare the image quality between the TGSE BLADE and RESOLVE methods.

Method: A total of 42 patients (23 males, 19 females; age range, 7-65 years; mean, 40.1 years) with surgically confirmed cholesteatoma in the middle ear were enrolled in this study. All patients underwent DWI (both the prototype TGSE BLADE DWI sequence and RESOLVE DWI sequence) using a 3-T scanner with a 64-channel brain coil.

Qualitative imaging parameters (imaging sharpness, geometric distortion, ghosting artifacts, and overall imaging quality) and quantitative imaging parameters (apparent diffusion coefficient [ADC], signal-to-noise ratio [SNR], contrast, and contrast-to-noise ratio [CNR] for the two diffusion acquisition techniques were assessed by two independent radiologists.

Result: Comparison of the qualitative scores indicated that TGSE BLADE DWI produced less geometric distortion and ghosting artifacts ($P < 0.001$) and higher image quality ($P < 0.001$) than RESOLVE DWI. Comparison of the evaluated quantitative image parameters between TGSE and RESOLVE showed that TGSE BLADE DWI produced a significantly lower SNR ($P < 0.001$) and higher parameter values (both contrast and CNR ($P < 0.001$)) than RESOLVE DWI.

The ADC ($P < 0.001$) measured by TGSE BLADE DWI (0.763×10^{-3} s/mm²) is significantly lower than that measured by RESOLVE DWI (0.928×10^{-3} s/mm²).

Conclusion: Comparing with RESOLVE DWI, TGSE BLADE DWI can significantly improve the image quality of cholesteatoma by reducing magnetic sensitive artifacts, distortion, and blurring. TGSE BLADE DWI is more valuable for the diagnosis of small-sized (2mm) cholesteatoma lesions compare with RESOLVE DWI image. However, TGSE BLADE DWI also has some disadvantages: the whole image intensity is slightly low, so that the anatomical details of the air-bone interface are not well shown, which is the place to be improved in the future.

Background

Cholesteatoma is a benign, gradually expanding and destructive epithelial lesion of the temporal bone that results in the erosion of adjacent bony structures and may lead to various complications.¹ In addition to the clinical features and otoscopic findings, the early diagnosis of cholesteatoma with imaging examinations, such as high-resolution computed tomography (CT) and magnetic resonance imaging (MRI), is important. From a surgical perspective, high-resolution CT remains the primary imaging technique for the diagnosis and characterization of cholesteatoma in the middle ear due to its high spatial resolution and good visualization of bone structures^{11,12}. However, in terms of the disadvantages, it is difficult to distinguish cholesteatoma from granulation tissue, fibrous tissue, or fluid on high-resolution CT². Based on the high resolution of soft tissue, MRI has gained increasing importance in the evaluation of cholesteatoma. Many studies have shown that MR diffusion-weighted imaging (DWI) has high sensitivity and specificity for identifying the presence of cholesteatoma due to its high keratin content¹³⁻¹⁵. However, conventional DWI uses an echo-planar imaging (EPI) trajectory to collect k-space data, and the obtained images may suffer from severe susceptibility artifacts at air-bone interfaces. Additionally, the image resolution is limited. Thus, it is difficult to use DWI in cases of a lesion less than 5 mm^{3,4} from the distortion area. To reduce image distortion, readout-segmented echo-planar imaging (RESOLVE) has been proposed, and this method can significantly improve head and neck DWI by reducing the echo spacing. Although RESOLVE DWI has a significantly improved image signal-to-noise ratio (SNR) and reduced image distortion, the partial volume effect and T2* blurring effect are not completely eliminated, it is difficult to detect small lesions (<2.5 mm)⁶⁻⁸. Periodically rotated overlapping parallel lines with enhanced reconstruction (PROPELLER) DWI is a non-echo planar fast spin-echo-based DWI sequence, and the central k-space is acquired in a rotating manner. The PROPELLER sequence is free of geometric distortion and susceptibility artifacts, but the scan time is long and imposes a high specific absorption rate (SAR), especially at high fields²⁸⁻³¹. To the best of our knowledge, the BLADE DWI technique has been reported to eliminate susceptibility artifacts by applying the 'blades' acquisition scheme in k-space⁵. Such a non-EPI technique was further optimized by using a TGSE method to increase the SNR efficiency and both achieve the detection of small (<2.5 mm) cholesteatomas and increase the resolution to decrease susceptibility artifacts, allowing for differentiation from granulation tissue⁵. Houchun H. et al.¹⁸ concluded that TGSE BLADE DWI exhibited less geometric distortion in the brain and reduced magnetic artifacts near the air-tissue interface than conventional SE-EPI. However, the use of TGSE BLADE DWI in studying ear lesions has not yet been reported. L.M.J. Lips et al.¹⁹ found that non-EPI DWI for the detection of residual or recurrent cholesteatoma is better at 3 T than 1.5 T. Hence, the purpose of this study was to evaluate the role of the TGSE BLADE DWI technique in the diagnosis of cholesteatoma at 3 T and to qualitatively and quantitatively compare the image quality between the TGSE BLADE and RESOLVE methods.

Methods

2.1 Patients

A total of 42 patients (23 males, 19 females; age range, 7-65 years; mean, 40.1 years) with surgically confirmed cholesteatoma were enrolled in this study from October 2018 to April 2019. Clinicopathological results were the gold standard for all patients.

Ethics and Consent to Participate

The study was approved by the Review Committee of Eye & ENT Hospital of Fudan University, and written informed consent was obtained from all patients.

2.2 Imaging technique

All patients underwent DWI (both the prototype TGSE BLADE DWI sequence and the commercially available RESOLVE DWI sequence) using a 3-T scanner (MAGNETOM Prisma, Siemens Healthcare, Erlangen, Germany) with a 64-channel brain coil.

The parameters for TGSE BLADE DWI were as follows: TR/TE = 4000/62 ms; slice thickness/gap = 2/0.2 mm; slices = 21; bandwidth = 520 Hz/Px; field of view (FOV) = 280 × 280 mm²; matrix = 192 × 192; voxel size = 1.5 × 1.5 × 2.0 mm³; number of excitations (NEX) = 1; diffusion mode = 4 scan trace; b = 0, 1000 s/mm²; turbo factor = 13; EPI factor = 3; and data acquisition time = 3 min 46 s. For RESOLVE DWI, the imaging parameters were as follows: TR/TE = 5020/53 ms; slice thickness/gap = 2/0.2 mm; slices = 21; bandwidth = 766 Hz/Px; FOV = 230 × 230 mm; matrix = 192 × 192; voxel size = 1.2 × 1.2 × 2.0 mm; diffusion mode = 4 scan trace; b = 0, 1000 s/mm²; and data acquisition time = 3 min 46 s.

2.3 Image assessment

2.3.1 Qualitative analysis of image quality

All images of 42 patients obtained by TGSE or RESOLVE were evaluated by two radiologists with 10 years of experience in ear MRI evaluation.

Each observer randomly and blindly evaluated the images without knowing the type of DWI sequence and compared the two different DWI sequences using the side-by-side display method. A final decision was made based on mutual consultation when there was a divergence in the assessment results.

Qualitative evaluation of images obtained by TGSE and RESOLVE was performed according to five criteria: image sharpness, geometric distortion, ghosting artifacts, and overall image quality. Image sharpness was assessed on a scale that ranged from 1 to 3. Both geometric distortion and ghosting artifacts were evaluated on a scale from 1 to 4, and the evaluation of geometric distortion included two parts: the whole image and the lesion in the ear. The overall image quality was also graded on a scale of 1 to 5. The detailed qualitative evaluation criteria are shown in Table 1. In Figure 1, images C and E represent geometric deformation of 4 (no distortion) and 2 (moderate distortion), respectively.

2.3.2 Qualitative analysis of image quality

The SNR, contrast and contrast-to-noise ratio (CNR) were the main evaluation criteria for the quantitative analysis of two sequence images. The apparent diffusion coefficients (ADCs) of the two sequences were compared simultaneously. On the b1000 TGSE and RESOLVE images, the SNR of the lesions in the region of interest (ROI) was defined as the ratio of the mean signal intensity of the lesion (S_{ROI}) to the standard deviation of the background noise (σ_{BG}) ($SNR = S_{ROI}/\sigma_{BG}$)⁹. The SNR of the brainstem was calculated by the same method, as follows: $SNR = S_B/\sigma_{BG}$. Contrast was defined as the ratio of the signal intensity of the lesion (S_{ROI}) to the signal intensity of the brainstem (S_B) on the b1000 map ($contrast = S_{ROI}/S_B$).

The CNR was defined as the difference between the S_{ROI} and S_B , divided by the standard deviation in the lesion ROI (σ_{ROI}) and the brainstem ROI (σ_B)^{6-8,10}, as follows:

See Formula 1 in the Supplemental Files.

The ROI of the lesion on the b1000 and ADC maps was manually drawn as 1 mm² at the level of the maximum diameter of the lesion, and the corresponding signal intensity and standard deviation were automatically generated on the MRI workstation. The ROI of the brainstem was defined by selecting 10 mm² of the brainstem, and the signal intensity and standard deviation of each ROI were automatically generated. A circular ROI of 10 mm² was set in the background on the b1000 map for all patients, and the standard deviation of the ROI was automatically generated. In selecting the ROI, areas affected by susceptible artifacts or volume effects were avoided.

The parameters were measured independently and randomly by two raters, with an interval of 2 weeks. The mean value of the two measurements was selected as the final data for further analysis. Compared with brain tissue on the DWI sequences, the diagnostic criterion for cholesteatoma was a very high signal intensity, corresponding to limited diffusion on the ADC maps^(3,20). The size of all lesions was determined on the basis of T2-weighted imaging (T2WI).

2.4 Statistical analysis

All statistical analyses and plots were performed and created using the SPSS 24.0 software package (Chicago, IL, USA), and $P < 0.05$ was considered statistically significant. The normality of all measurements from the TGSE and RESOLVE sequences was tested using the Shapiro-Wilk test. Significant differences in qualitative parameters between TGSE and RESOLVE DWI were determined using the Wilcoxon rank-sum test, and significant differences in quantitative parameters were determined using the paired t-test. The interreader correlation of the ADC as a quantitative index was evaluated using the intraclass correlation coefficient (ICC). The range of the ICC coefficient was set from 0 to 1.00, and the ICC was defined as follows: < 0.40, poor; 0.41-0.60, moderate; 0.61- 0.80, good; > 0.81, excellent^{16,17}. The mean ADCs of the lesions and brainstem measured by the two observers were further calculated, and the differences between them were assessed by paired t-test.

Results

3.1 Qualitative analysis of image quality

Comparison of the qualitative scores indicated that TGSE BLADE DWI produced less geometric distortion and ghosting artifacts ($P < 0.001$) and higher image quality ($P < 0.001$) than RESOLVE DWI. The average TGSE and RESOLVE scores were as follows: geometric distortion (whole), 3.97 ± 0.15 and 3.26 ± 0.26 ($P < 0.001$); geometric distortion (lesion), 3.95 ± 0.21 and 3.64 ± 0.48 ($P < 0.001$); ghosting artifact, 3.92 ± 0.26 and 3.07 ± 0.55 ($P < 0.001$); overall image quality,

4.85±0.35 and 4.16±.69, respectively. Both TGSE BLADE DWI and RESOLVE DWI had nearly perfect image sharpness ($P=0.23$; 2.85±0.35 versus 2.73±0.49). Table 1 shows a comparison of the qualitative parameter scores for TGSE BLADE DWI and RESOLVE DWI, and Figure 2 indicates the distribution of the qualitative scores for TGSE BLADE DWI and RESOLVE DWI. As shown in Figure 1, axial TGSE DWI could precisely define the cholesteatoma lesion in the right middle ear without geometric distortion or ghosting artifacts, whereas RESOLVE DWI showed significant artifacts at the air-bone interface (between the mastoid, i.e., the location of the cholesteatoma lesion, and the nasal sinus).

3.2 Quantitative analysis of image quality

Comparison of the evaluated quantitative image parameters between TGSE and RESOLVE showed significant differences between the two groups. TGSE BLADE DWI produced a significantly lower SNR ($P < 0.001$) and higher parameter values (both contrast and CNR ($P < 0.001$)) than RESOLVE DWI. The results of the statistical analysis are as follows (Table 1): SNR of cholesteatoma, 102.3±32.2 versus 493.7±241.6 ($P<0.001$); SNR of brainstem, 59.1±15.5 versus 289.8±140.9 ($P<0.001$); contrast, 1.79±0.35 versus 1.62±0.44 ($P=0.005$); CNR, 1.62±0.44 versus 2.7±2.6 ($P<0.001$).

In terms of measurement and evaluation of the ADC, values were measured in 40 cases, as the lesions were too small to be measured on the ADC maps in 2 cases, and excellent interreader agreement was obtained. Detailed interreader ICCs are shown in Table 2. All ADCs were measured twice by the two observers, and the average values were taken as the basis for further statistical analysis. As shown in Table 2, there was a significant difference in the ADC of the cholesteatoma between TGSE BLADE and RESOLVE DWI ($P<0.01$). The mean ADC of the cholesteatoma measured on TGSE (0.763×10^{-3} s/mm²) BLADE DWI was significantly lower than that measured on RESOLVE (0.928×10^{-3} s/mm²) DWI ($P<0.01$). Similarly, the ADC of the brainstem measured on TGSE (0.498×10^{-3} s/mm²) BLADE DWI was lower than that measured on RESOLVE (0.773×10^{-3} s/mm²) DWI ($P<0.01$). The box plot in Figure 3 shows the distribution of the lesion and brainstem ADCs measured on TGSE BLADE and RESOLVE DWI.

In this study, the measurement results in terms of lesion size in 42 patients showed that TGSE BLADE DWI could show small lesions more clearly than RESOLVE DWI. Compared with RESOLVE, TGSE had much better image quality at the air-bone interface (nasal sinus, middle ear, mastoid) and significantly reduced ghosting artifacts and distortion. Furthermore, as shown in Figure 4, axial TGSE BLADE DWI could completely and clearly show a small lesion (1.9 mm in width) located in the left tympanic cavity with less geometric distortion than RESOLVE DWI.

Discussion

DWI is increasingly applied for the evaluation of various diseases in many areas of the body. Conventional DWI (SS-EPI) is often used in head and neck diseases; however, due to interference with the T2* blurring effect and susceptibility artifacts of various tissues produced by non-movement, the image quality of conventional DWI (SS-EPI) is usually not satisfactory^{26,27}. Many studies^(3,21,22) have concluded that the size limit of cholesteatoma on EPI DWI is 5 mm and that smaller cholesteatoma lesions are easily missed on DW EPI. Compared with conventional SS-EPI DWI, RESOLVE has significantly improved image quality due to its low susceptibility-based image distortion and T2* blurring and its robust correction for motion-induced phase artifacts²³. RESOLVE DWI is more widely used in head and neck diseases than SS-EPI DWI. However, RESOLVE still has some shortcomings that need to be resolved, for instance, image artifacts and distortion (air-bone interface) that cannot be completely eliminated and a low diagnostic rate of small lesions (<2.5 mm)^{6-8,14,24}.

To the best of our knowledge, TGSE is a new technique, the use of DWI which in head and neck diseases has not been reported in the literature. The basic imaging principles of the TGSE BLADE technique were introduced by Li et al²⁵. In this study, compared to RESOLVE DWI, TGSE BLADE DWI significantly improved the image quality in cases of cholesteatoma by reducing susceptibility artifacts, distortion and blurring at the same scanning time (3 min 46 s). Moreover, TGSE BLADE DWI may be more valuable for the diagnosis of small cholesteatoma lesions (<2 mm).

Qualitative analysis of the image quality showed almost no geometric distortion or ghosting artifacts in the TGSE images, while in the RESOLVE images, obvious geometric distortion, mostly in the nasal cavity and mastoid, was present in 8 of 42 (20%) cases. Meanwhile, serious artifacts in the RESOLVE images were observed in 5 (12%) cases. Hu¹⁸ et al. also demonstrated that TGSE BLADE DWI produced less geometric distortion in the brain and signal pile-up in highly susceptible areas than conventional SE-EPI. The image quality of TGSE BLADE has also been significantly improved. In the quantitative analysis of image quality, TGSE BLADE DWI showed higher contrast and a higher CNR than RESOLVE DWI, which are prospective results due to the lack of previous reports on TGSE BLADE DWI.

This study shows a significant difference in the ADC between the TGSE BLADE and RESOLVE sequences, with a significantly lower ADC of the cholesteatoma ($P<0.01$) and brainstem ($P<0.01$) on TGSE BLADE DWI than on RESOLVE DWI. The average ADC for the cholesteatoma on RESOLVE DWI was 0.928×10^{-3} s/mm², which is consistent with the cholesteatoma ADC ($0.7-1.0 \times 10^{-3}$ s/mm²) previously reported in the literature³²⁻³⁴. The mean ADC of the cholesteatoma and brainstem on TGSE BLADE DWI was 0.763×10^{-3} s/mm² and 0.498×10^{-3} s/mm², respectively. These findings demonstrate that the ADC obtained in our study can provide an auxiliary basis for more clinical applications of TGSE BLADE DWI in the future.

However, there are also some limitations to our study: the number of patients included in this study is relatively small, and the error caused by manual measurement cannot be eliminated, which may affect the accuracy of the true range of the ADC on TGSE BLADE DWI. Meanwhile, TGSE BLADE DWI is not without its disadvantages. The overall image SNR of TGSE is slightly lower than that of RESOLVE, mainly because placement of the gradient echo with T2* decay effects in the center of k-space reduces the image quality of TGSE, which is consistent with previous pediatric brain research reported by Ui²⁶ et al.

Conclusion

In conclusion, TGSE BLADE DWI is an artifact-free technique with better image quality than RESOLVE DWI in the diagnosis of cholesteatoma. TGSE BLADE DWI is also superior to RESOLVE DWI in terms of image distortion, artifacts and lesion conspicuity. In addition, TGSE BLADE DWI appears to be more effective in detecting small lesions.

Declarations

Ethics approval and consent to participate

The study was approved by the Review Committee of Eye & ENT Hospital of Fudan University, and written informed consent was obtained from all patients. And for participants under 16 years old, the written informed consent was obtained from a parent or guardian.

Consent for publication

All authors of this article have agreed to publish this article.

Availability of data and material

The datasets used and analysed during the current study are available from the corresponding author on reasonable request

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

ZZS and SYR designed this study

SYR collected patient data and was a major contributor in writing the manuscript

HRJ and SY analyzed and evaluated two kinds of sequential images.

ZK and FCX provide guidance on magnetic resonance techniques

All authors read and approved the final manuscript.

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Abbreviations

ADC: apparent diffusion coefficient;

SNR: signal-to-noise ratio;

CNR: contrast-to-noise ratio;

SAR: specific absorption rate;

ROI: region of interest;

ICC: intraclass correlation coefficient;

References

1. Louw L. Acquired cholesteatoma pathogenesis: stepwise explanations. *The Journal of laryngology and otology*. Jun 2010;124(6):587-593.
2. Yates PD, Flood LM, Banerjee A, Clifford K. CT scanning of middle ear cholesteatoma: what does the surgeon want to know? *The British journal of radiology*. Oct 2002;75(898):847-852.
3. Vercruysse JP, De Foer B, Pouillon M, Somers T, Casselman J, Offeciers E. The value of diffusion-weighted MR imaging in the diagnosis of primary acquired and residual cholesteatoma: a surgical verified study of 100 patients. *European radiology*. Jul 2006;16(7):1461-1467.

4. De Foer B, Vercruysse JP, Pilet B, et al. Single-shot, turbo spin-echo, diffusion-weighted imaging versus spin-echo-planar, diffusion-weighted imaging in the detection of acquired middle ear cholesteatoma. *AJNR. American journal of neuroradiology*. Aug 2006;27(7):1480-1482.
5. Dhepnorrarat RC, Wood B, Rajan GP. Postoperative non-echo-planar diffusion-weighted magnetic resonance imaging changes after cholesteatoma surgery: implications for cholesteatoma screening. *Otology & neurotology : official publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology*. Jan 2009;30(1):54-58.
6. Bogner W, Pinker-Domenig K, Bickel H, et al. Readout-segmented echo-planar imaging improves the diagnostic performance of diffusion-weighted MR breast examinations at 3.0 T. *Radiology*. 2012;263(1):64-76.
7. Xu, X; Wang, Y; Hu, H; Su, G; Liu, H;(2017). Readout-segmented echo-planar diffusion-weighted imaging in the assessment of orbital tumors: comparison with conventional single-shot echo-planar imaging in image quality and diagnostic performance. *Acta Radiologica*, 58(12), 1457–1467.
8. Menglong Zhao; Zhuang Liu; Yan Shaet al. Readout-segmented echo-planar imaging in the evaluation of sinonasal lesions: A comprehensive comparison of image quality in single-shot echo-planar imaging. [J]. *Magn Reson Imaging*, 2016, 34: 166-72.
9. Kaufman L,Kramer D M,Crooks L E et al. Measuring signal-to-noise ratios in MR imaging.[J] .*Radiology*, 1989, 173: 265-7.
10. Xiaomei Song, Pogue Brian W,Jiang Shudong et al. Automated region detection based on the contrast-to-noise ratio in near-infrared tomography.[J] .*Appl Opt*, 2004, 43: 1053-62.
11. Yamashita Koji,Yoshiura Takashi,Hiwatashi Akio et al. Contributing factors in the pathogenesis of acquired cholesteatoma: size analysis based on MDCT. [J] .*AJR Am J Roentgenol*, 2011, 196: 1172-5.
12. Razek Ahmed Abdel Khalek Abdel,Ghonim Mohamed Rashad,Ashraf Bassem,Computed Tomography Staging of Middle Ear Cholesteatoma.[J] .*Pol J Radiol*, 2015, 80: 328-33.
13. De Foer Bert,Vercruysse Jean-Philippe,Bernaerts Anja et al. Middle ear cholesteatoma: non-echo-planar diffusion-weighted MR imaging versus delayed gadolinium-enhanced T1-weighted MR imaging–value in detection.[J] .*Radiology*, 2010, 255: 866-72.
14. Algin O,Aydin H,Ozmen E et al. Detection of cholesteatoma: High-resolution DWI using RS-EPI and parallel imaging at 3 tesla.[J] .*J Neuroradiol*, 2017, 44: 388-394.
15. Henninger Benjamin,Kremser Christian,Diffusion weighted imaging for the detection and evaluation of cholesteatoma.[J] .*World J Radiol*, 2017, 9: 217-222.
16. Tyng Chiang J,Chojniak Rubens,Pinto Paula N V et al. Conformal radiotherapy for lung cancer: interobservers' variability in the definition of gross tumor volume between radiologists and radiotherapists.[J] .*Radiat Oncol*, 2009, 4: 28.
17. Fleiss JL, Cohen J. The equivalence of weighted kappa and the intraclass correlation coefficient as measures of reliability. *Educ Psychol Meas* 1973;33:613– 619.
18. Houchun H,McAllister Aaron S,Jin Ning et al. Comparison of 2D BLADE Turbo Gradient- and Spin-Echo and 2D Spin-Echo Echo-Planar Diffusion-Weighted Brain MRI at 3 T: Preliminary Experience in Children.[J] .*Acad Radiol*, 2019, undefined: undefined.
19. Lips L M J,Nelemans P J,Theunissen F M D et al. The diagnostic accuracy of 1.5 T versus 3 T non-echo-planar diffusion-weighted imaging in the detection of residual or recurrent cholesteatoma in the middle ear and mastoid.[J] .*J Neuroradiol*, 2019, undefined: undefined.
20. Nevoux J,Lenoir M,Roger G et al. Childhood cholesteatoma.[J] .*Eur Ann Otorhinolaryngol Head Neck Dis*, 2010, 127: 143-50.
21. De Foer Bert,Vercruysse Jean-Philippe,Bernaerts Anja et al. The value of single-shot turbo spin-echo diffusion-weighted MR imaging in the detection of middle ear cholesteatoma.[J] .*Neuroradiology*, 2007, 49: 841-8.
22. Venail F,Bonafe A,Poirrier V et al. Comparison of echo-planar diffusion-weighted imaging and delayed postcontrast T1-weighted MR imaging for the detection of residual cholesteatoma.[J] .*AJNR Am J Neuroradiol*, 2008, 29: 1363-8.
23. Porter David A,Heidemann Robin M,High resolution diffusion-weighted imaging using readout-segmented echo-planar imaging, parallel imaging and a two-dimensional navigator-based reacquisition.[J] .*Magn Reson Med*, 2009, 62: 468-75.
24. Williams Marc T,Ayache Denis,Alberti Corinne et al. Detection of postoperative residual cholesteatoma with delayed contrast-enhanced MR imaging: initial findings.[J] .*Eur Radiol*, 2003, 13: 169-74.
25. Zhiqiang Li,Pipe James G,Lee Chu-Yu et al. X-PROP: a fast and robust diffusion-weighted propeller technique.[J] .*Magn Reson Med*, 2011, 66: 341-7.
26. Attenberger UI, Runge VM, Stemmer A, Williams KD, et al. Diffusion weighted imaging: a comprehensive evaluation of a fast spin echo DWI sequence with BLADE (PROPELLER) k-space sampling at 3 T, using a 32-channel head coil in acute brain ischemia.*Invest Radiol*. 2009 Oct;44(10):656-61.
27. De Foer B,Vercruysse J-P,Pilet B et al. Single-shot, turbo spin-echo, diffusion-weighted imaging versus spin-echo-planar, diffusion-weighted imaging in the detection of acquired middle ear cholesteatoma.[J] .*AJNR Am J Neuroradiol*, 2006, 27: 1480-2.
28. Kida Ikuhiro,Ueguchi Takashi,Matsuoka Yuichiro et al. Comparison of Diffusion-Weighted Imaging in the Human Brain Using Readout-Segmented EPI and PROPELLER Turbo Spin Echo With Single-Shot EPI at 7 T MRI.[J] .*Invest Radiol*, 2016, 51: 435-9.
29. Forbes K P,Pipe J G,Bird C R et al. PROPELLER MRI: clinical testing of a novel technique for quantification and compensation of head motion.[J] .*J Magn Reson Imaging*, 2001, 14: 215-22.
30. Pipe James G,Farthing Victoria G,Forbes Kirsten P,Multishot diffusion-weighted FSE using PROPELLER MRI.[J] .*Magn Reson Med*, 2002, 47: 42-52.
31. Kim T, Baek M,Park J et al. Comparison of DWI Methods in the Pediatric Brain: PROPELLER Turbo Spin-Echo Imaging Versus Readout-Segmented Echo-Planar Imaging Versus Single-Shot Echo-Planar Imaging.[J] .*AJR Am J Roentgenol*, 2018, 210: 1352-1358.
32. Russo Camilla,Elefante Andrea,Di Lullo Antonella M et al. ADC Benchmark Range for Correct Diagnosis of Primary and Recurrent Middle Ear Cholesteatoma.[J] .*Biomed Res Int*, 2018, 2018: 7945482.

33. Algin O,Aydin H,Ozmen E et al. Detection of cholesteatoma: High-resolution DWI using RS-EPI and parallel imaging at 3 tesla.[J] .J Neuroradiol, 2017, 44: 388-394.
34. Thiriat S,Riehm S,Kremer S et al. Apparent diffusion coefficient values of middle ear cholesteatoma differ from abscess and cholesteatoma admixed infection.[J] .AJNR Am J Neuroradiol, 2009, 30: 1123-6.

Tables

Table 1. Qualitative criteria for comparing image quality of TGSE and RESOLVE (b1000) sequences.

Image sharpness (anatomical structures: nasal sinus, ear, brain)
1. Completely unclear
2. Generally visible
3. Clearly visible
Geometric distortion
□ Cholesteatoma (size and border) □ Whole image
1. Severe distortion
2. Moderate distortion
3. Mild distortion
4. No distortion
Ghosting artifacts (interface of cholesteatoma and the temporal lobe)
1. Severe artifact, unable to distinguish lesions and normal tissues
2. Moderate artifact, part of the lesion can be distinguished from normal tissues
3. Mild artifact, no impact on lesion diagnosis
4. No artifact
Overall image quality
1. Nondiagnostic
2. Barely diagnosis
3. Diagnostic
4. Good
5. Excellent

Table 3. Comparison of ADC values between two observers

Location	ADC(mean/ $\times 10^{-6}$ s/mm ²)		P value	Inter-reader variability(ICC)	
	TGSE	RESOLVE		TGSE	RESOLVE
Cholesteatoma	0.763 $\pm$ 0.104	0.928 $\pm$ 0.141	<0.01	0.637	0.911
Brainstem	0.498 $\pm$ 0.103	0.773 $\pm$ 0.043	<0.01	0.885	0.759

Note: ADC,apparent diffusion coefficient; ICC, intra-class correlation coefficient

Figures

Table 2. Comparison of results of qualitative parameter evaluation between TGSE and RESOLVE images (42 patients).

Parameters	TGSE	RESOLVE	P value
Qualitative parameters			
1.Imaging sharpness	2.85±0.35	2.73±0.49	0.23
	3.97±0.15(whole)	3.26±0.76(whole)	<0.01
2.Geometric distortion	3.95±0.21(lesion)	3.64±0.48(lesion)	<0.01
3.Ghosting artifacts	3.92±0.26	3.02±0.55	<0.01
4.Overall imaging quality	4.85±0.35	4.16±0.69	<0.01
Quantitative parameters			
1.SNR(b=1000s/mm ²)			
Lesion	102.3±32.2	493.7±241.6	<0.01
Brainstem	59.1±15.5	289.8±140.9	<0.01
2.Contrast	1.79±0.35	1.62±0.44	=0.005
3.CNR(b=1000s/mm ²)	4.33±2.8	2.7±2.6	<0.01
Note: SNR, signal to noise ratio; CNR, contrast to noise ratio

Figure 1

A 51-year-old male with primary cholesteatoma in the right middle ear confirmed by right mastoidectomy. Axial T1WI (A), T2WI (B) showed the anatomical location of the cholesteatoma (arrow) in the right middle ear. (C, E): TGSE BLADE (b1000) and RESOLVE (b1000) DWI showed a restricted diffusion lesion (high signal) in the right mastoid bone. (D, F): The ADC on TGSE BLADE and RESOLVE DWI was 0.689×10-3 s/mm2 and 0.791×10-3 s/mm2, respectively. However, the cholesteatoma lesion (arrow) was not as clear on RESOLVE DWI as on TGSE DWI. Meanwhile, the structures of the nasal cavity were obviously distorted on the RESOLVE b1000 (E) map and ADC map (F), whereas almost no distortion was observed on the TGSE b1000 map and ADC map. Images C and E represent the geometric deformation values of the entire image as 4 (no distortion) and 2 (moderate distortion), respectively.

Figure 2

Bar chart showing a comparison of the qualitative imaging parameters between TGSE BLADE and RESOLVE DWI.

Figure 3

Box plot of the ADC of the cholesteatoma and brainstem showing significant differences in the ADC between TGSE and RESOLVE. The ADC of the cholesteatoma measured on TGSE and RESOLVE DWI was 0.763×10^{-6} s/mm² and 0.928×10^{-3} s/mm², respectively. The ADC of the brainstem measured on TGSE and RESOLVE DWI was 0.498×10^{-3} s/mm² and 0.773×10^{-3} s/mm², respectively.

Figure 4

A 44-year-old male with a small cholesteatoma (1.9 mm width) in the left tympanic cavity (white arrow). (a): Axial T1WI. (b): Axial T2WI showed the structure of the small cholesteatoma (white arrow). (c): Axial TGSE BLADE DWI (b1000) clearly showed a markedly high signal intensity for the small cholesteatoma

(white arrows) without artifacts. (e): Axial RESOLVE DWI (b1000) showed the high signal intensity of the small lesion (white arrow) with light geometric distortion and the bilateral middle ear mastoid process with a few artifacts (red arrow). (d, f): The ADC on TGSE BLADE and RESOLVE DWI was 0.737×10^{-3} s/mm² and 0.984×10^{-3} s/mm², respectively.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [formula1.PNG](#)