Diffusion-Weighted Zonal Oblique Multislice–EPI Enhances the Detection of Small Lesions with Diffusion Restriction in the Brain Stem and Hippocampus: A Clinical Report of Selected Cases

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ABSTRACT

SUMMARY: Diffusion restriction is the morphologic hallmark of acute ischemic infarcts and excitotoxic brain injury in various cerebral pathologies. Diffusion restriction is visible as hyperintensity on DWI and as hypointensity on ADC maps. Due to the vicinity of multiple anatomic structures in the brain stem and hippocampus, very small lesions with diffusion restriction may result in severe clinical symptomatology, but these small lesions easily go undetected on standard cerebral DWI due to insufficient spatial resolution, T2* blurring, and image artifacts caused by susceptibility-related image distortions. Diffusion-weighted zonal oblique multislice–EPI with reduced FOV acquisition permits a considerable increase in spatial resolution and enhances the visualization of very small pathologic lesions in the brain stem and hippocampus. Improved performance in the depiction of different pathologic lesions with diffusion restriction in the brain stem and hippocampus using this sequence compared with standard DWI in selected cases is presented.

ABBREVIATIONS: CN III = oculomotor nerve nucleus area; CN VI = abducens nerve nucleus area; DW = diffusion-weighted; sshot SE = single-shot spin-echo; TGA = transient global amnesia; ZOOM = zonal oblique multislice

Diffusion restriction is caused by different cerebral pathologies leading to cytotoxic edema by energy failure, altered intra- and extracellular ion and water concentrations, and excitotoxic brain injury due to extracellular increase of glutamate. These mechanisms may overlap in certain pathologies. Diffusion restriction is the main characteristic feature of an acute ischemic event; therefore, DWI is the only reliable sequence for detecting an acute ischemic event.

DWI is routinely used in brain protocols for the evaluation of various cerebral pathologies characterized by diffusion restriction. The limited spatial resolution of a standard single-shot spin-echo (sshot SE) EPI DWI, called “standard DWI” in our work, is an enormous disadvantage if the clinical symptomatology indicates a lesion in the brain stem and hippocampus.

This clinical report shows how diffusion-weighted (DW) zonal oblique multislice (ZOOM)-EPI can improve the detection of DWI abnormalities in pathologies in the brain stem and hippocampus by increasing spatial resolution, allowing the visualization of small lesions with diffusion restriction not visible on standard DWI.

Received October 19, 2017; accepted after revision March 5, 2018.

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http://dx.doi.org/10.3174/ajnr.A5635

In this clinical report, the MR images of 7 patients of a group with 44 patients (23 women and 21 men; 40–89 years of age; mean age, 76.4 years) are depicted. Informed and written consent for publication of patient data and images was obtained by all patients described in this study. All patients with various acute clinical symptoms all indicating a brain stem pathology (mainly characterized by nausea, vertigo, ataxia, nystagmus, gaze disorders) or hippocampal pathology with amnestic syndrome were examined by both standard transverse sshot SE EPI DWI (called “standard DWI”) and transverse DW ZOOM-EPI during the same examination. The acquisition of DW ZOOM-EPI followed immediately after the acquisition of the standard DWI on the same MR imaging scanner with an identical field strength. Identical image plane angulation was used in both transverse diffusion-weighted sequences.

Patient examinations were performed from October 2016 to August 2017 on a 1.5T Ingenia (Philips Healthcare, Best, the Netherlands) or a 3T Achieva (Philips Healthcare) scanner. Imaging parameters of DW ZOOM-EPI and of standard DWI are shown in Tables 1 and 2. In all patients, 3D FLAIR imaging and transverse T2 TSE sequences were added for possible confirmation of the suspected pathology.

In each patient, the presence or absence of acute ischemic lesions in the brain stem on standard DWI and on DW ZOOM-EPI was determined retrospectively. In 27 patients, no pathologic lesion was visible on both standard DWI and DW
ZOOM-EPI. In 9 patients both standard DWI and DW ZOOM-EPI showed an acute ischemic infarct with diffusion restriction, involving both the brain stem and cerebellum in 6 patients, only the cerebellum in 2 patients, and only the brain stem in 1 patient. All infarcts visible on both standard DWI and DW ZOOM-EPI had a minimum size of 1 cm. In 8 patients, mostly punctate acute ischemic foci, either in the brain stem, cerebellum, or hippocampi, were only visible on DW ZOOM-EPI. In 9 patients both standard DWI and DW ZOOM-EPI showed an acute ischemic infarct with diffusion restriction, involving both the brain stem and cerebellum in 6 patients, only the cerebellum in 2 patients, and only the brain stem in 1 patient. All infarcts visible on both standard DWI and DW ZOOM-EPI had a minimum size of 1 cm. In 8 patients, mostly punctate acute ischemic foci, either in the brain stem, cerebellum, or hippocampi, were only visible on DW ZOOM-EPI.

Despite the acquisition time of the DW ZOOM-EPI (3 minutes to 5 minutes and 30 seconds), no visually evident movement artifacts in the patients examined were observed, but a quantification of movement artifacts was not performed.

Case Series

Transient Global Amnesia. A 65-year-old female patient presented with antegrade and retrograde amnesia due to clinically suspected transient global amnesia (TGA) lasting for 18 hours (Fig 1). Punctuate diffusion restriction was demonstrated on DW ZOOM-EPI with ADC maps in the lateral hippocampal body as a specific TGA-associated lesion. No abnormality was visible on standard DWI or on FLAIR.

Hippocampal Ischemia. An 83-year-old woman with atrial fibrillation presented with acute hemiparesis on the left side and antegrade amnesia (Fig 2). Multiple punctate acute embolic ischemic infarcts with diffusion restriction were visible on DW ZOOM-EPI with ADC maps, namely in the mesencephalon along the pyramidal tract, in the left medial occipitotemporal gyrus, in the left hippocampus, and bilaterally in the posterior and postcentral area on the right. The punctate hippocampal infarct was not visible on standard DWI or FLAIR.

Acute Internuclear Ophthalmoplegia and Partial Oculomotor Nerve Palsy. A 44-year-old woman presented with acute internuclear ophthalmoplegia and a partial oculomotor nerve palsy on the left. The acute ischemic infarct in the oculomotor nerve nuclear area (CN III) and the medial longitudinal fascicle was visible on DW ZOOM-EPI and ADC maps but not on standard DWI and was only faintly apparent on FLAIR (Fig 3). The ischemic infarct was caused by an acute embolus from a pulmonary arteriovenous malformation.

Acute Internuclear Ophthalmoplegia and Acute Abducens Palsy. A 71-year-old man presented with acute internuclear ophthalmoplegia/abducens nerve palsy of the left side, skew deviation, and nystagmus to the right side. An acute ischemic infarct with diffusion restriction was visible on DW ZOOM-EPI and ADC maps involving the left medial longitudinal fascicle and the abducens nerve nuclear area (CN VI). Standard DWI and FLAIR images did not show any abnormality (Fig 4).

Acute Ischemic Infarct in the Left Inferior Cerebellar Peduncle. A 57-year-old woman presented with severe intractable vertigo, nystagmus, and vomiting due to isolated vestibular syndrome lasting 3 days. A punctate diffusion abnormality on DW ZOOM-EPI and ADC maps (Fig 5) in the left inferior cerebellar peduncle was present, not visible on standard DWI or FLAIR.

Acute Ischemic Infarct in the Right Nucleus Prepositus Hypoglossi. A 40-year-old female patient presented with acute forward and backward vertigo and horizontal nystagmus. A punctate diffusion abnormality was visible on DW ZOOM-EPI and ADC maps (Fig 6) in the right nucleus prepositus hypoglossi; the lesion was not depicted on standard DWI and on FLAIR.

Acute Ischemic Infarct in the Right Flocculus. A 51-year-old woman presented with vertigo and saccadic eye movements during the last 5 days. A punctate diffusion abnormality representing her infarction...
was present in the right flocculus on DW ZOOM-EPI and ADC maps (Fig 7). Standard DWI and FLAIR findings were normal.

**DISCUSSION**

Standard ss hot SE EPI DWI is prone to geometric distortions, mainly due to the long readout time and low bandwidth in the phase-encoding direction. Reduced-FOV imaging allows acquisition of a small FOV with either reduced geometric distortion (shorter readout time) or higher spatial resolution (same readout time) compared with standard EPI DWI. An FOV smaller than the object typically induces foldover artifacts. Numerous different techniques have been introduced in the past to prevent these, especially selective excitation methods that excite only the ROI such as “inner volume imaging” and suppression-based methods that apply bands to saturate signal external to the target FOV such as “outer volume suppression” or a combination of both.

Reduced-FOV imaging or ZOOM imaging or small-FOV imaging is a commonly used technique in the context of data acqui-
position of small FOVs within larger objects. In this work, a non-coplanar excitation combined with outer volume suppression, originally presented by Wilm et al., was used. This technique is now referred to as DW ZOOM-EPI, and the main applications using small-FOV imaging are imaging of the prostate, spinal cord, pancreas, breast, and heart, where a relatively small area of interest surrounded by tissue of less interest is depicted with high resolution. However, to date, the use of reduced-FOV imaging in the depiction of very small pathologic lesions with diffusion restriction in the brain stem and hippocampus has not yet been systematically evaluated. The imaging examples presented in this clinical report stress but do not prove the importance of reduced-FOV imaging for the visualization of small lesions in the brain stem and hippocampus.

The increased detectability of small lesions with diffusion restriction in the brain stem and hippocampus on DW ZOOM-EPI in comparison with standard DWI might have been influenced by several technical factors:

1) The registration effect: The standard DWI and the DW ZOOM-EPI slice selections may be slightly different. As a result, the comparison of visual lesion detectability may not entirely represent an effect of the sequence in these patients.

2) The difference in scan time: The total scan time and thus the signal-to-noise ratio differed between standard DWI and DW ZOOM-EPI. The increased scan time in DW ZOOM-EPI automatically increased the signal-to-noise ratio and could also affect the visibility of lesions.

3) The difference in the display window/level settings: Due to the differences in the imaging parameters between standard DWI and DW ZOOM-EPI, it was not possible to keep an identical display window/level. Window and level selection was at the discretion of the reviewer to optimally depict pathology.

Therefore, a next step might be a prospective study of standard DWI and DW ZOOM-EPI with constant imaging parameters to make a precise comparison of the 2 sequences. This would help clarify whether the improved visibility of small lesions originates from a higher SNR, higher resolution, reduced image distortion, or a combination of these factors.
CONCLUSIONS
Pathologies with diffusion restriction are routinely depicted by standard DWI. However, the visualization of very small lesions with diffusion restriction in the brain stem and hippocampus may be difficult on standard DWI. Tailored DW ZOOM-EPI enhances the visualization of very small lesions in the brain stem and hippocampus and thus can be the only MR image depicting the pathology. The acquisition of DW ZOOM-EPI may be recommended in selected patients presenting with specific brain stem syndromes or with clinical suspicion of hippocampal pathologies such as TGA or hippocampal ischemia and with negative standard DWI findings. The correct diagnosis of an ischemic-pathologic lesion can expedite correct subsequent therapy.

ACKNOWLEDGMENTS
The authors thank Dr Simon Rauch, Institute of Radiology, Kantonsspital Winterthur, Winterthur, Switzerland, for his support in the preparation of the manuscript.

Disclosures: Christoph Binkert—UNRELATED: Consultancy: Merit Medical Systems, Biotronik; Grants/Grants Pending: Cook, Merit Medical Systems. David Czeil—UNRELATED: Payment for Development of Educational Presentations: University of Zurich. Michael Wyss—UNRELATED: Employment: My position in the hospital is paid by Philips within the framework of a collaboration agreement. Comments: €4000 per year.* Erika Brüllmann—OTHER RELATIONSHIPS: Philips HealthSystems employee. *Money paid to the institution.

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