**Purpose**

(1) **Cerebrospinal fluid flow artifact**

Magnetic resonance imaging (MRI) in the cervical spine should ideally show anatomical detail surrounded by vertebra and thus needs high spatial resolution. Conventional MR imaging methods for the cervical spine assessment [1-3] show flow artifacts in the subarachnoid space and even inside the spinal cord arising from cerebrospinal fluid (CSF) flow pulsation. This prevents good definition of subarachnoid space structure, abnormalities or compression of nerve roots, intradural extramedullary tumors, and spinal cord lesions such as can be observed in multiple sclerosis. Some imaging techniques have reported excellent CSF-to-cord contrast [1, 4, 5]. For example, the 3D constructive interference in steady state (CISS) sequence provides excellent contrast [6]; however, the contrast inside the spinal cord is too poor and the acquisition time too long to be used as a screening approach. 2D multiple-echo data image combination (MEDIC) offers a high signal-to-noise ratio (SNR) and flow artifact suppression [7], which can be applied to imaging of the cervical spine, although it is not often used in routine imaging.

(2) **CSF-suppressed imaging**

DANTE (Delays Alternating with Nutation for Tailored Excitation) pulse trains are a rapid series of low flip angle RF pulses interspersed with gradients. It has been demonstrated that during a train of DANTE preparation pulses the longitudinal magnetization of flowing spins is largely attenuated relative to static tissue and fluid, whose longitudinal magnetization is mostly preserved [8]. Since the DANTE preparation is able to suppress the pulsating CSF signal, the contrast between spinal cord and CSF is maximized and the spinal cord signal itself and the subarachnoid space structures are expected to be more visualized and homogeneous because of the reduction of in flow artifact, whilst maintaining the grey matter and white matter contrast [9].

(3) **Purpose**

The purpose of this study is to demonstrate the image quality improvement of spinal cord images acquired with DANTE prepared 2D-TSE (DANTE-TSE) compared to images acquired with conventional 2D multiple-echo data image combination (MEDIC).

**Methods and Materials**
(1) Participants

Four healthy subjects (1 male and 3 females; mean age, 35.5 ± 7.1 years) were recruited from October 2012 to December 2012. The informed consent was obtained from all participants after the nature of this study had been fully explained.

Inclusion criteria included: no known health problems, age > 20 years, and no history of diseases which might affect the central nervous system.

Exclusion criteria included: absolute contraindication for MRI and the presence of an obvious abnormality on routine MRI sequences of the cervical spine.

(2) DANTE pulse trains and MR imaging acquisition parameters

The proposed DANTE imaging sequence is shown in Fig. 1 on page 4, indicating both the DANTE preparation module itself, as well as the proposed imaging readout module, such as the TSE. Np is the number of pulses applied in the DANTE module. Fig. 2 on page 4 shows the theoretical suppression of moving spins versus static tissue.

DANTE prepared 2D-TSE proton density weighted imaging (DANTE-PDWI), DANTE prepared 2D-TSE T2WI (DANTE-T2WI) and MEDIC images of the cervical spine were acquired in all subjects using a 3T scanner that incorporated a standard neck RF coil.

The acquisition parameters were:

DANTE-PDWI: TR/TE, 4000/13 ms; ETL, 9; NEX, 1; acquisition matrix, 256 × 251; slice thickness, 3 mm; 16 slices; acquisition time, 4 mins.

DANTE-T2WI: TR/TE, 4000/94 ms; ETL, 13; NEX, 1; acquisition matrix, 256 × 251; slice thickness, 3 mm; 16 slices; acquisition time, 4 mins.

MEDIC; TR/TE, 470/17 ms; NEX, 2; flip angle, 30; bandwidth, 260 Hz/pixel; acquisition matrix, 256 × 256; slice thickness, 3 mm; 30 slices; acquisition time, 4 mins; iPat, 2.

(3) Image analysis

Regions of interest (ROIs) were used for comparing DANTE-PDWI and DANTE-T2WI with MEDIC. Rectangular ROIs on a sagittal image of each subject, including the spinal cord and the arachnoid space, respectively, were manually selected at the same location in each subject by a trained neuroradiologist (Fig. 3).
Contrast-to-noise ratio (CNR) based on the background noise was performed between the spinal cord and CSF. F-test and histogram analyses were adopted for assessing the ROI signal variation caused by noise or flow artifact in the spinal cord. It has been reported that the contrast between grey matter and white matter in the axial images of DANTE-PDWI (14.4) was slight higher than that of MEDIC (12.9) [9]. Therefore the effect of the contrast was considered to be minimized for these images.

Images for this section:

Fig. 1: The DANTE preparation module (a) and multislice interleaved imaging acquisition (b) are applied before each of the imaging readout segments. Np is the number of RF pulses; tD is the time interval between successive pulses; pw = 60 ms and gw = 50 ms; TR is the repetition time of each complete slice or slab; and MD is the number of DANTE modules applied during the interleaved slice TR period.
Fig. 2: The Bloch equation simulation of different decay patterns of static tissue and moving blood/CSF when the DANTE module is used for multislice interleaved acquisition. The signal time courses of static tissue and moving blood are shown as -- and - - - -, respectively.
**Fig. 3:** Representative sagittal images of DANTE-PDWI (a), DANTE-T2WI (b), and two-dimensional multiple-echo data image combination (MEDIC) (c) are shown. (d) Example ROIs for the spinal cord and CSF are drawn on the MEDIC image.
Results

Fig. 4 on page 7 shows example DANTE-TSE and MEDIC images. The DANTE-TSE images allow identification of the ventral and dorsal nerve roots and the border of the dura mater of the CSF suppression, whilst maintaining the grey matter and white matter contrast. This is in contrast to the MEDIC sequence where these anatomical details are not evident.

The CNRs of DANTE-PDWI (25.97) and DANTE-T2WI (12.41) between the spinal cord and CSF showed a significant improvement compared with the CNR of MEDIC (5.79).

An F-test showed that there were significant differences between the variances of both DANTE-PDWI and MEDIC and between DANTE-T2WI and MEDIC (P < 0.05, each). The mean full widths at half maximum (FWHM) of DANTE-PDWI (105) and DANTE-T2WI (73) revealed a narrower spectrum than that of MEDIC (118), which indicates slightly more homogeneous intensity in DANTE-PDWI than that in MEDIC (Fig. 5 on page 7).

Images for this section:

![Fig. 4: DANTE-PDWI (a) and DANTE-T2WI (b) identify the ventral and dorsal nerve roots and the border of the dura mater compared with MEDIC (c).](image-url)
Fig. 5: Histograms of the image signal in the spinal cord ROI of 1 subject. The arrows show the full width at half maximum of DANTE-PDWI, DANTE-T2WI and MEDIC.
Conclusion

(1) Clinical implications for routine MR imaging

Conventional MR imaging shows less contrast between structures in the subarachnoid space and the surrounding CSF because of CSF flow pulsation. However MR images prepared with DANTE pulse trains are expected to enhance the detectability of abnormalities in the subarachnoid space without compromising visualization of potential lesions in the spinal cord. CSF signal suppression with DANTE preparation of 2D-TSE has the potential to provide a new routine MR imaging protocol for detecting abnormalities in both the spinal cord and the subarachnoid space.

(2) Limitations of the study

1. The contrast between spinal cord and CSF for DANTE-T2WI was half the contrast of DANTE-PDWI; however, T2WI is more commonly used for routine imaging than PDWI. Further improvement in image quality is required for DANTE-T2WI.

2. The number of subjects was limited.

3. MEDIC was used as the standard compared to DANTE-TSE although it is not often used for routine imaging.

(3) Conclusion

DANTE-prepared TSE imaging demonstrates robust CSF suppression which enables visualization of intradural extramedullary structures and provides an excellent spine-to-cord contrast and homogeneous contrast of spinal cord compared to MEDIC imaging.

References


**Personal Information**

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