Non-Contrast Bulk Flow Imaging of Cerebrospinal Fluid (CSF) using Time-Spatial Labeling Inversion Pulse (time-SLIP)

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PURPOSE

The cerebrospinal fluid (CSF) flow can be characterized in three types of flow movements; "to and fro", bulk motion, and turbulent flow. In the past decade, a two-dimensional cardiac gated phase contrast (PC) technique has been primarily used to study CSF flow. However, the PC technique allows only depiction of the "to and fro" motion by taking an average of phase changes during the cardiac cycle (1,2). Therefore, there is no report of observing the bulk motion and turbulent flow of CSF extended more than one cardiac cycle. In clinical study, it is important to observe whether CSF has normal bulk flow or is altered flow due to underlying disease such as hydrocephalus, syringomyelia, etc. In this study, we have proposed a new technique, time spatial labeling inversion pulse (time-SLIP), to investigate and observe bulk CSF flow between 1500 to 6000 ms.

MATERIALS and METHODS

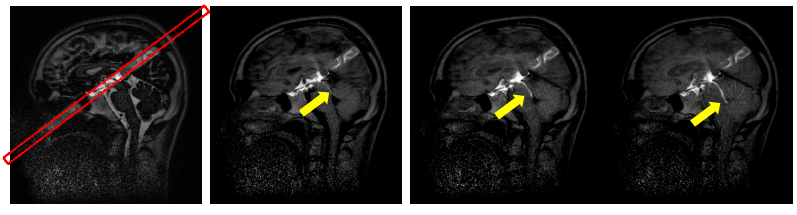
Time spatial labeling inversion pulse (time-SLIP) examinations were performed on eleven healthy volunteers (6 men and 5 women, age range 26-42 years, mean 34 years) using a clinical 1.5-T MRI scanner. Institutional review board approved the study and informed consent was obtained from all volunteers. A time-spatial labeling inversion pulse (time-SLIP) sequence diagram with ECG-triggered single shot half-Fourier fast spin echo (FSE) is described in ref [3]. A non-selective inversion recovery (IR) pulse (A) inverts all signals in the FOV from initial longitudinal magnetization (+Mz) to (-Mz). Immediately after the IR pulse (A), a free-hand spatially selective inversion pulse (B) is applied on the region of interest to be tagged or marked. Then, the longitudinal magnetization in the marked region is recovered to +Mz by the pulse B while the magnetization in the rest of the region remains at -Mz. After waiting a TI time, labeled or marked objects were acquired using single-shot two dimensional half-Fourier FSE. The free-hand IR pulse allows marking a region of interest (ROI) in any orientation. Typical time-SLIP imaging parameters were as follows; repetition time (TR) of 8 to 10 seconds, RR interval (about 10,000 ms), effective TE (TEeff) of 80 ms; echo train spacing of 5 ms; matrix size of 256x256; FOV of 26x26cm; bandwidth of 83.3kHz; echo train length (ETL) of 144 echoes, a 5-mm section slice image, ECG delay time from an R-wave to the beginning of the non-selective IR pulse (A) of 0 ms, and the labeled pulse width of 1 to 5 cm. The single-shot images with various TI times were obtained by repeating the single shot series 20 to 40 times with 50 to 200-ms incremental TI times starting from 1000 to 6000 ms. Total acquisition time was varied from 3 to 6 minutes depending on the number of single shot images. This technique was used to evaluate CSF flow in several volunteers and was applied and verified in regions, including the aqueduct of Sylvius, foramen of Monro, prepontine cistern and in the spinal canal.

RESULTS and DISCUSSION

Figure 1 shows a series of sagittal images obtained at various TI times where the labeling pulse is placed obliquely to the third ventricle. The TI times are varied incrementally by 200 ms, from 1500 to 4000 ms. As the TI time increases, the labeled CSF travels from the third to the fourth ventricle through the aqueduct. The mean CSF flow velocity can be calculated from the distance of movement and time travel (TI and effective TE, TEeff) [1]. In this case, the CSF moves about 20 mm over a TI of 5000 ms and a TEeff of 80 ms to give the mean velocity of about 4 mm/sec. Figure 2 shows sagittal C-spine images with placement of the labeling pulse in the area of C4 to C5. Note that up and down bulk CSF motions are seen during the TI times between 2000 ms and 4000 ms in the ventral side of subarachnoid space anterior to the spinal cord at the level of C4, as shown by the arrows. Figure 3 shows coronal brain images obtained using an axial labeling pulse applied to the third ventricle. The CSF reflux flows from the third ventricle to the lateral ventricle in normal volunteers. The CSF flow along the side walls of the lateral ventricle is depicted (yellow arrows). The CSF flow from the lateral ventricle to the third ventricle was also seen and appeared as low signal changes in the third ventricle. It can be concluded that CSF between the lateral ventricle and the third ventricle exchange very actively as well as between the third ventricle and the fourth ventricle. These observations were consistent in all eleven volunteers. The technical benefits include the ability to place the labeling pulse in any orientation, the ability to study not only the intracranial but also spinal CSF flow, and easy and short scan times to observe the flow characteristics of CSF.

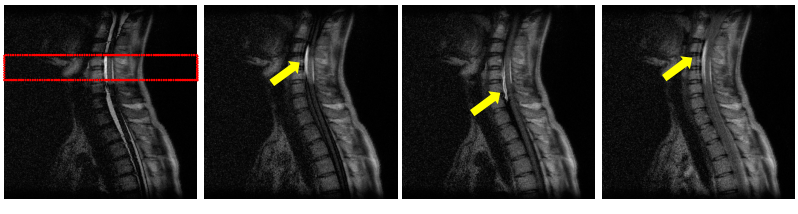
In conclusion, time-SLIP not only allows observation of bulk flow but also turbulent flow of CSF. Our results present a better understanding of CSF flow in normal volunteers, which is indicative of adding clinical value to diagnosis and treatment in patients with hydrocephalus, porencephaly, arachnoid cysts, hydrosyringomyelia and possibly pseudo-tumor cerebri. Clinical study is under investigation.

References: 1] Nitz WR, Radiology 183:395-405, 1992. 2] Alperin, N, MRM. 35:741-754, 1996. 3] Kanazawa H and Miyazaki M, ISMRM p140, 2002.



TI = 1000 ms TI = 2000 ms TI = 3000 ms TI = 4000 ms

Fig. 1 Sagittal brain images utilizing the t-SLIP technique with various TI times. The 1-cm labeling pulse was applied obliquely to the third ventricle. Note that the non-labeled CSF appears dark, whereas the labeled CSF shows higher signal intensity. As TI times increase, the labeled CSF moves from the third ventricle to the fourth ventricle, as indicated by arrows.



TI = 1000 ms TI = 2000 ms TI = 3000 ms TI = 4000 ms

Fig. 2 Sagittal C-spine images with various TI times. In the subarachnoid space anterior to the spinal cord at the level of C4, up and down bulk motion is identified between the TI of 2000 ms and 4000 ms, as indicated by arrows.

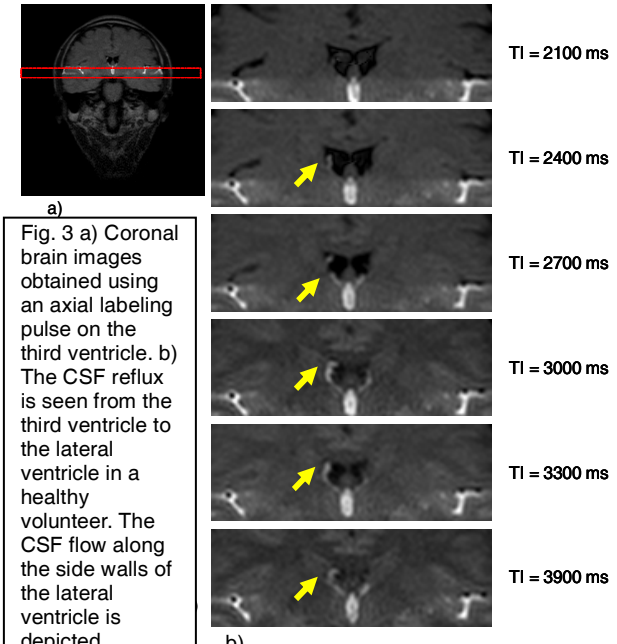


Fig. 3 a) Coronal brain images obtained using an axial labeling pulse on the third ventricle. b) The CSF reflux is seen from the third ventricle to the lateral ventricle in a healthy volunteer. The CSF flow along the side walls of the lateral ventricle is depicted (arrows).