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"磁振造影流速分析於腦脊髓液動態之評估(3/3)"

成果報告

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磁振造影流速分析於腦脊髓液動態之評估(3/3)
MR flow analysis in the evaluation of CSF hydrodynamics

計畫編號：NSC90-2314-B-002-256
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一、中文摘要

本計畫之目的在於發展影像分析技術，用於高空間時間解析度之腦脊髓液動態流速分析，以估計腦脊髓液產生率。十九位受試者參與實驗，掃瞄影像後以相關係數分佈圖及區域成長法自動選取大腦導水管區域進行腦脊髓液產生率自動計算。所求得健康受試者腦脊髓液產生率約為 332±137 ul/min，與侵入式量測法結果相符。若不以本計畫方式自動量測，則操作者所引起之平均誤差高達 24.1% (5.8~59.2%)。吾人結論相位對比磁振造影經過解析度最佳化以及分析自動化之後，應可使用於非侵入式腦脊髓液產生率之臨床評估。

關鍵詞：腦脊髓液產生率、磁振造影、相位對比。

Abstract

The purpose of this project was to determine the CSF production rate in healthy adults using cine phase-contrast MR imaging with high temporal and spatial resolutions plus dedicated image analysis software. 19 healthy adults were imaged. Correlation coefficient maps were generated based on pixel-by-pixel analysis of temporal flow patterns, from which the cross-sectional aqueduct area was defined using a region-growing algorithm. The CSF production rates were calculated using numerical integration. Operator-dependent imprecision and effects of temporal resolution were investigated. The automatic segmentation approach yielded average CSF production rate of 332±137 ul/min, in good agreement with literature values obtained with invasive ventriculolumbar perfusion measurements. Mean operator imprecision was 24.1% (5.8~59.2%). Phase-contrast MR imaging with sufficient temporal and spatial resolution is potentially an effective approach for measuring CSF production rate on a routine basis.

Keywords: CSF production rate, magnetic resonance imaging, phase contrast.

二、計畫緣由與目的

The production of CSF is known to be associated with intracranial homeostatic response to changes in the physiological environment such as the blood pressure or heart rate. Hence, clinical assessment of the CSF production rate may help in understanding its auto-regulatory alterations in response to certain pathophysiological states, such as aging-related brain atrophy or degeneration that accompanies the physiological environmental changes (1). Velocity-sensitive magnetic resonance (MR) imaging based on phase-contrast technique has recently evolved as an attractive alternative in quantitative assessment of the CSF production rate (2,3), due primarily to its noninvasive nature. The literature data reported for human CSF production rates, however, vary to a great extent. It is possible that the technical difficulties inherent in the MR imaging method are potential sources of inaccuracies. An optimization procedure for the noninvasive MR measurement of the CSF production rate, therefore, is certainly highly desirable.

In this study, we used two-dimensional cine phase-contrast MR imaging of the aqueduct of Sylvius at high temporal and spatial resolutions, combined with dedicated automatic image analysis, to achieve precise measurements of the CSF production rate. Some of the technical aspects that may potentially influence the precision of estimation were investigated.

Nineteen healthy young adults (15 males, 4 females, 21-39 years of age) underwent MR velocity mapping examinations on a 1.5 Tesla MR system (Siemens Vision+, Erlangen, Germany). For the purpose of velocity mapping, a 6-mm slice was selected perpendicular to the distal third of the aqueduct of Sylvius. A matrix size of 256x256 was used with 10-cm field-of-view to yield 0.39 mm in-plane spatial resolution. A cine phase-contrast gradient-echo sequence with TR of 45 ms was used to obtain phase images with bipolar velocity encoding gradients set at a maximum encoding velocity (V_{ENC}) of 20 cm/s. Sixty-four cardiac phases were acquired and re-arranged via retrospective ECG gating to form thirty images representing sequential phases in a cardiac cycle. Total acquisition time was about 10 minutes.

Derivation of CSF production rate was performed on the phase images corrected with respect to a nearby static tissue. Automatic segmentation of the aqueduct was performed using a method modified from a pulsatility-based segmentation approach (4). Using this principle, the temporal velocity profile of the pixel showing maximum CSF flow velocity was first derived, following which the Pearson's correlation coefficients with the above reference velocity profile were calculated for the temporal velocity profiles of all the other pixels. In this manner a correlation coefficient map, which exhibited better immunity to noise fluctuations than the original phase-contrast velocity map (Fig.1A), was obtained (Fig.1B). The area of aqueduct was subsequently defined from the correlation coefficient map using a region growing algorithm (Fig.1C).

The spatially averaged velocity as a function of cardiac phase was computed via summation over the aqueduct and divided by the area for all 30 phase images. The CSF production rate was obtained as the net CSF volume flowing through the aqueduct in the craniocaudal direction in one cardiac cycle, multiplied by the heart rate. A comparison was made with CSF production rate computed using manual definition (from three operators) of the aqueduct on velocity maps. The inter-operator agreement was then assessed and the results presented as coefficient of variations. Possible influence of the temporal resolution in image acquisition on measurement accuracy was also investigated.

三、結果與討論

The automatic outlining of the aqueduct of Sylvius was done with little difficulty using the pulsatility-based segmentation algorithm (Fig.1). Calculation of the CSF production rate with manual outlining of the aqueduct area showed coefficients of variations varied from 5.8% to 59.2% (mean 24.1 percentage points), suggesting an average imprecision of 24.1% to be expected. In contrast, operator dependency was obviously absent with objective automatic segmentation of the aqueduct of Sylvius.

Temporal profile of the CSF flow velocity (Fig.2A), along with its Fourier coefficients of frequency components

(Fig.2B), shows relatively large magnitude of the fundamental frequency component (i.e., the first harmonic corresponding to the heart rate) compared with the zero-frequency component (i.e., the net CSF flow velocity). The sum of the first three harmonics in the power spectra was larger than the zero-frequency components (net CSF flow) by a factor of 7 to 11. In addition, a temporal resolution of about 8 times the heart rate would lead to under-sampling aliasing error as large as 33% due to the fifteenth harmonic alone. The CSF production rate measured using the automatic analysis algorithm from the nineteen subjects was 332±137 ul/min, in good agreement with the CSF production rate of 347~370 ul/min reported from ventriculolumbar perfusion measurements (1), but lower than those obtained using early MR imaging methods (420~700 ul/min) (2,3).

Previous studies employing phase-contrast MR technique have reported values much larger than ours (2,3). We anticipate that these previous investigations may be prone to resolution imprecision plus operator-related inaccuracy, compared with the high temporal and spatial resolution in addition to the sophisticated image analysis software used in our study. Our results show that two dimensional cine phase-contrast MR imaging can be used for estimation of the CSF production rate, if objective analysis can be performed on images with sufficiently high temporal and spatial resolution. Using our approach we report CSF production rates in good agreement with literature values obtained using invasive ventriculolumbar perfusion measurements, and that no statistically significant circadian variations have been found. Phase-contrast MR imaging is an effective technique that can potentially help resolving the unanswered issues in human CSF secretion as well as in its relation to intracranial pathophysiology.

四、計畫成果自評

Our efforts spent in this project have created results substantially greater than that mentioned in this brief report. Overall, the three-year project has generated two journal papers published in the prestigious *American Journal of Neuroradiology* (5) and *Magnetic Resonance in Medicine* (6) (both on CSF-related MR techniques), one journal article submitted to *Radiology*, two journal articles under preparation, plus more than twenty international and domestic conference papers. Achievements from this project have raised the attention of other domestic medical centers, including Taipei Veteran General Hospital, as well as Johns Hopkins University Hospital who have approached us for mutual cooperation. In short, we have confidence that our results from this project should benefit both the medical centers as well as the patients suffering from CSF-related diseases such as hydrocephalus.

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六、圖表

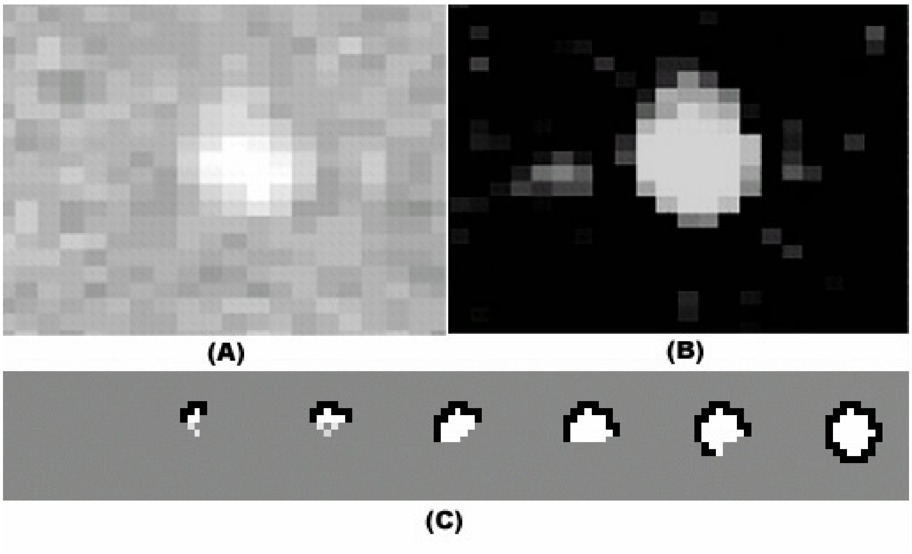

Figure 1. Graphs show definition of the aqueduct of Sylvius via automatic segmentation using a modified pulsatility-based segmentation algorithm. (A) The region-of-interest from the original phase image. (B) Image shows the correlation coefficient map, much less noisy than the original phase image in (A). (C) Series of images illustrate the region-growing algorithm (left to right) for the automatic segmentation of the aqueduct of Sylvius.

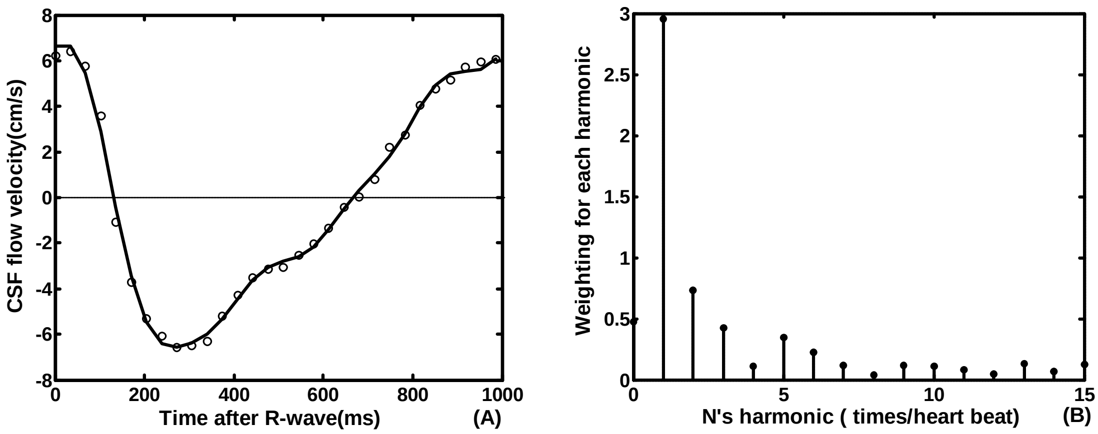

Figure 2. (A) Plots show the temporal pattern of the CSF velocity from a 27-year-old healthy male subject. (B) The Fourier coefficients of each harmonic shown in the power spectrum show that the net CSF flow is relatively small compared with the first three harmonics. Also note that the higher frequency components are not negligible in terms of CSF production rate measurements.