Curve-Fitting Aided Pressure Gradient Assessment in Aqueduct of Sylvius

M-Y. Chen[1], H-W. Chung[1], T-Y. Huang[2], and C-Y. Chen[3]

[1]Institute of Electrical Engineering, National Taiwan University, Taipei, Taiwan, [2]Department of Electrical Engineering, National Taiwan University of Science and Technology, Taipei, Taiwan, [3]Department of Radiology, Tri-Service General Hospital and National Defense Medical Center, Taipei, Taiwan

Introduction

Intracranial pressure (ICP) measurement was significant for diagnosis and treatment in hydrocephalus diseases. Noninvasive ICP MR estimation was proposed by Noam Alperin [1]. However, spatial and temporal limitations in cerebrospinal fluid (CSF) flow study of aqueduct of Sylvius, which were still bothered researchers' assessment. Since its small structure is deeply located in a brain, according to our past studies [2], the total pixels in aqueduct imaging were merely 9~25 in normal volunteers. Therefore, time-varying pressure gradient individually derived from each correspondingly spatial-averaged CSF velocity data, which might far identify with profile of velocities in these aqueduct-segmented pixels. This project aimed at evaluating through-plane flowing time-varying functions set by 2D curve-fitting method. By using a simplified Navier Stokes equation [1], we could depict deliberatively in ICP measurement. Here, we also compared 3 different 2D curve-fitting methods when they applied to cine phase contrast (PC) MR images.

Methods and Materials

All cine PC MR images were performed on a 1.5 Tesla system (Siemens Vision+, Erlanger, Germany) in Department of Radiology at the Tri-Service General Hospital (TSGH). Total 9 healthy normal volunteers (aged from 21 to 39, 5 male and 4 female) were imaging perpendicular to the proximal third of aqueduct of Sylvius with high temporal resolution. Through-plane imaging parameters were VENC=20cm/s, FOV=10 cm, 256x256 matrix size and retrospective gating, with 30 PC images from 64 phases. As Figure 1, one could show a to-and-fro aqueductal flow with a cine way, after automatic image segmentation with PUBS methods [2]. We adopted 3 different 2D curve-fitting methods, e.g. 4-order polynomial, parabolic and Gaussian fitting, and estimated their functions, in 30 time slots, with 15, 6 and 5 undetermined variables, respectively. We found that Gaussian method was the best fitting. Thus, we substituted time-varying Gaussian functions into Navier-Stokes (NS) equation, as equation (1). However, we skipped 3rd term on the right hand of equation with concerning low viscosity of CSF.

$$\nabla P = -\rho\left(\frac{\partial V}{\partial t} + V \cdot \nabla V\right) + \mu \cdot \nabla^2 V \text{....(1)}$$

$$\mathrm{R} = 1 - \frac{\mathrm{SSE}}{\mathrm{SST}} \text{......(2)}$$

Results

As Figure 2, we could compare these 3 different curve-fitting by plotting fitting-goodness (R) with time curve , as equation (2), where R was defined by 100% minus to the value of sum-of-square-error (SSE) divided by sum squares of total (SST). The fitting goodness values were 86.7%, 52.7% and 34.8% with Gaussian fitting, 4-order polynomial and parabolic method, respectively. However, the constrain in calculating R was that one should notice fitting illness during aqueductal velocity near to zero since signal-to-noise was too low to fit, as abrupt decline about 700 msec in blue curve of Figure 2.

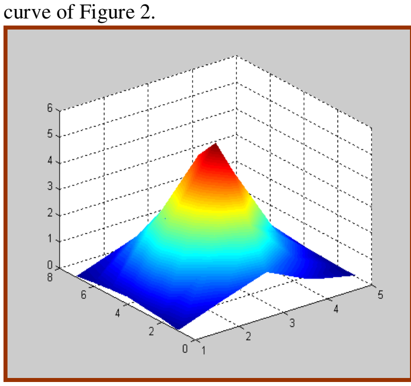

Figure 1. One of aqueductal flow profiles was measured from a young female adult.

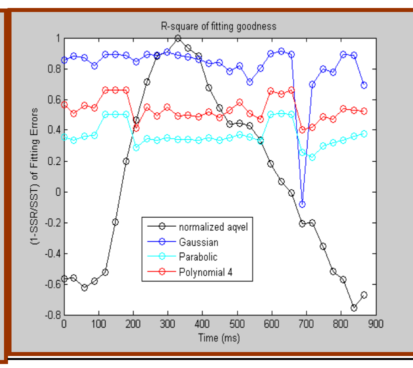

Figure 2. There were 3 different curve-fitting results and a normalized time-varying velocity curve.

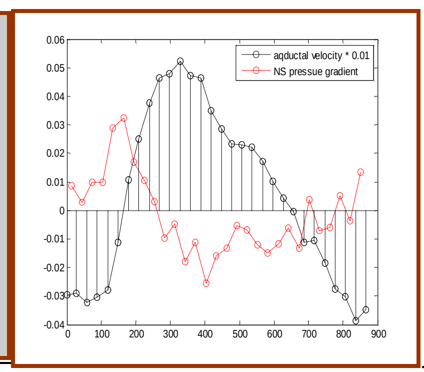

Figure 3. Time-varying pressure gradient (in mmHg/cm) calculated by NS equation and velocity curve (with magnitude was multiplied by 0.01).

Discussion

Note that the absence of turbulence flow in the aqueduct of Sylvius can be shown by calculating Reynolds number (in dimensionless), which was around 600 and much smaller than the threshold 2000 for unstable hydrodynamics. However, parabolic fitting did not show its predominated characteristics with laminar flow; on the contrary, parabolic fitting was an ill fitting. The main reason of the above might be too few pixels to fit. Thus, we adopted Gaussian fitting with the best figure-of-merit. Noam Alperin [1] also demonstrated the viscosity term in Navier Stokes equation was neglectable. Therefore, we got pressure gradient pattern to be consistent with related articles by using either invasive [4] or noninvasive [1] methods.

References

1. Alperin N et al.(2000) Radiology, Vol. 217, No. 3, p. 877-885.
2. Huang, Teng-Yi et al.(2004) Radiology, Vol. 232, No. 2, ,11, p. 603-608.
3. Alperin N, Lee SH. (2003) Magnetic Resonance in Medicine, 49:934–944.
4. O'Sullivan MG et al. (1994) J Neurosurg 1994; 80:46-50.