A Color-coding Technique for Quantitative Cinematic Visualization of the Cerebrospinal Fluid Flow Dynamics

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INTRODUCTION

A new color-coding technique for cinematic flow visualization is introduced to provide a more complete visualization of cerebrospinal fluid (CSF) movement. This technique can assist diagnosis of CSF flow abnormalities such as hydrocephalus, Arnold-Chiari malformation and hydromyelia, and helps surgical planning (1, 2). Traditional cinematic flow visualization in cine phase contrast MRI has been limited to the magnitude or one vector component of the velocity at a time, and thus the complex nature of the flow is not fully represented. This new color-coding technique quantitatively brings together both the magnitude and direction of the CSF flow velocity in one cinematic view.

MATERIALS AND METHODS

Data Acquisition and Velocity Calculation

A two-dimensional (2D) cine phase contrast technique was applied to collect CSF flow data at a mid-sagittal slice from a healthy brain on a 3T GE Signa system (GE Medical Systems, Milwaukee, WI). Velocities in all three directions were measured to investigate the flow dynamics based on the simple four-point method (3). Flow compensation and peripheral gating were applied. A low VENC (corresponding to a phase shift of 180°) of 5 cm/sec was chosen so that a reasonable velocity resolution could be achieved for CSF flow measurement. Other acquisition parameters were: TE = 8.4 ms, TR = 18 ms, flip angle = 20°, FOV = 24 cm, slice thickness = 5 mm, matrix size = 256 × 128, and number of excitation = 2. Images at sixteen equidistant time frames were reconstructed per cardiac cycle.

The CSF pathway was segmented for analysis based on the T_2-weighted fast spin echo (FSE) image, in which CSF was enhanced. The velocity of every pixel at the CSF pathway was calculated. The velocity components in the superior-inferior (S-I) and anterior-posterior (A-P) directions are used to demonstrate the visualization methods here. To reduce the possible spatially dependent offset velocity due to eddy currents or head motion, the velocity at each pixel location was corrected through subtraction by the time-average "velocity" of a nearby solid brain tissue "background" within a 29 mm × 29 mm region with this pixel at the center (4).

Velocity Color-coding Technique

Two (red and green) of the three primary colors were selected to represent the two velocity components. A color circle can be built based on the mixture of these two colors, with the color intensity representing the magnitude of the velocity and the hue of color representing the direction of the velocity. The velocity magnitude is linearly represented by the color intensity, which in-turn is based on the total amount of color. The center of the circle has zero color intensity, corresponding to zero velocity. The edge of the circle has the maximum color intensity, corresponding to the maximum velocity magnitude to represent. The angle of the velocity is represented by the linear combination of the two colors. One pure color, green in this example, represents the 0° velocity direction. The other pure color, red in this example, represents 360° velocity direction. This technique was applied to all pixels along the CSF pathway at all cardiac time frames collected. The color-coded velocity map was then overlaid on a high-resolution T_2-weighted FSE image.

RESULTS

Figure 1 demonstrates the application of the color-coding technique discussed. In this figure, three continuous time frames of the 16 cardiac frames are shown along with the color circle. In this example, a velocity of 5 mm/sec or higher is represented by the edge of the circle. This allows a good contrast to view the slow CSF flow.

DISCUSSION

The color-coding technique presented in this work brings together the information of both the magnitude and direction of the CSF flow in a single cinematic view. Since this technique is based on linear transformations of the velocity, the quantitative characteristics of the flow have been maintained. It is expected to provide assistance in diagnosis, surgical planning and in validating CSF flow mathematical dynamic models.

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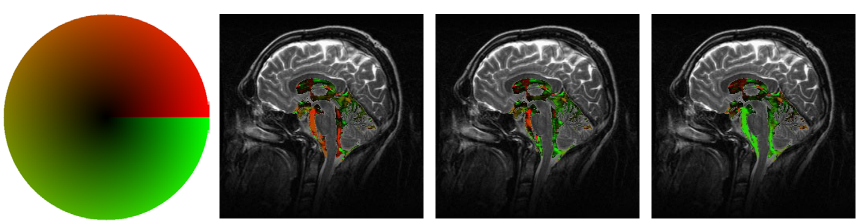

Figure 1. Three continuous time frames of the total 16 within a cardiac cycle are demonstrated in this figure with the velocity represented by the color circle (left most). The center of the color circle represents zero velocity, while the edge of the color circle represents velocity of 5 mm/sec or higher. The CSF color flow is overlaid on a T_2-weighted image where the flow images were acquired.