Spinal CSF Pulsations

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Knowledge of CSF production, distribution and absorption has gradually accumulated since the introduction of radionuclide scanning (Di Chiro 1966) and X-ray contrast cisternography (Du Boulay 1966). But the present understanding of cerebrospinal (CSF) flow is still incomplete and hampered by the fact that lumbar puncture of the closed system of the CSF spaces may disturb observations of physiological CSF movement.

With Magnetic Resonance imaging (MRI) normal and disturbed CSF circulation can be visualized and quantified noninvasively and a mapping of the flow pattern can be achieved in a variety of pathological conditions.

METHODS:

Our investigations were performed on a 1.5 Tesla Magnetom (Siemens Corp., Erlangen, FRG). Using ECG gated FLASH sequences (Fig.2) CSF flow was measured during the cardiac cycle in 120 normal volunteers and patients. With a time resolution of normally 75 ms, the CSF movement was calculated by flow induced signal enhancement on magnitude images and by analysis of the velocity-dependent phase of the protons on phase images. To obtain high contrast between flowing and stationary structures, a large flip angle of 90 degree was applied (Klose 1987, Schroth 1987). To monitor the dependency of CSF flow during respiration, RACE-real time acquisition of flow was performed by a special projection technique (Müller 1988). In addition a variety of phantom experiments and computer simulations was performed to quantify both methods.

**FIG.1. Left side:** Flow phantom to simulate oscillation and continuous laminar motion: Concentric acrylic tubes, perfused with water (passively driven by gravity acting on the difference in the water level in reservoirs at each end) are fixed on a wagggon, and moved sinusoidal through the magnetic field. By variations of the amplitude and frequency of the waggons motion and the flow velocity inside the tubes any kind of combination of flow and superimposed oscillating motions (as expected in the spinal canal) can be performed.

**Right side:** Race-real time phantom experiment (FLASH, TR=50ms, TE=10ms, flip angle = 90 degrees, without phase encoding gradient; the horizontal direction shows one dimensional fourier transformation in readout direction; the vertical axis represents the time of measurement (3.5sec from the top to the bottom). The middle column (a closed tube) indicates oscillation of the wagggon. Comparable to the CSF pulsations in the canals of the cervical spine, the intensity peaks in the lateral tubes are shifted against one another by half a cycle of the waggons oscillation (frequency: 60/min, amplitude: 6cm) due to the opposite directed flow in both lateral tubes (10 cm/sec).
selective HF pulses ($TR = 75 \text{ msec, } TE = 10 \text{ msec}$)

**Fig. 2:** ECG gated FLASH sequence for detection of signal changes within the cardiac cycle. Starting every second or third R-wave of the ECG, the same slice is excited 20 or 40 times in an orientation perpendicular to the expected flow.

**RESULTS AND DISCUSSION**

A striking feature of FLASH images is the high-intensity appearance of flowing structures, especially for motion perpendicular to the imaging plane. The mechanism for this signal enhancement is a wash in of fully relaxed spins between subsequent radio frequencies, whereas the signal intensity of stationary structures is decreased by saturation effects (Fig. 3 and 4).

**Fig. 3:** Diagram of computer simulated changes in magnitude and phase of spins for an increasing flow perpendicular to slices of 3, 5 and 10 mm thickness.

**Fig. 4:** Plot of signal intensity versus time for 20 FLASH excitations, starting with the R-wave of the ECG until the delay time of 1500 ms. Whereas the signal intensities of the spinal cord (1) and muscle tissue (2) decreases, due to saturation effects, the intensities of blood vessels remain high. The intensity peaks of the jugular vein (4) are caused by acceleration of the veinous blood flow during the cardiac diastole. Continuous blood flow in the internal vertebral veinous plexus (3).