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EDITORIAL (BY INVITATION) - VASCULAR NEUROSURGERY - ANEURYSM

# "Bucket" cerebrospinal fluid bulk flow—is it a fact or a fiction?

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Recently, a new controversy arose regarding net cerebrospinal fluid flow through aqueduct cerebri in man: from a theory of no flow [8], through the traditional notion that the flow is more or less equal to CSF production rate, to hyper intense flow with a rate several liters per day [5]. If the first is right, patient with non-communicating hydrocephalus would never improve after third ventriculostomy or shunting. If the last can be true, we should use sealed buckets instead of small collection bags in extraventricular drainage systems.

The main objective of the study of PK Eide and colleagues [5] was to use PCMRI as an accurate measurement of CSF net flow in the aqueduct during cardiac cycle in few patients, predominantly after aneurysm rupture. Results show that net CSF flow could reach 7 or 12 L per day. Such a "bucket" CSF flow has never been reported before; therefore, results should be treated with extreme caution, and the PCMRI technique used by the Authors, carefully validated. So far, CSF hypersecretion has been reported only in choroid papilloma [7]. In patients on extraventricular or lumbar drainage after SAH, CSF drainage rate very rarely increases above 20 mL per hour, never reaching extreme values of several liters per day (every neuroscience nurse emptying CSF drainage bags knows it).

Eksted [3] reported CSF production in "normal" patients (free from intracranial pathology), using potentially accurate method of pressure-controlled drainage, showing average CSF production 0.4 mL/min within range from 0.27 to 0.56 mL/min. In the literature, there is no evidence of CSF hypersecretion after SAH. Moreover, most probably, the resistance to CSF outflow [4] after SAH is normal or increased. With flow rate of 7 L per day, ICP resulting from Davson's equation [6] would be more than 50 mmHg, and patients would die like flies, not because of ischemia related to vasospasm, but because of intracranial hypertension.

There are also several technical concerns regarding accuracy of measurement of net aqueduct CSF flow with PCMRI:

A methodological work has shown [11] that PC MRI measures velocities of CSF flow with an average error of 9% and overestimates peak velocities. This is incompatible with an accurate measurement of net flow. Validity and the accuracy of any new method based on PCMRI should be demonstrated on phantoms or animals and an analysis of the reproducibility of the measurements should be done on the same patients.

PCMRI is a powerful and unique technic to quantify CSF velocity in non-invasive procedure. Nevertheless, this technique is not a real-time measurement and presents some limits that could impact the accuracy of net flow, especially when measurements come from small velocities of fluid flowing through a thin curved tube and presenting large oscillating amplitude.

For eight patients, it is strange that three different scanners were used [5] with different magnetic fields, magnetic gradients, and coils. Such different conditions provide different signal-to-noise ratios (SNR) and different accuracies in 6 min acquisition duration [1, 9, 11].

Spatial resolution in the slice [5] is quite good ($0.63 \times 0.63$ mm$^2$) for dilated aqueduct but 5 mm in diameter finally gives a poor global resolution. Especially, in front of small size of aqueduct, it is only represented by 4 voxels. In these cases, partial volume effect might seriously impact the measurements [1].

Velocity ENCoding (VENC) is an important parameter that defines the SNR of the acquisition; it must be as close as possible as the maximum velocity of the CSF during the cardiac cycle but higher is the VENC, lesser is the accuracy to measure small bulk velocities [1, 9].

Different VENCs were used to avoid aliasing [5], but when VENC is 25 cm/s, the accuracy to measure slow velocity is

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poor and could affect the final net flow. Even if CSF velocity reaches 25 cm/s during systolic cardiac phase, during the whole duration, the cardiac cycle CSF presents much slower velocities.

Finally, 6 min is long for a PCMRI acquisitions; patients can present slight movements. Moreover, cardiac cycle is not completely stable and can fluctuate. Breathing also impacts CSF flow. Real-time PCMRI has shown that during inspiration, there is upward CSF movement into the lateral ventricles and a reversal of direction in expiration phase [2, 10]. Those cardiac and respiratory changes limited a chance to measure accurate net flow from only one reconstructed cardiac cycle.

If a numbers given in [5] are real measurements free from errors, this is an amazing result, very far from common physiological knowledge. Many textbooks will need to be re-written. Before we do that, we need to become certain that the PCMRI methodology used in [5] is right. In conclusion, "bucket CSF flow" is not yet a fact. If we want to prove it, it would require much larger series of careful studies, coming probably not from one but multiple centers. We know Dr. Eide as a good and honest scientist, maybe with above average original and independent thinking; we hope that follow-up experiments will be conducted soon to solve this controversy.

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