Cine 2D Phase-Contrast MRI Free of Blood Flow Artifacts to Study Cervical Cerebrospinal Fluid Flow.

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Purpose: Cerebrospinal fluid (CSF) oscillations are altered in many neurological pathologies (i.e hydrocephalus, subaracnoidal hemorage, intracranial hyper/hypo tension, etc...). CSF dynamic is mainly measured in aqueduct of Sylvius and rarely in subarachnoid spaces (SAS) although circulation through this complex region plays an important role in brain compliance [1,2]. The major source of errors affecting the assessment of CSF dynamic in the SAS with 2D cine phase-contrast MRI (cine-PC) are inappropriate velocity encoding value (lower leads to aliasing and higher to less sensitivity) and vascular flow artifact in or around SAS. These bias flow quantification in these regions and make it difficult for an early and accurate diagnosis of impaired CSF flow [3]. Hanning window filter reduces such artifacts but the trade off is a decrease in spatial resolution [4]. This investigation aims to develop a new 2D cine-PC sequence to assess CSF flow free of blood artifacts and highly sensitive to slow velocity.

Materials and Methods: A conventional 2D cine-PC sequence (3T GE Healthcare) was modified by incorporating two spatial pre-saturation pulses (Hadamard pulses and double-sideband modulation) to be positioned in each side of the slice location and parallel to it. In addition the velocity encoding (Venc) was reduced to a minimum value of 2 cm/s. Retrospectively peripheral-gated acquisition was prescribed using 8 channels head coils and 32 cardiac phases (FOV=14cm^2, 75% phase, slice-thickness 5 mm, matrix=256x128, flip-angle=20°, BW=31.25 kHz, 1 Nex and 2 view per segment, minTE, duration <2mn). Fifteen consented adult patients with suspected hydrocephalus were scanned for this pilot study approved by the institutional review board. Three series were acquired: conventional with min allowed Venc = 5 cm/s and no sat-bands (*Conv*) versus newly developed one with parallel pre-saturation pulses and 2 velocity encoding Venc =5 cm/s (*Dev5*) and Venc=2 cm/s (*Dev2*). Stoke volume, flow max and ROI sections in foramen of Magendie (FM) and prepontine cistern (PPC) were segmented with the same constraints using home made software.

Results: The added sat-pulses has negligible effect on SNR (~3%) and the only change in VNR between developed and conventional sequences VNR_{conv}/VNR_{dev} is observed with *Dev2* and is ~ 2/5 (inverse of Venc=5/Venc=2). The advantages of sat-pulses are clearly demonstrated in the phase images (fig 1) where blood leakage artifact is suppressed in PPC and an enhancement of CSF flow is appreciated in FM. Wilcoxon test in FM showed significantly higher ROI section (p=0.01) with *Dev2* compared to *Conv*. In PPC, there was a significantly lower flow max (p=0.04) and higher ROI section (p<0.01) in *Dev2* compared to *Con*. All measures (stroke volume, ROI and flow max) obtained by *Dev2* and *Dev5* in PPC and FM correlate significantly (Pearson test) with the conventional sequence (Table 1).

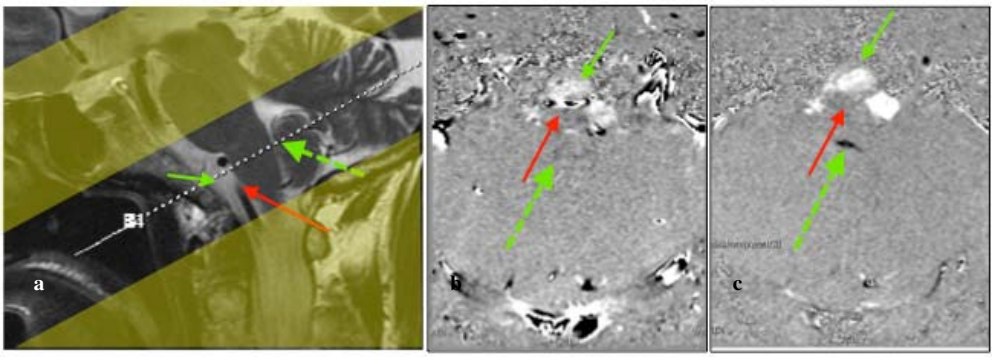

Figure 1: (a) scout sagittal T2W imaging showing the PC imaging plane (white dotted line) with 2 parallel pre-saturation pulses (yellow bands) to suppress blood artifacts. Red arrow points to basilar artery through the prepontine cistern (PPC) and green arrow points to foramen of Magendie (FM) where CSF appears in white intensity. The results of conventional cine-PC acquisition (b) show signal artifact resulting from blood flow through the basilar artery (red arrow) and PPC (green arrow) with lack of flow signal in FM (dotted green arrow). In contrary the developed sequence (c) clearly shows artifact free CSF flow (red arrow) in the PPC and CSF flow enhancement in FM (dotted green arrow).

Pearson	Prepontine cistern (PPC)		Foramen of Magendie (FM)	
	Conv vs *Dev5*	*Conv* vs *Dev2*	*Conv* vs *Dev5*	*Conv* vs *Dev2*
Stroke Volume	ρ=0.76 (p < 0.001)	ρ=0.81 (p < 0.001)	ρ=0.96 (p < 0.001)	ρ=0.87 (p < 0.001)
Flow Max	ρ=0.70 (p = 0.002)	ρ=0.59 (p = 0.002)	ρ=0.95 (p < 0.001)	ρ=0.72 (p < 0.001)
ROI section	ρ=0.67 (p = 0.004)	ρ=0.86 (p < 0.001)	ρ=0.85 (p < 0.001)	ρ=0.86 (p = 0.004)

Table 1: Pearson correlation results between conventional cine-PC *(Conv)* and our developed sequence using 2 velocity encoding values: Venc 5cm/s *(Dev5)* and Venc 2cm/s *(Dev2)*.

Discussion: The incorporation of saturation pulses in 2D cine-PC clearly demonstrates that FM is free of vascular artifact. Furthermore, the high significant correlation obtained between *Conv* and *Dev5* shows that adding saturation pulses does not alter the velocity measurements. In the other hand, decreasing Venc to 2 cm/s increases the sensibility of low velocity measurement, observed in all patients in PPC. In fact, the added saturation pulses highlight the existence of blood artifact from within and surrounding vessels in PPC with a CSF flowing at a velocity < 2cm/s. The reduced correlation between *Conv* and *Dev2* in the PPC might be due to higher sensitivity and greater accuracy when decreasing Venc to 2cm/s and also more precise delineation of CSF flow regions free of blood flow artifact [4,5].

Conclusion: Incorporting saturation-pulses to 2D cine-PC and reducing Venc to 2cm/s demonstrated better ROI delineation specially in complex geometry such as subarachnoidal cisterns and free of blood leakage signal in phase images. In addition our modifications maintain same SNR and spatio-temporal resolutions. The accuracy and improvement of CSF flow measurements in PPC and SAS will help to achieve better diagnosis [6] and follow up CSF circulation alteration in patients who need surgical intervention such as shunt or endoscopic third ventriculostomy [7].

References: [1] Wagshul et al, *J Neurosurg* (2006); [2] Tain et al, *JMRI* (2011); [3] Schroeder et al, *J Neurosurg* (2012); [4] Lagerstrand et al, *JMRI* (2006); [5] Wahlin et al., *JMRI* (2012); [6] Yoshida et al, *Magn Reson Med Sci*, (2009); [7] Bateman & Brown, *Childs Nerv Syst* (2012); [8] Hasiloglu et al, *Headache* (2012);