Phase contrast magnetic resonance imaging

- Comparison of fast and standard segmented techniques for detection of late gadolinium enhancement in acute myocardial infarction: a prospective clinical cardiovascular magnetic resonance trial
- Computed tomography and magnetic resonance imaging features of primary liver perivascular epithelioid cell tumor with renal angiomyolipoma: a case report and literature review
- Pitfalls in contrast enhanced ultrasound: lack of washout in malignant liver lesions. A scoping review
- A simplified method for generating maximum slope maps in ultrafast dynamic contrast-enhanced breast magnetic resonance imaging
- The impact of stenosis treatment on the hemodynamic crosstalk between carotid arteries
- Radiomics analysis based on dynamic contrast-enhanced MRI for predicting early recurrence after hepatectomy in hepatocellular carcinoma patients
- Diagnostic performances of adding transition and hepatobiliary phase to washout in gadoxetic acid-enhanced MRI for subcentimeter hepatocellular carcinoma
- Altered brain fluid dynamics in spontaneous intracranial hypotension

Phase-contrast magnetic resonance imaging (PC-MRI) is a specific type of magnetic resonance imaging used primarily to determine flow velocities. PC-MRI can be considered a method of Magnetic Resonance Velocimetry. It also provides a method of magnetic resonance angiography. Since modern PC-MRI is typically time-resolved, it provides a means of 4D imaging (three spatial dimensions plus time).

Key Differences

Feature	Phase Contrast MRI (PC-MRI)	Phase Contrast Cine MRI (PC-Cine MRI)
Temporal Resolution	Captures flow information as a static snapshot.	Provides time-resolved flow data throughout the cardiac cycle.
Data Acquisition	Usually a single-phase acquisition.	Gated to the cardiac cycle using ECG synchronization, generating a cine loop.
Primary Use	Quantification of average or peak flow velocities.	Evaluation of dynamic flow changes over time.
Applications	Broad applications in measuring steady or slow flow (e.g., large vessels, CSF).	Detailed analysis of pulsatile flow, especially in cardiovascular or CSF dynamics.
Output	Provides flow velocity and direction in a single state.	Generates a sequence of images showing changes over time (cine mode).

When to Use Which?

- **PC-MRI** is suitable for:
  - Cases where steady or average flow is of interest.
  - Quick assessments where temporal variation is not critical.
  - Static CSF studies or flow in large vessels with minimal pulsatility.
- **PC-Cine MRI** is ideal for:
  - Situations where flow varies significantly with the cardiac cycle.
  - Pulsatile CSF flow analysis, e.g., in aqueductal stenosis or Chiari malformation.

- Detailed cardiovascular studies like valve dysfunction or aortic flow.

How They Overlap

PC-Cine MRI builds upon PC-MRI by adding a temporal dimension, making it more specific for time-sensitive applications. Both techniques use similar principles of velocity encoding through phase shifts, but PC-Cine MRI requires additional ECG gating to track changes across the cardiac cycle.

If you're investigating a specific flow scenario, choosing between these methods depends on whether you need dynamic (cine) or static flow information.

Applications

Phase contrast MRI is one of the main techniques for magnetic resonance angiography (MRA). This is used to generate images of arteries (and less commonly veins) in order to evaluate them for stenosis (abnormal narrowing), occlusions, aneurysms (vessel wall dilatations, at risk of rupture) or other abnormalities. MRA is often used to evaluate the arteries of the neck and brain, the thoracic and abdominal aorta, the renal arteries, and the legs (the latter exam is often referred to as a "run-off").

Phase contrast magnetic resonance imaging, PC MRI, is a valuable tool allowing for non-invasive quantification of CSF dynamics, but has lacked adoption in clinical practice for Chiari malformation diagnostics. To improve these diagnostic practices, a better understanding of PC MRI-based measurement agreement, repeatability, and reproducibility of CSF dynamics is needed.

An anatomically realistic in vitro subject-specific model of a Chiari malformation patient was scanned three times at five different scanning centers using 2D PC MRI and 4D Flow techniques to quantify intra-scanner repeatability, inter-scanner reproducibility, and agreement between imaging modalities. Peak systolic CSF velocities were measured at nine axial planes using 2D PC MRI, which were then compared to 4D Flow peak systolic velocity measurements extracted at those exact axial positions along with the model.

Comparison of measurement results showed a good overall agreement of CSF velocity detection between 2D PC MRI and 4D Flow ($p = 0.86$), fair intra-scanner repeatability (confidence intervals ± 1.5 cm/s), and poor inter-scanner reproducibility. On average, 4D Flow measurements had a larger variability than 2D PC MRI measurements (standard deviations 1.83 and 1.04 cm/s, respectively).

Agreement, repeatability, and reproducibility of 2D PC MRI and 4D Flow detection of peak CSF velocities was quantified using a patient-specific in vitro model of Chiari malformation. In combination, the greatest factor leading to measurement inconsistency was determined to be a lack of reproducibility between different MRI centers. Overall, these findings may help lead to a better understanding of the application of 2D PC MRI and 4D Flow techniques as diagnostic tools for CSF dynamics quantification in Chiari malformation and related diseases [1)]

Phase contrast can quantitatively measure stroke volume in selected regions, notably the aqueduct of Sylvius, synchronized to the heartbeat. Judicious fine-tuning of the technique is needed to achieve maximal temporal resolution, and it has limited visualization of CSF motion in many CNS regions. Phase-contrast is frequently used to evaluate those patients with suspected normal pressure hydrocephalus and a Chiari I malformation. Correlation with successful treatment outcome has been problematic. Time-spatial labeling inversion pulse, with a high signal-to-noise ratio, assesses linear and turbulent motion of CSF anywhere in the CNS. Time-spatial labeling inversion pulse can qualitatively visualize whether CSF flows between 2 compartments and determine whether there is flow through the aqueduct of Sylvius or a new surgically created stoma. Cine images reveal CSF linear and turbulent flow patterns [2)]

Phase contrast MRI (PC-MRI) can be used to quantify cerebrospinal fluid flow at the level of the aqueduct of Sylvius by synchronizing the acquisition of the images with the cardiac cycle [3)].

The cerebrospinal fluid flow ed and its direction can be measured non-invasively via Phase contrast magnetic resonance imaging (Cine-Contrast MR). When CSF flow is obstructed at any level, hydrocephaly occurs [4) 5)].

Phase contrast imaging is an MRI technique that can be used to visualise moving fluid. It is typically used for MR venography as a non-IV-contrast requiring technique.

Spins that are moving in the same direction as a magnetic field gradient develop a phase shift that is proportional to the velocity of the spins. This is the basis of phase-contrast angiography. In the simplest phase-contrast pulse sequence, bipolar gradients (two gradients with equal magnitude but opposite direction) are used to encode the velocity of the spins. Stationary spins undergo no net change in phase after the two gradients are applied. Moving spins will experience a different magnitude of the second gradient compared to the first, because of its different spatial position. This results in a net phase shift. This information can be used directly to determine the velocity of the spins. Alternatively, the image can be subtracted from one acquired without the velocity encoding gradients to obtain an angiogram.

The PC MRI generates signal contrast between flowing and stationary nuclei by sensitising the phase of the transverse magnetisation to the velocity of motion.

Two data sets are acquired with opposite sensitisation, yielding opposite phase for moving nuclei and identical phases for stationary nuclei.

For stationary nuclei, the net phase is zero, and their signal is eliminated in the final image. However, flowing nuclei move from one position in the field gradient to another between the time of the first sensitisation and that of the second sensitisation. Because phase varies with position in the field, the net phase after subtraction of the two data sets is non-zero, and there is residual signal from flowing CSF.

When the two data sets are subtracted, the signal contribution from stationary nuclei is eliminated and only flowing nuclei are seen.

Before PC MRI data are acquired, the anticipated maximum CSF flow velocity must be entered into the pulse sequence protocol (velocity encoding (VENC)).

To obtain the optimal signal, the CSF flow velocity should be the same as, or slightly less than, the selected VENC. CSF flow velocities greater than VENC can produce aliasing artefacts, whereas velocities much smaller than VENC result in a weak signal.

The mean VENC value is 5–8 cm s−1 for standard CSF flow imaging. Low VENC values (2–4 cm s−1) can be helpful in the discrimination of communicating and non-communicating arachnoid cysts, and in the assessment of the ventriculoperitoneal shunt patency. In normal pressure hydrocephalus, significantly higher VENC values (20–25 cm s−1) should be chosen owing to hyperdynamic CSF flow within the cerebral aqueduct.

The signal initially contains phase and magnitude information. Magnitude and phase images can be generated for anatomy and velocity information, respectively. The result is that the greyscale intensity of each pixel is directly related to the velocity of CSF. Caudal flow of CSF is conventionally represented as shades of white on phase images, whereas cranial flow is by shades of black. Since it reflects the phase shifts, PC velocity image is far more sensitive to CSF flow than is the magnitude image. Two series of PC imaging techniques are applied in the evaluation of CSF flow, one in the axial plane, with through-plane velocity encoding in the craniocaudal direction for flow quantification, and one in the sagittal plane, with in-plane velocity encoding in the craniocaudal direction for qualitative assessment. Through-plane evaluation is performed in the axial oblique plane perpendicular to the aqueduct and is more accurate for quantitative analysis because the partial volume effects are minimised.

Quantitative CSF velocity and qualitative flow information can be obtained in 8–10 additional minutes in connection with routine MRI.

CSF flow is pulsatile and synchronous with the cardiac cycle, therefore cardiac gating can be used to provide increased sensitivity.

Cardiac gating can be provided with two different methods: prospective gating and retrospective gating. In retrospective gating, the computer follows the R wave and the data are acquired throughout the cardiac cycle. While the entire cardiac cycle can be sampled in retrospective gating, the prospectively gated acquisitions must be completed 100–200 ms before the next anticipated R wave. Thus, there appears to be large net flow of CSF in the systolic direction owing to partially sampled cardiac cycle in prospective gating. More accurate results can be obtained with retrospective gating when compared with prospective gating [6)].

see Phase contrast magnetic resonance angiography

see Phase contrast magnetic resonance imaging for idiopathic normal pressure hydrocephalus

1)
Williams G, Thyagaraj S, Fu A, Oshinski J, Giese D, Bunck AC, Fornari E, Santini F, Luciano M, Loth F, Martin BA. In vitro evaluation of cerebrospinal fluid velocity measurement in type I Chiari malformation: repeatability, reproducibility, and agreement using 2D phase contrast and 4D flow MRI. Fluids Barriers CNS. 2021 Mar 18;18(1):12. doi: 10.1186/s12987-021-00246-3. PMID: 33736664.
2)
Yamada S, Tsuchiya K, Bradley WG, Law M, Winkler ML, Borzage MT, Miyazaki M, Kelly EJ, McComb JG. Current and emerging MR imaging techniques for the diagnosis and management of CSF flow disorders: a review of phase-contrast and time-spatial labeling inversion pulse. AJNR Am J Neuroradiol. 2015 Apr;36(4):623-30. doi: 10.3174/ajnr.A4030. Epub 2014 Jul 10. Review. PubMed PMID: 25012672.
3)

Nitz WR, Bradley WG Jr, Watanabe AS, Lee RR, Burgoyne B, O'Sullivan RM, Herbst MD. Flow dynamics of cerebrospinal fluid: assessment with phase-contrast velocity MR imaging performed with retrospective cardiac gating. Radiology. 1992 May;183(2):395-405. PubMed PMID: 1561340.
4)

Weerakkody RA, Czosnyka M, Schuhmann MU, Schmidt E, Keong N, Santarius T, Pickard JD, Czosnyka Z: Clinical assessment of cerebrospinal fluid dynamics in hydrocephalus. Guide to interpretation based on observational study. Acta Neurolojica Scandinavia 124(2):85-98, 2011
5)

Yi KC, Kim HS, Hong SR, Chi JG: Absence of the septum pellucidum associated with a midline fornical nodule and ventriculomegaly: A report of two cases. J Korean Med Sci 25: 970–973, 2010
6)

http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3473435/