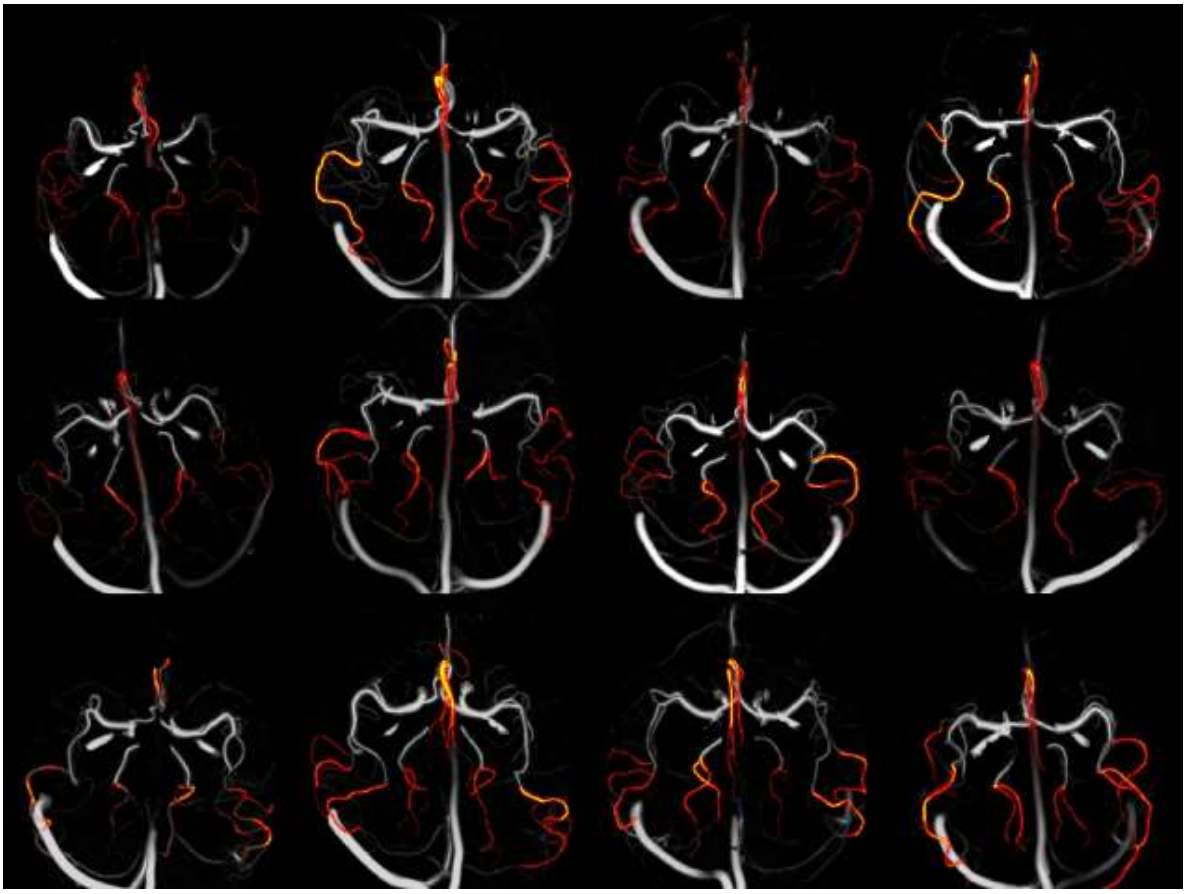
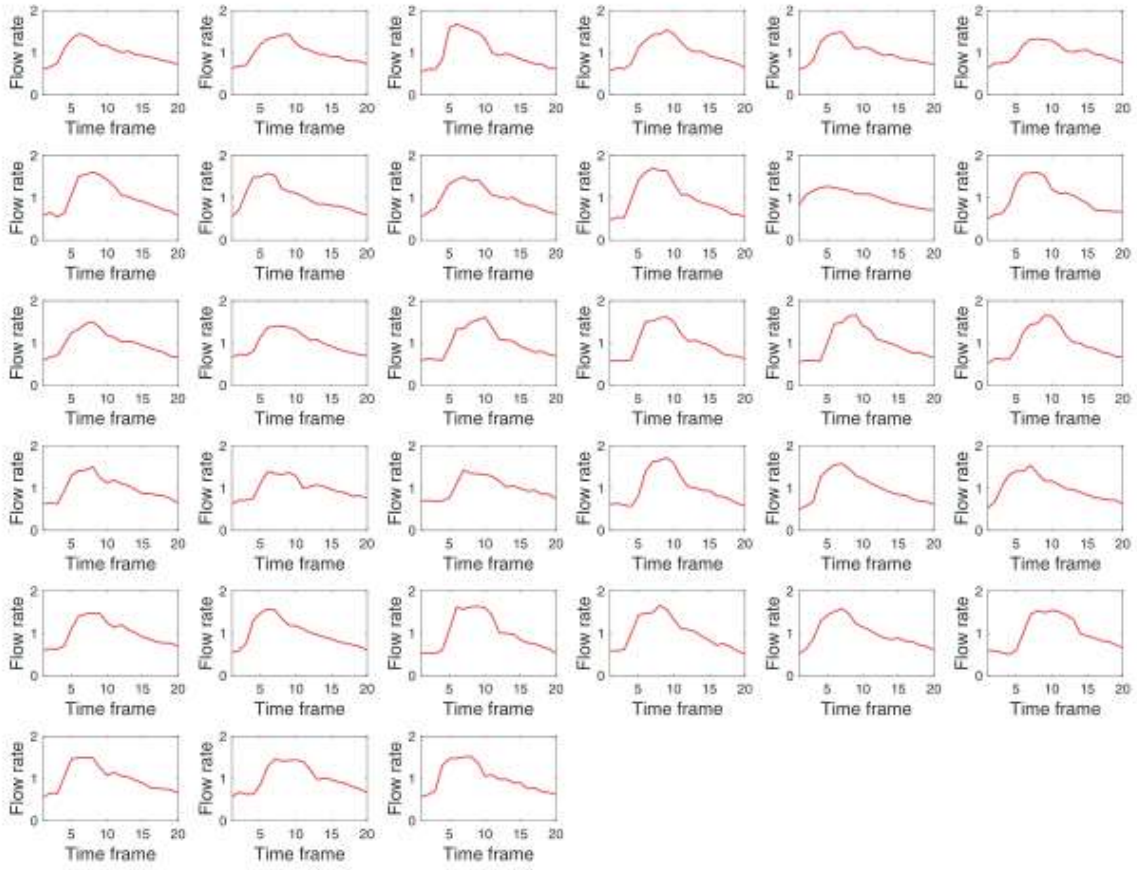
Characterizing pulsatility in distal cerebral arteries using 4D flow MRI - Supplementary information



Supplementary Fig. 1. Manually selected arteries for the internal reference.

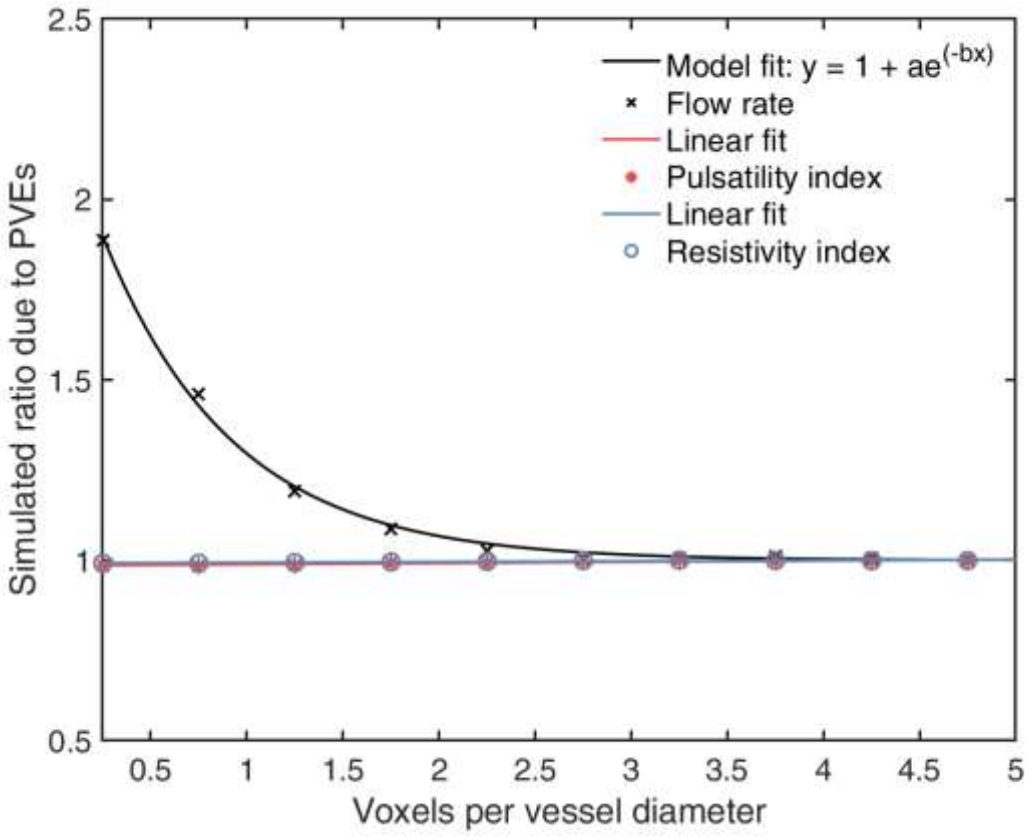
Maximum intensity projections of all cerebral vessels (in greyscale), and of manually selected arteries based on the manually drawn regions of interests (in heat), representing arteries at the ACA A3 level, MCA M3 level and PCA P3 level, as well as distal connecting segments. The manually selected arteries were used to derive 4D flow MRI

internal reference pulsatility and resistivity indices, in a subset (N = 12) of randomly selected participants.



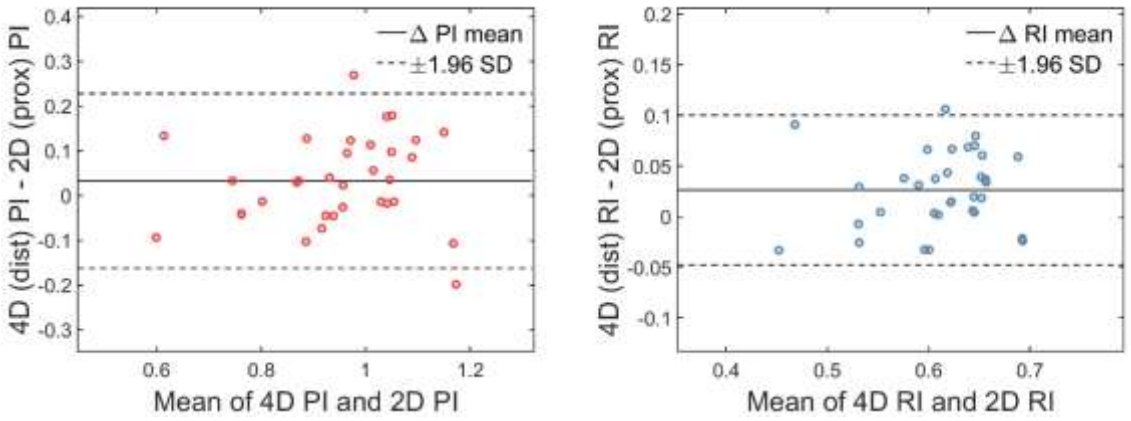
Supplementary Fig. 2. Distal cerebral arterial waveforms for all (N = 33) participants. The x-axis represents the cardiac cycle (subdivided over 20 time frames) and the y-axis represent the normalized (through division by the mean) flow rate, used to derive 4D flow

MRI distal cerebral arterial pulsatility and resistivity indices.



Supplementary Fig. 3. Simulated pulsatile flow and the impact of partial volume effects (PVEs). High resolution time resolved (sinusoidal) flow rate with a parabolic velocity profile simulated through a vessel cross section. Diameter pulsations, synchronized with the velocity pulsations, were simulated with a maximum dilation of 1.5%. The ratios represent simulated overestimations due to PVEs, where a ratio of 1 indicates that the

estimation is accurate. Collection of data into k-space was simulated for a high resolution flow. Field of view in k-space was then reduced, and in turn, the resolution in image space was reduced. Consequently, partial volume effects began to appear, resulting in overestimations in flow rate. However, the relative shape of the waveform was nearly the same, leaving pulsatility and resistivity indices nearly unaffected. In the simulations, a constant magnitude difference between the vessel and the surrounding tissue was used (as 4D flow MRI inflow effects are absent in the distal cerebral vessels), with twice as high magnitude within the vessel.



Supplementary Fig. 4. Bland-Altman analysis to examine the accuracy of the pulsatility and resistivity measures. Pulsatility and resistivity indices (PI and RI) were measured in distal cerebral arteries from 4D flow MRI composite flow waveforms and in their proximal feeding branches (ACA A2, MCA M1 and PCA P2) from 2D PCMRI composite flow waveforms.

Publication	Health status	Mean age	Flow location	Mean PI	Technique
The present study	Full sample /HT^+/HT^- /CVD/AD	78.6 /79.3/77.4 /80.6/82.5	Distal cerebral arteries (global measure)	0.97 /0.99/0.93 /1.02/1.13	4D flow MRI, 3 Tesla
*Rivera-Rivera et al., JCBFM (2016)[1]	Healthy/MCI/AD	74/73/73	MCA M1 PCA P1 PCA P2	1.15/1.25/1.45 1.2/1.55/1.5 1.2/1.4/1.65	4D flow MRI, 3 Tesla
Zarrinkoob et al., JCBFM (2016)[2]	Healthy	71	MCA M1 MCA distal ACA A1 ACA distal PCA P2	0.89 0.84 0.88 0.77 0.85	2D PCMRI, 3 Tesla
Geurts et al., Stroke (2018)[3]	Healthy/ICH/LI	Matched/61/58	BG perforators CSO perforators	0.94/1.02/1.07 1.08/1.17/1.18	2D PCMRI, 7 Tesla

Supplementary Tab. 1. Phase-contrast MRI based pulsatility index in cerebral arteries. In the present study, some participants were considered healthy while others had hypertension (HT), cerebral vascular disease (CVD) and Alzheimer's disease (AD). In Rivera-Rivera et al., healthy controls, mild cognitive impairment (MCI) and AD patients were included. In addition, exact PI values were not reported (*PI values in this table were visually identified from a bar graph). In Zarrinkoob et al., MCA distal was measured at the Sylvian fissure and ACA distal correspond to pericallosal arteries. In Geurts et al., healthy controls free from small vessel disease (SVD), deep intracerebral hemorrhage (ICH)

patients and lacunar infarcts (LI) were included. **Table inclusion criteria:** Related publications were found by conducting PubMed searches for "*phase contrast pulsatility index*", "*4D flow MRI pulsatility index*" or "*flow+MRI pulsatility index*". Only phase-contrast MRI based studies of cerebral arteries distal to the circle of Willis (i.e. ACA, MCA or PCA) or of more distal arteries were included. A minimum sample size of 10 individuals with a mean age above 50 years was also required. **Abbreviations:** PI = pulsatility index. ACA = anterior cerebral artery. MCA = middle cerebral artery. PCA = posterior cerebral artery. CSO = semioval center. BG = basal ganglia.

1. Rivera-Rivera LA, Turski P, Johnson KM, et al. 4D flow MRI for intracranial hemodynamics assessment in Alzheimer's disease. *J Cereb Blood Flow Metab*. 2016;36(10):1718-1730. doi:10.1177/0271678X15617171

2. Zarrinkoob L, Ambarki K, Wahlin A, et al. Aging alters the dampening of pulsatile blood flow in cerebral arteries. *J Cereb Blood Flow Metab*. 2016;36(9):1519-1527. doi:10.1177/0271678X16629486

3. Geurts LJ, Zwanenburg JJM, Klijn CJM, et al. Higher Pulsatility in Cerebral Perforating Arteries in Patients With Small Vessel Disease Related Stroke, a 7T MRI Study. *Stroke*. December 2018:STROKEAHA118022516. doi:10.1161/STROKEAHA.118.022516