Demonstration of direct and complete collateral compensation during carotid artery compression by MR flow monitoring

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Introduction- The actual moment that the internal carotid artery (ICA) is blocked by a thrombus may put a patient at increased risk of ischemia. Because the moment of occlusion is unpredictable, knowledge of the cerebral hemodynamics at the moment of complete ICA occlusion is currently limited. Transcranial Doppler (TCD) ultrasound with compression of the common carotid artery, SPECT measurements during balloon test occlusion and EEG monitoring during carotid endarterectomy demonstrated adequate collateral compensation within seconds to minutes after carotid occlusion. However, thus far no study reported the *quantitative* contribution of the compensational flow increase of the contralateral ICA and vertebro-basilar arteries after ICA occlusion. In this study, we examined the volume flow (ml/s) in the contralateral ICA and the basilar artery (BA) with on-line two dimensional phase contrast magnetic resonance angiography (MRA) monitoring during manual compression of one ICA in 15 healthy subjects.

Methods- 15 healthy volunteers were trained with TCD feedback to perform adequate digital compression of the common carotid artery with the index and middle finger contra-lateral to the side of the compressed common carotid artery. After a resting condition, the common carotid artery was compressed for a 30 seconds period (see Fig. 1). For eight subjects the compression experiment was repeated once. All experiments were performed on a 1.5T clinical MR scanner (Intera NT, Philips Medical Systems, Best, The Netherlands). During compression of one of the ICA's, on-line flow measurement was done with the following acquisition: 2D quantitative phase contrast flow measurement with FOV 192x192 mm^2, matrix 128x128, 5 mm slice, TE/TR/flip = 9/16/15, flow compensated, 1 signal average, venc = 150 cm/s, 4.1 sec/dynamic (for planning of the slice, see Fig. 2). During measurement, the data was transferred to and displayed at an image processing computer that executed on-line flow quantification software as described in [1,2] and provided on-line feedback. For flow analysis, mean and standard deviation of the flow was calculated for subsequent measurement points of the resting state (n > 10) and during compression (n between 7 and 9) for both ICA's and the basilar artery. Average flow change was calculated by averaging all compression experiments (n=23).

Results - In Figure 1, a typical example of the compression experiments is given, showing flow decrease at the compressed ICA and flow increase for the compensating arteries. As demonstrated in Fig. 3, the average volume flow in the compressed ICA decreased with 4.88 ml/s to 0.15 ml/s ($p<0.01$), the average volume flow in the contralateral ICA increased with 3.27 ml/s to 8.96 ml/s ($p<0.01$) and in the basilar artery with 1.92 ml/s to 4.46 ml/s ($p<0.01$). The flow in the contralateral ICA increased with 36% from the resting condition and the basilar artery with 76% from the resting condition. The total decrease in flow of 4.88 ± 0.27 ml/s was directly compensated for by the increase in collateral compensational flow of 5.19 ± 0.36 ml/s. Figure 4 shows the decrease in volume flow versus the increase from compensating arteries for the individual experiments (each individual once and 8 subjects with a repeated compression). The line of identity represents exact compensation.

Discussion and conclusion - Using on-line 2D phase contrast MRA monitoring, this is the first study which demonstrates the ability of the cerebral vasculature for direct, fast (within seconds), and –on average- complete collateral compensation for a drop in perfusion pressure caused by occlusion of the one of the internal carotid arteries. It should be mentioned that the investigated population included young and healthy volunteers, and that patients might show a different hemodynamic behavior. As can be seen in Fig. 4, there are also individual differences, which might be related to differences in the actual anatomy of the circle of Willis (presence of absence of certain collateral arteries), but the number of subject in this study is currently too low to determine statistically significant relations in that respect. For flow measurement, a standard low resolution flow measurement was used, which – despite the low resolution– could measure quantitative flow because the mentioned flow modeling and image processing was used. It is concluded that the on-line MR flow measurement allowed for the detection of immediate and complete collateral compensation of a temporary flow decrease in one of the brain feeding arteries.

References - [1] R. van der Weide et al. JMRI (2000); 12: p. 623 [2] C.J.G. Bakker et al, JMRI (1999); 10: p. 845

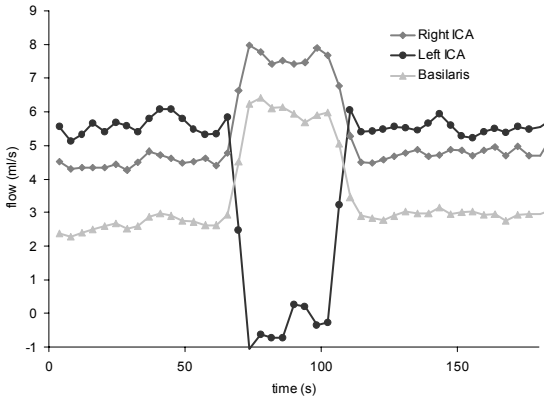

Figure 1. *Example of the on-line measurement of the volume flow (ml/s) in the right internal carotid artery (ICA), left ICA and basilar artery before, during and after digital compression of the left ICA. During compression the flow of the left ICA drops slightly below zero, some retrograde flow and an immediate compensation is observed as flow volume increase in the right ICA together with a considerable flow increase in the basilar artery. After ending the compression the volume flow returns to resting values.*

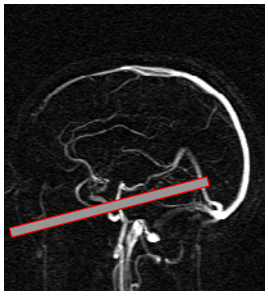

Figure 2. *Planning of the 2D phase contrast MRA slice for online flow measurements (perpendicular to the ICAs and BA).*

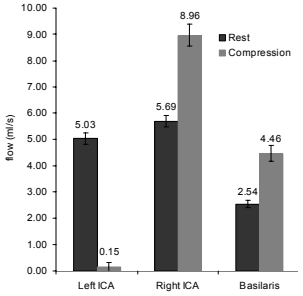

Figure 3. *Absolute change in volume flow in the compressed internal carotid artery (left ICA), the contralateral ICA and BA.*

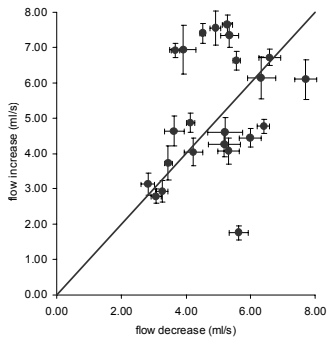

Figure 4. *Increase in volume flow via the contralateral internal carotid artery (ICA) plus basilar artery (y-axis) versus the decrease in volume flow via the ICA on the side of the digital compression (x-axis). The line of identity is also shown. In most of the subjects the direct compensational flow increase in the contralateral ICA and basilar artery was balanced with flow decrease in the compressed ICA.*