Distribution of cerebral blood flow in the nucleus caudatus, nucleus lentiformis, and thalamus in patients with a carotid artery stenosis

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Introduction

The decision whether to operate patients with a symptomatic internal carotid artery (ICA) stenosis is predominantly based on two factors: the presence of recent clinical symptoms and the severity of the stenosis. The location and type of ischemic event indicates whether the stenosis is symptomatic and should be treated. However, there is a large variability in the perfusion territories of the brain feeding arteries. A recent study suggested that in 11% of the patients with cortical or border zone infarcts the wrong artery was expected to be symptomatic (1). In patients with a stenosis of the ICA, the variability of the perfusion territories of the cerebral arteries may be even larger due to collateral blood flow routes. For the basal ganglia, this imposes an even greater difficulty as they can be fed from different brain feeding arteries. Regarding the basal ganglia, this often imposes difficulty in identifying the symptomatic artery in daily clinical practice. The aim of our study was to assess the influence of ICA stenosis on the distribution of cerebral blood flow to the nucleus caudatus, nucleus lentiformis and thalamus with regard to collateral blood flow through the circle of Willis.

Methods

Fifty-four subjects were investigated on 3 Tesla MRI scanner; 36 patients with an ICA stenosis and 18 healthy age- and sex-matched control subjects (11 ♂ and 7 ♀; mean ± SD: 67 ± 7 years). Of the patients, 21 were asymptomatic (13 ♂ and 8 ♀; mean age ± SD: 69 ± 7 years) and 15 symptomatic (9 ♂ and 6 ♀; mean age ± SD: 71 ± 7 years), with a transient ischemic attack or non-disabling infarct on the side of the stenosis within three months before inclusion. The MR protocol consisted of MR angiography, two consecutive 2D phase-contrast MRI measurements for detecting the presence of collateral flow in the circle of Willis and a planning-free regional perfusion ASL sequence for determination of the flow territories of the ICAs and the basilar artery. (2, 3) Selective labeling was accomplished by spatial manipulation of the labeling efficiency within the labeling plane, by applying additional gradients between the labeling pulses in sets of 5 dynamics: no labeling applied (control), non-selective labeling applied (globally perfusion weighted), labeling varied in right-left (RL) direction (distance of 50 mm between full label and control situation), labeling varied in anterior-posterior (AP1) direction (distance of 18 mm between full label and control situation) and labeling varied in AP direction (AP2, similar to AP1, but shifted 9 mm in posterior direction compared to the previous dynamic). The flow territories of the left ICA, right ICA and basilar artery were identified by means of k-means clustering. (4) Assessment of the perfusion-territories of the basal ganglia and flow direction through the circle of Willis was performed by one independent reader (NS). Differences were tested with a two-tailed Fishers' exact test.

Table1 | Prevalence of various types of blood supply to the basal ganglia.

	Ipsi-lateral ICA	Contra-lateral ICA	VBA	Both ipsi- and contra-lateral ICA	Ipsi-lateral ICA and VBA	Contra-lateral ICA and VBA
Nucleus caudatus						
healthy control	18 (100%)	0 (0%)	-	0 (0%)	-	-
symptomatic	15 (100%)	4 (27%) *	-	4 (27%) *	-	-
asymptomatic	19 (95%)	1 (5%)	-	0 (0%)	-	-
Nucleus lentiformis						
healthy control	18 (100%)	-	1 (6%)	-	1 (6%)	-
symptomatic	15 (100%)	-	1 (7%)	-	1 (7%)	-
asymptomatic	20 (100%)	-	0 (0%)	-	0 (0%)	-
Thalamus						
healthy control	15 (83%)	1 (6%)	16 (89%)	1 (6%)	13 (72%)	1 (6%)
symptomatic	12 (80%)	2 (13%)	15 (100%)	1 (7%)	12 (80%)	2 (13%)
asymptomatic	15 (75%)	2 (10%)	16 (80%)	0 (0%)	11 (55%)	2 (10%)

*Note: The basal ganglia could fed by more than one artery. * indicates a significant difference compared to healthy control subjects. ($p < 0.05$, two-sided Fishers' exact test)*

Results

Figure 1 shows the perfusion territories and circle of Willis of a patient with a symptomatic right-sided ICA stenosis. Table 1 summarizes the prevalence of various perfusion patterns to the nucleus caudatus, nucleus lentiformis, and thalamus in healthy control subjects, symptomatic, and asymptomatic patients. In the patients with a symptomatic ICA stenosis, there was a contribution of the contralateral ICA to the nucleus caudatus in 4 of 15 (27%) compared to none of the 18 control subjects ($p = 0.03$). In 1 of the 19 (5%) asymptomatic patients, the contralateral ICA contributed to the nucleus caudatus; this did not reach statistical significance compared to healthy control subjects or symptomatic patients. No significant differences were found in perfusion territorial patterns of the nucleus lentiformis and thalamus between healthy control subjects, symptomatic, and asymptomatic patients. In subjects with a contralateral ICA contributing to the nucleus caudatus there was collateral flow via the ipsilateral A1 segment of the circle of Willis in 4 of 5 subjects (80%) compared to 1 of 48 subjects (2%) without a contributing contralateral ICA ($p < 0.01$, shown in table 2). No significant differences were found in the perfusion territorial patterns of the nucleus lentiformis and thalamus between subjects with antegrade or retrograde flow in the ipsilateral A1 segment.

Table 2 | Prevalence of collateral flow via the A1 segment of the circle of Willis compared in subjects with or without a contralateral ICA contributing to the nucleus caudatus.

Contributing contralateral ICA	Ipsilateral A1 segment flow: Antegrade	Retrograde	Total
Yes	1 (20%)	4 (80%)	5
No	47 (98%)	1 (2%)	48
Total	48	5	53

Note: statistical significance: $p < 0.01$ (two-sided Fishers' exact test)

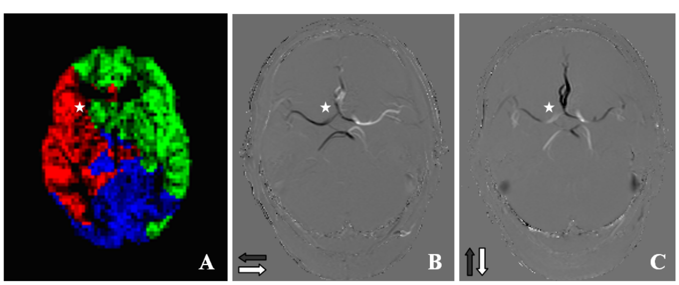

Figure 1 | Perfusion territory image (A) of a patient with a right sided symptomatic ICA stenosis. Colors represent the perfusion territory of the right ICA (red), left ICA (green) and the vertebrobasilar arteries (blue). The nucleus caudatus on the right side is fed from the contralateral ICA (aside white star). The nucleus lentiformis on both sides are fed from the ipsilateral ICA. Furthermore, a portion of both thalami are fed from the right ICA, while the rest is supplied by the vertebrobasilar arteries. Circle of Willis on two-dimensional phase-contrast MRA scan phase encoded in the right-left direction (B) and anterior-posterior direction (C). Blood flowing to the patient's anterior and right direction is black and blood flowing to the patient's posterior and left direction is white. There is collateral flow towards the right hemisphere via the right A1 segment (retrograde flow, black in B, white in C, indicated by white star).

Conclusions

Our study shows that in patients with a stenosis of the ICA the basal ganglia may be supplied with blood from the contralateral ICA through collaterals. In patients with a symptomatic ICA stenosis, we found that in some patients the basal ganglia were fed from the contralateral carotid artery. This was not present in patients with an asymptomatic stenosis. Furthermore, contribution of the contralateral ICA to the nucleus caudatus was accompanied with collateral flow through the A1 segment of the circle of Willis. Non-invasive visualization of the perfusion territories of the basal ganglia, as presented in the present study, may facilitate future treatment decisions in patients with ICA stenosis.

References

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