Brain CT-perfusion: correlation between completeness of the circle of Willis and haemodynamic changes in cases of not-acute atherosclerotic occlusion of main brachiocephalic arteries

Poster No.: C-2366
Congress: ECR 2016
Type: Scientific Exhibit
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Keywords: Vascular, Anatomy, Neuroradiology brain, CT-Angiography, CT, CT-Quantitative, Diagnostic procedure, Contrast agent-intravenous, Arteriosclerosis, Ischaemia / Infarction
DOI: 10.1594/ecr2016/C-2366

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Aims and objectives

Atherosclerosis is a chronic systemic disease which causes gradual narrowing of the arterial blood vessels up to occlusion. According to the data from studies, in group of patients over 65 years old, up to 75% of men and 64% of women could have carotid atherosclerotic plaques [1]. Neurological symptoms severity is frequently associated with increasing of narrowing brachiocephalic arteries, but even carotid occlusion could be asymptomatic [2].

Up to 20% of all ischemic strokes are caused by internal carotid artery (ICA) atherosclerosis [3] and up to 15% of large vessel infarctions may be caused by ICA occlusion [4]. Risk of strokes even with asymptomatic patients may be increased due to different factors such as bilaterally narrowing of brachiocephalic arteries and poor cerebral collateral blood supply [5,6].

Occlusion of the main brachiocephalic artery may cause brain ischemia or infarction by embolism from the occlusion region, acute impairing of brain perfusion or both mechanisms in combination [2]. Main compensatory mechanisms which prevent brain hypoperfusion in case of blood circulation disorder are composed of hemodynamics and metabolic components. The cerebral collateral circulation, which is qualified as assisted vascular channels, also stabilizes central blood flow [7]. Collateral circulation may maintain cerebral perfusion in case of chronic ICA occlusion, and Circle of Willis is the most important source of the collateral brain circulation [2].

Correct preclinical research of asymptomatic patients and comprehensive approach to such patients are necessary for the reliable detection the groups of risk.

Ultrasonography, contrast CT and MRY and contrast angiography are useful for characterization of prevalence rate of brachiocephalic steno-occlusive disease and arterial anatomy of the collateral circulation [7]. Numerous of the modern techniques such as xenon-enhanced CT, SPECT-CT, PET-CT, CT perfusion, and MR perfusion, can assess cerebral blood flow quantity and thereby functional status of brain tissue [7].

Nowadays, CT perfusion (CTP) is one of the most widely available methods for accurate qualitative and quantitative estimation of cerebral blood circulation [8-10].

In view of the aforesaid the aim of this study is to evaluate correlation between anatomical variations of the circle of Willis and brain CT-perfusion parameters in group of patient with unilateral brachiocephalic artery occlusion due to general atherosclerosis.
Methods and materials

29 adult patients (26 male, 3 female) with atherosclerotic disease in conjunction with non-acute atherosclerotic occlusion of main brachiocephalic arteries were enrolled in our retrospective study. MDCT-angiography of brachiocephalic arteries, brain MDCT and brain MDCT-perfusion were performed to all selected patients during hospital admission.

All MDCT-studies were performed on the 256-slice MDCT (Brilliance iCT, Philips Healthcare, Cleveland, OH) and on the 64-slice MDCT (Brilliance 64, Philips Healthcare, Cleveland, OH).

MDCT-angiography was performed by using standard scanning protocols and identical bolus enhancement. Examination quality was equally good for reliable estimates degree of main brachiocephalic artery stenosis and presence of occlusion. Brachiocephalic trunk (BCT), subclavian arteries, common carotid arteries (CCA), internal and external carotid arteries (ICA and ECA), and vertebral arteries (VA) were estimated along the entire length. The arterial anatomy of the intracranial collaterals was estimated in the same studies. Basic group of patients was divided in groups and subgroups, depending on the anatomical completeness of the Circle of Willis.

Non-contrast brain MDCT were performed by using standard scanning protocols too with slice thickness 2-2.5 mm. Presence, prevalence and localization of postichemic stroke changes were estimated in all examinations.

Brain MDCT perfusions were performed by using standard and low-dose protocols and identical bolus contrast enhancements. All of the obtained data for quantitative and qualitative assessment was received at the workstation by using content solution "Brain perfusion" (Philips Medical System). Quality of all perfusion maps was sufficient for reliable estimates of quantitative perfusion parameters, which includes cerebral blood flow (CBF), cerebral blood volume (CBV), mean transit time (MTT) and time to peak (TTP).

To assess global cortical perfusion in ipsilateral and contralateral hemispheres and inter-hemispheric perfusion difference, mean selected parameters were measured in following brain regions of interest (ROI): two symmetric ROI in the right and left anterior cerebral artery territory, 2 symmetric ROI in the right and left middle cerebral artery territory and 2 symmetric ROI in the right and left posterior cerebral artery territory.

Comparison of quantitative parameters between formed groups and subgroups of patients was generally carried out by using relative measure for statistical analysis. For this purpose the percentage of inter-hemispheric differences was mathematically
calculated for every selected artery territory and totally for ipsilateral and contralateral hemispheres in all of the cases.

Subjective visual inter-hemispheric perfusion differences were independently evaluated by two radiologists using a 3-point scale, were «3» means significant difference in color of mapping between ipsilateral and contralateral hemispheres, «2» means poorly resolved color-difference between two hemispheres and «1» means absent of visual difference in color of mapping between two hemispheres.

All obtained absolute and relative parameters were reported as mean ± SD. Results were compared by nonparametric tests. The significance level was 0,05.
Results

Following results of atherosclerosis prevalence were received after the estimation of diagnostic findings from MDCT-angiography extracranial arteries: 29 patients with a total of 44 occlusions of main brachiocephalic arteries, including 2 cases with BCT occlusion, 3 cases with right CCA occlusion, 12 cases with right ICA occlusion, 2 cases with right ECA occlusion, 2 cases with right VA occlusion, 4 cases with left CCA occlusion, 11 cases with left ICA occlusion, 1 cases with left ECA occlusion, 4 cases with left VA occlusion, 3 cases with left subclavian artery occlusion.

28 patients had unilateral carotid artery occlusion (15- right-side occlusion and 13- left-side occlusion) and 19 of that patients (67,85%) had simultaneous significant (>50%) atherosclerotic stenosis on the contrary side, including 7 cases of sub-occlusion. One patient had bilateral internal carotid artery occlusion.

After the estimation of the anatomy of the intracranial arteries, only in 8 cases all 7 segments of Circle of Willis were found. In 11 cases only one segment was absent, and in 10 cases 2 or more different segments were absent (Table 1)

Table 1. Disposition of patients in depending on absence of arterial segments of Circle of Willis.

<table>
<thead>
<tr>
<th>Absent artery</th>
<th>AComA¹</th>
<th>right PComA²</th>
<th>left P#om#²</th>
<th>right PCA³</th>
<th>left PCA³</th>
<th>right ACA⁴</th>
<th>left ACA⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(11 patients)</td>
<td>2</td>
<td>3</td>
<td>-</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2(9 patients)</td>
<td>-</td>
<td>7</td>
<td>6</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>3(1 patients)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

¹ AComA - anterior communicating artery
² PComA - posterior communicating artery
³ PCA - posterior cerebral artery
⁴ ACA - anterior cerebral artery
Thereunder, basic group of patients was divided into two main groups: "First group" with totally complete Circle of Willis (n=8) and "Second group" with incomplete Circle of Willis (n=21).

In turn, "Second group" was divided in two subgroups depending on number of absent arterial segments: "1 subgroup" with incomplete Circle of Willis because of absent one arterial segment (n=11) and "2 subgroup" with absent more than one arterial segment (n=10) which include 9 cases with 2 absent segments and 1 case with 3 absent segments.

The analysis of the data from non-contrast brain MDCT had shown that a total of 10 patients (34,48%) hadn't got any post-ischemic gliosis changes in brain and cerebellum hemispheres. Post-ischemic changes were found in 19 (65,52%) cases, including 5 cases (26,32%) of lacunar post-ischemic changes, 9 cases (47,36%) of post-ischemic gliosis in less than one brain region and 5 cases (26,32%) of big territory of gliosis involved more than one of brain regions.

No significant differences were found in presence or absence of post-ischemic changes or in the size of gliosis between "First" and "Second" main groups, but there was a significant difference in presence of post-ischemic gliosis changes between "First group" and "2 subgroup" (p=0,003) and in the size of gliosis between "First group" and "1 subgroup" (p=0,009).

Subjective visual inter-hemispheric cerebral perfusion differences in basic group of patients were found in all cases: 9 cases of poorly resolved difference between ipsilateral and contralateral hemispheres were estimated as "1-point" on subjective visual scale, 8 cases of moderately inter-hemispheric difference without severe visual hypoperfusion were estimated as "2-point" on-scale and 12 cases of extremely intense inter-hemispheric difference, with severe hypoperfusion in ipsilateral hemisphere were estimated as "3-point" on-scale.

There is no significant difference in visual inter-hemispheric cerebral perfusion differences between "First" and "Second" main groups and in subgroups.

Comparison of the inter-hemispheric difference in quantitative perfusion parameters (CBV, CBF, MTT, TTP) was executed between 2 main groups and 2 subgroups in selected brain regions.

No significant inter-hemispheric difference of brain perfusion was found in the regions of anterior cerebral arteries in comparison between main groups and additory subgroups (p>0,005).

Significant inter-hemispheric perfusion difference was found in the regions of middle cerebral arteries between "First" and "Second" groups (in CBF parameter p=0,035, in
MTT parameter $p=0.012$), between "First group" and "1 subgroup" (in MTT parameter $p=0.034$) and between "First group" and "2 subgroup" (in CBF parameter $p=0.018$, MTT parameter $p=0.010$).

Significant inter-hemispheric perfusion difference was found in the regions of posterior cerebral arteries between "First" and "Second" groups (in MTT parameter $p=0.041$), between "First group" and "2 subgroup" (in MTT parameter $p=0.018$) and between "1 subgroup" and "2 subgroup" (in CBF parameter $p=0.039$).
Fig. 1: CT-angiography of brachiocephalic arteries of the 65 years old patient, with unilateral, left-side CCA occlusion (arrow).

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Fig. 2: CT-angiography of intracranial arteries of the same 65 years old patient, with totally presence of all 7 segments of Circle of Willis.

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Fig. 3: Brain MDCT-perfusion maps of the same 65 years old patient. No significant differences were found in main quantitative perfusion parameters, which includes cerebral blood volume (a), cerebral blood flow (b), mean transit time (c) and time to peak (d) between ipsilateral (left) and contralateral (right) hemispheres.

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Fig. 4: CT-angiography of intracranial arteries of the 72 years old patient, with incompletes of the Circle of Willis, because of absence 2 arterial segments: right posterior communicating artery (arrow) and left posterior cerebral artery (head of the arrow).

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Fig. 5: Brain MDCT-perfusion maps of the same 72 years old patient. Significant visual differences were found in main quantitative perfusion parameters, which includes cerebral blood flow (b), mean transit time (c) and time to peak (d) between ipsilateral (left) and contralateral (right) hemispheres. No significant visual inter-hemispheric differences were found in cerebral blood volume (a).

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Conclusion

Atherosclerosis is the severe chronic disease commonly characterized by coexistent affection of main brachiocephalic arteries up to unilateral or bilateral occlusion. In our study, up to 34.48% of the examined patients with carotid occlusions hadn’t got ischemic strokes, but up to 26.32% of the patients had large strokes in their medical history.

Received data shows us the necessity of complex preclinical research and detection of the patients at risk.

Moreover, our study demonstrates the importance of cerebral collateral blood supply for blood flow stabilization due to significant correlation between anatomical completeness of the Circle of Willis and inter-hemispheric brain perfusion difference for main quantitative perfusion parameters (CBF and MTT, \( p<0.005 \)), primary in the regions of middle and posterior cerebral arteries.
References