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Hands-on Course 4

Neurosonology in the diagnosis of neurovascular disorders - Level 1

Role of ultrasound in posterior circulation stroke

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This course on "Neurosonology in the diagnosis of neurovascular disorders" aims primarily at neurologists in training and those wishing to refresh and/or update their basic knowledge in the field. This lecture, in particular, will give an overview of the clinical applications of ultrasound in patients with ischemic stroke of the posterior circulation in order to obtain an etiological diagnosis, guide treatment, improve clinical outcome and abate recurrent stroke risk.

Posterior circulation stroke accounts for 20-25% of ischemic strokes, but it is more difficult to recognize and treat effectively than other stroke types. Stroke mimics (acute peripheral vestibular dysfunction, basilar migraine, toxic or metabolic disturbances, Miller-Fisher syndrome, posterior reversible encephalopathy syndrome, neuroinflammatory or infectious disorders, etc.) must be excluded, while stroke chameleons (eg. reduced consciousness level or global amnestic syndrome due to bilateral thalamic ischemia, confusion or delirium secondary to bilateral occipital stroke, isolated vertigo due to medial vermis infarction, etc.) should be recognized and treated as true stroke syndromes. Preceding posterior circulation TIA's or other brainstem symptoms, especially if recurrent, indicate a high risk of impending ischemic stroke and should prompt a complete neurovascular assessment. In fact, a delayed or incorrect diagnosis may have devastating consequences, such as severe disability or even death.
The most common causes of posterior circulation stroke are: vertebro-basilar occlusive disease (32%), cardiac embolism (25%), aortic arch embolism (15%), penetrating artery and branch disease (15), other causes including paradoxical embolism (13%). With regards to vertebro-basilar stenosis or occlusion, the most important determinant is atherosclerosis, but in young patients dissection is also an important etiology. Less common causes include vasculitis and dolichoectasia; in younger people, this latter condition might be a clue to Fabry’s disease. Frequently (70%) there are multiple lesions: bilateral intracranial (35%), or one intracranial lesion and one extracranial lesion (35%). With regards to stroke mechanism, artery-to-artery embolization is the most frequent, while hemodynamic ischemia is the least frequent type of stroke.

The risk of recurrent stroke after posterior circulation ischemia is at least as high if not higher than anterior circulation stroke. Moreover, vertebro-basilar stenosis increases the risk threefold, and basilar occlusion is associated with high mortality or severe disability, especially if blood flow is not restored in the vessel. For patients with symptomatic vertebrobasilar stenosis, the risk of recurrent stroke is almost 25% in the first 90 days. Therefore it is crucial, to identify as rapidly as possible which patients are at highest risk of early recurrent stroke, as the most important determinant of outcome of posterior circulation stroke is the nature of the causative vascular disease underlying the stroke itself.

Non-invasive vascular imaging is of course the first choice for the diagnosis of vertebro-basilar obstructive disease, and this includes CTA, MRA and ultrasound. Neurovascular assessment is even more important in posterior circulation stroke than in anterior circulation stroke as sensitivity of brain MRI is lower in the former. In fact, false negatives can occur in up to 20%
of cases in early investigation of patients with posterior circulation ischemic syndrome. The first important differentiation of the underlying pathogenesis is small vessel versus large vessel disease, because the former has a relatively benign prognosis, while the latter can have lethal consequences and requires a rapid diagnostic workup in order to meet therapeutic windows in due time.

In the table below are shown the different arterial segments of the posterior circulation, the frequency of disease and the most frequent pathogenesis.

<table>
<thead>
<tr>
<th>Arterial Segment</th>
<th>Frequency of Disease</th>
<th>Pathogenesis (most probable mechanism)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V0</td>
<td>frequent</td>
<td>Atherosclerosis rarely Traumatic Dissection</td>
</tr>
<tr>
<td>V1</td>
<td>rare</td>
<td>Dissection</td>
</tr>
<tr>
<td>V2</td>
<td>rare</td>
<td>Dissection rarely Compression/Trauma</td>
</tr>
<tr>
<td>V3</td>
<td>very rare</td>
<td>Dissection rarely Arteritis/Compression</td>
</tr>
<tr>
<td>V4</td>
<td>frequent</td>
<td>Atherosclerosis</td>
</tr>
<tr>
<td>BA</td>
<td>frequent</td>
<td>Atherosclerosis (mainly in proximal segment) Embolic (mainly in distal segment)</td>
</tr>
<tr>
<td>SA</td>
<td>frequent</td>
<td>Atherosclerosis rarely Arteritis</td>
</tr>
</tbody>
</table>

The origin of the vertebral artery, V0, is the most frequent site of atherosclerotic stenosis, followed by the intracranial segment, V4, of the vertebral artery and by the basilar artery. Traumatic dissection is more frequent at V0, while the most frequent sites of spontaneous dissection are V1 and V3. Embolic obstruction is most frequent at the third distal segment of the basilar artery, compression at V3, and arteritis at the subclavian artery.
Neurosonology of the brain supplying neck arteries, and large intracranial arteries with colour-coded duplex scanning and transcranial Doppler has added considerably to our present understanding of vertebro-basilar occlusive disease. Ultrasound investigation of patients with a clinical suspicion of posterior circulation ischemia should include a complete study of the posterior circulation: i) a morphological and hemodynamic assessment of the extracranial portion of both VAs: the origin (V₀) and the tortuous V₃ segment are better insonated by a low-frequency sector probe, while the extraforaminal segment (V₁) and the intraforaminal segment (V₂) are better studied by a high frequency linear transducer; ii) a hemodynamic evaluation of the intracranial portion of the VAs (V₄ segment), of the basilar artery (BA) and of the posterior cerebral arteries (PCAs) along with a documentation of collateral flow pathways. The intracranial vessels should be investigated with a phased array transducer (≥2 MHz) via the transforaminal (V₄, proximal BA) and transtemporal (distal BA, PCA) approach.

The first methodological golden rule is to always perform an extracranial examination before a transcranial insonation, in order to avoid misinterpretation of findings. There are three other methodological golden rules that should be followed: 1. Investigate all segments of the VA from V₀ to V₄, as a complete insonation of both extra- and intra-cranial VA segments is strongly advisable, whenever pathology in the posterior circulation is suspected. Studying only the V₂ segment is misleading since it does not allow to recognize moderate stenosis in V₀, V₁ or V₃ nor occlusion/high grade stenosis in V₄. 2. Check for waveform changes along the course of the VA. 3. Check for waveform differences between right and left VA. This will disclose flow abnormalities (direct signs, indirect signs) and clarify selection of subsequent imaging modalities.
A hemodynamically significant (>50%) stenosis, regardless of its nature (e.g. atherosclerosis, dissection), leads to a focal increase of the blood flow velocity. For the vertebro-basilar system, we lack systematic data for classification and quantification of stenoses, but a good estimation can be based on multiple ultrasound findings: focal peak systolic velocity (PSV) increase, activation of collaterals and indirect signs. A moderate stenosis (50-69%) will show a focal PSV increase (>140 cm/s at the origin, or a stenotic/pre-stenotic PSV ratio >2), while a severe stenosis (>70%) will also show indirect hemodynamic signs (pre-stenotic flow signal with a low diastolic velocity and increased preripheral resistance; post-stenotic flow signal with a delayed systolic flow rise and dampened waveform), contralateral VA compensation, activation of cervical collaterals (from external carotid artery and thyrocervical trunk branches).

An occlusion of the vertebro-basilar system is characterized by absent Doppler signal, just like a carotid occlusion. However, if the occlusion is located in the proximal segment of the VA, post-occlusional flow from thyrocervical trunk branches (deep cervical artery) and/or from external carotid artery branches (occipital artery) is a common finding especially in case of contralateral VA hypoplasia.

Ultrasound aids also in the identification of the nature of the obstructive disease: while atherosclerotic plaques are common at \( V_0 \), a typical sign of dissection (i.e. irregular stenosis, thickened hypo- or isoechogetic vessel wall indicating the presence of an intramural hematoma, a double lumen) occurs primarily at \( V_3 \) or \( V_2 \) segments. Another rare but clinically important condition causing stenosis is arteritis; some arterites have specific ultrasound findings: the halo sign of arteritis temporalis (Horton’s arteritis, giant cell arteritis), isoechogetic common carotid thickening
(macaroni sign) and subclavian steal of Takayasu disease (pulseless syndrome). If multiple stenotic lesions are detected in various vertebro-basilar segments in a patient with a sub-arachnoid hemorrhage, vasospasm should be considered. Cerebral vasospasm remains a significant source of morbidity and mortality in patients with subarachnoid hemorrhage after aneurysmal rupture. It can be detected, graded and monitored by transcranial ultrasound. Soustiel’s ratio (mean flow velocity of BA/mean flow velocity of extracranial VA sampled at the first cervical level) is applied for grading vasospasm in the basilar artery. Vasospasm should not be suspected until Soustiel ratio exceeds 2.

Mechanical (“rotational”) obstruction of one vertebral artery during head and neck rotation and extension is frequent and physiological, but very rarely symptomatic because this requires (near) occlusion of the companion vertebral artery as the vertebro-basilar system is quite resistant to critical flow drop as long as systemic blood pressure is in a normal range. When symptomatic, we speak of Bow-Hunter’s syndrome and this is characterized by a significant (>20%) reduction of PSV in the BA and PCA during head turns, accompanied by the onset of symptoms. The symptoms of BHS range from transient vertigo to posterior circulation stroke. The underlying pathology is dynamic stenosis or compression of the VA by abnormal bony structures such as osteophyte, disc herniation, cervical spondylosis, tendinous bands or tumors.

Transcranial ultrasound is the only diagnostic method that can detect clinically silent emboli; this requires continuous monitoring of the major intracranial arteries and according to the current consensus the duration of the monitoring should be at least one hour. MES are robust surrogate markers for increased stroke risk in both symptomatic and asymptomatic
carotid artery stenosis. MES are also valid surrogate markers for verifying antithrombotic efficacy and a key for individualized stroke medicine. However, there are only preliminary studies in posterior circulation stroke patients, in which the detection of MES was associated with severe intracranial vertebrobasilar stenosis and embolic infarction. Moreover, the position of the probe and the insonation through the transfemoral bone window are not suitable for clinical routine.

Right to left shunt (RLS) detection is also a useful ultrasound application in the clinical routine. There are some reports about the predominance of posterior-circulatory infarction in provoked RLS patients which suggests that the Valsalva maneuver may promote RLS and paradoxical embolization to the posterior circulation.

Stroke is a dynamic disease, consequently static neuroimaging studies (CT, MRI) characterize this process only partially; ultrasound monitoring in parallel with clinical evaluation offer invaluable information on the pathophysiology of stroke allowing for tailored treatment. Acute thrombotic or embolic large artery occlusions in the vertebral-basilar system are ideal candidates for fibrinolysis with rtPA (within the 4.5 h time window), or for catheter-based thrombectomies using stent retrievers. Intracranial occlusion can be directly or indirectly detected by ultrasound. Direct criteria for proximal occlusion include no flow signal (TIBI 0) and minimal flow signal (TIBI 1), while blunted flow signal (TIBI 2) and dampened flow signal (TIBI 3) are criteria for distal occlusion. Indirect criteria of intracranial arterial occlusion comprise high resistance in the feeding vessel or in the proximal segment of the occluded vessel, flow diversion and signs of collateralization. Analogously to intracranial occlusion, intracranial stenosis criteria are direct and indirect. Direct criteria include progressive
focal increase of blood flow velocities in $\geq 50\%$ stenosis or paradoxical velocity decrease with very severe stenosis, near-occlusion or diffuse intracranial disease. Indirect criteria are the same as for occlusion: high resistance in the feeding vessel or in the proximal segment of the severely stenotic vessel, flow diversion and signs of collateralization. Therefore, ultrasound monitoring can be used to follow therapeutic effects.

The subclavian steal phenomenon is caused by a stenosis/occlusion of the subclavian artery (SA) proximal to the vertebral artery origin. The degree of the stenosis of the SA correlates with flow changes in the vertebral artery best seen in the V2 segment. A SA stenosis of about 50% leads to an early systolic deceleration of the VA flow followed by a rounded systolic peak. This phenomenon is probably caused by the Venturi effect at the ostium of the VA. A SA stenosis of $>80\%$ leads to an incomplete steal with bidirectional VA waveform. A complete steal with a retrograde flow is found in case of a very high-grade stenosis or occlusion of the SA. Only rarely is a steal phenomenon associated with hemodynamically caused ischemic brain stem symptoms and this is why the steal phenomenon should strictly be separated from the subclavian steal syndrome.

Intracranial arterial blood flow steals can be observed in chronic disease (eg. subclavian artery stenoses, arterio-venous malformations, fistulas), but also in patients with acute ischemic stroke. Flow diversion is the hallmark of a steal and can occur at any level of the intracranial circulation (large proximal vessels, small distal vessels). Flow diversion appears as: 1. a compensatory increase of blood flow velocity in the donor vessel due to recruitment of collaterals by vasodilation in tissues with compromised perfusion. This represents a natural steal by vessels distal to an arterial occlusion; or 2. Flow direction changes during the cardiac
cycle, for example a subclavian steal present at rest or evoked by a hyperemia test; or 3. Paradoxical velocity decrease in the affected vessels and simultaneous velocity increase in normal vessels, in response to vasodilatory stimuli. This represents the “reversed” Robin Hood principle (i.e. rob the poor to feed the rich). Thus, when a pressure gradient favors the normally perfused brain parenchyma, a collateral vessel, which normally acts with a compensatory mechanism delivering sufficient supplies, can become deleterious for the patient by further depriving brain regions at risk of supply.

Ultrasound has also some limitations. Compared to contrast-enhanced MRA and CTA, ultrasound has a lower sensitivity, especially for moderate grade stenosis. The main challenges in detecting, suspecting and differentiating VA lesions are related to the following limitations of current ultrasound testing: 1. only a limited (segmental) assessment of the VA course is attainable and short areas of a stenosis or occlusion can elude direct detection; 2. VAs can have multifocal or elongated lesions that do not produce typical abnormal findings on ultrasound and can mimic benign hypoplasia/atresia; 3. VAs are located deep and ultrasound imaging could be inconclusive while VA origin might simply be unassessable. At the end this justifies a low sensitivity (70%) compared to DSA. However, ultrasound is highly specific (about 98%), and it is a very quick and non-invasive first line approach to imaging the vertebro-basilar system.

Overall Neurosonology of the posterior circulation provides not only imaging, but mainly accurate information on cerebral hemodynamics that can be collected directly at the bed-side of the patient thus representing the ideal modality for following disease progression and therapeutic effects.
References:


