Journal of Neuroradiology (2014) 41, 336—341

Available online at ScienceDirect www.sciencedirect.com

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ORIGINAL ARTICLE

Non-invasive evaluation of proximal vertebral artery stenosis using color Doppler sonography and CT angiography

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Available online 31 December 2013

KEYWORDS
Color Doppler sonography;
CT angiography;
Digital subtraction angiography;
Vertebral artery proximal stenosis;
Non-invasive evaluation

Summary
Background and purpose: A reliable and safe diagnostic procedure for vertebral artery (VA) stenosis is needed, but none is generally accepted yet. In our study, we evaluated symptomatic VA stenoses using color Doppler sonography (CDS). CT angiography (CTA) has been employed as a non-invasive reference method. Next, we tested the accuracy for medium to high degree stenoses by digital subtraction angiography (DSA).
Materials and methods: Sixty-two symptomatic patients with a proximal VA stenosis were examined prospectively with CDS and CTA. The VA diameters by both methods were correlated. The stenotic peak systolic velocity (PSV1) and its ratio to the post-stenotic segment (PSVr) were analysed using receiver operating characteristic curve (ROC). Cut-off values for PSV1 and PSVr defining moderate and severe stenosis were assessed. In stenoses $\geq$ 50%, an additional search for correlation with DSA was carried out.
Results: Mean VA diameter was 3.561 mm (95% CI 3.361—3.760) by CDS and 4.180 (95% CI, 3.950—4.411) by CTA, accompanied with significant similarity in Pearson' correlation (0.847, $P < 0.001$). The PSV1 and PSVr appeared to be equally accurate for VA stenoses of 50% or more (PSV 1—AUC 0.814, $P < 0.001$, cut-off velocity $\geq$ 1.35 m/s, PSVr—AUC 0.819, $P < 0.001$ with a cut-off value $\geq$ 2.2). Final Spearman' correlation of CTA results vs DSA was highly significant (0.823, $P < 0.001$).
Conclusion: Our results endorse the non-invasive combination of CDS with CTA in the evaluation of VA stenosis as a reliable diagnostic algorithm, tightly correlating with DSA.

Abbreviations: AUC, Area under the curve; CI, Confidence interval; CDS, Color Doppler (duplex) sonography; CTA, Computed tomographic angiography; DSA, Digital subtraction angiography; ICA, Internal carotid artery; MRA, Magnetic resonance angiography; PSV, Peak systolic velocity; PSVr, Peak systolic velocity ratio (PSV stenotic/post-stenotic); ROC, Receiver operating characteristic; VA, Vertebral artery.

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http://dx.doi.org/10.1016/j.neurad.2013.11.003

Introduction

Progress in modern non-invasive or minimally invasive diagnostic methods (CDS, CTA and MRA) has improved detection and evaluation of pathological changes in the vertebral arterial system [1,2]. Ischemia in vertebrobasilar circulation, often caused by stenotic processes of vertebral arteries, is considered a severe form of stroke, with a mortality of 20—30% [3]. According to some authors, stenoses of these arteries are responsible for up to one half of ischemic events in their nutritive region [4,5].

The advances of interventional neuroradiology with transluminal angioplasty and stenting opened a new era of relatively safe treatment of atherosclerotic stenoses in brain supplying arteries, especially in the internal carotid artery (ICA) [6,7]. While this territory is documented in large series of patients, only smaller cohorts register high safety and good results of angioplasty also in vertebral arteries. Successful effects (up to only 30% of residual stenosis) are reported in 94—98%, periprocedural complications being only 2% [8—11]. Although there is no general consensus on treatment of the VA stenoses so far, recent recommendations consider interventions in secondary stroke prevention, when optimal conservative treatment did not prevent recurrent clinical symptoms [8]. With the increasing number of centers providing diagnostics and possible interventional treatment, the objective assessment of these lesions should be available. However, due to a relatively small percentage of patients who have an indication for vertebral angioplasty, the diagnostic procedures should be as non-invasive and safe as possible.

Ultrasonographic diagnostics, as a well available screening, is employed often as a first choice method. However, its accuracy depends on individual skill and especially on a well-defined examination procedure and utilized parameters. Some studies report CTA and contrast-enhanced MRA as more sensitive for detection of vertebral stenoses [12], while others show low degree of concordance between CTA or MRA on one side and ultrasonography on the other [13,14]. On the contrary, some singular studies, using ultrasonographic hemodynamic criteria in an exact examination protocol, found the CDS results highly comparable with those of DSA. Therefore, their authors considered CDS to be an accurate procedure in this indication [15,16].

Although DSA is still considered a gold standard with the advantage of enabling an immediate angioplasty, it is accompanied with non-negligible risk and discomfort for the patient. Therefore CTA and contrast-enhanced MRA are routinely used as second reference miniinvasive methods.

The aim of this study was to test the usefulness and accuracy of the non-invasive combination of CDS and CTA, attempting in this way to restrict DSA only for final proof of high grade stenoses. In contrast to studies, operating with rather discrepant cut-off values of CDS findings compared to DSA, our intention was to select procedures more suitable for routine screening, thus avoiding DSA as much as possible. First, we compared directly a precise ultrasonographic scanning procedure in patients with ischemic stroke or TIA, harbouring stenotic initial VA segments, with their findings on CTA. We assessed the CDS sensitivity and specificity in evaluation of stenoses over 50%, searching for ''non-invasive'' cut-off values. In the second step, positive non-invasive results were further validated by comparison with DSA.

Materials and methods

Among patients presenting with either transitory or persisting symptoms of vertebrobasilar ischemia examined in our neurosonological laboratory in the period 2006—2010, sixty-two persons (average age 66.79 years, age range 45—84 years, 42 males), suspected as having a proximal significant atherosclerotic VA lesion (based on CDS screening), were enrolled in the study. Exclusion criteria covered all hemodynamically significant lesions, which could influence the blood flow in the evaluated vertebral artery: an ICA occlusion or stenosis $\geq$ 70%, coexisting occlusion or $\geq$ 70% stenosis of the contralateral VA, of the vertebrobasilar junction or basilar artery, stenosis of subclavian artery causing a steal syndrome, atrial fibrillation and a severe circulatory insufficiency. Hypoplastic VA and coexisting mild to moderate stenoses that did not cause collateral flow changes were not considered as exclusion criteria. All study subjects were informed about all intended examinations as well as collected data and signed an informed consent form for the protocol approved by the local IRB. All included persons were examined prospectively by CDS and CTA within an interval of less than 14 days. Finally, DSA was performed only in patients with suspected $\geq$ 50% VA stenosis, based on CDS and CTA, in order to prove the diagnosis. Due to ethical reasons, other patients were not exposed to this invasive procedure.

Ultrasonography

Ultrasonography (CDS) was performed on Toshiba Core-Vision Pro and Toshiba Nemio equipment (Toshiba Medical Systems Corp., Tochigi—Ken, Japan) with a linear array, multi-frequency transducer (5—10 MHz), as needed with an additional convex transducer (3.5—6.0 MHz) for imaging of the vertebral origin and phased array transducer (transcranial 2.0—3.5 MHz) for insonation of the distal vertebrobasilar region from suboccipital approach. During all examinations, the prevertebral part of the subclavian artery and the VA origin (V0) were detected using a combination of approaches and planes of imaging. Next, both the V1 and V2 segments were examined in B-mode, color Doppler and pulsed-wave Doppler mode. Hemodynamics were defined by peak systolic velocity (PSV), end-diastolic velocity (EDV), time-averaged (mean) velocity (Vmean) and the index of pulsatility (PI). Attention was paid to the angle of insonation [17—19]. Maximum velocities (jet) were detected at each stenotic VA proximal segment (assessment of PSV1, stenotic). Next, the post-stenotic blood flow velocities (PSV2) were measured in the distal V1 segment, namely 15 mm below the transverse process of C6, where the arterial lumen diameter in the diastolic phase was also assessed. We measured the diameter between the lumen-intima reflections of the anterior and posterior walls, without the color Doppler image. This site of reference, used earlier [1] and described in detail by us, was preferred over measurements in the intervertebral segment V2, in order to obtain a better positioning of the