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Original Article

Diagnostic performance of different perfusion algorithms for the detection of angiographical spasm

Saif Afat[a], Carolin Brockmann[b], Omid Nikoubashman[a,c], Marguerite Müller[a], Kolja M. Thierfelder[d], Wolfgang G. Kunz[d], Ulrike Haberland[e], Marc A. Brockmann[b], Konstantin Nikolaou[f], Martin Wiesmann[a], Ahmed E. Othman[a,e,*]

[a] *Department of Diagnostic and Interventional Neuroradiology, RWTH Aachen University, 52074 Aachen, Germany*
[b] *Department of Neuroradiology, University Hospital Mainz, 55131 Mainz, Germany*
[c] *Department of Diagnostic and Interventional Radiology, RWTH Aachen University, 52074 Aachen, Germany*
[d] *Institute for Clinical Radiology, Ludwig-Maximilians-University Hospital Munich, Marchioninistr. 15, 81377 Munich, Germany*
[e] *Siemens Healthcare GmbH, Forchheim, Germany*
[f] *Department for Diagnostic and Interventional Radiology, Eberhard Karls University Tuebingen, University Hospital Tuebingen, 72076 Tübingen, Germany*

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ABSTRACT

Purpose. – To assess the diagnostic utility of different perfusion algorithms for the detection of angiographical terial spasm.

Method. – During a 2-year period, 45 datasets from 29 patients (54.2 ± 10,75 y, 20 F) with suspected cerebral vasospasm after aneurysmal subarachnoid hemorrhage were included. Volume Perfusion CT (VPCT), Non-enhanced CT (NCT) and angiography were performed within 6 hours post-ictus. Perfusion maps were generated using a maximum slope (MS) and a deconvolution-based approach (DC). Two blinded neuroradiologists independently evaluated MS and DC maps regarding vasospasm-related perfusion impairment on a 3-point Likert-scale (0 = no impairment, 1 = impairment affecting < 50%, 2 = impairment affecting > 50% of vascular territory). A third independent neuroradiologist assessed angiography for presence and severity of arterial narrowing on a 3-point Likert scale (0 = no narrowing, 1 = narrowing affecting < 50%, 2 = narrowing affecting > 50% of artery diameter). MS and DC perfusion maps were evaluated regarding diagnostic accuracy for angiographical arterial spasm with angiography as reference standard. Correlation analysis of angiography findings with both MS and DC perfusion maps was additionally performed. Furthermor, the agreement between MS and DC and inter-reader agreement was assessed.

Results. – DC maps yielded significantly higher diagnostic accuracy than MS perfusion maps (DC:*AUC* = .870; MS:*AUC* = .805; *P* = 0.007) with higher sensitivity for DC compared to MS (DC:sensitivity = .758; MS:sensitivity=.625). DC maps revealed stronger correlation with angiography than MS (DC: *R* = .788; MS: *R* = 694; = < 0.001). MS and DC showed substantial agreement (*Kappa* = .626). Regarding inter-reader analysis, (almost) perfect inter-reader agreement was observed for both MS and DC maps (*Kappa* ≥ 981).

Conclusion. – DC yields significantly higher diagnostic accuracy for the detection of angiographic arterial spasm and higher correlation with angiographic findings compared to MS.

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Introduction

Both surgical and interventional treatment options of ruptured intracranial aneurysms are associated with high rates of success in general [1,2]. Cerebral vasospasm, however, occurs quite frequently in patients with ruptured intracranial aneurysm and therefore constitutes a major prognostic factor [3]. Due to delayed cerebral ischemia (DCI), which vasospasm is usually associated with major neurological and cognitive disabilities can be serious consequences [4,5]. Cerebral vasospasm usually occurs between the 4th and 12th

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Abbreviations: ACA, Anterior cerebral artery; AUC, Areas Under the Curve; CBF, cerebral blood flow; CBV, cerebral blood volume; DC, Deconvolution model; DCI, delayed cerebral ischemia; MCA, middle cerebral artery; MS, maximum slope model; MTT, mean transit time; CT N, CT non-contrast; ROC-, Receiver-Operator-Characteristics-; TTD, time-to-drain; TTP, time-to-peak; VPCT, Volume Perfusion CT.

* Corresponding author. Department of diagnostic and interventional radiology, University Hospital Tuebingen, Hoppe-Seyler-Straße 3, 72076 Tuebingen, Germany.
E-mail address: ahmed.e.othman@googlemail.com (A.E. Othman).

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day after subarachnoid hemorrhage. Clinical signs of vasospasm include deterioration of consciousness and oftentimes focal neurological deficits [6]. In order to minimize complications and thereby improve patient outcome, an early detection of vasospasm is crucial. Patients with subarachnoid hemorrhage are usually under intensive clinical monitoring with frequent neurological examinations. However, due to the sedated or unconscious condition of many patients with vasospasms, neurological examination can be difficult and inconclusive. Therefore, further diagnostic tools such as transcranial doppler ultrasound [7] and Volume Perfusion CT (VPCT) are commonly performed for monitoring of patients with subarachnoid hemorrhage [8–11]. Despite the high radiation dose [12], VPCT is a sufficient tool for assessment of cerebral vasospasm and it is recommended in the current guidelines [13,14]. There are different algorithms for post-processing of VPCT images. The majority of the commercially available perfusion packages use either a maximum slope (MS) or a deconvolution (DC) based-approach. Temporal perfusion maps have been shown to be most sensitive for cerebral vasospasms [15,16]. For instance, previous studies have shown that mean transit time (MTT) and time to drain (TTD) maps show highest diagnostic accuracy compared to cerebral blood flow (CBF) and cerebral blood volume (CBV) maps [16–19]. Since MTT maps can only be calculated using the DC based-approach, it could be assumed that DC is superior to the MS model, which is unable to calculate MTT maps. The MS model, however, calculates the temporal map time to peak (TTP), which has also been shown to be sensitive for vasospasms [11]. To date, the question which post-processing algorithm (MS or DC) is more sensitive for cerebral vasospasms is unanswered. Therefore, in this study we aimed to compare both algorithms regarding the diagnostic accuracy for the detection of angiographical arterial spasm. Based on our observation in clinical routine, we hypothesize that DC is more sensitive than MS for the detection of vasospasms.

Methods and materials

Patient characteristics

This retrospective study was approved by the local institutional board, which waived requirement for informed patient consent. We searched our prospectively maintained database for patients presenting with aneurysmal subarachnoid hemorrhage between 2015 and 2016. Patients were included if they met the following criteria:

- suspected cerebral vasospasm;
- available non-contrast CT (NCT) images, VPCT images and 3-vessel or 4-vessel cerebral angiography, all acquired within 6 hours;
- available follow-up NCT > 24 h post ictus;
- available clinical data at admission and at discharge. Patients were excluded if NCT, VPCT or angiography images were non-diagnostic.

Image acquisition

All NCT and VPCT data were acquired using a clinical CT scanner (40-slice, Siemens Somatom AS, Siemens Healthineers, Erlangen, Germany).

NCT images were acquired with the following acquisition parameters: tube-current-time product = 385 mAs, tube voltage = 120 kVp.

VPCT data were acquired with 40 ml intravenous contrast bolus injection at a flow rate of 5.0 ml/s followed by a saline flush (scan length = 84.0 mm, tube voltage = 80 kV, tube-current-time product = 180 mAs, acquisition time = 45 s, temporal sampling = 1.5 s, slice thickness = 10.0 mm).

Image post processing

Perfusion images (source data) were post-processed using a commercial perfusion package (VPCT-Neuro, Siemens AG Healthcare, Erlangen, Germany). Perfusion maps were generated using both MS and DC algorithms. Using MS, the perfusion maps CBV, CBF and TTP were generated; using DC, the maps CBV, CBF, MTT and TTD were generated. In both cases, motion correction and 4D noise reduction options were applied as provided by the perfusion software. HU-based semi-automatic segmentation of the brain tissue was performed. The arterial input function was set in the anterior cerebral artery (ACA) and the venous outflow in the superior sagittal sinus. Relative thresholding was applied to remove major vessels (10% of max. enhancement in the superior sagittal sinus).

Image evaluation

Perfusion maps and NCT

Perfusion maps derived from MS and DC were evaluated regarding the presence of perfusion abnormalities indicating vasospasm by two blinded independent neuroradiologists (AO and SA, four years and two years experience in diagnostic neuroradiology, respectively).

Each vessel segment on angiography was assigned to a vascular territory on VPCT, according to Wintermark et al. [16]: A1 was assigned to the inferior slab of the ACA, A2 and the distal ACA were assigned to the superior slab of the ACA. M1 was assigned to the deep MCA, M2 to the inferior slab of the MCA and distal MCA to the superior slab of the MCA. P1 was assigned to the thalamus and the distal PCA was assigned to the PCA.

The above-mentioned vascular territories were assessed for perfusion impairment indicating vasospasm on a 3-point Likert scale (0 = no impairment, 1 = impairment affecting < 50% of the vascular territory, 2 = impairment affecting > 50% of the vascular territory).

Both neuroradiologists evaluated the same territories mentioned above on NCT images in consensus for cerebral infarction. Territories, which were positive for cerebral infarction on NCT were excluded (Fig. 1).

Cerebral angiography

A third neuroradiologist (CB; experience: 10 years diagnostic neuroradiology and 5 years interventional neuroradiology) evaluated the corresponding intracranial vessels (16 vascular segments) on cerebral angiography series for angiographic arterial spasm on a 3-point Likert scale (0 = no spasm, 1 = spasm affecting < 50% of vessel diameter, 2 = spasm affecting > 50% of vessel diameter) as described before by Wintermark et al. [16].

Statistical analyses

SPSS, version 22 was used for statistical analyses. Receiver-Operator-Characteristics- (ROC-) analysis was performed to assess diagnostic accuracy of MS and DC for the detection of angiographic arterial spasm with cerebral angiography as standard of reference. Diagnostic accuracy, sensitivity and specificity were calculated for all extents of angiographic arterial spasm. Therefore, each vessel segment on angiography was assigned to the corresponding territory on perfusion maps as described by Wintermark et al. [16]. In a separate step, diagnostic accuracy, sensitivity and specificity were calculated only for severe angiographic spasm (> 50% of arterial diameter). Furthermore, Spearman's correlation coefficients were calculated for the angiography, MS and DC maps. Comparison of the Spearman's correlation coefficients was performed using the Fisher

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