Computed Tomography Perfusion Deficits during the Baseline Period in Aneurysmal Subarachnoid Hemorrhage Are Predictive of Delayed Cerebral Ischemia

Yuxia Duan, MD,* Haoli Xu, MD,* Rui Li, MD,* Kuikui Zheng, MD,* Zilong Hu, MD,* Nan Wu, MD,† Yunjun Yang, MD,* Qichuan Zhuge, MD,‡ and Weijian Chen, MD*

Background and Purpose: Delayed cerebral ischemia (DCI) is a frequent and fearful complication following aneurysmal subarachnoid hemorrhage (aSAH). The aim of this study is to assess the diagnostic accuracy of computed tomography perfusion (CTP) during an admission baseline period for the prediction of DCI. *Methods:* Fifty-four aSAH cases were screened by baseline CTP within 3 days after aSAH and were reexamined with CTP 7-17 days after aSAH. Relative cerebral blood volume, relative cerebral blood flow (CBF), and relative mean transit time were measured. DCI was confirmed by a combination of noncontrast CT, CTP reexamination, and clinical assessment of neurologic deficits. Quantitative baseline and reexamination CTP data for all patients were compared between DCI and without DCI groups using Student's *t*-tests. The quantitative baseline and reexamination CTP data of DCI patients were compared using paired Student's *t*-tests. The χ^2 test was used to evaluate incidences of DCI between different baseline relative CBF levels. The optimal cutoff value for each parameter was established by receiver operating characteristic curve analysis. *Results:* Of the patients included in this study, 33.3% (18 of 54) developed DCI. There was a significant difference in the incidence of DCI among different baseline relative CBF subsets ($\chi^2 = 38.00$, $P < .05$). A relative CBF of .84 had the highest specificity and sensitivity of predicting DCI. *Conclusion:* CTP parameters during the baseline period can be helpful for the early identification of aSAH patients who are at high risk for DCI. **Key Words:** Aneurysm—subarachnoid hemorrhage—perfusion—cerebral ischemia.

From the *Department of Radiology, Zhejiang Provincial Key Laboratory of Aging and Neurological Disorder Research, The First Affiliated Hospital of Wenzhou Medical University, Wenzhou, Zhejiang, China; †Department of Radiology, Shandong Provincial Qianfoshan Hospital, No.16766, Jingshi Street, Jinan, Shandong, 250014, China; and ‡Department of Neurosurgery, Zhejiang Provincial Key Laboratory of Aging and Neurological Disorder Research, The First Affiliated Hospital of Wenzhou Medical University, Wenzhou, Zhejiang, China.

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Yuxia Duan and Nan Wu contributed equally to this work.

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Address correspondence to Weijian Chen, MD, Department of Radiology, The First Affiliated Hospital of Wenzhou Medical University, Nanbaixiang Street, Ouhai District, Wenzhou, Zhejiang 325000, China. E-mail: wyyycwj@163.com.

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Introduction

Delayed cerebral ischemia (DCI) is a serious complication that frequently follows aneurysmal subarachnoid hemorrhage (aSAH) and leads to poor functional outcomes.[1] Clinically, DCI is usually defined as a new ischemic lesion detected by imaging examinations, a gradual decrease in consciousness, or unexplained neurologic deterioration. A number of causes can contribute to such deterioration, for example aneurysm rebleeding, hydrocephalus, infections, pulmonary edema, and metabolic disturbances, which makes the diagnosis of DCI difficult.[2] Thus, identification of ischemic lesions by follow-up imaging examinations is the appropriate method for confirmation.

It is widely agreed that the main preceding factor of DCI is vasospasm, which may demonstrate early alterations in cerebral perfusion,[3] although the pathophysiology of DCI is still not clearly understood. However, many patients develop DCI without vasospasm.[2,4] It is important to diagnose DCI with an examination investigating cerebral ischemia rather than vasospasm.[5] Computed tomography perfusion (CTP) provides important and sufficient hemodynamic information on the status of the brain, and it has been suggested that decreased cerebral blood flow (CBF) and prolonged mean transit time (MTT) that occur between 4 and 14 days after aSAH are related to DCI.[5] Most scholars have suggested that CBF decreased progressively after aSAH, which results from vasospasm in both large and micro vessels.[6]

Patients at high risk for DCI might be identified at an early period, and effective treatment could be taken to improve their prognosis and prevent complications such as neurologic deficits and infarction. Some researchers have attempted to find predictors by CTP. Pham[7] found that time to peak derived from CTP is also a sensitive and early predictor of DCI, and some studies showed that CBF seems the best prognosticator for the development of DCI.[8] It remains unclear which parameter of baseline cerebral perfusion is of best value in predicting DCI. The purpose of this study is to assess the diagnostic accuracy of CTP during an admission baseline period, defined as days 0-3 following aSAH, for the prediction of DCI and to find out which parameter is the best.

Materials and Methods

Clinical Materials

Fifty-four patients with aSAH, from August 2011 to September 2012, were screened by baseline CTP within 2 hours to 3 days after aSAH at our institution. Reexamination CTP was performed according to the protocol of the research center for delayed ischemic neurologic deficits 7-17 days after aSAH. The following were the inclusion criteria: (1) ≥18 years of age; (2) with aSAH located around the circle of Willis or lateral fissure; and (3) admitted within 72 hours after aSAH. The following were the exclusion criteria: (1) with cardiac or renal function failure; (2) with trauma or serious artery disease, cerebrovascular malformation, or a preexisting neurologic deficit; (3) pregnant; or (4) with allergic history to contrast material. Fifty-four patients meeting the above conditions were studied. The age of patients ranged from 34 to 79 years, and the mean age was 57 years. Twenty patients were male and 34 patients were female. Forty-five patients underwent coil embolization, six patients were treated through microsurgical clipping, and three patients were under conservative treatment. All patients underwent angiography and received nimodipine intravenously via a micropump at the rate of 2 mL/h during hospitalization. Clinical features of the patients were acquired by clinical assessment of neurologic deficits. Our study was approved by our institutional review board.

CT Examination

All images were performed using a LightSpeed Plus 16 section clinical CT scanner (GE Healthcare, Waukesha, WI). Image acquisition parameters were as follows:

1) Noncontrast CT (NCCT) transaxial CT of the whole brain (section thickness of 5 mm, no overlap, slices parallel to orbitomeatal line, 80 kVp, 120 mAs)
2) Dynamic CTP imaging (50 seconds of constant scanning at the level of basal ganglia, 4 mm × 5 mm slices, no overlap, 80 kVp, 200 mAs) and contrast medium Omnipaque administration 50 mL, delay of 7 seconds, bolus 4.0 mL/s

Picture Postprocessing and Parameter Collection

CTP data were transferred to a postprocessing workstation (CTP 3, ADW 4.2; GE Healthcare). Cerebral blood volume (CBV), MTT, and CBF were calculated with the software using time–density curves. Time–density curves based on the passage of the contrast agent through the anterior cerebral artery and the superior sagittal sinus yielded the arterial input function and the venous output function, respectively. CBF, CBV, and MTT maps were analyzed for qualitative perfusion deficits. Qualitative analysis was finished by two neuroradiologists independently of each other, and a concurrence was reached finally to determine the presence of qualitative perfusion deficits, defined as areas of CBF reduction, MTT prolongation, and CBV reduction separate from subarachnoid hemorrhage itself or surgical intervention. Quantitative analysis was conducted using a standardized method of region of interest (ROI) placement on and measuring of two slices (levels of basal ganglia). The two slices closest to the baseline CTP scan were matched to two corresponding slices at the same level on CTP reexamination. On each slice, eight ROIs, including the territory of anterior cerebral artery, the territory of posterior cerebral artery, the basal ganglia, the anterior watershed, and the posterior watershed in