MEDICAL SCIENCE MONITOR

CLINICAL RESEARCH

e-ISSN 1643-3750
© Med Sci Monit, 2019; 25: 9067-9072
DOI: 10.12659/MSM.917995

Received: 2019.06.09
Accepted: 2019.08.19
Published: 2019.11.29

Computed Tomography Perfusion Imaging Quality Affected by Different Input Arteries in Patients of Internal Carotid Artery Stenosis

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

BC 1 **Xugao Chen**
DE 1 **Jianxun Zou**
CF 1 **Lijuan Bao**
BC 2 **Jinge Hu**
AG 1 **Guowei Ye**

1 Department of Radiology, The People's Hospital of Lishui, Lishui, Zhejiang, P.R. China
2 Department of Public Health, Community Health Centre of Shuidong Community, Lishui, Zhejiang, P.R. China

Corresponding Author: Guowei Ye, e-mail: ygw777777@163.com
Source of support: Zhejiang Medical and Health Science and Technology Project (2019KY803)

Background: The aim of this study was to explore the influence of different input arteries on the parameters of computed tomography (CT) perfusion imaging for patients with different degree of stenosis of internal carotid artery (ICA).

Material/Methods: Forty patients were enrolled in the present study and divided into mild, moderate, severe stenosis and occlusion groups respectively with each 10 patients in each group. In reconstruction of cerebral CT perfusion (CTP) images, each raw perfusion image was reconstructed 3 times based on different reference input artery, including bilateral middle cerebral artery (MCA) and basilar arteries (BA). Region of interest (ROI) was drawn in the central territories of bilateral anterior cerebral artery, middle cerebral artery and posterior cerebral artery. And regional cerebral blood flow (rCBF) regional cerebral blood volume (rCBV), mean transit time (MTT), time to peak (TTP) and delay time (DT) were obtained from those ROI corresponding perfusion images.

Results: In patients with mild and moderate ICA stenosis, there was no significant difference of perfusion parameters based on different input arteries (*P*>0.05). However, in severe ICA stenosis and occlusion CBF, MTT, and DT were significant different in affect side of the MCA group compared to the others (*P*<0.05).

Conclusions: Large intracranial artery can be selected as the input artery for patients with mild to moderate ICA stenosis, while for patients with severe stenosis and occlusion of ICA, the contra lateral middle cerebral artery or basilar artery would be better choice.

MeSH Keywords: **Carotid Stenosis • Diagnosis • Tomography Scanners, X-Ray Computed**

Full-text PDF: https://www.medscimonit.com/abstract/index/idArt/917995

1602 3 2 24

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System] [ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica] [Chemical Abstracts/CAS]

Background

Stenosis or occlusion of internal carotid artery (ICA) is an important cause of chronic cerebral ischemia [1–4]. The degree of ICA stenosis is closely related to the changes of cerebral hemodynamics [5–8]. Computed tomography perfusion (CTP) combined with CT angiography (CTA) can comprehensively evaluate the condition of cerebral and cervical vessels and the changes of cerebral hemodynamics [9,10]. In the post-processing of CTP images, it is necessary to select an input artery as a reference to determine the start time of the first circulation, and then analyze the cerebral parenchyma blood perfusion. Study have shown that [11] intracranial display of good arbitrary artery as the input artery, does not affect the results of perfusion. However, another study [12] also indicated that the selection of different input arteries will have an impact on partial perfusion parameters. Therefore, how to select the input artery to ensure the accuracy of perfusion parameters is still worth discussing. The purpose of this study was to investigate the effect of different input arteries on the parameters of cerebral perfusion in patients with ICA stenosis in different degrees, and to provide practical basis for reasonable selection of input arteries in these patients.

Material and Methods

Patients inclusion

Forty consecutive patients (18 males, 45%) aged 41 to 85 years old with an average age of 67.56±16.36 years who were diagnosed as chronic cerebral ischemia and were examined by craniocerebral CTP combined with head and neck CTA in our hospital were enrolled. CTA confirmed ICA as mild, moderate, or severe stenosis and occlusion in 10 patients. All cases were unilateral carotid artery stenosis and excluded patients with obvious intracranial or vertebral artery stenosis. All the patients provided written informed consent. The study was approved by the Medical Ethics Committee of the Six Affiliated Hospital of Wen Zhou Medical University.

Scanning method

Toshiba Aqulilion One 320 row volume CT was used for whole brain perfusion scanning. Low dose scanning parameters (80 kV, 150–300 mA) were selected. The current of CTA tube in arterial phase was 300 mA, and the rest were 150 mA. The scan was delayed for 7 seconds after injection. The arterial interval was 2 seconds and the venous interval was 5 seconds. The total scan time was about 60 seconds. The whole brain dynamic volume data of 19 phases were obtained. All images were volume scanned. The rotation time of the tube was 0.5 seconds, the thickness of the tube was 0.5 mm, and the coverage was 16 cm. After completing brain CTP, neck CTA scan from the aortic arch to the skull base was added to obtain the image of the carotid artery.

Image processing

The data were imported into a special software package for image post-processing. Three groups of input arteries, M1 segment of left and right middle cerebral artery and basilar artery were selected by manual single-point sampling. The superior sagittal sinus was chosen as the output vein. Singular value decomposition was used to generate cerebral flow (CBF), cerebral volume (CBV), mean transit time (MTT), peak time (TTP) and delayed time (DT) and other parameters. Regions of interest (ROI) was mapped in bilateral anterior, middle and posterior cerebral artery blood supply areas and abnormal perfusion centers by mirror technique. Six circular regions of interest (ROI) with a diameter of 2.0 cm were placed symmetrically on the midline of the brain to measure the perfusion values of the corresponding areas. When ROI was measured and analyzed, 3 groups of ROI were measured at the same level, while avoiding large vessels and calcification. Each ROI was measured at least twice, and the average perfusion value of each ROI was taken as the perfusion parameter value of the side.

CTA evaluation of cervical vessels

The CTA data of the neck was transmitted to the workstation for surface reconstruction, maximum density projection display and measurement of the narrow segment. According to the experimental standard of symptomatic carotid endarterectomy in North America [13], mild stenosis was 0% to 29%, moderate stenosis was 30% to 69%, severe stenosis was 70% to 99%, and complete occlusion was 100% (Figure 1). The stenosis rate was calculated to be (1-the area of the most narrow end lumen/the area of the distal normal diameter)×100%.

Statistical analysis

SPSSl7.0 (SPSS, Inc., Chicago, IL, USA) statistical software was used for data analysis. The measurement data are expressed as ($\bar{\chi}$±s). Firstly, the data are analyzed by normality test and homogeneity test of variance, which conform to the normality and homogeneity of variance. The comparison among groups is conducted by one-way ANOVA. Non-parametric test was used for non-conformity to normality or homogeneity of variance, with $P<0.05$ as the significant difference.

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System] [ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica] [Chemical Abstracts/CAS]

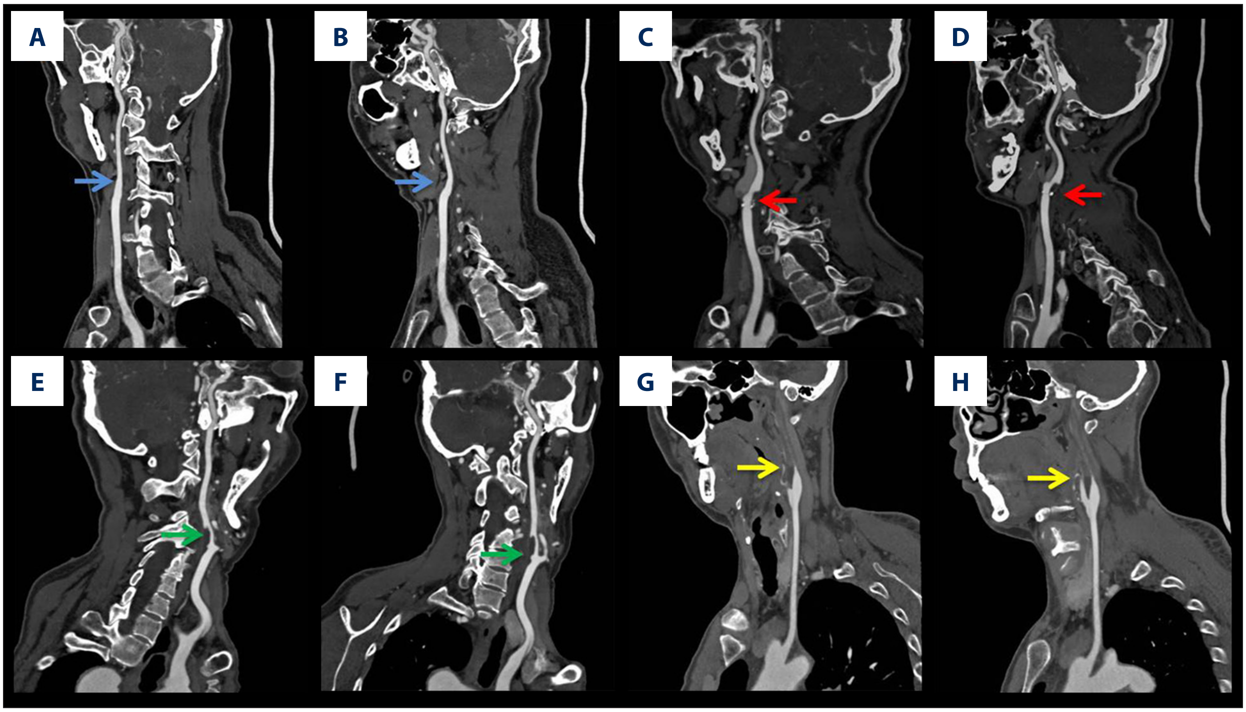

Figure 1. Computed tomography angiography evaluation of cervical vessels. (**A, B**) Mild stenosis was 0% to 29% (blue arrow). (**C, D**) Moderate stenosis was 30% to 69% (red arrow). (**E, F**) Severe stenosis was 70% to 99% (green arrow). (**G, H**) Complete occlusion was 100% (yellow arrow).

Table 1. CTP parameters in mild and moderate groups between different input artery.

Groups	CBF (mL/100 g·min)		CBV (mL/100 g)		MTT (s)		TTP (s)		DT (s)	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
BA	28.01±6.33	26.79±5.23	2.01±1.33	2.42±1.15	4.00±1.30	4.42±1.55	16.34±1.34	16.42±1.15	1.34±0.34	1.42±0.15
MCA intact side	28.23±6.15	27.02±6.15	2.42±1.15	2.42±1.85	4.42±1.15	4.32±1.51	17.42±1.15	16.42±1.16	1.42±0.75	1.42±065
MCA affected side	29.02±7.33	28.09±7.53	2.49±1.55	2.32±1.19	4.42±1.26	4.47±1.15	16.42±1.15	17.42±1.35	1.42±0.95	1.42±0.59
F	0.33	0.37	0.12	0.10	0.12	0.13	0.32	0.33	0.13	<0.001
P	0.80	0.76	0.92	0.94	0.92	0.90	0.81	0.80	0.90	1.00

CTP – computed tomography perfusion; CBF – cerebral blood flow; CBV – cerebral blood volume; MTT – mean transit time; TTP – time to peak; DT – delay time; BA – basilar arteries; MCA – middle cerebral artery.

Results

CTP parameters in mild and moderate groups between different input artery

In patients with mild and moderate ICA stenosis, there was no significant difference of CT perfusion parameters based on different input arteries ($P>0.05$) (Table 1).

CTP parameters in severe and occlusion groups between different input artery

In patients with severe ICA stenosis and occlusion, MCA and BA on the normal side of ICA were selected as the input arteries and the perfusion parameters were not statistical difference ($P>0.05$). However, CBF, MTT, and DT were significant different in affect side of the MCA group compared the other 2 groups ($P<0.05$) (Figure 2). However, there was no significant difference of CBV and TTP between different groups ($P>0.05$) (Tables 2, 3).

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System] [ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica] [Chemical Abstracts/CAS]

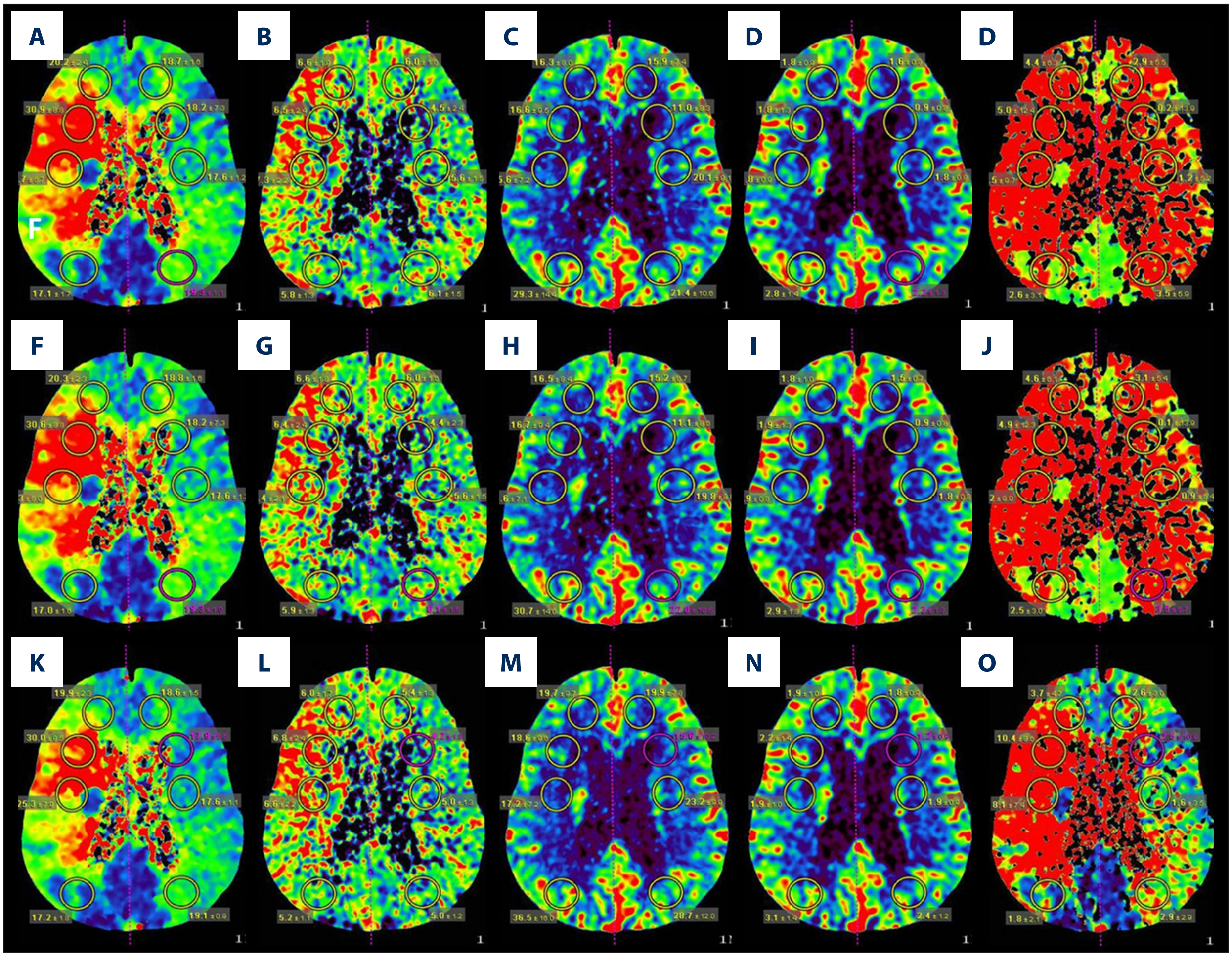

Figure 2. Male, 65-years-old, with severe stenosis of the lumen at the beginning of ICA on the right side. The perfusion maps of MCA and BA on the contralateral side were obtained. The perfusion parameters of each artery supplying area and abnormal perfusion area were similar (**A–J**). The perfusion maps of MCA on the affected side were different from those of the former 2 groups, CBF, MTT, and DT had no significant changes in CBV and TTP (**K–O**). ICA – internal carotid artery; MCA – middle cerebral artery; BA – basilar arteries; CBF – cerebral blood flow; MTT – mean transit time; DT – delay time; CBV – cerebral blood volume; TTP – time to peak.

Discussion

Craniocerebral CTP scans the selected area dynamically in the same layer after bolus injection of contrast medium to obtain the time-density curve (TDC) of each pixel [9,14,15]. Then different mathematical models were applied to calculate the perfusion parameters and to evaluate the perfusion of brain tissue. There are 2 computational methods for CTP imaging: non-deconvolution and deconvolution [16]. Non-deconvolution model is based on the assumption that the venous outflow can be neglected in the first-pass state of contrast medium, and enhanced TDC can be obtained without extravasation of contrast medium. The deconvolution model is relatively independent and is not limited by the assumption of organ hemodynamics, which improves the accuracy of measurement [17–19]. In different studies, the applied mathematical models, perfusion parameters and imaging schemes are also different, which leads to the lack of strict comparability among researchers [20].

The singular value decomposition plus deconvolution algorithm is used in 320 row CT, which is a further improvement of the deconvolution algorithm [21]. The thickness of the original layer is the thinnest to 0.5 mm, and the detector covers 16 cm. The perfusion range of the brain develops from local to whole brain. Zhaoqian et al. [22] evaluate the influence of different input arteries on cerebral perfusion parameters in 320-row whole brain CTP image post-processing. However, in patients with chronic cerebral ischemia, it is not known whether the selection of the ipsilateral MCA as the input artery after stenosis of the carotid artery and ICA will affect the perfusion results.

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System] [ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica] [Chemical Abstracts/CAS]

Table 2. CTP parameters in severe and occlusion groups between different input artery.

Groups	CBF (mL/100 g·min)		CBV (mL/100 g)		TTP (s)		MTT (s)		DT (s)	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
BA	27.01±9.33	26.70±7.29	2.81±1.03	2.42±1.75	4.60±1.50	4.72±1.35	17.34±1.38	16.92±1.05	1.94±0.34	1.82±0.75
MCA intact side	28.93±8.15	27.82±6.95	2.42±1.15	2.52±1.65	4.32±1.65	4.32±1.59	17.92±1.75	17.42±1.76	1.82±0.85	1.79±0.45
MCA affected side	24.82±7.83	23.69±7.03	2.79±1.35	2.32±1.24	5.61±1.86	5.48±1.95	18.22±1.55	17.82±1.65	1.02±0.95	0.82±0.54
F	3.38	3.07	0.17	0.39	4.35	4.13	0.38	0.42	5.13	5.68
P	0.002	0.003	0.90	0.77	0.000	0.001	0.78	0.71	0.000	0.000

CTP – computed tomography perfusion; CBF – cerebral blood flow; CBV – cerebral blood volume; MTT – mean transit time; TTP – time to peak; DT – delay time; BA – basilar arteries; MCA – middle cerebral artery.

Table 3. Comparison of post-processing perfusion values of different input arteries in abnormal perfusion area of severe stenosis and occlusion groups.

Groups	CBF (mL/100 g·min)		CBV (mL/100 g)		MTT (s)		TTP (s)		DT (s)	
	Affected side	Intact side	Affected side	Intact side	Affected side	Intact side	Affected side	Intact side	Affected side	Intact side
BA	21.41±7.03	26.79±6.09	1.98±1.73	2.12±1.85	5.60±1.57	4.12±1.75	21.34±2.38	17.92±2.75	1.14±0.31	1.32±0.53
MCA intact side	22.97±8.65	26.92±6.75	1.82±1.15	2.03±1.67	5.32±1.65	4.39±1.59	20.92±2.75	17.92±2.27	1.22±0.75	1.59±0.48
MCA affected side	17.87±6.83	22.69±6.63	2.09±1.61	2.32±1.28	7.91±1.86	5.48±2.15	25.22±2.59	20.89±2.05	0.12±0.25	0.92±0.24
F	5.32	3.37	0.36	0.43	4.93	4.13	3.38	2.62	6.93	4.62
P	0.000	0.001	0.79	0.70	0.000	0.000	0.001	0.003	0.000	0.000

CTP – computed tomography perfusion; CBF – cerebral blood flow; CBV – cerebral blood volume; MTT – mean transit time; TTP – time to peak; DT – delay time; BA – basilar arteries; MCA – middle cerebral artery.

In this study, MCA and BA on both sides were selected as input reference arteries for patients with different degrees of ICA stenosis, and superior sagittal sinus was used for both output veins. In 20 patients with unilateral ICA mild to moderate stenosis, there was no significant difference in perfusion parameters obtained by different input arteries among the three groups. The results are consistent with those reported by Zhaoqian et al. [22]. Considering that mild and moderate ICA stenosis may have less effect on hemodynamics, the effect of different input arteries on perfusion parameters is not obvious. However, this study found that for patients with severe ICA stenosis and occlusion, the perfusion parameters obtained by different input arteries in the 3 groups were significantly different. The results showed that MCA on the affected side had significant effects on CBF, MTT, and DT when it was used as the input artery. The results were similar to those reported by Wintermark et al. [23], but had no significant effects on CBV and TTP. The reason may be that the blood flow velocity and vascular permeability of the involved artery stenosis are different from those of the non-involved artery, resulting in the difference of CBF, MTT, and DT.

However, in this study, there were 3 cases of severe stenosis and 1 case of occlusion with no significant difference in post-processing perfusion parameters, and no abnormal changes in cerebral blood flow perfusion images. When stenosis occurs in head and neck vessels, CTP manifestations are related to the degree of stenosis and collateral opening [24]. When stenosis or occlusion occurs, the regulation mechanism of cerebrovascular activation makes the distal stenosis compensatory dilatation and collateral vessels open, such as anterior and posterior communicating arteries, in order to maintain the cerebral blood flow at a relatively normal level. In this study, 4 patients with severe unilateral ICA stenosis and occlusion were studied.

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System] [ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica] [Chemical Abstracts/CAS]

The shape of Willis ring was intact, and the collateral circulation of pia mater was established. Considering the above reasons, no abnormal changes of CTP were observed.

There were limitations to this study. The sample size is slightly insufficient, which needs to be further studied by increasing the sample size. Patients with severe bilateral ICA stenosis or occlusion were not included in the observation.

Conclusions

We believe that in CTP post-processing of patients with unilateral ICA stenosis or occlusion of varying degrees, patients with mild or moderate ICA stenosis can choose any larger artery in the brain as the input artery, without affecting perfusion parameters. For patients with severe ICA stenosis or occlusion, non-invasive arteries such as MCA and BA on the contralateral side should be selected as input arteries to ensure more accurate cerebral perfusion parameters.

Conflict of interest

None.

References:

1. Akioka N, Takaiwa A, Kashiwazaki D et al: Clinical significance of hemodynamic cerebral ischemia on cognitive function in carotid artery stenosis: A prospective study before and after revascularization. Q J Nucl Med Mol Imaging, 2017; 61: 323–30
2. Kastrup A, Ernemann U, Nägele T, Gröschel K: Risk factors for early recurrent cerebral ischemia before treatment of symptomatic carotid stenosis. Stroke, 2006; 37: 3032–34
3. Murphy RE, Moody AR, Morgan PS et al: Prevalence of complicated carotid atheroma as detected by magnetic resonance direct thrombus imaging in patients with suspected carotid artery stenosis and previous acute cerebral ischemia. Circulation, 2003; 107: 3053–58
4. Meng R, Mi X, Sun D: Risk factors for recurrent carotid-artery stenosis following stenting treatment. Med Sci Monit, 2019; 25: 2429–34
5. Lin W, Ma X, Deng D, Li Y: Hemodynamics in the circle of Willis with internal carotid artery stenosis under cervical rotatory manipulation: A finite element analysis. Med Sci Monit, 2015; 21: 1820–26
6. Vernieri F, Pasqualetti P, Diomedi M et al: Cerebral hemodynamics in patients with carotid artery occlusion and contralateral moderate or severe internal carotid artery stenosis. J Neurosurg, 2001; 94: 559–64
7. Guppy KH, Charbel FT, Loth F, Ausman JI: Hemodynamics of in-tandem stenosis of the internal carotid artery: When is carotid endarterectomy indicated. Surg Neurol, 2000; 54: 145–52; discussion 152–53
8. Liu M, Nie ZY, Li RR et al: Correlation of brain perfusion with white matter hyperintensity, brain atrophy, and cognition in patients with posterior cerebral artery stenosis and subjective cognitive decline. Med Sci Monit, 2018; 24: 5729–38
9. Zhang Q, Ba C, Zhang M et al: Tumor growth assessment by computed tomography perfusion imaging (CTPI), perfusion-weighted imaging (PWI), and diffusion-weighted imaging (DWI) in a rabbit pleural squamous cell carcinoma VX2-implanted model. Med Sci Monit, 2018; 24: 6756–64
10. Trojanowska A, Drop A, Jargiello T et al: Changes in cerebral hemodynamics after carotid stenting: Evaluation with CT perfusion studies. J Neuroradiol, 2006; 33: 169–74
11. Ferreira RM, Lev MH, Goldmakher GV et al: Arterial input function placement for accurate CT perfusion map construction in acute stroke. Am J Roentgenol, 2010; 194: 1330–36
12. Liu JH, Gao SJ, Shi Q, Fu Q: [The study of the influence of different input artery on CT perfusion parameters.] Journal of China Clinic Medical Imaging, 2007;18: 579–81 [in Chinese]
13. Eliasziw M, Fox AJ, Sharpe BL, Barnett HJ: Carotid artery stenosis: External validity of the North American Symptomatic Carotid Endarterectomy Trial measurement method. Radiology, 1997; 204: 229–33
14. Huang C, Liang J, Lei X et al: Diagnostic performance of perfusion computed tomography for differentiating lung cancer from benign lesions: A meta-analysis. Med Sci Monit, 2019; 25: 3485–94
15. Liang JX, Bi XJ, Li XM et al: Evaluation of multislice spiral computed tomography perfusion imaging for the efficacy of preoperative concurrent chemoradiotherapy in middle-aged and elderly patients with locally advanced gastric cancer. Med Sci Monit, 2018; 24: 235–45
16. Zeng GL: Compensating for non-stationary blurring by further blurring and deconvolution. Int J Imaging Syst Technol, 2009; 19: 221–26
17. Deniffel D, Boutelier T, Labani A et al: Computed tomography perfusion measurements in renal lesions obtained by Bayesian estimation, advanced singular-value decomposition deconvolution, maximum slope, and Patlak models: Intermodel agreement and diagnostic accuracy of tumor classification. Invest Radiol, 2018; 53: 477–85
18. Rajendran K, Leng S, Jorgensen SM et al: Measuring arterial wall perfusion using photon-counting computed tomography (CT): Improving CT number accuracy of artery wall using image deconvolution. J Med Imaging (Bellingham), 2017; 4: 044006
19. Zeng D, Zhang X, Bian Z et aL: Cerebral perfusion computed tomography deconvolution via structure tensor total variation regularization. Med Phys, 2016; 43: 2091
20. Kishimoto M, Tsuji Y, Katabami N et al: Measurement of canine pancreatic perfusion using dynamic computed tomography: Influence of input-output vessels on deconvolution and maximum slope methods. Eur J Radiol, 2011; 77: 175–81
21. Sasaki M, Kudo K, Ogasawara K, Fujiwara S: Tracer delay-insensitive algorithm can improve reliability of CT perfusion imaging for cerebrovascular steno-occlusive disease: Comparison with quantitative single-photon emission CT. Am J Neuroradiol, 2009; 30: 188–93
22. Chen Z, Pan YN, Zhang J: [Influence of different input artery on whole-brain CT perfusion parameters with 320-detector row CT in acute cerebral infarction.] Chinese Journal of Medical Imaging Technology, 2016; 32: 970–74 [in Chinese]
23. Wintermark M, Sincic R, Sridhar D, Chien JD: Cerebral perfusion CT: Technique and clinical applications. J Neuroradiol, 2008; 35: 253–60
24. Yang F, Shi W-Q, Shi J et al: [The application of the whole brain CT perfusion combined with CT angiography techniques in the evaluation of transient ischemic attack patients.] Chinese Journal of Radiology, 2013; 47: 988–92 [in Chinese]

Indexed in: [Current Contents/Clinical Medicine] [SCI Expanded] [ISI Alerting System] [ISI Journals Master List] [Index Medicus/MEDLINE] [EMBASE/Excerpta Medica] [Chemical Abstracts/CAS]