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ORIGINAL ARTICLE

Cerebral Perfusion Computed Tomography with a New Scanning Protocol and Reduced Scanning Time: Retrospective Review

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ABSTRACT

Objective: *To retrospectively analyse the quantitative change in cerebral blood flow, cerebral blood volume, and mean transit time after adopting a new protocol for perfusion computed tomography (PCT) where the delay time for scanning was changed from 5 to 8 seconds and acquisition time decreased from 50 to 42 seconds.*

Methods: *All elective cerebral PCTs performed from June to October 2009 were retrieved. The original dataset and extracted dataset (excluding the first 3 seconds and last 5 seconds of the original dataset which corresponded to the new protocol) were pair-wise processed in the same workstation. This entailed using the same arterial input and venous output functions; 12 identical regions of interest were applied. Perfusion parameter values were compared using the Wilcoxon rank signed test. Significance was declared at an $\alpha \leq 0.05$.*

Results: *A total of 45 PCTs with and without acetazolamide challenge were included, yielding 540 regions of interest. The mean percentage differences of cerebral blood flow, cerebral blood volume, and mean transit time between the two datasets were significant ($p < 0.001$) but small (5.9%, 5.0% and 4.2%, respectively). In the extracted datasets, the absolute values remained within a 15.0% difference in 97.0% of the cerebral blood flows, 99.8% of the cerebral blood volumes, and 99.6% of the mean transit times. With the new protocol, on average a 15.9% reduction in radiation dosage was achieved.*

Conclusion: *By adopting our new scanning protocol for cerebral PCT, a significant reduction in radiation dosage was achieved, while the changes in cerebral blood flow, cerebral blood volume, and mean transit time values were considered acceptable.*

Key Words: *Cerebrovascular disorders; Perfusion imaging; Radiation dosage; Stroke; Tomography, X-ray computed*

中文摘要

應用新掃描方案及掃描時間縮短的CT腦灌注成像：回顧性研究

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目的：在新的電腦斷層（CT）灌注成像方案中，掃描延遲時間由5秒增至8秒，而採集數據時間則從50秒減至42秒。本研究回顧分析採用這種新方案後，在腦血流量、腦血容量和對比劑平均通過時間方面的變化。

方法：分析2009年6月至10月期間所有CT腦灌注成像的紀錄。在同一工作站配對處理原始數據和提

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取數據（捨棄前3秒和最後5秒的原始數據使之和新掃描方案一致）。處理過程需要使用相同的動脈輸入和靜脈輸出功能；並採用12個相同的感興趣區。應用Wilcoxon秩和檢驗比較灌注參數值。$\alpha \leq 0.05$表明差異有顯著性。

結果：共有45個CT灌注成像，其中部份有乙酰唑胺（acetazolamide）負荷，產生540個感興趣區。兩組數據在腦血流量、腦血容量和對比劑平均通過時間的平均百分比差異具顯著性（$p < 0.001$），但差異偏小（分別為5.9%、5.0%和4.2%）。提取數據中，在97.0%的腦血流量，99.8%的腦血容量和99.6%的平均通過時間的絕對值仍在15.0%差異範圍內。新方案令輻射劑量平均減少了15.9%。

結論：通過採用新的CT腦灌注成像方案，輻射劑量顯著減少，而腦血流量、腦血容量和對比劑平均通過時間值的變化仍可接受。

INTRODUCTION

Cerebral perfusion computed tomography (PCT) provides valuable haemodynamic information in the assessment and clinical decision making of acute and chronic cerebrovascular disease.[1,2] This technique involves repeated image acquisition over a selected volume of the head to obtain dynamic computed tomography (CT) images of the brain parenchyma during intravenous contrast injection. Data are subsequently processed offline using dedicated workstations to generate measurements of cerebral blood flow (CBF), cerebral blood volume (CBV), and mean transit time (MTT). These can be calculated and displayed both qualitatively in the form of colour maps and quantitatively by defining regions of interest (ROIs), allowing areas of infarcts and ischaemia to be determined.

In PCT, repeated image acquisition necessitates high radiation doses. In addition, patients with chronic cerebrovascular disease may need to undergo a second PCT after acetazolamide challenge,[3] which translates to twice the amount of radiation dose compared with that delivered in a single PCT. PCT also typically goes hand in hand with CT angiography of the cerebral and neck vessels, which also requires delivery of higher radiation dosages to patients. On 8 October 2009, the US Food and Drug Administration issued an initial notification about excess radiation during PCT.[4,5] Thus, the radiation dose incurred in PCT should not be underestimated and the importance of dose optimisation has to be emphasised. The amount of radiation delivered in PCT depends on various factors such as the acquisition parameters of the PCT that include the frequency and duration of image acquisition. However, while changing the scanning parameters of PCT can affect the amount of radiation delivered, potentially they may also affect CBF, CBV and MTT values and hence the overall accuracy and reliability of the examination. It is therefore important to strike a balance between the radiation dose and the diagnostic accuracy. In 2009, our department decided to develop a new PCT scanning protocol to reduce the radiation dosage incurred in this examination. In our previous PCT protocol, the delay time of scanning was 5 seconds after contrast injection and the acquisition time was 50 seconds. Observations from the attenuation-time curves of previous PCT scans showed that the arterial bolus usually did not reach the cerebral circulation within the first few seconds of injection, and that both the arterial input and venous output usually leveled off a few seconds before the end of acquisition. A new PCT scanning protocol was therefore adopted in January 2010. This entailed an increase in delay time to 8 seconds and a shortened acquisition time to 42 seconds (Figure). The purpose of this study was to retrospectively validate the CBF, CBV, and MTT values obtained after adopting the new PCT protocol.

METHODS

All patients who underwent elective cerebral PCT from June to October 2009 were retrieved from the radiology information system of our department and a total of 38 patients were identified. These patients were referred to us by neurologists and neurosurgeons for workup or follow-up of known subacute or chronic cerebrovascular disease, either for recruitment in clinical trials or planning for intervention such as endovascular stenting and bypass surgery. These scans were performed on a 64-slice multidetector CT scanner (LightSpeed VCT; GE Healthcare, Waukesha [WI], USA). A total of 50 ml of non-ionic iodinated contrast agent (Iopamiro 300, Bracco, Milan, Italy) were injected intravenously by a power injector at a rate of 4 ml per second. Five seconds

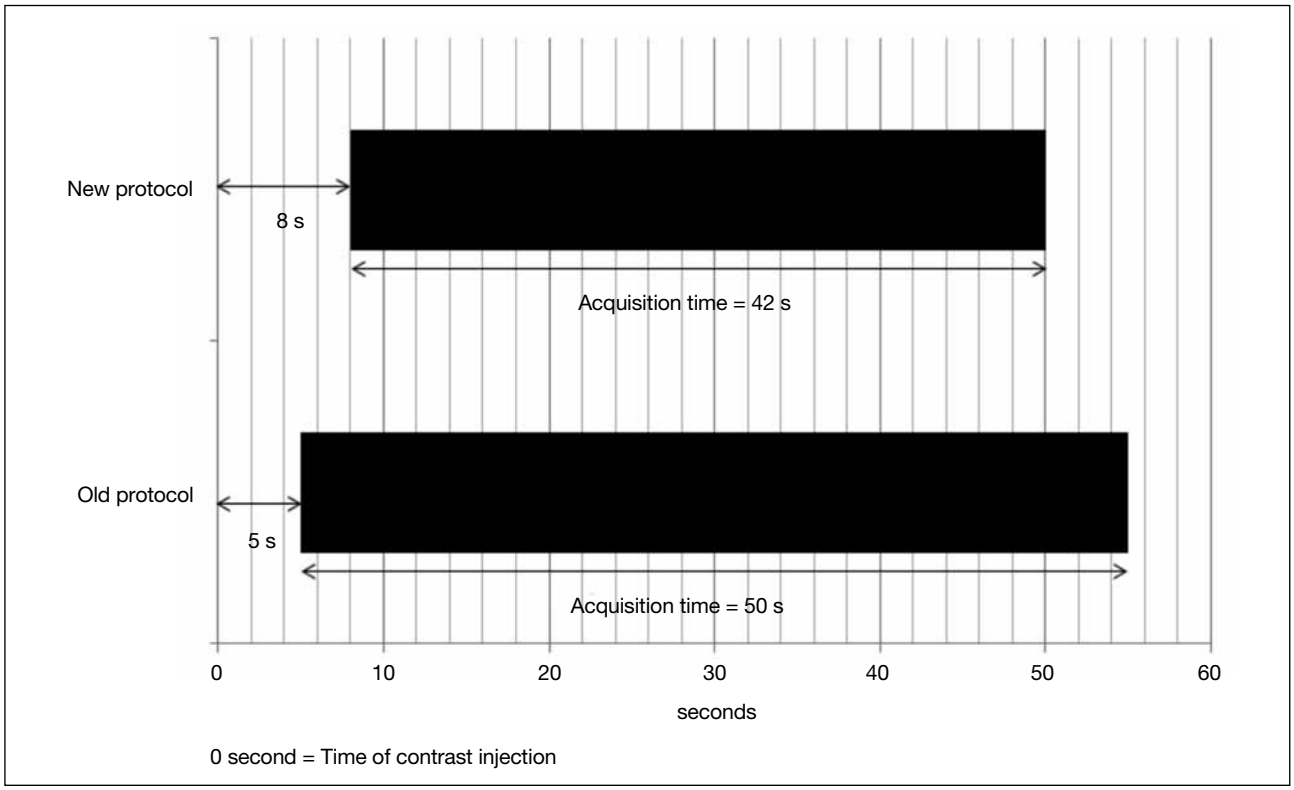

Figure. Illustration of the difference between the new and old perfusion computed tomography protocol in terms of delay time and acquisition time.

after contrast injection, 99 consecutive acquisitions were acquired at a frequency of two acquisitions per second. Each acquisition contained eight consecutive slices and the slice thickness was 5 mm, i.e., a 4-cm scan width was obtained from each acquisition and a total of 792 images were generated from each PCT. Prior to the PCT, a plain CT scan was obtained and the scan coverage of the subsequent PCT was chosen by the in-charge radiologist to include the basal ganglia and corona radiata. The parameters of the PCT were as follows: 80 kV, 200 mAs, rotation time 0.5 sec, field of view 25 cm, and matrix 512 x 512. The PCT data were retrospectively processed in the same workstation (Advantage Workstation version 4.5; GE Healthcare, Waukesha [WI], USA) using commercially available perfusion software based on a delay-insensitive deconvolution algorithm (CT Perfusion 4). Movement correction function was enabled. The software allowed extraction of a second perfusion dataset, which excluded the first 48 images (equivalent to 3 seconds) and last 80 images (equivalent to 5 seconds) of the original dataset and corresponded to the new scanning protocol. Paired original and extracted perfusion datasets were processed using the same arterial input and venous outflow functions (by automatic selection), and 12 ROIs were manually drawn for both anterior cerebral, middle cerebral, and posterior cerebral artery territories at the basal ganglia and corona radiata levels. These were at the same location and slice level. The corresponding CBF, CBV, and MTT values were obtained and compared using the Wilcoxon rank signed test by IBM SPSS Statistics (version 20). The percentage difference between the PCT parameters obtained from the original datasets and those obtained from the extracted datasets were also calculated for each pair of datasets. PCT scans performed outside the levels of basal ganglia and corona radiata were excluded, as were studies with significant movement artefact.

RESULTS

Of the 38 patients identified, levels of basal ganglia and corona radiata were outside the coverage of PCT in five patients, while one had significant motion during the scan, for which reason they were excluded from the study. As a result, 32 patients (16 male and 16 female) were included and their mean age was 60 (range, 16-

88) years. Of these 32 patients, 14 also underwent a second PCT for acetazolamide challenge, yielding 46 PCT datasets. One post-acetazolamide PCT showed significant movement artefacts and was therefore excluded, giving the final 45 PCT datasets for analysis. 540 ROIs were generated from each of the original datasets and extracted datasets. The mean CBF, CBV, and MTT obtained from the original and extracted datasets are given in Table 1. The differences in CBF, CBV and MTT between the original and extracted datasets were statistically significant ($p < 0.001$ for CBF, CBV, and MTT). However, the mean percentage differences of all ROIs were considered small (5.9%, 5.0%, and 4.2% for the respective perfusion parameters). In the extracted datasets, the absolute difference values remained within 15% in 97.0% of the CBF measurements, 99.8% of the CBV measurements, and 99.6% of the MTT measurements, when compared with the original datasets (Table 2). The mean volume CT dose index decreased from 590 mGy to 496 mGy after adopting the new protocol. i.e., a 15.9% reduction in radiation dosage was achieved.

DISCUSSION

There is no standard scanning protocol for cerebral PCT. The scanning technique depends on manufacturer's

Table 1. Summary of cerebral blood flow, cerebral blood volume, and mean transit time parameters in the new and old protocols.

Region of interest	Mean ± standard deviation		Mean of % difference between original and extracted dataset
	Old protocol	New protocol	
Cerebral blood flow (ml/100 g/min)			
Basal ganglia-right ACA	15.02 ± 4.10	15.90 ± 4.32	6.69
Basal ganglia-right MCA	24.66 ± 6.40	25.50 ± 6.79	4.54
Basal ganglia-right PCA	20.76 ± 7.75	21.93 ± 8.00	7.06
Basal ganglia-left ACA	15.92 ± 5.34	16.59 ± 5.08	6.08
Basal ganglia-left MCA	25.01 ± 6.89	25.83 ± 6.93	4.91
Basal ganglia-left PCA	20.80 ± 6.36	21.98 ± 6.77	7.19
Corona radiata-right ACA	15.38 ± 4.04	16.37 ± 4.18	7.30
Corona radiata-right MCA	20.00 ± 3.99	20.89 ± 4.14	5.21
Corona radiata-right PCA	21.12 ± 7.89	22.06 ± 8.28	5.79
Corona radiata-left ACA	16.87 ± 5.78	17.51 ± 5.41	6.05
Corona radiata-left MCA	21.44 ± 6.23	22.19 ± 6.19	4.58
Corona radiata-left PCA	20.60 ± 5.90	21.41 ± 5.88	5.45
Cerebral blood volume (ml/100 g)			
Basal ganglia-right ACA	1.44 ± 0.45	1.48 ± 0.44	4.90
Basal ganglia-right MCA	2.12 ± 0.50	2.15 ± 0.50	4.71
Basal ganglia-right PCA	1.81 ± 0.52	1.85 ± 0.54	5.12
Basal ganglia-left ACA	1.43 ± 0.45	1.46 ± 0.47	4.97
Basal ganglia-left MCA	2.03 ± 0.40	2.06 ± 0.41	4.68
Basal ganglia-left PCA	1.90 ± 0.52	1.94 ± 0.53	5.43
Corona radiata-right ACA	1.49 ± 0.43	1.51 ± 0.40	5.29
Corona radiata-right MCA	1.81 ± 0.44	1.84 ± 0.44	5.04
Corona radiata-right PCA	1.79 ± 0.51	1.83 ± 0.53	5.10
Corona radiata-left ACA	1.49 ± 0.40	1.52 ± 0.39	4.99
Corona radiata-left MCA	1.76 ± 0.42	1.79 ± 0.44	4.22
Corona radiata-left PCA	1.77 ± 0.41	1.80 ± 0.42	5.22
Mean transit time (sec)			
Basal ganglia-right ACA	7.29 ± 1.66	7.14 ± 1.71	4.27
Basal ganglia-right MCA	6.94 ± 1.41	6.74 ± 1.40	3.66
Basal ganglia-right PCA	6.88 ± 0.88	6.66 ± 0.86	4.81
Basal ganglia-left ACA	6.85 ± 1.09	6.68 ± 1.11	4.28
Basal ganglia-left MCA	6.63 ± 0.98	6.45 ± 0.94	3.50
Basal ganglia-left PCA	6.99 ± 0.70	6.83 ± 0.73	5.01
Corona radiata-right ACA	7.48 ± 1.94	7.17 ± 1.86	4.74
Corona radiata-right MCA	7.30 ± 1.71	7.08 ± 1.65	3.86
Corona radiata-right PCA	6.88 ± 1.16	6.68 ± 1.11	4.45
Corona radiata-left ACA	6.85 ± 1.19	6.67 ± 1.15	3.71
Corona radiata-left MCA	6.71 ± 1.03	6.51 ± 1.10	3.68
Corona radiata-left PCA	6.75 ± 0.81	6.57 ± 0.73	4.92

Abbreviations: ACA = anterior cerebral artery; MCA = middle cerebral artery; PCA = posterior cerebral artery.

Table 2. Summary of change in perfusion computed tomography parameters between new and old protocols.

	Mean of % difference between original and extracted dataset of all ROIs	% of measurement based on extracted dataset that were within 15% of the absolute value using the original dataset
CBF	5.9%	97.0%
CBV	5.0%	99.8%
MTT	4.2%	99.6%

Abbreviations: ROIs = regions of interest; CBF = cerebral blood flow; CBV = cerebral blood volume; MTT = mean transit time.

specifications and policy of individual institutions. Changing the parameters of PCT such as acquisition time and the frequency of acquisition can change the radiation dose and at the same time affect the parameter values and ultimately the accuracy of the examination. Three studies have been carried out to study the effect of changing the temporal sampling interval in PCT on relevant parameter values. One study recommended a temporal scan resolution of two images per second for the best detection and depiction of ischaemic areas,[6] while two others advocated sampling intervals greater than 1 second[7] and even up to 3 seconds,[8] so as to reduce radiation dose. Konstas et al[9] also suggested separating the acquisition into more than one phase with higher acquisition frequency in the initial phase and lower frequencies in the subsequent phase. However, no previous study has investigated the effect of changing the acquisition time on the parameter values. Our study evaluated whether shortening the acquisition duration (with a concomitant increase in delay time after contrast injection) and thus reducing the radiation dose incurred, would significantly affect the PCT parameters. Our findings suggest that the magnitude of CBF, CBV, and MTT changes were small when the scanning duration was reduced from 50 to 42 seconds and the delay time was increased from 5 to 8 seconds. Apart from diminishing the radiation dose, our new protocol was potentially less susceptible to movement artefact, because a shorter scanning time can decrease the chance of patient movement during image acquisition.

We have also investigated the potential clinical impact by adopting the new protocol. Using xenon CT with acetazolamide challenge, Webster et al[10] recommended a decrease in CBF of greater than 5% from baseline to indicate tissues at higher risk of stroke. In our study, 13 patients underwent CT perfusion with acetazolamide challenge. Of these, five had one or more ROIs which met Webster's criteria of higher risk of stroke as processed in the original datasets, so we were able to reproduce these results using the extracted datasets.

The implication of a decrease in radiation dose is important in this patient population. PCT contributes a high radiation dose due to the need for multiple image acquisition and every effort should be made to reduce the radiation dose to be as low as reasonably achievable.[2] In addition, the number of patients with first-ever stroke in Hong Kong is increasing as the population ages,[11] and therefore we expect more patients to be referred for PCT. Furthermore, cerebrovascular disease is a chronic condition, so that the patients suffering from it are prone to develop recurrent strokes and may require multiple radiological examinations, including plain cerebral CT, or a CT angiogram or digital subtraction angiogram of the neck and cerebral vessels. Finally, some of the patients may undergo follow-up PCTs to evaluate treatment response. Thus, the impact of cumulative radiation has to be anticipated in this population, and collaboration between radiologists and referring clinicians can streamline indications for referral to attain most benefit.

The potential drawback of our new PCT protocol is the possibility of obtaining an incomplete tissue concentration curve in patients with poor cardiac output, atrial fibrillation and proximal internal carotid artery occlusion or a hairline lumen.[9] However, it can be difficult to define or predict an acquisition time to ensure that a tissue concentration curve is complete for all patients. Also, by prolonging the acquisition time to obtain a complete tissue concentration curve for patients who may be prone to an incomplete tissue concentration curve means an increase in radiation dosage to all patients undergoing PCT.

Our limitation of this study was that we did not evaluate the effect of the new protocol on PCT data using other workstations employing the maximum slope method, or use a delay-sensitive deconvolution algorithm. In both instances, different mathematical models are adopted[12] and therefore changes in perfusion parameters may be more pronounced. Another potential limitation was the presence of undetectable and non-correctable motion in some CTP data, which could affect the placement of identical ROIs in the original versus extracted datasets. Finally, PCTs from acute stroke patients were not included in this study, as they underwent such imaging by another CT scanner installed in the emergency department.

CONCLUSION

By adopting our new cerebral PCT scanning protocol with shortened acquisition time and increase in delay time to scanning, the changes in CBF, CBV, and MTT values could be considered acceptable when compared with our previous protocol and achieved a significant reduction in radiation dosage.

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