CT Brain Perfusion Radiation Dosimetry on a 128 slice MDCT; What Is All The Hue and Cry About?

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Purpose

To evaluate radiation dose to patients undergoing CT Brain perfusion (CTP) study and to discuss practical and technical measures in reducing radiation dose without compromising image quality.

CTP allows accurate quantitative assessment of brain tissue perfusion in the critical emergency setting. It is generally well tolerated, can be performed in a timely manner and is readily accessible compared to Magnetic Resonance (MR) perfusion studies. Standard Computed Tomography (CT) systems can be used with the only extra cost of the post-processing software. There is no question that CTP constitutes a valuable addition to the diagnostic neuroradiological tools in a modern healthcare facility.

Dynamic CTP involves sequential CT slices acquired in cine mode during the intravenous (IV) administration of iodinated contrast medium. For each pixel, time-density profiles of contrast enhancement are obtained using dedicated post-processing software. From these curves, several perfusion-related parameters are calculated and displayed as colour-coded parameter maps. The perfusion parameters most commonly used include cerebral blood flow (CBF), cerebral blood volume (CBV) and mean transit time (MTT). An example of a typical perfusion study with salvageable penumbra is illustrated in Fig. 1.

With technical improvements of spiral CT and the introduction of multi-detector computed tomography (MDCT) scanners, the number of images obtained per dynamic CTP study has increased steadily, and may be expected to increase further in the future with the introduction of 320 slice MDCT and dual source scanners. Therefore, it is critical to limit the radiation exposure to the patient to minimise risk of radiation induced harm. Reducing the tube voltage and using highly concentrated contrast media have been recommended to increase signal-to-noise ratio (SNR) and reduce radiation exposure (1).
Fig. 1: 59 year old male with sudden onset dysphasia and dense left sided hemiplegia. CTP shows evolving Right Middle cerebral artery (MCA) ischemia with infarct core in right lentiform nucleus, markedly reduced CBF of 5ml/100ml.min and CBV of 0.5mls/100ml. Large penumbra seen in right frontal and posterior temporal lobe. CTA confirmed right proximal MCA occlusion.

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Methods and Materials

A retrospective analysis of patient radiation doses obtained from routine CTP studies over the past 18 months (July 2010 to January 2012) performed at our institution was conducted. Incomplete examinations and examinations that required additional runs due to technical errors or contrast injection issues were not included in this data analysis.

109 patients aged between 18-80 years met criteria to be included in this study. Routine CTP scan protocol consisted of unenhanced head to exclude haemorrhage, exclude other obvious cause for neurological symptoms and to identify ischaemic changes, CTP phase to acquire perfusion data and to determine salvageable penumbra, and finally CT angiogram (CTA) from aortic arch to circle of willis (COW) to identify likely site of occlusion and mapping of cerebral vasculature for embolisation techniques.

Patients underwent CTP study on a Siemens 128 slice MDCT scanner with adaptive 4D spiral mode ©. 125 ml of IV contrast (loversyl © 74% w/v) routinely loaded into an auto-injector. For the perfusion phase, 50 ml of contrast is injected at 6ml/s, with the remaining 75 ml injected at 4ml/s for the CTA phase.

Dose reduction techniques were divided into three categories:

1. Manual user techniques:
   - Lower kVp (80 kV cf. 100 kV) and reduced gantry rotation time for the CT perfusion phase (2)
   - Lower mAs (200 mAs cf. 500 mAs) and increased pitch (0.75 cf. 0.8) for the CTA phase
   - Patient positioning with chin down (scan plane parallel to orbitomeatal line) to achieve near whole brain coverage in one rotation for the perfusion phase.
   - Reducing overbeaming and optimal collimation

2. Inherent scanner techniques:
   - Automatic iterative dose reduction scanner processing
   - mAs modulation

3. Reduced scan sequences in follow up imaging:
   - Follow up CTP studies requiring only CTP scan and omitting CTA
Resulting images were considered diagnostic in the clinical setting and were formally reported by the Radiologists at our institution. Detailed technical factors are included in Fig. 2. These "dose reduction technique" doses where then compared to "standard technique" doses in order to establish the average reduction in dose using the "ImPACT’s CT dosimetry tool"(3). An example of detection of small lesions using dose saving technique is given in Fig. 3.

Patient dose reports for every examination were automatically generated after each study e.g. Fig. 4. Computed Tomography Dose Index volume (CTDI_{vol}) and Dose Length Product (DLP) results were analysed and an average dose calculated based on the generated reports. The dose from the scout topogram and contrast monitoring phase were not included in the calculations. The DLP was then converted into an effective dose (mSV) by using k-conversion factors as set out in the Internal Commission on Radiation Protection (ICRP) 103 publication (4,5,6).
Images for this section:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unenhanced head</th>
<th>Neuroperfusion (CTP)</th>
<th>CTA brain (perfusion protocol)</th>
<th>CTA brain (standard protocol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage (kVp)</td>
<td>120</td>
<td>80</td>
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<td>100</td>
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<tr>
<td>Tube current (mAs)</td>
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<td>200</td>
<td>200</td>
<td>500</td>
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<td>Number of slices (n)</td>
<td>40</td>
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<td>Rotation time (s)</td>
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<td>4D mode</td>
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<td>0.75</td>
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<tr>
<td>Dose (CTD/vol mGy)</td>
<td>73.12</td>
<td>218.8</td>
<td>17.42</td>
<td>37.74</td>
</tr>
</tbody>
</table>

**Fig. 2:** Technical factors for routine stroke protocol study. Standard CTA brain factors have been provided to show the difference in settings for our perfusion protocol.

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**Fig. 3:** CTP demonstrating small right lacunar infarct on low kVp technique scan (80 kVp) which is confirmed on day 2 MR diffusion scan.
Fig. 4: Typical dose report for CT perfusion study.

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Results

The average total dose for routine protocol CTP study was CTDI$_{vol}$ of 338 mGy and DLP of 4153 mGycm. This equates to 8.71 mSv, with the perfusion phase on average almost three times the dose of unenhanced scan (5.26 mSv and 1.83 mSv respectively). Fig. 5.

By implementing a number of dose reduction techniques, considerable reductions in dose were achieved with no compromise to diagnostic image quality. By lowering the kV from 100 kV to 80 kV, the effective dose for the perfusion phase was reduced by 53% (5.26 mSv cf. 11.17 mSv). By reducing the mAs from 500 mAs to 200 mAs and increasing the pitch from 0.75 to 0.8, the effective dose for the CTA phase was reduced by 62% (1.62 mSv cf. 4.32 mSv). These combined dose savings resulted in an overall dose reduction of approximately 50% (8.71 mSv cf. 17.32 mSv) for a routine protocol CTP study.

DISCUSSION

Stroke in Australia is the second single greatest cause of mortality and leading cause of disability (7). There is growing awareness around radiation safety in CTP scans in recent times, especially after the United States Food and Drugs Administration (U.S. FDA) review about significant radiation adverse events. As of 26th October 2010, some 385 patients from six hospitals had experienced deleterious adverse events whereby they were found to have been exposed to excess radiation CTP scans. Obvious deterministic signs such as hair loss or skin erythema were apparent in the examined region (Fig. 6), along with the cumulative increased stochastic risks involved.

The advancing ability of modern CT scanners along with the increasing ease of access, has resulted in a significant increase in radiation population burden over recent decades. CT scanning comprises approximately 15% of radiologic examinations but represents the largest single source of medical radiation exposure, accounting for approximately 70% of the radiation dose to patients (8).

As for any radiation examination, the ‘as low as reasonably achievable’ (ALARA) principle along with the fundamental concepts of justification and optimisation must always be adopted by all radiology staff. However, with the over growing complexity of modern CT scanners and demands of more comprehensive scanning protocols, it is often difficult to implement such changes in the clinical setting.
For example, if CTP is used for other applications like tumour perfusion and permeability imaging, the radiation dose is likely to be higher because of prolonged scanning times. Such studies should be performed only once to identify the tumour grade and as a guide for biopsy.

Developing methods for dose reduction for CT protocols consequently takes a team effort of physicists, radiologists and technicians to determine the best compromise between diagnostic image quality and radiation dose (9). This may be as simple as adjusting protocols for repeat imaging in follow up cases such as omitting CTA phase for vasospasm, or utilising Magnetic Resonance (MR) perfusion studies where available.

In terms of future direction and research, it is worth considering how the use of 320 slice MDCT scanners and dual-source scanners will impact on patient radiation dose burden. The available literature reports further dose reduction protocols with the benefit of whole brain coverage (10,11).
Images for this section:

<table>
<thead>
<tr>
<th>Average Parameters</th>
<th>Unenhanced</th>
<th>Perfusion</th>
<th>CTA</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>CTDIvol (mGy)</td>
<td>61</td>
<td>249</td>
<td>28</td>
<td>338</td>
</tr>
<tr>
<td>DLP (mGycm)</td>
<td>872</td>
<td>2509</td>
<td>772</td>
<td>4153</td>
</tr>
<tr>
<td>Effective Dose (mSV)</td>
<td>1.83</td>
<td>5.26</td>
<td>1.62</td>
<td>8.71</td>
</tr>
</tbody>
</table>

**Fig. 5:** Average dose for separate phases of CTP study

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Fig. 6: CTP related hair loss within the perfusion field of view.

Conclusion

Responsible radiation use is a hot topic, with the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) recently releasing a national set of dose reference levels (DRL) for adult MDCT scans (12). Currently, there is no set DRL for CTP studies, however FDA review has set a "reasonable alert level" at CTDI$_{vol}$ of 1 Gy and the American Association of Physicists in Medicine (AAPM) recommends CTDI of 500 mGy (13).

According to the available literature on deterministic dose thresholds, temporary and permanent epilation occurs at doses of 3 Gy and 7 Gy respectively (14,15). Cataract formation (after latency period) occurred after doses between 2-10 Gy for acute exposure to low linear energy-transfer (LET) radiation (16).

Our institution performs a relatively large number of scans with an average dose well below these recommendations as a result of simple dose reduction techniques that result in approximately 50% reduction in effective dose. This is comparable to the available literature on "low dose/dose reduction" techniques for CT brain scans (17,18,19). Awareness and attention must be made with cumulative doses in repeat and follow-up studies, especially in a short time period as doses may well creep up towards these recommended dose thresholds.

CTP is a valuable tool in acute stroke evaluation and judicial practice of this modality directly influences patient care within acceptable dose limits.
Personal Information

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