Brief Communication

Computed Tomography Perfusion Imaging on Traumatic Cerebral Contusion: A Preliminary Report

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Abstract

Background: **Brain ischaemia and infarction are the leading factors in morbidity and mortality of traumatic brain injury. This study aimed to determine the perfusion status of pericontusional hypodense areas in traumatic cerebral contusion**

Methods: **Ten patients involved in motor vehicle accidents were enrolled in this study, and contusions were diagnosed from plain computed tomography scans of the brain. Subsequent computed tomography perfusion (CTP) was performed to analyse the perfusion of pericontusional hypodense areas, which were divided into 4 regions of interest (ROI).**

Results: **Most ischaemic perfusion was found in ROI 6 (affecting 60% of patients), although the mean of the perfusion parameters were normal. A significant positive correlation was found between the perfusion status in the pericontusional area nearest to the skull vault (ROI 3) and its distance/thickness to the skull vault (r = 0.698, P = 0.025). Two adjacent pericontusional hypodense areas (ROI 4 and ROI 5) showed a significant positive correlation with each other (r = 0.667, P = 0.035) in terms of perfusion status. The presence of a hypodense pericontusional area is suggestive of oedema and perfusion disturbances.**

Conclusion: **CTP is a useful, fast, and appropriate method in evaluating perfusion of pericontusional hypodensity area that may help the treating physician to provide an appropriate treatment to the patient.**

Keywords: *brain contusion, emission-computed tomography, medical imaging, oedema, perfusion, trauma*

Introduction

Brain injury is the leading factor in morbidity and mortality following head trauma/injury. The devastating personal, social, and financial consequences of traumatic brain injury (TBI) are compounded by the fact that most people with TBI are young and otherwise healthy. Advances in the current management of TBI, including brain imaging, have led to increased survival rates in cases that would have previously been fatal (1). Because brain function is exceedingly complex, brain injury and recovery are also complex (2). Therefore, diagnostic imaging is extremely important in TBI patients to understand the clinical implications. To make matters even more complex, an early computed tomography (CT) scan does not identify which patients will develop neurological deficits, even after minor head injury. Although there is no consensus regarding which patients should be scanned, many authors agree that an abnormal result has a major impact on a patient's management (3). CT scan is a sensitive diagnostic tool for the evaluation of acute head injury; however, the prognostic ability of conventional CT scan has limited value.

Cerebral contusions are characterised by mixed densities of lesions, which are commonly surrounded by perilesional hypodense areas in close contact with the internal surface of the skull. Cerebral contusions have a tendency to enlarge over time and become significant space-occupying lesions, which exert a mass effect to surrounding brain parenchyma. This leads to an increased intracranial pressure with subsequent clinical deterioration or worsening neurological condition. A survey of 729 patients with TBI by the TBI European Brain Injury Consortium found that cerebral contusions alone (44%) or in association with subdural haematoma (29%) were the most frequent causes for delayed surgical intervention (4). In addition, ultrastructural studies have provided evidence that progressive neuronal damage leads to a growing area of

necrosis, which enhances the role of cerebral contusions as a vector of secondary brain damage (5). Therefore, cerebral contusions can become a major therapeutic challenge because they have the potential to become growing masses, mixed with presumably viable tissue, which may be of critical functional importance whenever surgical removal of the lesion is contemplated in neurologically eloquent areas, i.e., areas involved in critical functions (6). Several studies on ischaemic stroke have revealed that hypodense areas in plain brain CT scans have regional alterations in perfusion. Most CTP studies have been performed in ischaemic stroke patients, and only a few studies have examined CTP in patients with TBI (7). Therefore, the purpose of this study was to ascertain the perfusion status of the hypodense pericontusional area.

Materials and Methods

All experimental protocols were approved by the Ethical Committee (Human) Universiti Sains Malaysia (USMKK/PPK/JKEP(M)-191 USM) and institutional informed consent guidelines were followed regarding the consent of the patient or his/her legal representative. All adult patients with trauma were prospectively identified in the emergency room of the Hospital Universiti Sains Malaysia (HUSM) as candidates for enrolment from July 2007 to November 2008. Inclusion criteria were in-patients, with minimum age of 15 years, who had a traumatic brain contusion observed on a plain CT scan of the brain and cervical C1–C2. Patients were excluded if they were pregnant, did not give their informed consent, sustained an infratentorial brain contusion, had subarachnoid haemorrhage, had extradural haemorrhage, or were required to undergo any surgical or endovascular intervention post-TBI.

The series consisted of 10 patients (8 men and 2 women) with a median age of 25 years, age range of 16–48 years, and interquartile age range of 17–33 years. A multidetector CT scanner (Light speed; General Electric Medical Systems, Milwaukee, WI) to obtain a helical plain CT scan of a 3.75 mm thick basal section and a 7.5 mm thick supratentorial axial section, and the sections containing the largest contusion/intraparenchymal haematoma were selected.

Computed tomography perfusion (CTP) is initiated by injecting 50 mL (320 mg/mL) iodinated contrast media (iodixanol) into each patient's peripheral vein through a 20-gauge cannula at 4 mL/s using an angiographic power injector. The scan was delayed for 4 seconds, and the total scan time was 45 seconds. We obtained 4 sections per second with a thickness of 5.0 mm/section and an image matrix of 512 x 512. The scan was set at 80 kV with a current of 190–200 mA. A total of 180–200 images were obtained and sent to a workstation for review and post-processing. All CTP examinations were well-tolerated, and there were no reported side effects (e.g., allergic reaction to the contrast media or extravasation). The CTP software in the CT workstation (AW 3.1) was used for the analysis of perfusion parameters: cerebral blood flow (CBF), cerebral blood volume (CBV), and mean transit time (MTT). We selected images of the largest diameter of the contusion. A small region of interest (ROI) was drawn in an artery (ROI 1) and vein (ROI 2). The artery nearest to the contusion was selected, and sagittal or transverse sinuses were selected for the ROI placement in the vein. The arterial curve should be displayed before the venous curve because the venous height was higher and later than the arterial curve. The pericontusional hypodense area was drawn with cursor and divided into 4 quadrants named ROI 3, ROI 4, ROI 5, and ROI 6. A correlation of pericontusional hypodensity area was not matched with rainbow colour changes of post-processing generated CTP images. ROI 3 was the closest to the skull vault, and it was followed by ROI 4, ROI 5, and ROI 6 in a clock-wise fashion if the contusion was on the left side (Figure 1) and a counter-clock-wise fashion if the contusion was on the right side. After drawing the ROIs, the cursor was placed and the function algorithm was selected. The CBF, CBV, and MTT values of each ROI were calculated. CBF of less than 20 mL/100 g/min, CBV of less than 2.0 mL/100 g, and MTT of more than 8 seconds were considered as abnormal (8).

Results

The median size of the contusion was 52.00 mm^2 (range, 14.00–493.00 mm^2, interquartile range, 34.75–196.50 mm^2). The mean (SD) distance of the contusion from the nearest skull vault was 5.35 (6.73) mm; median, 2.35 mm; range 0.80–18.10 mm; and interquartile range, 1.37–7.25 mm. Ischaemic perfusion, which affected 60% of the patients, was mostly seen in ROI 6. ROI 4 displayed the largest hypodense pericontusional area, 114.00 (SD 212.00) mm^2, and ROI 6 showed the smallest area, 48.80 (SD 44.28) mm^2. Mean values of CBV, CBF, and MTT were within normal limits in all ROIs (Table 1).

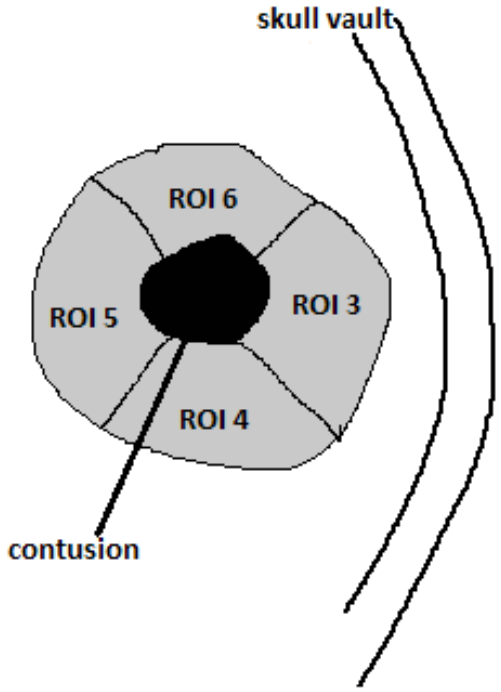

Figure 1: Diagrammatic presentation of the hypodense pericontusional area in each region of interest (ROI), if the contusion was on the left side.

The mean values of the perfusion parameters of the hypodense pericontusional area in ROI 6 were 4.13 (SD 6.19) mL/100 g, 21.44 (SD 16.39) mL/100 g/min, and 3.58 (SD 1.98) seconds for CBV, CBF, and MTT, respectively.

Because the data were not normally distributed, the Spearman correlation statistical test was used to evaluate the relationship of the parameters (Tables 2 and 3). A significant positive correlation (r = 0.667, P = 0.035) was observed between the perfusion of the hypodense pericontusional areas of ROI 4 and ROI 5 (Table 2). Significant positive correlations were also observed between the distance of the contusion to the nearest skull vault and the perfusion of the hypodense area in ROI 3 (r = 0.698, P = 0.025) and ROI 6 (r = 0.642, P = 0.046). Interestingly, a significant negative correlation was observed between the perfusion of the hypodense pericontusional area of ROI 3 and the size of the hypodense area of ROI 4 (r =-0.698, P = 0.025). In addition, there are significant positive correlation between size of contusion and size of pericontusional hypodensity area in each ROI 3 (r = 0.839, P = 0.002), ROI 4 (r = 0.723, P = 0.018), ROI 5 (r = 0.842, P = 0.002), and ROI 6 (r = 0.717, P = 0.020) (Table 3).

Discussion

CTP has been introduced as a simple imaging technique that can be used in routine clinical practice. It has gained recognition in management cases of acute stroke and other cerebrovascular disorders because it is able to provide information about the cerebral perfusion status. Most CTP studies have been performed on ischaemic stroke cases; only a few studies have been performed on TBI. The results of the present study showed that there were significant perfusion changes in cases of TBI, which expands the use of CTP technique in the management of TBI.

The values of the perfusion parameters of the hypodense pericontusional area in ROI 6, which was the region that showed the most ischaemic perfusion, were comparable to a study by Soustiel et al. (6), which reported values of 2.9 (SD 1.3) mL/100 g for CBV, 26.2 (SD 11.9) mL/100 g/min for CBF, and 6.7 (SD 2.9) seconds for MTT. Another study of pericontusional areas also revealed a normal CBF value of 42.5 (SD 15.8) mL/100 g/min despite all of their patients having a Glasgow Coma Scale (GCS) score of less than 10 (9). Our study consisted of an initial GCS score of more than 12 without any endovascular or surgical interventions. CBF is the initial indicator of CTP parameters that denotes perfusion disturbances (10). However, a study by Schroder et al. (11) found that oedematous pericontusional areas showed a CBF value of 17.5 (SD 4.0) mL/100 g/min. Interestingly, all 11 patients in the Schroder et al.'s study had severe head injuries (GCS of 8 or less), which likely accounted for the CBF value. Compared with this study, the GCS scores of all 10 of the patients in the present study were above 12, and none of the patients underwent any surgical interventions that would have affected the GCS scores.

We observed significant positive correlations between the distance of the contusion and perfusion of the hypodense pericontusional area in ROI 3 and ROI 6. A related study by Rosand et al. (12) revealed that the perihaematoma perfusion parameter was increased as a function of the distance from the skull. This meant that an increase in the distance of the contusion from the nearest skull vault increased/improved the perfusion. In the present study, this distance–perfusion interaction was stronger in ROI 3 compared with ROI 6.

There was a significant positive correlation between the perfusion of the hypodense pericontusional areas in ROI 4 and ROI 5. This correlation suggested that both of these areas

Table 1: Perfusion parameters of the pericontusional hypodensity in each region of interest (ROI)

Perfusion parameter	ROI 3	ROI 4	ROI 5	ROI 6
CBV (mL/100 g)	6.19 (6.94)	3.32 (3.65)	2.99 (3.76)	4.13 (6.19)
CBF (mL/100 g/min)	40.07 (25.33)	25.82 (22.11)	28.68 (33.05)	21.44 (16.39)
MTT (s)	5.34 (4.28)	5.53 (4.84)	4.07 (2.55)	3.58 (1.98)

Data are expressed as mean (SD).
Abbreviation: CBF = cerebral blood flow, CBV = cerebral blood volume, MTT = mean transit time

Table 2: Spearman correlations between the perfusion, the distance of the contusion from the nearest skull vault and the size of the hypodense pericontusional area of ROI 3, ROI 4, ROI 5, and ROI 6 (n = 10).

	PROI 3 r (P value)	PROI 4 r (P value)	PROI 5 r (P value)	PROI 6 r (P value)
PROI 3	1.000	0.102 (0.779)	-0.102 (0.779)	0.408 (0.242)
PROI 4	0.102 (0.779)	1.000	0.667 (0.035)*	0.250 (0.486)
PROI 5	-0.102 (0.779)	0.667 (0.035)*	1.000	0.583 (0.077)
PROI 6	0.408 (0.242)	0.250 (0.486)	0.583 (0.077)	1.000
Distance of contusion#	0.698 (0.025)*	0.178 (0.622)	0.285 (0.425)	0.642 (0.046)*
Size of ROI 3	-0.0175 (0.629)	0.071 (0.845)	0.249 (0.487)	0.321 (0.366)
Size of ROI 4	-0.698 (0.025)*	0.214 (0.553)	0.356 (0.312)	-0.071 (0.845)
Size of ROI 5	-0.522 (0.122)	0.213 (0.554)	0.569 (0.086)	0.284 (0.426)
Size of ROI 6	-0.393 (0.261)	0.428 (0.218)	0.428 (0.218)	0.107 (0.769)

Distance was measured from site of contusion to the nearest skull vault. * $P < 0.05$ indicates significance by Spearman correlation test.
Abbreviation: ROI = region of interest, PROI = perfusion of ROI

have a similar regional blood supply. We also observed a significant negative correlation between the size of the hypodense pericontusional area in ROI 4 and the perfusion of the hypodense pericontusional area in ROI 3. Thus, when the size of the hypodense pericontusional area increased in ROI 4, a reduction of perfusion in ROI 3 is expected. This finding also suggested the possibility of both ROI 3 and ROI 4 sharing the same branches of regional blood supply. A study by Schroder et al. (11) revealed that microvascular complications in the hypodense pericontusional area were due to external compression from the swelling of podocytic processes. Additionally, some vascular occlusion occurred because of stasis of erythrocytes and leucocytes.

In this study, we observed a strong association between the size of the contusion and the size of the hypodense pericontusional area in each ROI. These data suggested that any changes in the size of the contusion would significantly influence the size of the hypodense pericontusional area in each ROI. In this study, ROI 4 displayed the largest hypodense pericontusional area, 114.00 (SD 212.00) mm², and ROI 6 showed the smallest area, 48.80 (SD 44.28) mm². A study of CTP parameters haemorrhagic hypertensive stroke by Abdullah et al. (13), which had divided similar perihaematoma hypodensity area to ROI 4 to ROI 6, also found that ROI 4 had the largest perihaematoma area, 194.10 (SD 155.21) mm²; however, they observed the smallest area in ROI 3. The relative size of the ROI in the pericontusional area was smaller than the perihaematoma area. This might be due to a smaller surrounding mass effect by the contusion compared with the intracerebral haematoma because the contusion was smaller than intracerebral haematoma caused by haemorrhagic hypertensive stroke.

The size of hypodense pericontusional areas of each ROI were strongly related to each other, and any changes of the size of the hypodense pericontusional area in one ROI would affect the neighbouring ROIs. This could result from

Table 3: Spearman correlations between the size of the hypodense pericontusional areas of ROI 3, ROI 4, ROI 5, and ROI 6 (n = 10).

	Size of contusion r (P value)	Size of ROI 3 r (P value)	Size of ROI 4 r (P value)	Size of ROI 5 r (P value)	Size of ROI 6 r (P value)
Size of ROI 3	0.839 (0.002) **	1.000	0.716 (0.020) *	0.760 (0.011) *	0.720 (0.019) *
Size of ROI 4	0.723 (0.018) *	0.716 (0.020) *	1.000	0.827 (0.003) **	0.817 (0.004) **
Size of ROI 5	0.842 (0.002) **	0.760 (0.011) *	0.827 (0.003) **	1.000	0.875 (0.001) **
Size of ROI 6	0.717 (0.020) *	0.720 (0.019) *	0.817 (0.004) **	0.875 (0.001) **	1.000

*P < 0.05 and ** P < 0.01 indicate significance by Spearman correlation test.
Abbreviation: ROI = region of interest

a significant correlation between the size of the contusion and the size of the hypodense pericontusional area in each ROI, which might be attributed to the mass effect by the contusion that lead to hypodensity changes of pericontusional area .

The major limitation of this study was the small sample size. Some of the potential subjects had to be excluded because we were unable to analyse their CTP results due to movement during images acquisition, and some patients refused consent. A technical limitation of the present study was that our machine could only encompass a 20.0 mm thickness of the contusion. Our CTP results may have been affected because part of the contusion could not be included. In the future, a similar study with a larger sample size should be performed for better statistical analysis in order to yield results that are more significant.

Conclusion

This study showed abnormal perfusion was found in the pericontusional hypodensity area that mostly affected in ROI 6 with reduced value of CBF and CBV with normal MTT. In conclusion, this study highlighted that hypodense pericontusional areas not only reflect oedema but it also have an ischaemic component.

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Authors' Contributions

Conception and design: AHAK, WMSJ, ARIG
Provision of patients: ARIG
Obtaining of funding, collection and assembly of data, analysis and interpretation of the data, drafting of the article: AHAK
Critical revision of the article: WMSJ
Final approval of the article: AHAK, WMSJ

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