Received:
9 June 2015

Revised:
23 February 2017

Accepted:
28 February 2017

<https://doi.org/10.1259/bjr.20150472>

Cite this article as:

Ukmar M, Degrassi F, Pozzi Mucelli RA, Neri F, Mucelli FP, Cova MA. Perfusion CT in acute stroke: effectiveness of automatically-generated colour maps. *Br J Radiol* 2017; **90**: 20150472.

FULL PAPER

Perfusion CT in acute stroke: effectiveness of automatically-generated colour maps

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Objective: To evaluate the accuracy of perfusion CT (pCT) in the definition of the infarcted core and the penumbra, comparing the data obtained from the evaluation of parametric maps [cerebral blood volume (CBV), cerebral blood flow (CBF) and mean transit time (MTT)] with software-generated colour maps.

Methods: A retrospective analysis was performed to identify patients with suspected acute ischaemic strokes and who had undergone unenhanced CT and pCT carried out within 4.5 h from the onset of the symptoms. A qualitative evaluation of the CBV, CBF and MTT maps was performed, followed by an analysis of the colour maps automatically generated by the software.

Results: 26 patients were identified, but a direct CT follow-up was performed only on 19 patients after 24–48 h. In the qualitative analysis, 14 patients showed perfusion abnormalities. Specifically, 29 perfusion deficit areas were detected, of which 15 areas suggested the penumbra and the remaining 14 areas suggested the infarct. As for automatically software-generated maps, 12 patients showed perfusion abnormalities. 25 perfusion deficit areas were identified, 15 areas of which suggested the penumbra and the other 10 areas the infarct. The

McNemar's test showed no statistically significant difference between the two methods of evaluation in highlighting infarcted areas proved later at CT follow-up.

Conclusion: We demonstrated how pCT provides good diagnostic accuracy in the identification of acute ischaemic lesions. The limits of identification of the lesions mainly lie at the pons level and in the basal ganglia area. Qualitative analysis has proven to be more efficient in identification of perfusion lesions in comparison with software-generated maps. However, software-generated maps have proven to be very useful in the emergency setting.

Advances in knowledge: The use of CT perfusion is requested in increasingly more patients in order to optimize the treatment, thanks also to the technological evolution of CT, which now allows a whole-brain study. The need for performing CT perfusion study also in the emergency setting could represent a problem for physicians who are not used to interpreting the parametric maps (CBV, MTT etc.). The software-generated maps could be of value in these settings, helping the less expert physician in the differentiation between different areas.

INTRODUCTION

Neuroimaging plays a key role in the evaluation of patients with suspected ischaemic stroke. Multimodal CT imaging protocols including parenchymal imaging (unenhanced CT), vascular imaging (CT arteriography) and tissue perfusion [perfusion CT (pCT)] can be acquired within a few minutes, thereby providing information on tissue vitality, the occlusion site and the collateral circulation conditions. The pCT, in particular, can generate prompt qualitative and quantitative parameters concerning cerebral perfusion; such parameters allow a distinction between normal tissue, ischaemic but not irreversibly injured tissue ("penumbra") and the infarcted core.¹ Ischaemic "penumbra" defines

cerebral tissue that is still salvageable in spite of decreased perfusion, which can potentially be recovered using either systemic or locoregional recanalization therapies.

pCT has been enforced in association with CT arteriography and unenhanced CT in order to identify patients eligible for revascularization in the context of an acute stroke.² On this basis, the concept of "time is brain" has been challenged by the ideas of "pathophysiology is brain" and "imaging is brain".^{3,4}

Dedicated software provide pCT maps that can be used in the evaluation of the vitality of ischaemic tissues: while the

infarcted core typically shows a uniform decrease in cerebral blood flow (CBF) and cerebral blood volume (CBV), the penumbra shows a reduction of the CBF value with a preserved or even increased CBV due to the vasodilation of the precapillary arteries and venous obstruction. Recent studies have suggested that CT can provide accurate information on both supratentorial and infratentorial perfusion deficits.⁵

Recently, 256-slice CT equipment (or even 320–640) has been introduced in clinical practice, which allows the assessment of volumes reaching 16 cm, thereby enabling the evaluation of the whole brain.^{6–9} With an increase in field, we can expect a better definition of both the infarcted core and the penumbra, as well as the detection of additional lesions that might otherwise have been missed owing to lower coverage.

Several previous studies mainly focused on the use of pCT as a means of choosing the thrombolytic treatment by assessment of the existence of an ischaemic penumbra.^{10,11} There are only a few studies available in the literature that consider the accuracy of pCT in the actual diagnosis of acute stroke^{12,13} and that have evaluated the practical use of pCT as a form of diagnostic investigation for patients who resorted to the emergency department with acute stroke symptoms.¹⁴

The purpose of the present study was to assess the accuracy of pCT in the definition of the infarcted core and the ischaemic penumbra, as well as to compare the data obtained from the evaluation of parametric maps [CBV, CBF and mean transit time (MTT)] with software-generated colour maps.

METHODS AND MATERIALS

All studies were performed with one of the latest generation CT (Brilliance iCT 256 slices; Philips Medical Systems, Best, Netherlands) that allowed three-dimensional axial acquisitions on a whole brain volume with a reconstruction of the slices set to 5 mm using a series of repeated movements of the scanner table.

The acquisition protocol involves the i.v. injection of 75 ml of contrast medium, followed by a 40-ml saline bolus, both administered at an injection rate of 4 ml s⁻¹. The acquisitions were carried out every 4 s, the total duration being 60 s. The exposure parameters used were 80 kVp and 150–200 mAs.

The pCT data also provided angiographic maximum intensity projection elaborations of the arterial intracranial circulation.

Patient selection

Our study was based on a retrospective analysis aimed at identifying those patients who had reached the emergency department with a suspected acute ischaemic stroke and had undergone unenhanced CT and pCT within 4–5 h from the onset of the symptoms. The time range for pCT and direct CT follow-up was quite varied from patient to patient, with a variation ranging from 24 h to 48 h. Exclusion criteria were inadequate pCTs owing to technical reasons (excessive motion artefacts, bolus suboptimal time and insufficient post-processing). However, patients who had not undergone a direct CT follow-up were included in the study, acting as a control group.

The study was approved by the ethics committee.

Analysis of the perfusion CT images

Raw data were sent to a separate console (Extended Brilliance Workstation v. 3.0; Philips Medical System (Best, Netherlands); running brain perfusion software); there, the perfusion maps and specifically the CBF, CBV and MTT maps, were obtained after positioning a region of interest manually in correspondence to an artery and a vein.

CBF maps are generated by the ratio between CBV and MTT. This software relies on the central volume principle and uses a closed-form (non-iterative) deconvolution for the evaluation of MTT. The areas below the density–time curves are used to assess the CBV.

A qualitative evaluation of the CBV, CBF and MTT maps was performed initially (referred to as qualitative analysis hereinafter). Possible colourimetric asymmetries in the three maps and abnormalities in relation to the surrounding cerebral cortex were assessed. When a perfusional deficit was suspected in the maps, it was compared with the direct scan in order to exclude false positives (FPs) caused by beam hardening artefacts, chronic infarct or overlapping with liquor spaces.

The lesions included in the scan were divided into two categories: either the ischaemic penumbra, if an area visually showed an increased MTT or decreased CBF with preserved CBV, or the infarcted tissue, if an area visually showed an increased MTT or reduced CBF with a decreased CBV. In the event of an infarcted area (core) with an adjacent area of the ischaemic penumbra, they were considered as two separate areas. Contiguous perfusion alterations, which persisted in the axial images above, below and within the same vascular territory, were taken into consideration as a single large lesion.

Subsequently, the colour maps automatically generated by the software were evaluated. The software generated a colour map for each patient: areas with high MTT and preserved CBV appeared green, suggesting an ischaemic penumbra, whereas the areas with high MTT but decreased CBV appeared red, suggesting a stroke.

Prior to this, specific threshold values were set up in the software to calculate the green areas (MTT >7 s or 145% of the contralateral healthy area and CBV >2.0 ml/100 g) and the red areas (MTT >7 s or 145% of the contralateral healthy area and CBV <2.0 ml/100 g) as described by Wintermark *et al.*¹¹ The inclusion criteria for the software-generated lesions were the following: areas >1 cm², lesions affecting the cerebral parenchyma and lesions outside the areas affected by motion artefacts or chronic strokes present on direct scan. The lesions that did not meet these inclusion criteria were excluded. Contiguous perfusion alterations that persisted in the axial images above, below and within the same vascular territory were considered a single larger lesion.

pCT investigations in which no alterations of the qualitative and the software-generated colour maps analyses were highlighted were considered negative.

To evaluate the diagnostic accuracy of pCT in the detection of ischaemic alterations, the direct CT follow-up was re-evaluated in search of hypodense areas that could be attributed to the infarcted tissue. The areas identified on follow-up CTs were then compared with the pCT studies for an anatomic correlation.

All the data (qualitative interpretation of maps, software-generated colour map evaluation, scans and maps comparison, correspondence between the two methods) were evaluated by two experienced neuroradiologists in consensus.

Statistical analysis

As far as both analyses are concerned, lesions were considered true positives (TPs) for infarcted tissues if there was an anatomic correspondence to a new hypodense area on direct CT follow-up (no visible or barely detectable on unenhanced emergency CT scans). An FP was given to lesions in the case the infarcted tissue displayed no anatomic correspondence with the CT follow-up. A lesion was classified as false negative (FN) if a new onset hypodense lesion showed on direct CT follow-up that had not also been identified in the perfusion maps (in this case, it could be an FN for both the infarcted tissue and the ischaemic penumbra in the perfusion maps, which were considered as an FN for stroke).

Ischaemic penumbra areas, again in both analyses, were considered TP either when they evolved into infarcted tissues on direct CT follow-up or, alternatively, when these areas did not come into view on direct CT follow-up, but their location showed a concordance to the clinical onset (for example, a perfusion alteration visible on the maps at the level of the basal ganglia in a patient presenting contralateral emiplegia).

An FP area for the ischaemic penumbra in the perfusion maps was taken into consideration when there was a negative direct CT on follow-up with clinical discordance (the location of the perfusion alteration does not suggest the clinical onset of the patient).

Therefore, the following were evaluated:

- the correspondence between the lesions identified in the qualitative analysis and the lesions spotted in the software-generated colour maps
- The correspondence between the infarcted area (core) in the software-generated colour maps and the ischaemic lesion on direct CT follow-up.

The McNemar's test is used to compare qualitative analysis of the maps and automatically software-generated colour maps in highlighting infarcted areas proved later at CT follow-up. This is the most suitable test for a study with low number sample.

RESULTS

A total of 26 patients met the inclusion criteria.

5 out of the 26 patients did not show perfusion abnormalities on pCT and did not undergo a CT follow-up and 2 patients showed perfusion abnormalities on pCT but did not undergo a CT follow-up, while a direct CT was performed on the remaining 19 patients after 24–48 h. Only four out of these patients underwent a systemic thrombolysis treatment.

Qualitative analysis of the cerebral blood volume, cerebral blood flow and mean transit time parameters

5 out of the 19 patients who underwent a direct CT follow-up showed no perfusion abnormalities. Out of these five patients, two resulted as true negative (TN), whereas the remaining three were FN, given that the control CT showed an infarcted lesion.

As for the remaining 14 patients, 5 of them showed only 1 area of perfusion deficit, whereas 9 presented >1.

Specifically, 29 perfusion deficit areas were identified, 15 areas suggested the ischaemic penumbra, all of which resulted as TP, and 14 areas suggested the infarct, of which 13 areas were TP and 1 area was FP.

One infarcted lesion (in a patient already presenting another infarcted lesion that had resulted as positive on the map) had not been highlighted, thus becoming one FN. The data are summarized in (Table 1).

Automatically software-generated colour maps

Of the 19 patients who underwent CT follow-up, 7 patients showed no lesions meeting the inclusion criteria in the software-generated colour maps.

Out of these seven patients, two resulted as TN, while five resulted as FN, given that the control CT showed an infarcted lesion.

Table 1. Categorization of lesions for qualitative colour map analysis using four different parameters

19 patients with direct CT follow-up	5 patients without pCT abnormalities			2 TN
				3 FN
	14 patients with pCT abnormalities	29 areas of perfusion deficit (9 patients with >1)	15 suggesting ischaemic penumbra	15 TP
			14 suggesting infarcted area	13 TP
				1 FN ^a

FN, false negative; FP, false positive; pCT, perfusion CT; TN, true negative; TP, true positive.

^aOne FN infarcted lesion in a patient with concomitant presence of one further identified lesion on the maps.

Table 2. Categorization of lesions for automatically software-generated colour maps

	7 patients without pCT abnormalities			2 TN	
				5 FN	
19 patients with direct CT follow-up	12 patients with pCT abnormalities	25 areas of perfusion deficit (8 patients with >1)	15 suggesting ischaemic penumbra	14 TP	
				1 FP	
			10 suggesting infarcted area	9 TP	
				1 FP	
					3 FN ^a
					1 FN ^b

FN, false negative; FP, false positive; pCT, perfusion CT; TN, true negative; TP, true positive.

^aOne FN ischemic penumbra area in a patient with concomitant presence of further identified lesion on software-generated colour maps.

^bThree FN infarcted lesions in patients with concomitant presence of further identified lesions on software-generated colour maps.

Of the remaining 12 patients, the map highlighted 1 single lesion in 4 patients, while >1 lesion appeared in 8 patients (Table 2).

Specifically, 25 perfusion deficit areas were identified, 15 suggested the ischaemic penumbra, of which 14 were TP and 1 was FP, and 10 areas suggested the infarct, of which 9 were TP and 1 was FP.

Three infarcted lesions (in patients with concomitant presence of further lesions) had not been highlighted, thus becoming three FN. There was also one FN the ischaemic penumbra area. The data are summarized in (Table 2).

Concordance between colour maps and automatically generated colour maps

As for the 14 patients who showed abnormalities in the qualitative analysis and who did undergo CT follow-up, 15 out of the 29 areas with a detected perfusion deficit could be related to the ischaemic penumbra and 14 areas to the infarcted core. As for the 15 areas that could be associated with the ischaemic penumbra in the qualitative analysis, 14 of them showed concordance with the software-generated colour maps. Only one case showed no concordance where the software-generated maps did not highlight any area of the penumbra. This area (at the basal ganglia level, near another infarcted area shown by both methods) detected in the qualitative analysis but not in the software-generated maps is an FN referable to the software-generated maps, since the quantitative data turned out to be compatible with an area of the ischaemic penumbra after positioning a region of interest on this level. In at least three cases, we observed a concordance, even though the software underestimated the size of the lesion.

Of the 14 infarcted areas, 10 areas showed concordance (Figure 1); of these, only 1 case was an FP both in the qualitative and software-generated map analysis, while 4 areas displayed discordance. As for all four areas, the qualitative analysis spotted an infarcted region that was not detected by the software-generated maps. More specifically, in the first two areas, the software-generated maps showed no abnormalities affecting the pons Varolii area (Figure 2), where instead the CT follow-up highlighted the infarcted tissue. Therefore, these

lesions were TP for the qualitative analysis and FN in the software-generated maps. In another patient's case, the software-generated maps did not show any lesions affecting the putamen (therefore, an FN in the software maps and a TP for the qualitative analysis). In yet another patient, the software-generated maps underestimated the perfusion alteration, highlighting an already infarcted area (affecting the external capsule) as an ischaemic penumbra, and was therefore considered an FP of the ischaemic penumbra and an FN of an infarcted area.

In the five patients who underwent CT follow-up that did not show perfusion abnormalities compatible with recent ischaemic lesions in the colour map qualitative analysis, a complete concordance to the software-generated maps was observed; specifically, two cases were TNs and three cases were FNs (Figure 3).

20 infarcted areas were identified at the follow-up CT; 4 patients presented 2 simultaneous infarcted areas. Out of the 20 infarcted areas, 9 areas were highlighted as infarcted with both methods, 4 areas were identified as infarcted only through qualitative analysis, another 4 areas were not identified by either method and 3 infarcted areas represented the evolution of the ischaemic penumbra identified by both methods. All the areas are summarized in Table 3. 17 of these infarcted areas belong to the vascularized territory of the middle cerebral artery.

The evaluation using McNemar's test between qualitative analysis of the maps and automatically software-generated colour maps in the identification of infarcted areas proved later at CT follow-up provided a *p*-value >0.05. This means that there is no statistically significant difference between the two methods of evaluation. However, qualitative analysis sensitivity was higher (80%) than that of software-generated colour maps (60%) in the identification of infarcted areas.

Finally, in the case of the concordance between the software-generated maps and the ischaemic lesion observed on CT follow-up, the maps showed 10 red ischaemic areas; in 9 cases, there was concordance to the CT follow-up, while only 1 case showed no concordance because of the presence of an FP. Moreover, the software-generated maps did not show any

Figure 1. (a–d) Perfusion maps (a) demonstrating abnormalities on all four parameters in the head of caudate nucleus and parietal lobe on the left side: the mean transit time (MTT) map shows a wider alteration consistent with an area of ischaemic penumbra around an already infarcted area. The software-generated colour maps (b) show a good concordance, highlighting the already infarcted areas in red (head of caudate nucleus and parietal lobe) and the area of ischaemic penumbra in green. No alterations suggesting ischaemic lesions are present at initial transverse head CT image (c), while the CT follow-up image (d) shows two hypodense ischaemic lesions that correlate well with the perfusion maps. CBF, cerebral blood flow; CBV, cerebral blood volume.

perfusion alteration that would suggest an infarct in eight of the infarcted lesions visible in the control CT.

DISCUSSION

In association with CT arteriography and unenhanced CT, the use of pCT is becoming progressively more widespread and available in emergency departments for the identification of patients suitable for revascularization treatment after an acute stroke.^{3,4}

With this study, we aimed at evaluating the diagnostic accuracy of pCT in highlighting perfusion deficits by comparing the qualitative analysis of the maps of the four different parameters (CBV, CBF, MTT and time to peak) and the software-generated colour maps. The results obtained also intend to identify the role of pCT in the every day practice and management of acute strokes.

To an extent, and considering the qualitative analysis and the areas of ischaemic penumbra, the obtained value equal to 100%

of TP areas certainly has depended on the criteria stated in the section “Materials and methods”, which was used as the basis of classification of a TP area. Regarding the areas of ischaemic penumbra surrounding an area of the infarcted tissue (confirmed on follow-up CT), it was definitely more plausible to consider them as TPs. Less plausible, and surely a limit of our study, was to consider an isolated area of perfusion deficit (without associated core) as a TP for the ischaemic penumbra. It is indeed known and described in a recent study by Best et al¹⁵ that the accurate interpretation of perfusion parameters may be difficult both in the event of anatomic cerebrovascular variants and in physiological conditions determining benign oligoemia, which leads to false penumbras. As a result of this, five possible causes of penumbra are known, each of which produce a different imaging pattern: upstream flow limitation, a chronic or evolving ischaemic condition, vascular dysregulation, patient head angulation during scanning and variations in the cerebrovascular anatomy. We probably overestimated the areas of

Figure 2. (a-c) The maps (a) show decreased cerebral blood volume (CBV) and cerebral blood flow (CBF) with elevated mean transit time (MTT) and TTP in pons Varolii on the left side, consistent with infarction. The software-generated colour maps (b) do not show any alterations in pons Varolii. CT follow-up image (c) confirms infarct in the pons Varolii on the left side.

ischaemic penumbra, as reported in the existing literature, and included areas of hypoperfusion due to benign oligoemia.^{16–18} Nevertheless, in our study most areas suggesting ischaemic penumbra corresponded to quite large areas; as described in literature by Chang et al,¹⁹ there is a positive correlation between the increase in size of the lesion and its likelihood to be a TP ischaemic lesion.

Moreover, we must underline that the majority of the 19 patients who underwent CT follow-up were already manifesting a significant clinical onset, which was highly predictive of pCT positivity.

When analyzing the infarcted areas, only one case showed an FP, specifically in an area of cerebral parenchyma, right next to the Sylvian fissure and close to the cranial theca. The location, adjacent to the cranial theca and to a wide liquor space, may also have contributed to the overestimation of the lesion.

In relation to the FN infarcted areas located in the basal ganglia area, Biesbroek et al¹⁹ demonstrated how lacunar strokes represent a large amount of the FNs on pCT in an extensive meta-analysis of the diagnostic accuracy of pCT for acute strokes. Furthermore, in one case, a lesion was close to an old lesion, which may hinder its identification by the software in the qualitative evaluation on the four parameter maps as well as on the software-generated colour maps (Figure 3). One of the possible explanations lies in the incorrect evaluation of recent perfusion abnormalities.

In one subject, the FN derived from the presence of a stroke affecting the left putamen, which was deductible on direct CT as a small hypodensity. A possible explanation may be the presence of premature reperfusion on the part of adjacent collateral circulation with an omitted identification of areas with decreased CBV. We must bear in mind that the software reconstructs the images with a 5-mm thickness; if an area with decreased CBV is adjacent (above or below) to an area with normal or perhaps increased CBV due to collateral circulation, values are averaged and may thus possibly hinder its identification as an area of stroke.

As previously described in the literature, in our study, CBV also proved to be the parameter with the greatest sensitivity for the infarcted core, while MTT and time to peak have a high sensitivity but low specificity for perfusional deficits.^{20,21}

In the software-generated colour maps, we observed five FN studies; in three cases, the software-generated maps, as well as the qualitative analysis, showed no lesions in the basal ganglia area, two lacunar strokes and an ischaemic lesion close to a previous stroke. As far these aspects are concerned, we make reference to the observations made previously for the qualitative analysis.

In the other two studies, the software-generated maps did not show two lesions affecting the pons Varolii level (Figure 2) which, on the other hand, were highlighted by the qualitative analysis. As previously described in the existing literature, the perfusion software is markedly less reliable in the elaboration of data at the infratentorial level.²²

In a recent case study by Ho et al,² a smaller quantity of FN studies was found in the software-generated maps than in our study. This is most likely owing to the fact that we obtained whole-brain coverage, while in the Ho et al study,² the coverage was equal to 4 cm and focused on the basal ganglia area and thus did not include the brain stem, where we know the software does not elaborate data reliably. It is indeed reported in the literature how 256-slice equipment allows an almost complete coverage of the brain, also enabling the study of the infratentorial region. Nonetheless, more artefacts leading to FNs can occur at this level.²²

Furthermore, there were other FN areas in patients with the concurrent presence of TP areas. Again, in two patients, the software-generated maps did not recognize any abnormalities at the basal ganglia level (putamen); in one patient, the qualitative analysis was positive. In these cases, the explanation may be the premature reperfusion on the part of the adjacent collateral circulation with no visualization of decreased CBV areas.

As for the 14 TP areas of the penumbra out of the 15 penumbra areas described, they were probably overestimated, as

Figure 3. (a-d) The perfusion maps (a) demonstrating a small perfusion deficit in the basal ganglia on the left side; the change, however, correlates with a chronic stroke on direct scan. The software-generated colour maps (b) show a small green area which, in this case too, correlates with the chronic ischaemic area, thus not meeting the inclusion criteria. The initial CT image (c) shows the chronic ischaemic area in the basal ganglia on the left side (already visible in previous examinations). However, the CT follow-up image (d) shows the presence of a new lesion next to the chronic lesion. This was a false-negative perfusion CT study. CBF, cerebral blood flow; CBV, cerebral blood volume; MTT, mean transit time.

in the qualitative analysis. We observed how the software-generated maps underestimate the size of the lesion in part of the patients, as compared with the qualitative analysis, irrespective of the cerebral region. In one patient, once again in the basal ganglia area, the software-generated map underestimated the infarcted lesion (already slightly visible on direct CT as a hypodensity), highlighting it as an area of the penumbra (green), whereas in the qualitative analysis, it already proved to be an infarcted tissue. Probably, this case too was due to partial volume effects caused by a reconstruction thickness of 5 mm, in which small areas with an already decreased CBV are masked by adjacent areas of collateral circulation. In our study, these aspects were particularly evident at the basal ganglia level and the software-generated maps were less sensitive in relation to them, as compared with the qualitative analysis of the maps of the four different parameters.

Regarding the FP infarcted area, only one case presented as an FP, which was an FP according to the qualitative analysis as well. To be precise, it was the area of cerebral parenchyma right next to the Sylvian fissure and close to the skull, as described earlier.

In many cases, the software-generated maps showed infarcted areas or areas of ischaemic penumbra that were actually overlapping with chronic ischaemic lesions already described on direct CT; as delineated in the exclusion criteria, these lesions had to be discarded, thus underlining how extremely important it is to always correlate the maps with the unenhanced CT so as not to incur FPs.

A very high percentage of the TP ischaemic penumbra (93%) was also found in the software-generated maps and was certainly overestimated data, as in the case of the qualitative analysis. As already described in the qualitative analysis of the 19 patients

Table 3. Infarcted areas identified at follow-up CT and their correlation to perfusion CT images

Nº	Location of infarcted areas at follow-up CT	QA; SGM
1	Insula ^a	QA: penumbra (TP)
		SGM: penumbra (TP)
2	Parietal–temporal ^a	QA: infarct (TP)
		SGM: infarct (TP)
3	Basal ganglia ^a	QA: negative (FN)
		SGM: negative (FN)
4	Pons	QA: infarct (TP)
		SGM: negative (FN)
5	Frontal–parietal ^a	QA: infarct (TP)
		SGM: infarct (TP)
6	Pons	QA: infarct (TP)
		SGM: negative (FN)
7	Parietal ^a	QA: penumbra (TP)
		SGM: penumbra (TP)
8	Putamen ^a	QA: negative (FN)
		SGM: negative (FN)
9	Basal ganglia ^a	QA: negative (FN)
		SGM: negative (FN)
10	Putamen–insula ^a	QA: infarct (TP)
		SGM: infarct (TP)
11	Putamen ^a	QA: infarct (TP)
		SGM: negative (FN)
12	Thalamus	QA: negative (FN)
		SGM: negative (FN)
13	Parietal ^a	QA: infarct (TP)
		SGM: infarct (TP)
14	Caudate nucleus ^a	QA: infarct (TP)
		SGM: infarct (TP)
15	External capsule ^a	QA: infarct (TP)
		SGM: penumbra (FN)
16	Caudate nucleus ^a	QA: infarct (TP)
		SGM: infarct (TP)
17	Parietal ^a	QA: penumbra (TP)
		SGM: penumbra (TP)
18	Temporal ^a	QA: infarct (TP)
		SGM: infarct (TP)
19	Basal ganglia–external capsule ^a	QA: infarct (TP)
		SGM: infarct (TP)
20	Frontal–parietal ^a	QA: infarct (TP)
		SGM: infarct (TP)

FN, false negative; QA, qualitative analysis; SGM, software-generated map; TP, true positive.

^aAreas belong to the vascularized territory of the middle cerebral artery.

who had undergone CT follow-up, the majority was already manifesting a significant clinical onset, which was highly predictive of CT positivity.²

When analyzing the concordance between the qualitative analysis of the colour maps and the software-generated maps in reference to ischaemic penumbra areas, in one patient no concordance was highlighted; this was probably owing to the fact that the examination was slightly invalidated by motion artefacts and the software was therefore less reliable in the elaboration of the software-generated maps. It is worth remembering that among the most frequent causes of FN in the software-generated maps, there are small lacunar strokes, the coverage of the cerebral parenchyma and the motion artefacts.¹⁹

As for the areas of the ischaemic penumbra, an almost complete concordance was obtained, even though the software-generated maps usually underestimate the size in comparison with the qualitative analysis. In our study, perfusion deficits were all quite extensive; they were therefore well represented in both analyses, with only a few cases of lacunar strokes that were not detected by either analysis. Clinical records with a greater amount of smaller ischaemic lesions would have possibly granted the qualitative analysis a higher sensitivity in their detection.

As far as the infarcted areas were concerned, the concordance was smaller; four lesions showed discordance (two lesions at the pons, one at the putamen and one at the external capsula), and, as previously mentioned, there was a greater sensitivity in the qualitative analysis of the maps of the four different parameters in highlighting the infarcted areas affecting the brain stem and the basal ganglia level, in comparison with the software-generated maps.

These results require confirmation by record upgrading; however, preliminary data have provided a trend in favour of qualitative analysis (sensitivity: 80% vs 60%) in highlighting infarct lesions.

CONCLUSION

In this study, we demonstrated how pCT has a good diagnostic accuracy in the identification of acute vascular ischaemic lesions.

The limits of identification of the lesions mainly lie at the pons level and in the basal ganglia area. From a management, prognostic and therapeutic point of view, all these areas are, however, hardly salvageable, since they are vascularized by the terminal arteries and, therefore, prematurely infarcted. Instead, pCT allowed us to distinguish the infarcted tissue (core) from the ischaemic areas (penumbra) in the remaining areas. Therefore, it proved useful in the recognition of the tissues that were salvageable after appropriate therapy.

The use of 256-slice CT essentially allows the study of the whole parenchyma, thus enabling a correct assessment of the extension of the lesions, even though with some limits at the infratentorial level.

Our study also demonstrated how the use of software-generated maps is favourable in the evaluation of ischaemic lesions in emergency conditions, as well as being particularly useful for operators with less expertise. In fact, software-generated pathological areas, green (penumbra) and red (infarcted tissue), respectively, proved to be more easily recognizable as compared with the surrounding normal tissue. Moreover, there is a greater definition between the penumbra and the infarcted area. As a whole, the overall perception of the suffering region is more immediate, thus allowing a higher rapidity and a greater interpretation ease for less skilled operators.

Furthermore, software-generated maps allow a higher intra-observer and interobserver reproducibility.

However, we cannot disregard the assessment of the maps of the single parameters for a more accurate evaluation. In fact, qualitative analysis has proven to be more sensitive in the detection of perfusion lesions, even if owing to low number of samples, we have not provided a statistically significant difference between the two methods.

The exact quantification of ischaemic damage and especially the evaluation of still viable cerebral parenchyma is important for the choice of treatment. CT perfusion offers the possibility to discriminate between the normal tissue, penumbra (ischaemic but salvageable tissue if treated in time) and infarcted tissue.

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