Perfusion CT in Patients With Spontaneous Lobar Intracerebral Hemorrhage

Effect of Surgery on Perihemorrhagic Perfusion

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Background and Purpose—The aim of the present study was to investigate cerebral hemodynamics in patients requiring surgical treatment for lobar intracerebral hemorrhage.

Methods—Twenty patients who underwent surgery to remove a lobar spontaneous intracerebral hemorrhage were scanned before and after surgery using perfusion CT mapping. Mean transit time, time to peak of the residue function, cerebral blood volume, and cerebral blood flow were measured in 4 defined regions of interest.

Results—Preoperatively, time to peak of the residue function, cerebral blood volume, and cerebral blood flow were significantly impaired in the perihemorrhagic zone as compared with the ipsilateral and contralateral hemisphere. Perihematomal perfusion improved significantly after clot evacuation and there was no difference in time to peak of the residue function, cerebral blood flow, and cerebral blood volume values between the perihemorrhagic zone and ipsilateral as well as contralateral hemisphere after surgical treatment.

Conclusions—Our findings illustrate distinct perihemorrhagic perfusion impairments in a selected patient population with lobar intracerebral hemorrhage as evident by impaired time to peak of the residue function, cerebral blood flow, and cerebral blood volume and their improvement after early surgical treatment. Whether these early improvements in hemodynamic measurements may influence secondary neuronal injury and ultimately clinical outcome, as opposed to the natural course of spontaneous intracerebral hemorrhage remains unclear. (Stroke. 2012;43:759-763.)

Key Words: intracerebral hemorrhage | perfusion CT | surgical treatment

Spontaneous intracerebral hemorrhage (SICH) accounts for 10% to 20% of all strokes and is characterized by high morbidity and mortality.1 To date, the optimal management of SICH remains uncertain and therefore additional pathophysiological knowledge is needed.2-4 In this respect, cerebral perfusion imaging studies, either based on MRI or CT technology, have gained importance over the last decade for patients with SICH.5-7 The main use of such studies is to identify tissue at risk of secondary neuronal injury, especially in brain tissue surrounding the hematoma.8 The identification of critical perihematomal hypoperfusion might facilitate decision-making in the treatment of these patients. The majority of recent perfusion studies demonstrate perihemorrhage hypoperfusion for deep SICH, but there are still conflicting interpretations of these findings.6,9,10 Additionally, little is known about the impact of early surgical treatment on perihemorrhagic perfusion in patients with space-occupying lobar SICH.

Therefore, we investigated the time course of cerebral hemodynamics in patients who underwent surgical treatment for lobar SICH. Hemodynamics were measured using perfusion CT (PCT) both before and early after surgical hematoma removal.

Subjects and Methods

Data Acquisition

All patients admitted to the Heinrich-Heine University Medical Centre with ischemic or hemorrhagic (intracerebral or subarachnoid hemorrhage) stroke undergo standard CT and PCT imaging. This retrospective analysis includes data from 20 patients, who underwent surgical treatment for space-occupying, lobar SICH and had received PCT scanning according to the stroke imaging protocol. The decision for surgical treatment was made independently of, and before, inclusion in the present analysis. Criteria for inclusion were: (1) patients >18 years; (2) medical and neurological state amenable to follow-up imaging; (3) intracerebral hematoma present on initial nonenhanced CT; (4) symptom onset <12 hours at the time of admittance to our department; and (5) informed consent obtained for scientific data analysis from the patient or a legal representative. Criteria for exclusion from the study were: (1) renal insufficiency or history of contrast agent allergy; (2) pregnancy; (3) clinical instability or radiological signs of herniation; (4) deep thalamic/putaminal or
Definition of PHZ
The outer margin of the PHZ (ROI A) was defined based on overlap between the CT and T_max maps and the following characteristics: (1) the perihematomal area on CT; and (2) a T_max deviation of more than twice the SD of mean T_max values in the healthy contralateral mirrored zone (ROI B). The inner margin of the PHZ (ROI A) was defined in correspondence to intracerebral hemorrhage location on CT and after exclusion of 0 perfusion values within the hematoma (Figure 1).

All PCT values within the medial and lateral margin in ROI A were then expressed as mean values. Identical ROIs were applied for postoperative PCT measurements.

Statistical Analysis
Statistical analyses were performed using SPSS Version 15.0.1 (SPSS Inc, Chicago, IL). For each test, P<0.05 was used as the level of significance. For independent samples with metric variables, the t test was used to determine the difference between the mean values. If sample variances differed significantly, Welch adaptation of the t test was used. For related samples such as when comparing pre- and postoperative values, the paired t test was used. Finally, Pearson product-moment correlation was used to investigate the relation of PCT impairment to hematoma volume.

Results
A total of 40 PCT studies from 20 patients (8 females and 12 males), before and after the surgical removal of the hematoma, were included and pooled in the final analysis. The mean age within the cohort was 59.5±11.2 years (mean±SD). Hematoma volume was 68.5±35.9 mL (mean±SD). The intracerebral hemorrhage location was: frontal (n=7), temporal (n=6), parietal (n=5), and occipital (n=2). The intracerebral hemorrhage side was the left hemisphere in 12 patients and the right hemisphere in 8. There were no imaging- or contrast-agent-related complications. Furthermore, the PCT imaging process did not slow the treatment sequence: median time span and interquartile range from admission until initial PCT scan (PCT 1) was 0.35 hours (interquartile range, 18.25 minutes), 2.10 hours from PCT 1 (interquartile range, 50.75 minutes) until surgery, and 4.58 hours (interquartile range, 195.5 minutes) after surgery until PCT 2. Median length of surgery was 3:24 hours.

Focal PCT Analysis in ROI A (PHZ) Compared With ROI B (Contralateral Zone)
The initial T_max measurements were significantly (P<0.0001) prolonged in ROI A (4.1 seconds; 95% CI, 3.64–4.55) as compared with ROI B (2.41 seconds; 95% CI, 2.07–2.75), and they improved significantly postoperatively in ROI A (P<0.0001). Postoperatively, there was no difference (P=0.2025) between the 2 ROIs (A: 2.36 seconds; 95% CI, 1.72–2.99; B: 1.90 seconds; 95% CI, 1.72–2.99). CBF and CBV values were significantly decreased in ROI A (59.18 mL/min/100 g; 95% CI, 46.16–72.21; P=0.0057 and 21.10 mL/min; 95% CI, 17.08–25.11; P=0.0148, respectively) as compared with ROI B (88.2 mL/min/100 g; 95% CI, 72.1–104.2 and 28.63 mL/min; 95% CI, 23.95–33.3, respectively). After hematoma removal, CBF and CBV values increased (P=0.01 and P=0.039, respectively) in ROI A as compared with ROI B.
with preoperative measurements, and CBV and CBF values adjusted between the 2 ROIs (P = 0.6083 and P = 0.7179, respectively). Mean transit time values were elevated in both ROIs and did not differ between ROI A and ROI B (3.92 seconds; 95% CI, 3.41–4.44 and 3.69 seconds; 95% CI, 3.35–4.03, respectively; P = 0.4307) initially or after surgical hematoma removal (P = 0.7972; Figures 2 and 3). Preoperative impairment of T_max in ROI A was correlated with hematoma volume (P = 0.048, R = 0.448). This correlation was no longer evident after hematoma evacuation (P = 0.551, R = −0.142).

**Hemispheric PCT Analysis in ROI C (Ipsilateral Hemisphere Excluding the Hematoma and PHZ) and ROI D (Contralateral Hemisphere) Before and After Hematoma Removal**

Hemispheric T_max values were increased in the hemisphere bearing the hematoma (ROI C: 2.97 seconds; 95% CI, 2.31–3.63) before surgery as compared with the contralateral hemisphere (ROI D: 2.16 seconds; 95% CI, 1.57–2.74). This difference approached statistical significance (P = 0.061). After hematoma removal, T_max values nearly matched in both ROIs (P = 0.88). CBF in ROI C and in ROI D (99.6 mL/min/100 g; 95% CI, 73.11–126.1 and 96.25 mL/min/100 g; 95% CI, 72.67–119.9) did not differ before or after hematoma removal (P = 0.435 and P = 0.7363, respectively). CBV was 32.58 mL/min (95% CI, 26.08–39.08) in ROI C and 36.74 mL/min (95% CI, 26.67–46.81) in ROI D initially and, after surgery, adapted between the ipsilateral and contralateral hemisphere (ROI C: 30.16 mL/min; 95% CI, 24.53–35.8; ROI D: 32.05 mL/min; 95% CI, 23.37–40.83, respectively; P = 0.7075). Mean transit time was globally elevated in both hemispheres initially and, similar to the focal measurements, did not improve in either hemisphere after surgical hematoma removal (ROI C: P = 0.62; ROI D: P = 0.47).

**Intrahemispheric Analysis of ROI A (PHZ) and ROI C (Ipsilateral Hemisphere Excluding the Hematoma and PHZ)**

T_max was primarily impaired in the PHZ (ROI A: 4.10 seconds; 95% CI, 3.41–4.44 versus ROI C: 2.97 seconds; 95% CI, 2.31–3.63; P = 0.0056). After hematoma removal, T_max improved significantly in ROI A and there was no difference between the ROIs (P = 0.6321). Before treatment, CBF values in ROI A were significantly (P = 0.008) decreased compared with ROI C (59.18 mL/min/100 g; 95% CI, 46.16–72.21 and 99.60 mL/min/100 g; 95% CI, 73.11–126.1, respectively). After hematoma evacuation, there was significant improvement of CBF in the PHZ and no difference compared with the remaining hemisphere (ROI A versus C: P = 0.9). CBV values followed the same trend (CBV before surgery: ROI A: 21.10 mL/min; 95% CI, 17.08–25.11 versus ROI C: 32.58 mL/min; 95% CI, 26.08–39.08; P = 0.004). After surgical hematoma removal, there were no significant differences between the CBV values in ROI A and C (P = 0.715). Mean transit time values did not differ significantly within the affected hemisphere before (P = 0.696) and after hematoma removal (P = 0.813; Figure 4).
Using PCT, this study found that $T_{\text{max}}$, CBF, and CBV were impaired in the PHZ when compared with the remaining ipsilateral hemisphere and the contralateral equivalent zone. Furthermore, impaired perihematomal perfusion resolved after clot evacuation and there was no postoperative difference in $T_{\text{max}}$, CBF, or CBV between the ROIs. The correlation between preoperative perihematomal $T_{\text{max}}$ impairment and hematoma volume was no longer evident after surgery.

PCT is increasingly used to investigate perihematomal perfusion in patients with SICH. Previous studies illustrated a gradient of decreasing cerebral perfusion toward intracerebral hematoma, that is, in the PHZ. Depressed PCT parameters around SICH are believed to be a consequence of edema, increased local tissue pressure, and the presence of toxic blood products. These data are supported by experimental animal studies.

However, PCT has not yet been used to investigate early changes in cerebral perfusion after surgery for lobar SICH. Additionally, the majority of previous PCT studies focused on distinctively smaller intracerebral hematoma (range of mean hematoma volume, 17.5–26.8 mL) compared with mean hematoma volumes in our patient population ($68.5\pm45.5$ mL SD). The data from our study may not define a threshold for surgical treatment based on PCT measurements because a much larger patient collective with lobar SICH would be necessary to correlate patient outcome data with hemodynamic parameters.

In summary, our findings demonstrate early improvement of CT-based perihematomal perfusion parameters after acute surgical treatment. Our data are consistent with the previous assumption that lobar intracerebral hematomas can lead to increased local pressure with subsequent compression of the microvasculature, translating in initial $T_{\text{max}}$, CBF, and CBV impairment. Whether the early improvement of perfusion parameters after surgical hematoma removal may prevent secondary mechanic, ischemic, or toxic damage in the perihemorrhagic zone remains unclear. Future prospective studies on lobar SICH should investigate PCT measurements with a
focus on $T_{\text{max}}$ throughout the course of treatment in correlation with clinical characteristics.

Conclusions

Our findings illustrate distinct perihemorrhagic perfusion impairments in a selected patient population with lobar intracerebral hemorrhage as evident by impaired $T_{\text{max}}$, CBF, and CBV and their improvement after early surgical treatment. Whether these early improvements of hemodynamic measurements may influence secondary neuronal injury and, ultimately, poor clinical outcome, as opposed to the natural course of SICH, remains unclear.

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Disclosures

None.

References

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