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

Spee4ntaneous intracerebral hemorrhage (SICH) accounts for 10% to 20% of all strokes and is characterized by high morbidity and mortality. To date, the optimal management of SICH remains uncertain and therefore additional pathophysiological knowledge is needed.

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. The main use of such studies is to identify tissue at risk of secondary neuronal injury, especially in brain tissue surrounding the hematoma. The identification of critical perihematoma hypoperfusion might facilitate decision-making in the treatment of these patients. The majority of recent perfusion studies demonstrate perihematoma hypoperfusion for deep SICH, but there are still conflicting interpretations of these findings. 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...
Focal PCT Analysis in ROI A (PHZ) Compared With ROI B (Contralateral Zone)

The initial $T_{\text{max}}$ 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 ($P=0.039$, respectively) as compared with ROI B ($P=0.0057$ and 21.10 mL/min; 95% CI, 17.08–25.11; $P=0.0148$, respectively) as expected. The difference between the mean values was highly significant ($P<0.0001$) between the 2 ROIs (A: 2.36 seconds; 95% CI, 2.07–2.75; 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. These findings suggest that the impact of focal ischemia not only differs among ROIs but also with time.
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\text{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\text{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 E: 2.16 seconds; 95% CI, 1.57–2.74). This difference approached statistical significance (P = 0.061). After hematoma removal, T\text{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 = 0.061). 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\text{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\text{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 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).
Discussion

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 hematomas, 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 hematomas (range of mean hematoma volume, 17.5–26.8 mL) compared with mean hematoma volumes in our patient population (68.5±45.5 mL SD). PCT uses a mathematical model to measure tissue perfusion and the numeric values remain to be validated in the context of SICH. Additionally, we proposed a combined mathematical and radiological definition of the PHZ. The advantage of this method is that interindividual (ie, variation in the extent of PHZ due to hematoma features) and intraindividual (ie, variation in the extent of the PHZ over time) differences in PHZ extension are accounted for. Furthermore, the PHZ in the acute phase of SICH can be difficult to outline on CT, increasing the risk of inclusion of artificially depressed PCT values, especially in the vicinity of the hematoma. Hence, the assumption of a size-steady PHZ (ie, 1 cm) in PCT, without confirmation by MRI T2 or fluid-attenuated inversion recovery images, might be false for larger intracerebral hematomas. The interpretation of our results mainly relies on knowledge derived from animal models or stroke studies, because the literature on hemodynamic assessment of surgically treated patients is scarce. 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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