Additional intraventricular hemorrhage (IVH) has been identified as a strong and independent negative prognostic predictor causing higher mortality, morbidity, and disability after spontaneous intracerebral hemorrhage (ICH).1–3 Several different pathophysiological mechanisms seem to contribute to this deleterious effect. Clotting of the aqueduct leads to the most severe complication of IVH, namely, acute obstructive hydrocephalus, which has been shown to further worsen the prognosis in such patients.4 Apart from this injury mechanism, ventricular blood has been shown to exert a mass effect and reduce cerebral blood flow in the periventricular brain tissue in animal models of IVH.5,6 Especially the so-caused damage of brain stem structures may explain the prognostic significance of third and fourth ventricle blood volume, demonstrated in clinical studies.7,8 Finally, blood and its breakdown products cause inflammation of the ependymal layer and the subependymal brain tissue,5,6,9 and also inflammation and fibrosis of the arachnoid mater, thereby leading to a delayed communicating hydrocephalus.10

Considering those pathomechanisms, there seems to be a clear rationale for the fast removal of blood and blood breakdown products from the ventricular system. Intraventricular fibrinolysis (IVF), that is, the administration of fibrinolytic agents as recombinant tissue plasminogen activator (rtPA) into the ventricles, seems to be an emerging and promising treatment strategy,11 which is currently being investigated in a large phase III multicenter trial (Clot Lysis: Evaluating Accelerated Resolution of Intraventricular Hemorrhage [CLEAR-III]).12,13

In the context of IVF, rtPA toxicity has been a source of concern because animal studies have shown that rtPA may exert dose-dependent proedematous and neurotoxic effects.6 Moreover, a recent small retrospective clinical study has indicated that there may be an increase in perihemorrhagic edema (PHE) after ICH. rtPA doses used in the current study seem to be safe regarding PHE. (Stroke. 2013;44:362-366.)

Key Words: intracerebral hemorrhage ■ intraventricular fibrinolysis ■ intraventricular hemorrhage ■ perihemorrhagic edema ■ recombinant tissue-type plasminogen activator ■ semiautomatic volumetry ■ X-ray computed tomography

A
dditional intraventricular hemorrhage (IVH) has been identified as a strong and independent negative prognostic predictor causing higher mortality, morbidity, and disability after spontaneous intracerebral hemorrhage (ICH).1–3 Several different pathophysiological mechanisms seem to contribute to this deleterious effect. Clotting of the aqueduct leads to the most severe complication of IVH, namely, acute obstructive hydrocephalus, which has been shown to further worsen the prognosis in such patients.4 Apart from this injury mechanism, ventricular blood has been shown to exert a mass effect and reduce cerebral blood flow in the periventricular brain tissue in animal models of IVH.5,6 Especially the so-caused damage of brain stem structures may explain the prognostic significance of third and fourth ventricle blood volume, demonstrated in clinical studies.7,8 Finally, blood and its breakdown products cause inflammation of the ependymal layer and the subependymal brain tissue,5,6,9 and also inflammation and fibrosis of the arachnoid mater, thereby leading to a delayed communicating hydrocephalus.10

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deterioration and herniation.\textsuperscript{16,17} We aimed to investigate the effect of intraventricular rtPA on PHE evolution after ICH and compared the course of PHE in a large retrospective cohort of patients treated with IVF and controls matched for ICH volume.

**Methods**

**Patient Selection**
The study was approved by our local ethics committee. Patients treated between January 2006 and October 2011 were identified retrospectively from our institutional ICH database. The cohort treated with IVF (IVF group) consisted of patients with spontaneous ICH <40 mL and secondary IVH, initially causing acute obstructive hydrocephalus. Controls were selected among patients with spontaneous ICH and secondary IVH without obstruction of the third and fourth ventricles, who did not receive IVF (control group). For better comparison of the course of PHE between the 2 groups, patients were matched for initial ICH volume (±5 mL). Spontaneous ICH was diagnosed when no other cause than hypertension or amyloid angiopathy was found. To allow sufficient evaluation of the time course of PHE in both groups, only patients who received >3 computed tomography (CT) scans covering at least the first 10 days of treatment were included in the analysis.

**Neuroimaging and Assessment of PHE and ICH Volume**
Neuroimaging was performed on a fourth-generation CT scanner (Somatom 64, Somatom AS+, Siemens Healthcare, Erlangen, Germany). Each CT scan consisted of 10 to 12 slices of 4.8 mm thickness for the skull base and 10 to 12 slices of 7.2 mm thickness for the cerebrum. CT images were acquired using the orbito-meatal plane. Absolute volumes of ICH and PHE were obtained using a semiautomated volumetric algorithm as described elsewhere.\textsuperscript{18} The course of PHE was assessed on CT scans performed in the course of treatment. Different time points were merged to time clusters for better comparison between the 2 groups (day 1, days 2–3, 4–6, 7–9, and 10–12). Relative PHE (rPHE) was calculated as a ratio of PHE volume and initial ICH volume.

**Intraventricular Hemorrhage**
According to our institutional protocol, IVF was performed in patients with spontaneous ICH <40 mL and obstructive hydrocephalus caused by IVH, who were treated with an external ventricular drain (EVD). IVF was started at the earliest 12 hours after symptom onset and 6 hours after EVD insertion. No patient was included with IVF starting later than 48 hours after symptom onset. Before treatment, the position of the ventricular catheter was confirmed by CT. rtPA was applied via the EVD under sterile conditions. After application of the fibrinolytic agent, the EVD was clamped for 30 to 60 minutes and then reopened. Intracranial pressure was monitored continuously during the clamping time. Until July 2008, a single dose of 4 mg rtPA and a dosing interval of 12 hours up to a maximum cumulative dose of 20 mg rtPA were used. Starting in August 2008, the dosing regimen was altered according to the preliminary results of the Clot Lysis Evaluation Accelerated Resolution of Intraventricular Hemorrhage trial (CLEAR-IVH; single dose of 1 mg rtPA, dosing interval 8 hours, maximum cumulative dose 12 mg rtPA).\textsuperscript{19} IVF was discontinued as soon as the third and fourth ventricles were no longer obstructed with ventricular blood, or if the maximum cumulative dose of rtPA was reached. During IVF, daily CT scans were performed to evaluate the resolution of ICH, Lumbar drainage (LD) was inserted as soon as the third and fourth ventricles had been cleared from blood if clamping of EVD was not possible over a period of at least 24 hours without intracranial pressure elevation, as described previously in detail.\textsuperscript{10}

**Assessment of Ventriculitis**
In all patients treated with EVD or LD, cerebrospinal fluid (CSF) was examined routinely every other day or when signs indicating an infection (eg, leukocytosis or fever of unknown origin) occurred. Ventriculitis was diagnosed according to the criteria described by Lozier et al\textsuperscript{20} if low CSF glucose level, high CSF protein, and CSF pleocytosis was found. Antibiotic therapy was started even if CSF culture was negative. Thus, a retrospective distinction between aseptic and infective ventriculitis was not sufficiently possible.

**Statistics**
Data are presented as mean±SD if not indicated differently. Statistical analyses were performed using the IBM SPSS Statistics 19 software package. A 2-tailed t test was used to compare differences between patient characteristics. A repeated-measure ANOVA was performed to examine the influence of IVF on rPHE at different time points. A multiple regression analysis was run to identify the impact of different patient characteristics on rPHE as well as the impact of cumulative IVF dose on rPHE. Representatively, regression and correlation analysis was performed for data of day 1, days 4–6, and days 10–12. A P value <0.05 was considered statistically significant.

**Results**

**Baseline Clinical Data**
Between January 2006 and October 2011, a total of 64 patients with ICH, IVH, and obstructive hydrocephalus who were treated with IVF were identified from our institutional ICH database. Sixty-four controls were selected from the remaining 246 patients with ICH and IVH using ICH volume matching. The matching algorithm resulted in similar mean ICH volumes in both groups (IVF group: 20.01±17.5 mL; control group: 20.08±17.1 mL). Time from symptom onset to initial CT was 6.0±6.0 hours in the IVF group and 6.1±6.3 hours in the control group (P=0.89). Secondary rebleeding with hematoma expansion of >30% of the initial hematoma volume occurred in 11 patients (17.2%) of the IVF group and in 14 patients (21.9%) of the control group (P=0.51). In the IVF group, 5 patients receiving 1 mg of intraventricular rtPA per application (14.7%) and 6 patients (20%) receiving 4 mg of rtPA suffered a hematoma expansion of >30% (P=0.59). There was no relationship between cumulative dose of ventricular rtPA and the occurrence of a hematoma expansion of >30% (R²=0.001; P=0.80). Clinical and radiological characteristics are summarized in Table 1.

**Course of PHE**
As demonstrated in Figure 1, rPHE increased significantly over time in both groups (F[1,63]=33.79; P<0.001) and showed an almost identical course in patients treated with IVF and controls (F[1,63]=0.39; P=0.844). Maximum rPHE was reached after 9.7±5.8 days after onset in the IVF group and after 9.2±5.5 days in the control group (P=0.97). Per definition, absolute PHE volume and absolute ICH volume account for rPHE. Absolute PHE volume at admission was strongly correlated with absolute ICH volume at admission (R²=0.476; P<0.001). None of the other clinical characteristics significantly accounted for rPHE. Thus, absolute ICH volume remains an exclusive factor accounting for rPHE. IVF had no influence on rPHE at any time point (Table 2). The evolution of rPHE (changes in rPHE in correlation to rPHE at admission [ΔrPHE]) within the examined time course was not influenced by IVF either (mean ΔrPHE between
**Table 1. Clinical, Demographic, and Radiological Characteristics**

<table>
<thead>
<tr>
<th></th>
<th>IVF Group (n=64)</th>
<th>Control Group (n=64)</th>
<th>P  Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (mean±SD), y</td>
<td>64±10.9</td>
<td>69±15.1</td>
<td>0.04</td>
</tr>
<tr>
<td>Men (n)</td>
<td>34</td>
<td>39</td>
<td>0.38</td>
</tr>
<tr>
<td>NIHSS (median [IQR])</td>
<td>21 (24)</td>
<td>13 (15.5)</td>
<td>0.001</td>
</tr>
<tr>
<td>GCS (median [IQR])</td>
<td>8.5 (11)</td>
<td>13 (4.75)</td>
<td>0.001</td>
</tr>
<tr>
<td>mRS (median [IQR])</td>
<td>1 (2)</td>
<td>1 (1)</td>
<td>0.93</td>
</tr>
<tr>
<td>ICH lobar (n)</td>
<td>3</td>
<td>23</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ICH ganglionic (n)</td>
<td>59</td>
<td>33</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ICH cerebellar/brain stem (n)</td>
<td>2</td>
<td>8</td>
<td>0.02</td>
</tr>
<tr>
<td>Statin use (n)</td>
<td>14</td>
<td>8</td>
<td>0.16</td>
</tr>
<tr>
<td>Hypertonia (n)</td>
<td>59</td>
<td>60</td>
<td>0.74</td>
</tr>
<tr>
<td>Warfarin use (n)</td>
<td>9</td>
<td>15</td>
<td>0.20</td>
</tr>
<tr>
<td>Aspirin use (n)</td>
<td>18</td>
<td>18</td>
<td>1.00</td>
</tr>
<tr>
<td>Aspirin + Dipyridamole use (n)</td>
<td>0</td>
<td>1</td>
<td>0.32</td>
</tr>
<tr>
<td>Osmotic therapy (Mannitol; n)</td>
<td>30</td>
<td>25</td>
<td>0.37</td>
</tr>
<tr>
<td>Hypothermia (n)</td>
<td>11</td>
<td>9</td>
<td>0.57</td>
</tr>
<tr>
<td>Use of EVO (n)</td>
<td>64</td>
<td>31</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Duration of external ventricular drainage (mean±SD), d</td>
<td>8.8±8.0</td>
<td>9.2±5.7</td>
<td>0.81</td>
</tr>
<tr>
<td>Use of lumbar drainage (n)</td>
<td>44</td>
<td>14</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Duration of lumbar drainage (mean±SD), d</td>
<td>7.0±5.0</td>
<td>5.8±2.6</td>
<td>0.38</td>
</tr>
<tr>
<td>Ventriculitis (n)</td>
<td>5</td>
<td>2</td>
<td>0.245</td>
</tr>
<tr>
<td>Cumulative dose of IV-rtPA (mean±SD), mg</td>
<td>8±6.01</td>
<td>0</td>
<td>...</td>
</tr>
<tr>
<td>ICH volume d1 (mean±SD), mL</td>
<td>20.01±17.5</td>
<td>20.08±17.1</td>
<td>...</td>
</tr>
<tr>
<td>PHE volume d1 (mean±SD), mL</td>
<td>16.7±11.4</td>
<td>18.1±15.5</td>
<td>0.46</td>
</tr>
<tr>
<td>IIV volume d1 (mean±SD), mL</td>
<td>26.8±19.2</td>
<td>9.2±13.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>GRAEB score d1 (median [IQR])</td>
<td>8 (2)</td>
<td>3 (2)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>LOS days (mean±SD)</td>
<td>22±12.5</td>
<td>18±8.2</td>
<td>0.04</td>
</tr>
<tr>
<td>Intrahospital mortality (n=)</td>
<td>4</td>
<td>3</td>
<td>0.70</td>
</tr>
</tbody>
</table>

d1 indicates day 1; EVD, external ventricular drain; GCS, Glasgow coma scale; ICH, intracerebral hemorrhage; IQR, interquartile range; IVF, intraventricular fibrinolysis; IVH, intraventricular hemorrhage; IV-rtPA, intraventricularly administered recombinant tissue plasminogen activator; LOS, length of stay; mRS, modified Rankin scale; NIHSS, National Institutes of Health Stroke Scale; and PHE, perihemorrhagic edema.

**Influence of IVF Dosage**

Thirty patients (mean ICH volume 17.45±16.65 mL) had received 4 mg intrathecal rt-PA per application (high dose group) and 34 patients (mean ICH volume 22.18±18.26 mL) 1 mg (low dose group). ICH volume did not differ significantly (P=0.339) between both subgroups. Mean cumulative intraventricularly administered rtPA was 3.79±3.43 mg in the low dose group and 11.86±5.4 mg in the high dose group. Four patients in the high dose group received <7 mg intrathecal rt-PA cumulative, and 5 patients in the low dose group >7 mg cumulative. As can be seen in Figure 2, the cumulative dose had no effect on rPHE at days 10 through 12 (R²=0.014; P=0.347). There also was no effect on rPHE at days 4 through 6 (R²=0.010; P=0.423; data not shown). Concerning the effect of a single application dose, no significant difference could be seen in the rPHE evolution between patients who received 4 mg of rtPA per application (Delta-rPHE days 10–12; 1.00±1.3) and patients who received 1 mg of rtPA per application (Delta-rPHE days 10–12; 0.54±0.83; P=0.09).

**Discussion**

The key finding of the present study is that patients with ICH, IVH, and obstructive hydrocephalus treated with intraventricular fibrinolysis (gray line, intraventricular fibrinolysis [IVF] group) compared with controls (black line, control group). No difference between rPHE of both groups could be shown (F(1,63)=0.39; P=0.844).

**Figure 1. Course of mean relative perihemorrhagic edema (rPHE) ±SE of the mean from onset up to days 10 through 12 of patients treated with intraventricular fibrinolysis (gray line, intraventricular fibrinolysis [IVF] group) compared with controls (black line, control group). No difference between rPHE of both groups could be shown (F(1,63)=0.39; P=0.844).**

**Table 2. Evolution of Relative Perihemorrhagic Edema in Patients Treated With Intraventricular Fibrinolysis (IVF Group) Compared With Controls (Control Group)**

<table>
<thead>
<tr>
<th>Relative Perihemorrhagic Edema</th>
<th>IVF Group (n=64)</th>
<th>Control Group (n=64)</th>
<th>P  Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td>1.05±0.63</td>
<td>1.16±0.67</td>
<td>0.54</td>
</tr>
<tr>
<td>Days 2–3</td>
<td>1.28±0.76</td>
<td>1.32±0.72</td>
<td>0.75</td>
</tr>
<tr>
<td>Days 4–6</td>
<td>1.52±0.99</td>
<td>1.53±0.84</td>
<td>0.92</td>
</tr>
<tr>
<td>Days 7–9</td>
<td>1.64±1.31</td>
<td>1.66±0.95</td>
<td>0.91</td>
</tr>
<tr>
<td>Days 10–12</td>
<td>1.81±1.39</td>
<td>1.73±0.95</td>
<td>0.92</td>
</tr>
</tbody>
</table>

Data are mean±SD.
should be considered. First, the mean ICH volume in the treatment and control group of Ducruet et al was larger compared with our cohort. Moreover, there was an imbalance in the ICH size between the 2 groups, although the difference was not significant. Nevertheless, considering the small sample size of this study, such a difference may have influenced the findings reported by the authors because previous studies have shown that rPHE is inversely associated with ICH volume. Second, PHE is difficult to delineate and to assess on CT imaging. Ducruet et al used the investigator-based ABC/2 method to determine ICH and PHE volumes on CT, which may have caused higher inaccuracy compared with the semiautomatic volumetric algorithm used in the present study. This algorithm has been developed within a prospective study and validated against PHE volume assessed on MRI.

Although the role of PHE as a factor worsening morbidity and mortality after ICH has not been well established, it may be of particular importance in large ICH, in which additional mass effect may be detrimental. Our study only included patients with small hemorrhages with a mean ICH volume of 20±17.5 mL, in which this aspect may be of secondary concern. Moreover, IVF using rtPA has been mainly investigated and is currently being evaluated in smaller ICH (<30 mL in the ongoing multicenter phase III CLEAR-IVH trial). Concerning secondary rebleeding, we could not find a significant difference between the IVF group and controls. Compared with the published results of the phases A and B of the CLEAR-IVH trial, rebleeding was slightly less common in our study but comparable in the IVF group. However, we observed more rebleeding in the control group. A possible explanation can be derived from the retrospective design of our analysis with all consequences concerning imbalances between both groups. Furthermore, Naff et al evaluated symptomatic rebleeding, whereas we examined hematoma expansion of >30%. This definition was necessary, because >83% of our patients had been mechanically ventilated during the first week after bleeding, and clinical evaluation of symptomatic rebleeding was strongly limited in this cohort. A recently published systematic review of studies investigating IVF in patients with secondary IVH reports a lower overall rebleeding rate compared with our data; however, the studies included in this review were mainly relatively small case series. Therefore, this aspect remains not satisfyingly elucidated yet, and the final results of CLEAR-III must be awaited. We also could not demonstrate a correlation between the rtPA dose used for IVF and rebleeding rate. However, the statistical power of our study may have not been sufficient to detect a possible influence. In this context, our findings support the safety of intraventricularly administered rtPA, considering its possible effect on PHE and rebleeding.

Apart from the possible influence of intraventricular rtPA on the perihemorrhagic area, animal studies have raised concerns that periventricular structures and the ependymal layer may be damaged by dose-dependent rtPA-mediated neurotoxicity, leading to edema of periventricular tissue. Furthermore, Ducruet et al also reported increased occurrence of aseptic meningitis in rtPA-treated patients. In our study, only the occurrence of ventriculitis without any further differentiation was recorded, and no significant difference was found between patients treated with IVF and controls. In light of the relatively scarce experimental and clinical data, at this time, it still remains unclear whether mechanisms of rtPA-mediated neuronal damage, as described in ischemic injury, play an important role in the setting of ICH with ventricular involvement. Considering the relatively low doses of rtPA used for IVF, blood breakdown products, released in higher concentrations after IVF, may be more harmful to the surrounding brain tissue than the fibrinolytic agent itself. In this context, faster and more effective drainage of IVH after lysis may be crucial to attenuate inflammatory damage. Of course, in the absence of experimental or histopathologic data, those interpretations remain speculative. Prospective data are necessary to possibly confirm our data and to address further questions such as influence of ventricular rtPA on periventricular matter.

Our study has several limitations that should be considered when the results are interpreted. First, this was a retrospective study; however, it was performed at a single center and, therefore, institutional protocols for management of increased intracranial pressure and severe IVH were consistent within the investigated groups. Moreover, a relatively large number of patients could be included in our analysis. Despite this, we cannot exclude that statistical power may have not been sufficient to detect small rPHE differences between both groups. Second, because of a change in our institutional protocol for IVF in 2008, 2 different dosing regimens were used for IVF.
However, the rtPA doses applied before and after the change in our treatment protocol varied within an acceptable range and were close to the doses currently investigated in the CLEAR-III trial. The 2 dosing subgroups were not matched for ICH volume, was identical in involvement. rtPA on PHE evolution after ICH with severe ventricular involvement. The 2 dosing subgroups were not matched for ICH were close to the doses currently investigated in the CLEAR-our treatment protocol varied within an acceptable range and were close to the doses currently investigated in the CLEAR-III and dose of intraventricular fibrinolysis: The Clot Lysis: Evaluating Accelerated Resolution of IVH (CLEAR IVH) program. Stroke. 2012;43:1666–1668.


Intraventricular Fibrinolysis Does Not Increase Perihemorrhagic Edema After Intracerebral Hemorrhage
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