Early cisternal fibrinolysis is more effective than rescue spasmolysis for the prevention of delayed infarction after subarachnoid haemorrhage

Roland Roelz, Christian Scheiwe, Jürgen Grauvogel, Istvan Csok, Volker Arnd Coenen, Jürgen Beck, Peter C Reinacher

ABSTRACT

Background To compare the efficacy of two different concepts of cisternal therapy—PREVENTIVE fibrinolysis plus on-demand spasmolysis versus RESCUE spasmolysis—for the prevention of cerebral vasospasm (CVS) and delayed cerebral infarction (DCI) in patients with aneurysmal subarachnoid haemorrhage (aSAH).

Methods Retrospective analysis of 84 aSAH patients selected for cisternal therapy for DCI prevention. 66 high-risk patients received PREVENTIVE cisternal therapy to enhance blood clearance. Either stereotactic catheter ventriculocisternostomy (STX-VCS) or intraoperative placement of a cisterno-ventriculostomy catheter (CVC), followed by fibrinolytic cisternal lavage using urokinase was performed. In case of vasospasm, nimodipine was applied intracereally. 22 low-risk patients who developed CVS against expectations were selected for STX-VCS as RESCUE intervention for cisternal spasmolysis with nimodipine. Rates of CVS and mean flow velocities of daily transcranial Doppler (TCD) ultrasonographies were evaluated.

Results Despite a higher prespecified DCI risk, patients selected for PREVENTIVE intervention primarily aimed at blood clearance had a lower DCI rate compared with patients selected for intracranial spasmolysis as a RESCUE therapy (11.3% vs 18.2%). After intrathecal treatment onset, CVS (TCD>160 cm/s) occurred in 45% of patients with PREVENTIVE and 77% of patients with RESCUE therapy (p=0.013). A stronger response of CVS to intrathecal nimodipine was observed in patients with PREVENTIVE intervention as the mean CVS duration after start of intrathecal nimodipine was 3.2 days compared with 5.8 days in patients with RESCUE therapy (p=0.026).

Conclusions PREVENTIVE cisternal therapy directed at blood clearance is more effective for the prevention of CVS and delayed infarction compared with cisternal RESCUE spasmolysis.

Trial registration number DRKS00016532.

INTRODUCTION

Delayed cerebral infarction (DCI) is an important contributor to the high morbidity and fatality of aneurysmal subarachnoid haemorrhage (aSAH). Neither preventive nor therapeutic strategies to reduce the burden of DCI reaching level-I evidence are available.

Intrathecal therapies directed at clearance of intracranial blood or dilation of vasospastic vessels represent promising DCI therapies.

We introduced intrathecal therapies into aSAH management in 2015. In principle, two different concepts were applied. Patients at high risk for DCI (ie, poor clinical grade and high amount of blood) were selected for PREVENTIVE intrathecal therapy: cisternal catheters were placed during (cisterno-ventriculostomy through the fenestrated lamina terminalis, cisterno-ventriculostomy catheter, CVC) or soon after (sterotactic catheter-ventriculocisternostomy, STX-VCS) aneurysm securing. Fibrinolytic lavage was applied using urokinase to enhance blood clearance. In case of vasospasm, patients received intrathecal nimodipine for spasmolysis. In contrast, patients at low DCI risk who developed cerebral vasospasm (CVS) against expectations were selected for RESCUE intrathecal therapy: STX-VCS was performed for cisternal application of nimodipine.

Here, we compare the efficacy of these two different concepts of intrathecal therapy aiming at DCI prevention.

PATIENTS AND METHODS

Data from this study are available on reasonable request and in accordance with European data protection rules. The study took place in the neurosurgical department of a tertiary referral centre. It was performed according to the Declaration of Helsinki and is reported in accordance with institutional guidelines. Patients admitted before January 2019 were retrospectively included and informed consent was waived by our independent ethics committee. Patients admitted as of January 2019 were enrolled in our prospective aSAH registry (registered at the German Clinical Trials Register: DRKS00016532) and provided informed consent.
The study is reported according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for reporting of observational studies. Two surgical methods for obtaining catheter access to the basal cisterns and apply cisternal lavage were used as previously reported.4 5 In patients with (1) aneurysm coiling or (2) RESCUE intervention a stereotactic catheter ventriculocisternostomy (STX-VCS) was performed. Stereotactic procedures were performed using a Leksell G-Frame (Elekta, Stockholm, Sweden). A right or left frontal twist drill burr hole (3.5 mm) was performed under stereotactic guidance. Standard EVD catheters (typically 2.8 mm diameter) were stereotactically implanted via the lateral ventricle, the foramen of Monroi, the third ventricle, perforating the floor and entering the prepontine cistern, creating a third ventriculocisternostomy.

A CVC for PREVENTIVE intrathecal therapy was placed via the fenestrated lamina terminalis in patients who were (A) considered at high risk for DCI and (B) underwent clipping of aneurysms that required access to the chiasmatic region nevertheless (typically: clipping of anterior cerebral artery, middle cerebral artery, internal carotid artery (ICA) - including posterior communicating artery and posterior circulation artery, World Federation of Neurosurgical Societies (WFNS) and modified Fisher scores were collected. The amount of cisternal and ventricular blood on the initial cranial CT was measured semiquantitatively using the Hijdra scale.6 7 Presence or absence of DCI as visualised by cranial imaging was recorded applying the Vergouwen criteria.8 9 Independent assessment of DCI was performed by a rating board. The prespecified DCI risk of all patients was estimated by application of the de Rooij score.10

METHODS

Methods of cisternal lavage
Two surgical methods for obtaining catheter access to the basal cisterns and apply cisternal lavage were used as previously reported.4 5

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RESULTS

Baseline characteristics
Eighty-four (29.9%) of 281 patients with aSAH admitted between October 2015 and October 2020 were selected for intrathecal therapies on the basis of individual treatment decisions. Sixty-two (74%) were selected for PREVENTIVE intervention with the primary goal of intracranial blood clearance using fibrinolytic (urokinase) lavage. Two methods to deliver cisternal lavage were applied in patients selected for PREVENTIVE intervention: 51 patients received a stereotactic catheter-ventriculocisternostomy (STX-VCS). In 11 patients, a CVC running through the sylvian fissure into the third ventricle via the fenestrated lamina terminalis was placed during microsurgical clipping of the ruptured aneurysm. Twenty-two low-risk patients who developed CVS against expectations were selected for intrathecal RESCUE therapy and STX-VCS was performed to apply nimodipine intracisternally.

Clinical and demographic characteristics of PREVENTIVE and RESCUE patient cohorts are shown in table 1. Patients selected for PREVENTIVE intervention were older (61 vs 52 years), had worse admission WFNS grades, higher intracranial blood amounts (Hijdra sum scale: 26.3 vs 16.5), and differed in aneurysm location from patients with RESCUE intervention. Accordingly, the prespecified DCI-risk (de-Rooij score) for patients with PREVENTIVE intervention was significantly higher compared with patients with RESCUE intervention (47.5% vs 37.7%).

The mean time between aSAH onset and the intervention for cisternal lavage therapy was 53 hours (2.2 days) in patients with PREVENTIVE intervention and 161 hours (6.7 days) in patients with RESCUE intervention.
Four (18%) patients in the RESCUE cohort underwent endovascular therapy for CVS. In all cases, these interventions were performed before intrathecal therapy was commenced. Two (3%) patients in the PREVENTIVE cohort underwent endovascular interventions for CVS.

These interventions were performed after initiation of intrathecal therapy.

**Intrathecal drug use**

Table 2 summarises the use of intrathecal drugs in both groups. According to the respective concept of intrathecal therapy, 98% of patients selected for PREVENTIVE intervention received intrathecal urokinase and 100% of patients selected for RESCUE therapy received nimodipine. One patient with PREVENTIVE intervention was immediately treated with nimodipine. Vice versa, 58% of patients with PREVENTIVE intervention developed CVS and—on demand—received nimodipine. Fibrinolytic therapy was performed in only 14% of patients with RESCUE intervention and was applied after cessation of CVS to enhance blood clearance. In the same sense, opposing use durations of Urokinase and nimodipine were used in both groups.

**Cerebral vasospasm**

The mean MFV on the first 20 days after aSAH in patients with PREVENTIVE and RESCUE intervention differed significantly between day 4 and 14 since (1) patients with PREVENTIVE intervention did not show the aSAH characteristic MFV peak around days 7–10 and (2) MFV was not immediately normalised after the intervention in patients with RESCUE therapy (figure 1).

**Burden of vasospasm**

Figure 2 shows the respective percentage of patients with sonographic vasospasm in both groups on the first 20 days after aSAH.

Table 3 summarises the rates and durations of sonographic vasospasm in both groups before and after the intervention for intrathecal therapy. Overall, 29 of 62 patients (47%) selected for PREVENTIVE intervention ever had sonographic vasospasm (MFV increase to 160 cm/s or higher). Twenty of 22 patients (91%) selected for RESCUE therapy ever had sonographic vasospasm. Two patients had clinical vasospasm/delayed neurological deterioration. The duration of vasospasm was considerably longer both before and after intervention in the RESCUE therapy group.
To compare the response of CVS to intrathecal nimodipine in patients with PREVENTIVE versus RESCUE intervention, we normalised the transcranial Doppler (TCD) ultrasonographies (TCD) values to the time point of first ever intrathecal nimodipine administration. For this analysis, we excluded patients who did not receive intrathecal nimodipine (ie, 26 patients from the PREVENTIVE group) (figure 3). In patients with PREVENTIVE intervention, nimodipine start led to a rapid reduction of CVS: the mean TCD values decreased to subcritical levels on the following day. Remarkably, the response of CVS to a RESCUE application of nimodipine was considerably weaker: the mean TCD values remained above 160 cm/s for 5 days. Accordingly, the burden of vasospasm was substantially higher in patients with RESCUE therapy.

Delayed cerebral infarction

The observed DCI rates in patients with PREVENTIVE and RESCUE intervention were 11.3% (7 of 62 patients) and 18.2% (4 of 22 patients), respectively. For both groups, this was below the prespecified DCI-risk according to the de Rooij score (figure 4).

DISCUSSION

Our experience with both a PREVENTIVE intrathecal intervention primarily directed at blood clearance and a RESCUE intervention directed at intrathecal spasmolysis shows that addressing the root cause of CVS—cisternal and ventricular blood—by PREVENTIVE cisternal fibrinolysis is more effective for the prevention of CVS and DCI than intrathecal RESCUE spasmolysis.

In keeping with the pertinent literature, both treatment concepts were associated with a significant reduction of the DCI rate. A ca. 50% reduction was observed for patients selected for RESCUE therapy. Patients selected

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<th>Table 3 Burden of vasospasm (days with TCD &gt;160 cm/s preintervention and postintervention)</th>
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p-values of parameters reaching statistically significant differences between groups are marked in bold font. RR, relative risk; TCD, transcranial Doppler.

Figure 1 Mean maximum mean flow velocity (MFV) in patients with PREVENTIVE and RESCUE intervention. Mean (±SE) daily maximum MFV in transcranial Doppler ultrasonography of patients with PREVENTIVE (blue line) and RESCUE (red line) intervention. The mean MFV was significantly lower in patients with PREVENTIVE intervention on days 4 through 14. Patients with PREVENTIVE intervention lacked the characteristic peak increase of MFV around day 5–10. aSAH, aneurysmal subarachnoid haemorrhage.

Figure 2 Percent of patients with vasospasm: PREVENTIVE versus RESCUE therapy. Percentage of patients with PREVENTIVE and RESCUE intervention with MFV exceeding 160 cm/s (critical vasospasm) on the first 20 days after aSAH. aSAH, aneurysmal subarachnoid haemorrhage; MFV, mean flow velocities; TCD, transcranial Doppler.

Figure 3 Response of cerebral vasospasm to intrathecal nimodipine. Daily mean MFV of patients with PREVENTIVE and RESCUE intervention normalised to the day of first-ever intrathecal nimodipine application. MFV, mean flow velocities.
chronically vasospastic cerebral arteries show a (receptor-independent) depressed contractile response to all vasoactive substances.\textsuperscript{15}

Second, if no fibrinolysis has been performed, surrounding blood clots may impede intrathecal administration of nimodipine to reach its target of action and, thereby, limit spasmolytic efficacy. In summary, intrathecal therapies represent promising approaches to reduce DCI in patients with aSAH and various approaches have found clinical application.\textsuperscript{8} Both fibrinolytic and spasmolytic therapies have been used and remain under investigation. The basal cisterns appear to be the most promising target for delivery of such therapies since cisternal fibrinolysis successfully reduced DCI\textsuperscript{16} but both intraventricular fibrinolysis\textsuperscript{17} and spasmolysis\textsuperscript{18} have failed to prevent DCI. Our results underscore the importance of a preventive treatment approach and indicate that early cisternal blood clearance is a powerful method for DCI prevention. Reacting to established CVS by cisternal spasmolysis is less effective. Accordingly, a randomised clinical trial to assess safety and efficacy of PREVENTIVE cisternal therapy is recruiting (EudraCT 2017-000868-15).\textsuperscript{8}

**Study limitations**
Our study is subject to the general constraints of retrospective analyses. We have tried to exclude potential bias by independent assessment of important endpoints (DCI). The baseline characteristics of the two groups analysed in this paper are different, making a direct comparison difficult. A validated method for estimating the DCI risk (de Rooij score) was therefore used to compare the capacity of the two treatment strategies for DCI prevention.

**Conclusions**
Preventive cisternal therapy directed at blood clearance is more effective for the prevention of CVS and delayed infarction compared with cisternal rescue spasmolysis.

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**Contributors**
RR: study conceptualisation, data collection and interpretation, statistical analyses, visualisation, drafting of the manuscript. RR is responsible for the overall content as the guarantor. RR accepts full responsibility for the work and the conduct of the study, had access to the data and controlled the decision to publish. CS: data curation, study supervision, interpretation of data, reviewed the manuscript for important intellectual content. JS: data curation, reviewed the manuscript for important intellectual content. IC: data collection and analysis, reviewed the manuscript for important intellectual content. JC: study conceptualisation, data curation, project administration, reviewed the manuscript for important intellectual content. PCR: study conceptualisation, collection and interpretation of data, drafting of the manuscript.

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**Competing interests**
None declared.

**Patient consent for publication**
Not applicable.

**Ethics approval**
The study was approved by the independent Ethics Committee, Medical Centre-University of Freiburg, Germany; reference numbers: 575/16, 184/18.

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REFERENCES