Specific management in specialized hospital facilities has been shown to improve process quality and outcomes in a variety of diseases.\(^1\)–\(^3\) In the context of neurological disorders, this applies to the treatment of acute stroke in Stroke Units\(^4\) or of intracranial hemorrhages in hospitals with organized stroke care or neurosurgery facilities.\(^4,\)\(^5\) Correct prehospital diagnosis is important because it avoids admissions to nonappropriate hospitals with suboptimal care or leading to time-consuming secondary patient transfers. In addition, prehospital diagnostic work-up can accelerate emergency management by in-advance notification of hospital teams.\(^6,\)\(^7\) However, diagnosis of neurological disorders is often difficult for the variety of symptom presentations and causes. For example, initial diagnosis of stroke in an emergency department yielded a stroke mimic rate of 19%, based on history and clinical examination only.\(^8\) If additional laboratory findings and a computed tomographic (CT) scan were available, the stroke mimic rate was only 4%.\(^9\) In the prehospital setting with usually limited diagnostic equipment and neurological expertise, correct diagnosis is even more difficult. Sensitivity of stroke diagnosis on the basis of validated prehospital stroke scores was reported between 74% and 95% with positive predictive values (PPVs) between 13% and 99%.\(^10\) The feasibility of advanced prehospital neurological work-up, including CT imaging of the brain and point-of-care laboratory, has recently been shown in 2 projects using specialized ambulances.\(^11,\)\(^12\) In the Pre-Hospital Acute
Neurological Therapy and Optimization of Medical Care in Stroke (PHANTOM-S) study, patient care in the Stroke Emergency Mobile (STEMO) was safe, increased the rate of intravenous thrombolysis in patients with ischemic stroke and reduced time to treatment.\textsuperscript{12,13} In the present evaluation, we investigated whether prehospital care in the STEMO concept leads to improved delivery of patients with cerebrovascular diseases (CVDs) to appropriate hospitals.

**Materials and Methods**

Details of PHANTOM-S and the pilot study were previously described.\textsuperscript{12-14} The proportion of patients referred to specialized centers was a prespecified secondary outcome for several diagnostic categories.

**Stroke Emergency Mobile**

STEMO is a specialized ambulance equipped with a CT scanner (CereTom; NeuroLogica, Danvers, MA), point-of-care laboratory devices (ABX Micros 60; Horiba Medical, Irvine, CA; CoaguChek XS Plus, Roche Diagnostics, Mannheim, Germany; i-STAT Portable Clinical Analyzer; American Screening Corporation, Shreveport, LA) and teleradiology technology (VIMED-STEMO; MEYTEC GmbH, Werneuchen, Germany). Teleradiology technology was used for transmission of CT imaging to a hospital-based neuroradiologist on call and documentation of readings in the medical report on board. STEMO is staffed with a neurologist, a paramedic, and a radiology technician. All participating neurologists have experience of \textsuperscript{>2}-year clinical neurology and a special education in emergency medicine. In addition to the clinical practice as a physician, this education includes \textsuperscript{>6}-month practice on an intensive care unit, 6-month experience in anesthesiology or in an emergency department. The radiology technician is also trained as a paramedic assistant (Rettungssanitäter). STEMO and the team were based at a fire station close to the city center of Berlin. The dispatch center communicated with STEMO via radio connection. The catchment area was defined by a calculated \textsuperscript{>75}\% probability of arriving at scene within 16 minutes. This area included \textsuperscript{\approx}300,000 inhabitants.

**Conventional Emergency Medical Services**

In Germany, normal ambulances are staffed with \textsuperscript{\geq}1 paramedic (Rettungssanist) with a professional training of 2 years. The second patient on ambulances is either another paramedic or a paramedic assistant with an education of \textsuperscript{\approx}3 months (520 hours). Emergency physicians (Notärzte) are simultaneously deployed in case of critically ill patients. In Berlin, this applies to patients with stroke only in the case of decreased level of consciousness or unstable vital parameters. The Emergency Medical Services (EMS) in Berlin is organized and operated by the Berlin Fire Brigade with STEMO as an integrated specialized ambulance. EMS personnel in Berlin are trained in acute stroke assessment during professional education and as part of non-systematic EMS stroke training conducted by various Stroke Units. A directive of the Chief EMS officer to deliver all suspected patients to hospitals with Stroke Units is in place since 2011. The city of Berlin has a well-established stroke care infrastructure with 14 Stroke Units serving as acute and monitoring stroke units.\textsuperscript{6}

**Study Design**

From May 2011 to January 2013 (21 months), we compared weeks with STEMO care (STEMO weeks) and weeks without STEMO care (control weeks). The acute stroke dispatch was activated in the dispatch center in case of a suspected acute stroke with symptom onset either within 4 hours or unknown. For this purpose, the dispatch center used a previously validated algorithm to identify patients with a high probability for stroke.\textsuperscript{6} STEMO operated in randomized weeks from 7:00 AM to 11:00 AM all days of the week. For randomization of study periods, we used 4-week blocks as described in detail before.\textsuperscript{14}

During STEMO weeks, STEMO (if available) and an additional regular ambulance were simultaneously deployed. The paramedics on the regular ambulance were able to cancel STEMO before its arrival based on their first assessment. During non-STEMO weeks and during STEMO weeks in case of STEMO unavailability, regular ambulances were deployed. Within this conventional care system, an emergency physician was coalarmed simultaneously only in case of reported unstable vital parameters or reduced consciousness.

**Patients**

All patients with acute stroke dispatch were included, except for patients aged <18 years. Patients who received regular care were transported after prehospital assessment to the nearest hospital that seemed to be appropriate to the EMS staff—except of patients who refused hospital admission or requested admission to a specific hospital. Patients who received STEMO care were physically examined by the STEMO neurologist after arrival. If necessary, point-of-care laboratory including blood count, glucose, electrolytes, international normalized ratio, and creatinine was performed. A CT scan was performed if indicated for immediate therapeutic decisions or for patient’s triage. An additional CT angiography was performed whenever additional information about specific arterial occlusion was requested. Imaging data were sent via teleradiology to the neuroradiologist on call, who interpreted these immediately and gave feedback to the STEMO physician. In difficult cases including decisions about thrombolysis, a senior neurologist was involved via telephone or videoconferencing. Thereafter, patients were transported to the nearest appropriate hospital according to the judgment of the emergency physician (again respecting the patient’s preferences). If STEMO was not available (in case of a simultaneous alarm or maintenance), patients received regular care as described for control weeks. In the present analysis, we compared patients with STEMO deployment (STEMO deployed regardless of actual STEMO care) and without STEMO deployment (all patients during control weeks and patients during STEMO weeks without STEMO deployment). In addition, we determined short-term outcome as provided by the acute hospital discharge status.

**Diagnostic Accuracy of Prehospital Diagnosis**

Hospital discharge diagnoses were categorized according to the documented International Classification of Diseases-Tenth Revision discharge codes into CVDs (G45.x except G45.4), I60.x, I61.x, I63.x, and I64.x), other neurological diagnoses (A8.x, A35.x, C70.x, C71.x, C72.x, F0.x, F1.x, G0.x-G99.x, H46.x-H48.x, H51.x, H53.1-H53.4, H54.x, H81.x, R25.x-R29.x, R55.x, S00.x-S09.x, and T39.x-T65.x) and non-neurological diagnoses (all others). Intracranial hemorrhage comprises spontaneous intracerebral hemorrhages, traumatic intracerebral hemorrhages, subdural hematoma, epidural hematoma, and subarachnoid hemorrhages. Prehospital diagnoses established in STEMO were compared with final discharge diagnoses. Diagnostic accuracy was calculated with sensitivity, specificity, PPV, and negative predictive value.

**Data Collection**

All patients with stroke dispatch received a deidentified alphanumeric code by the Dispatch Center. Clinical data were documented by participating hospitals in case report forms. The case report forms were sent to the Center for Stroke Research Berlin. Data were merged using the alphanumeric code with deidentified databanks provided by the fire brigade and the Berlin Stroke Registry.\textsuperscript{16} Information about demographics, comorbidities (atrial fibrillation and diabetes mellitus), discharge diagnosis, and discharge status (in-hospital death, referral to another hospital and discharge home) were taken from case report forms. Secondary emergency referral was defined as referral to another hospital within 2 days from admission. Additional information about prehospital diagnosis was retrieved for patients cared on Stroke Units serving as acute and monitoring stroke units. The Emergency Medical Services (EMS) in Berlin is organized and operated by the Berlin Fire Brigade with STEMO as an integrated specialized ambulance. EMS personnel in Berlin are trained in acute stroke assessment during professional education and as part of non-systematic EMS stroke training conducted by various Stroke Units. A directive of the Chief EMS officer to deliver all suspected patients to hospitals with Stroke Units is in place since 2011. The city of Berlin has a well-established stroke care infrastructure with 14 Stroke Units serving as acute and monitoring stroke units.\textsuperscript{6}
Ethics
The study was approved by the Charité Ethics Committee, the Data Protection Commissioner of the state of Berlin, and data protection representatives of participating hospitals. Three-month functional follow-up is not reported in this study because it could only be collected in patients who had given signed informed consent. This was eventually restricted to patients cared in STEMO making a comparison with conventional care impossible.

Statistical Analysis
Pearson $\chi^2$ test or Fisher exact test were used to compare categorical variables. The Mann–Whitney U test was used for comparisons of continuous variables. A 2-sided significance level of $\alpha=0.05$ was used. Standardized plausibility checks were performed under statistical supervision. All analyses were conducted with IBM-SPSS version 19 statistics software.

Results
A total of 7098 stroke dispatches were activated by the Dispatch Center of the Berlin Fire Brigade. Patient inclusion is summarized as a flow chart in the Figure. Hospital documentation was available for 6182 (94%) of 6573 patients with hospital admission. During STEMO weeks, STEMO could not be deployed in a high proportion of patients ($n=1409; 44\%$) either because STEMO was already in operation ($n=1288; 91\%$) or because of maintenance ($n=121; 9\%$). Of 1804 STEMO deployments, 349 (19%) were cancelled before STEMO arrival. In-hospital data were collected from 28 hospitals. Patient characteristics were well balanced between the 2 groups except for slightly higher rates of atrial fibrillation and diabetes mellitus in the STEMO group (Table 1). We found an almost equal proportion of patients with CVD, neurological but non-CVD patients, and non-neurological patients in both groups. Table 2 shows transport destinations and short-term outcomes. With regard to admissions of patients to hospitals without a Stroke Unit, there were no significant differences in hospital deliveries for patients with non-neurological or neurological but non-CVD diagnoses. For the group of patients with CVD and the subgroup of patients with ischemic stroke, we found a significantly lower proportion of patients delivered to hospitals without Stroke Unit in the STEMO group (patients with CVD, 5.5% versus 11.6%; $P<0.01$ and patients with ischemic stroke, 3.9% versus 10.1%; $P<0.01$). In the STEMO group, patients with intracranial hemorrhages were significantly less frequently delivered to hospitals without neurosurgery (11.3% versus 43.0%; $P<0.01$). Secondary emergency referrals to another hospital were more frequent in patients with cerebrovascular events and in particular in patients with intracranial hemorrhages when cared in conventional care. However, these differences did not reach statistical significance. No differences in outcomes were found in the group of non-neurological patients. In the groups of all neurological patients (and those without CVD), there was a trend toward higher rates of patients discharged home (all neurological patients, 63.5% versus 60.8%; $P=0.096$ and neurological patients without CVD, 83.5% versus 79.5%; $P=0.08$) in patients with STEMO deployment. Except for patients with non-CVD neurological diseases, in-hospital mortality was consistently lower for patients in the STEMO group (not reaching statistical significance). Prehospital diagnostic accuracy on cerebrovascular events revealed a sensitivity of 89%, specificity 77%, PPV 79%, and negative predictive value 87% (Tables 3 and 4).

Discussion
Patient care within the STEMO-concept was associated with more frequent delivery of patients with cerebrovascular events to appropriate hospitals in particular for patients without a Stroke Unit, there were no significant differences in hospital deliveries for patients with non-neurological or neurological but non-CVD diagnoses. For the group of patients with CVD and the subgroup of patients with ischemic stroke, we found a significantly lower proportion of patients delivered to hospitals without Stroke Unit in the STEMO group (patients with CVD, 5.5% versus 11.6%; $P<0.01$ and patients with ischemic stroke, 3.9% versus 10.1%; $P<0.01$). In the STEMO group, patients with intracranial hemorrhages were significantly less frequently delivered to hospitals without neurosurgery (11.3% versus 43.0%; $P<0.01$). Secondary emergency referrals to another hospital were more frequent in patients with cerebrovascular events and in particular in patients with intracranial hemorrhages when cared in conventional care. However, these differences did not reach statistical significance. No differences in outcomes were found in the group of non-neurological patients. In the groups of all neurological patients (and those without CVD), there was a trend toward higher rates of patients discharged home (all neurological patients, 63.5% versus 60.8%; $P=0.096$ and neurological patients without CVD, 83.5% versus 79.5%; $P=0.08$) in patients with STEMO deployment. Except for patients with non-CVD neurological diseases, in-hospital mortality was consistently lower for patients in the STEMO group (not reaching statistical significance). Prehospital diagnostic accuracy on cerebrovascular events revealed a sensitivity of 89%, specificity 77%, PPV 79%, and negative predictive value 87% (Tables 3 and 4).

Figure. Study flow chart. STEMO indicates Stroke Emergency Mobile.
There was no statistically significant difference in short-term outcomes, but the observed trends toward better outcome in the STEMO group are in line with previously established evidence. STEMO care reduced the inadequate delivery of patients with ischemic stroke to a hospital without Stroke Unit, with ischemic strokes or intracranial hemorrhages. Table 1 presents patient characteristics, and Table 2 details transport destinations and short-term outcome.
Unit by >50% and of patients with intracranial hemorrhage to a hospital without neurosurgery by >60% (relative risk reduction). This may be the consequence of improved prehospital diagnosis or of better persuasion of patients by emergency physicians. Secondary referrals of patients with cerebrovascular events were higher in conventional care. However, the majority of patients with cerebrovascular events delivered to a hospital without Stroke Unit remained in the hospital of primary delivery, despite recommendations that all patients with acute stroke should be treated on a Stroke Unit.17 This indicates that primary delivery is crucial for the place of acute care. The results of the STEMO prehospital diagnostic accuracy on cerebrovascular events (sensitivity, 89%; specificity, 77%; PPV, 79%; and negative predictive value, 87%) compare well with the validation results of the Recognition of Stroke in the Emergency Room (ROSIER) scale (sensitivity, 93%; specificity, 83%; PPV, 90%; and negative predictive value, 88%).18 With shorter observation time, affirmation of a stroke diagnosis is often more difficult, particularly in most frequent stroke mimics of Todd paresis or migrainous aura. Rather than a single factor, the combination of preselection via the dispatch center, specialist neurological assessment, diagnostic support with CT, as well as point-of-care laboratory, and telemedicine all add to diagnostic accuracy. Of note, the specialization of the emergency team on board the STEMO did not result in poorer outcomes in patients with non-neurological diseases. Admission rates of patients with ischemic stroke to a primary stroke center vary between regions. Data from the United States show that only 55% of patients have access to a primary stroke center within 60 minutes, and only 28% of patients with stroke in New Zealand were managed on a Stroke Unit.19,20 These low rates may be a consequence of the shortage of hospitals with specialized departments. However, even after implementation of a prehospital stroke triage policy in the Chicago metropolitan area with 17 primary stroke centers, the admission rate of patients with ischemic stroke to these stroke centers was only 81.1%.21 Although it is difficult to compare these data with ours, the 96% correct admission rate for this group of patients reflects a clear improvement when compared with conventional care. Hence, the STEMO concept offers additional potentials on top of increased thrombolysis rate and reduction of onset-to-treatment time.11,12,22 Although improved outcomes could not be proved on the basis of hospital discharge data alone, there is established evidence that patients with stroke benefit from treatment in organized stroke care.23 The advantages of this specialized ambulance have to be weighed against the costs of the project, including expenses for investments, staff, and consumables. This is currently under investigation in another analysis of the PHANTOM-S trial. Strengths of the study are the high number of patients with participation of 28 hospitals. A limitation of the study is that we could only compare the concept of specialized prehospital care in 1 ambulance with conventional care in multiple regular ambulances. To avoid a selection bias, we did include all patients with STEMO deployment in the STEMO group although the STEMO operation was cancelled in a substantial number of patients in this group (19%). Misallocation rates were even lower in patients who were eventually cared by STEMO (3.2% in patients with ischemic stroke and 8.9% in patients with intracranial hemorrhage). Another limitation of the study is the unavailability of diagnostic accuracy in conventional care because prehospital paramedic assessment is not regularly documented as diagnosis in the Berlin EMS system. In addition, generalizability of the STEMO system to other healthcare systems has not been shown yet. For example, it may be difficult to train vascular neurologists in emergency medicine in countries without emergency physicians working in EMS. Finally, we are not able to provide functional outcome results as the study methodology did not allow the collection of long-term outcome.

**Table 2. Continued**

<table>
<thead>
<tr>
<th></th>
<th>Conventional Care Group</th>
<th>STEMO Group</th>
<th>PValue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary emergency referrals</td>
<td>19 (12.6)</td>
<td>3 (4.8)</td>
<td>0.09</td>
</tr>
<tr>
<td>In-hospital mortality, n (%)</td>
<td>20 (13.2)</td>
<td>6 (9.7)</td>
<td>0.47</td>
</tr>
<tr>
<td>Discharged home, n (%)</td>
<td>50 (33.1)</td>
<td>18 (29.0)</td>
<td>0.56</td>
</tr>
</tbody>
</table>

STEMO indicates Stroke Emergency Mobile.

*Cerebrovascular events include ischemic or hemorrhagic stroke and transient ischemic attacks.

**Table 3.** Test Parameters for Prehospital Stroke Diagnosis Validated Against Final Discharge Diagnosis of Cerebrovascular Events*

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>True-positives</td>
<td>611</td>
</tr>
<tr>
<td>False-positives</td>
<td>162</td>
</tr>
<tr>
<td>True-negatives</td>
<td>529</td>
</tr>
<tr>
<td>False-negatives</td>
<td>76</td>
</tr>
</tbody>
</table>

*Cerebrovascular events include ischemic or hemorrhagic stroke and transient ischemic attacks.

**Table 4.** 95% CI for Prehospital Stroke Diagnosis Validated Against Final Discharge Diagnosis of Cerebrovascular Events*

<table>
<thead>
<tr>
<th></th>
<th>Estimated Value</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>0.89</td>
<td>0.86–0.91</td>
</tr>
<tr>
<td>Specificity</td>
<td>0.77</td>
<td>0.73–0.80</td>
</tr>
<tr>
<td>Positive predictive value</td>
<td>0.79</td>
<td>0.76–0.82</td>
</tr>
<tr>
<td>Negative predictive value</td>
<td>0.87</td>
<td>0.85–0.90</td>
</tr>
</tbody>
</table>

CI indicates confidence interval.

*Cerebrovascular events include ischemic or hemorrhagic stroke and transient ischemic attacks.

**Conclusions**

The STEMO concept improves the triage of patients with cerebrovascular events in the prehospital setting. Additional studies are needed to show that this observation holds true in other areas and translates into improved patients outcomes.

**Appendix**

STEMO Consortium: Berliner Feuerwehr, Berlin, Germany; BRAHMS GmbH, Hennigsdorf, Germany;
Charité-Universitätsmedizin Berlin, Berlin, Germany; MEYTEC GmbH, Werneuchen, Germany.

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Disclosures

Dr Audebert reports receiving speaker honoraria from BMS, Lundbeck Pharma, Pfizer, Sanofi, EVER Neuropharma, and Boehringer Ingelheim. He has a consultant or advisory relationship to Roche Diagnostics, Lundbeck Pharma, and Bayer Vital. The other authors report no conflicts.

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