Background and Purpose—Pre- and intrahospital time delays are major concerns in acute stroke care. Telemedicine-equipped ambulances may improve time management and identify patients with stroke eligible for thrombolysis by an early prehospital stroke diagnosis. The aims of this study were (1) to develop a telestroke ambulance prototype; (2) to test the reliability of stroke severity assessment; and (3) to evaluate its feasibility in the prehospital emergency setting.

Methods—Mobil, real-time audio–video streaming telemedicine devices were implemented into advanced life support ambulances. Feasibility of telestroke ambulances and reliability of the National Institutes of Health Stroke Scale assessment were tested using current wireless cellular communication technology (third generation) in a prehospital stroke scenario. Two stroke actors were trained in simulation of differing right and left middle cerebral artery stroke syndromes. National Institutes of Health Stroke Scale assessment was performed by a hospital-based stroke physician by telemedicine, by an emergency physician guided by telemedicine, and “a posteriori” on the basis of video documentation.

Results—In 18 of 30 scenarios, National Institutes of Health Stroke Scale assessment could not be performed due to absence or loss of audio–video signal. In the remaining 12 completed scenarios, interrater agreement of National Institutes of Health Stroke Scale examination between ambulance and hospital and ambulance and “a posteriori” video evaluation was moderate to good with weighted $\kappa$ values of 0.69 (95% CI, 0.51–0.87) and 0.79 (95% CI, 0.59–0.98), respectively.

Conclusion—Prehospital telestroke examination was not at an acceptable level for clinical use, at least on the basis of the used technology. Further technical development is needed before telestroke is applicable for prehospital stroke management during patient transport. (Stroke. 2012;43:2086-2090.)

Key Words: acute care ■ emergency medicine ■ telemedicine

See related article, p 2029.

Thrombolytic therapy in acute ischemic stroke has to be administered within 4.5 hours after symptom onset.1 Pre- and in-hospital time delays as well as misallocation of patients with stroke are major concerns in acute stroke management leading to delayed or inability to provide thrombolysis.2,3 Time from onset of stroke symptoms to treatment with thrombolysis is crucial for outcome after ischemic stroke.4 Telemedicine technology has been shown to provide immediate stroke expertise and improve acute stroke care such as administration of thrombolytic therapies.5,6 Telemedicine-equipped ambulances in acute stroke management (telestroke ambulances) could provide early prehospital stroke diagnosis and advanced prehospital information of patients with stroke such as time of onset, stroke severity, and syndrome. This might lead to improvement of time management, referral of patients to adequate specialized hospitals, and identification of patients eligible for thrombolysis. Moreover, the implementation and evaluation of mobile telemedicine systems in the emergency medical services has been recommended by the American Heart Association.7,8 However, studies that have investigated the use of mobile telemedicine systems in acute prehospital stroke care are scarce. Up to now, evaluation of video transmission from an ambulance-located telemedicine system has been reported in one project, the mobile telemedicine for the Brain Attack Team (TeleBAT).9,10 Furthermore, several studies provide evidence that remote assessment of stroke severity such as National Institutes of Health Stroke Scales (NIHSSs) is feasible and reliable in the interhospital setting.11,12 However, data on prehospital real-time stroke severity assessment by a hospital-based stroke physician in patients during ambulance transport in a moving vehicle are limited. Recently, cellular video phone examination of stroke severity using a simplified NIHSS examination was reported to be reliable, but the examination was not conducted in a real ambulance but in remote locations of a hospital.13
The aims of this study were (1) to develop a telestroke ambulance prototype; (2) to test the reliability of remote stroke severity assessment; and (3) to evaluate the feasibility of telestroke examination in an inner-city prehospital stroke scenario using Universal Mobile Telecommunications System-based cellular real-time audio–video (AV) communication technology.

**Methods**

**Concept**

Three ambulances of the Berlin fire brigade were equipped with wireless cellular communication technology (telestroke ambulances) as part of StrokeNET, a Berlin-based telemedicine project. The concept of StrokeNET is to implement a telemedical stroke network in Berlin through (1) AV connection between telestroke ambulances and certified stroke centers of Charité University Hospitals; and (2) implementation of telestroke networks for close cooperation between these stroke centers and local hospitals as shown in Figure 1. Aims of StrokeNET are to improve pre- and early intrahospital stroke care and reduce time to appropriate in-hospital treatment by (1) early prehospital stroke diagnosis using telestroke ambulances; and by (2) providing remote stroke expertise in local hospitals without 24/7 neurological service. To test the technical solution of (1), a pilot study was set up to investigate the AV quality, reliability of stroke severity assessment, and overall feasibility of the proposed telestroke ambulance prototype in a prehospital stroke emergency scenario. The analysis was prospectively planned with an ambulance route starting in a suburb of Berlin in the early morning (7 AM) and driving on streets with variable surface toward the Berlin city center (arriving at the central Alexander Pl at 1 PM) and driving back to the suburb fire station with arrival at 3 PM.

**Telemedicine System**

Three telestroke ambulances were equipped with a prototype mobile telemedical device (VIMED CAR) that was developed as part of the StrokeNET project. This transmission unit enables a bidirectional encoded broadband AV communication through a commercial network provider using third-generation mobile networks with maximum uplink of 1.2 mbit/s (high-speed packet access) and maximum downlink of 2 mbit/s. The communication is primarily performed using a high-speed downlink packet access (HSDPA) mobile telephone communications protocol. In the case of HSDPA unavailability, the system switches to the next fastest technology according to availability: Universal Mobile Telecommunications System (UMTS), Enhanced Data Rates for GSM Evolution, General Packet Radio Service. Interaction with the Windows-based system is performed by a touch screen monitor. A specialized microphone and a radial audio rendering system enable clear speech comprehension without the need for a headset, irrespective of background vehicle or ambient noise using reverb and echo cancelling software. Each telestroke ambulance is equipped with a “head” and a “body” camera that can be switched externally by the hospital-based examiner. Both cameras were placed at the ceiling of the telestroke ambulance. The “head” camera allows an optical zoom that can be activated by external hospital-based control.

**Telestroke Assessment**

Mobile telestroke ambulance NIHSS assessment was performed by 3 different raters: by a hospital-based stroke physician (Rater 1), by an emergency physician in the ambulance guided through telemedicine (Rater 2), and “a posteriori” by a stroke physician on the basis of video documentation (Rater 3). Two actors were trained in simulation of right and left middle cerebral artery stroke syndromes with differing severity (NIHSS: 2, 3, 5, and 24). All raters (H.J.A., T.G.L., C.W.) were trained and certified on the examination of the NIHSS (www.trainingcampus.net). During mobile telestroke ambulance, NIHSS assessment one rater (C.W.) and 2 stroke actors were in the ambulance. Raters were blinded to the consecutive stroke scenarios. AV signal quality was rated by Rater 1 and Rater 2 in 30 stroke scenarios (starting a new videoconference every 15 minutes) at different locations in the greater Berlin city area as shown on the map (Figure 2). Audio quality was predefined as 1 (continuously comprehensive audio signal), 2 (predominantly comprehensive), 3 (more...
comprehensive than incomprehensive), 4 more incomprehensive than comprehensive), 5 (frequent loss of signal, predominantly incomprehensive), and 6 (no signal or continuously incomprehensible). Video signal quality was predefined as 1 (continuously assessable video signal), 2 (predominantly assessable video signal), 3 (more assessable video signal than inaccessible), 4 (more inaccessible than accessible), 5 (frequent loss of signal, predominantly inaccessible), and 6 (no signal or continuously inaccessible).

Statistical Methods
Interrater reliability was tested using weighted $\kappa$ statistic as described in general and for stroke severity assessment.14,15 The weighted $\kappa$ value is qualified as follows: $<0.40$ defines poor agreement, between 0.40 and 0.75 defines moderate, and $>0.75$ defines good agreement. SAS software (SAS 9.2; SAS Institute Inc, Cary, NC) was used for all analyses. Written permission was obtained from all subjects who are shown in the figure. The study was approved by the Ethics Committee of Chariti¨-Universitaetsmedizin Berlin.

Results
A mobile telestroke ambulance prototype was developed that enables bidirectional AV communication between the hospital and moving ambulance. To evaluate the feasibility of telestroke examination in a real-time emergency setting of acute stroke, we performed 30 NIHSS assessments within the Berlin city region.

In 12 scenarios, NIHSS assessment could be completed with a mean NIHSS of 4 for all 3 raters (interquartile range [IQR], 3–5.75). Mean bit rate for completed assessments was 148.7 kbps (SD± 30.1). Median audio signal quality was 2 (IQR, 2–3.75) for Rater 1 and 2 (IQR, 2–3) for Rater 2. Median video signal quality was 4 (IQR, 2–5) for Rater 1 and 2 (IQR, 1–2) for Rater 2. Interrater reliability of 12 completed NIHSS examinations was moderate between the hospital (Rater 1) and ambulance (Rater 2) with weighted $\kappa$ values of 0.69 (95% CI, 0.51–0.87) and good between “a posteriori” video evaluation (Rater 3) and ambulance (Rater 2) with 0.79 (95% CI, 0.59–0.98). Results for interrater reliability for NIHSS items are shown in detail in the Table. Distribution of expected scores for 12 scenarios with completed NIHSS assessment was 5, 3, 2, 3, 5, 3, 24, 2, 5, 5, 24, and 5, respectively. There were no differences in nonagreement scoring between lower or higher NIHSS score scenarios.

In our emergency ambulance scenario, completion of NIHSS assessment could not be performed in 18 of 30 scenarios as a result of poor quality, loss, or absence of AV signal. AV connection was best in the suburban area early morning, worsened with shorter distance to the city center, and was worst at noon with no successful AV connections between 12:15 and 2:30 pm. Description of locations in the inner Berlin city area with AV communication tests for NIHSS assessment is shown in Figure 2.

In 14 sessions, AV connections were not sufficient for NIHSS assessment. In 2 sessions, assessment of NIHSS was interrupted after examination of NIHSS item No. 1 (level of consciousness), in one session after item No.3 (visual field), and in one session after item No. 6 (motor leg). Examples of NIHSS assessment of different items are shown in Figure 3.

For all 30 scenarios, overall signal quality was poor for audio (median values [IQR] Rater 1: 5.5 [3–6], Rater 2: 6 [2–6]) and video signal (Rater 1: 6 [4–6], Rater 2: 6 [2–6]).

Table. Interrater Reliability in 12 Stroke Scenarios With Completed NIHSS Examination

<table>
<thead>
<tr>
<th>Completed NIHSS Examination</th>
<th>Hospital Versus Car ($\kappa$, SEM)</th>
<th>Video Versus Car ($\kappa$, SEM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1a) LOC call name</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>(1b) LOC questions</td>
<td>0.64 (0.217)</td>
<td>0.77 (0.167)</td>
</tr>
<tr>
<td>(1c) LOC commands</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>(2) Best gaze</td>
<td>0.63 (0.333)</td>
<td>0.63 (0.333)</td>
</tr>
<tr>
<td>(3) Visual field</td>
<td>0.57 (0.126)</td>
<td>0.57 (0.126)</td>
</tr>
<tr>
<td>(4) Facial palsy</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>(5a) Motor left arm</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>(5b) Motor right arm</td>
<td>0.83 (0.166)</td>
<td>0.83 (0.166)</td>
</tr>
<tr>
<td>(6a) Motor left leg</td>
<td>0.86 (0.086)</td>
<td>0.86 (0.086)</td>
</tr>
<tr>
<td>(6b) Motor right leg</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>(7) Limb ataxia</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(8) Sensory</td>
<td>0.59 (0.174)</td>
<td>0.77 (0.151)</td>
</tr>
<tr>
<td>(9) Best language</td>
<td>0.92 (0.08)</td>
<td>0.92 (0.08)</td>
</tr>
<tr>
<td>(10) Dysarthria</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>(11) Extinction and inattention</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

NIHSS indicates National Institutes of Health Stroke Scale; LOC, level of consciousness.

Discussion
We developed a novel telestroke ambulance prototype and tested its feasibility of remote assessment of stroke severity in the prehospital emergency setting.

The results of our feasibility study showed that remote NIHSS-based mobile assessment of stroke symptoms in a moving ambulance car was only feasible in approximately 40% of scenarios, mostly during morning hours in the Berlin outer-city area. Overall stability of AV connection was not at an acceptable level for clinical use. Thus, prehospital
Mobile telemedicine systems for optimization of patient care during transport in moving ambulances have been described, but stability of AV transmission for real-time examination is challenging.\textsuperscript{16,17} To the best of our knowledge, reports on remote ambulance-based assessment of stroke severity are limited to one project, the mobile TeleBAT. Similar to our study, TeleBAT primarily tested the feasibility of stroke evaluation and assessment of stroke symptoms using a modified NIHSS in an “actor” patient simulation scenario of acute stroke with trained health care professionals.\textsuperscript{10} The authors stated that TeleBAT is a valid and reliable mobile telemedicine system in evaluating stroke severity between a moving ambulance and a hospital-based stroke physician. However, TeleBAT used a pretransmission capturing and selection of video image sequences with an average image transfer of 8.3 per minute.\textsuperscript{17} Specific stroke symptoms such as ataxia cannot be assessed appropriately with this technique. Furthermore, in our opinion, sufficient broadband AV connection that allows a bidirectional, real-time communication (high-quality videoconferencing) as provided in interhospital telestroke networks\textsuperscript{5,18} is crucial, especially in the emergency setting with background noise, space limitations, and urgency.\textsuperscript{8} In addition, interrater agreement of the complete NIHSS score was not reported in the TeleBAT study that makes it difficult to compare results.

In our study, technical difficulties that account for insufficient AV signal quality were (1) frequent disconnection of cellular technology when moving from cell-to-cell within the network; and (2) high-capacity use of UMTS cells within the inner Berlin city area (Figure 2). This phenomenon is often called the “iphone effect,” because it has dramatically increased by the fast raise of mobile Internet consumption with limited transmission capacity in the designated UMTS cells. Besides regular advances in cellular communication technology, future efforts to resolve these issues may be that providers allow a “prioritization” of privileged users within cells, that is, emergency telestroke ambulance and parallel use of several cellular phones from different providers to stabilize and expand the bandwidth. Compared with our technology, other evolving broadband technologies such as WiMAX (Worldwide Interoperability for Microwave Access) may provide new technical capabilities with much higher data transfer rates with > 100 mbit/s. However, bandwidth must be split among users in one cell and thus leads to lower speeds in practice. Moreover, other technologies such as 4G/LTE (fourth-generation long-term evolution) are promising future options for the application in the emergency medical services due to the fact that besides higher bandwidth, “network prioritization” of users within cells is possible.

However, in our study interrater reliability of NIHSS assessment was moderate to good in stroke scenarios with continuous, sufficient AV connection. Thus, our preliminary findings should encourage further studies to overcome the technical problems of mobile AV communication into moving ambulances. The transfer of mobile telestroke systems and telemedicine infrastructure into emergency medical services is a promising approach for future improvement of acute stroke care and outcome after stroke as promoted by the American Heart Association.\textsuperscript{8} Two thirds of patients with acute stroke are delivered by emergency medical services.\textsuperscript{19} Thus, telestroke ambulances and other application of telemedicine into the emergency medical services may certainly be useful for, for example, prehospital early diagnosis of acute stroke, on-scene triage for adequate referral to specialized hospitals in cases of high-risk patients, and prenotification of emergency departments, but so far evidence is limited. Currently, novel concepts of “bringing the hospital to the patients” are being examined for acute stroke management. Fassbender and coworkers developed a “mobile stroke unit” equipped with CT to perform prehospital thrombolytic therapies if indicated in a rural area.\textsuperscript{20,21} Recently, the prehospital acute neurological therapy and optimization of medical care in stroke patients (PHANTOM-S) study introduced the stroke emergency mobile unit to apply prehospital thrombolysis in the Berlin inner-city catchment area.\textsuperscript{22} The stroke emergency mobile unit is an advanced life support ambulance equipped with a CT scanner, point-of-care laboratory, and a mobile telecommunication support for teleradiology and teleconferencing. However, as a consequence of this feasibility study, on-site presence of an experienced stroke physician remained compulsory. If future studies using advanced cellular technology provide evidence that evaluation of stroke severity in the ambulance is reliable, remote telestroke consultation into “mobile stroke units” might replace the need for permanent presence of on-site stroke expertise.

Limitations of our study are that we did not involve real patients with stroke for safety reasons at this stage, but evaluated health professionals in simulating different stroke syndromes. Second, completion of NIHSS assessment could only be performed in 12 of 30 patients. Thus, due to the small number of cases, reliability of remote NIHSS examination in telestroke ambulances should be evaluated in larger studies. Third, we only evaluated stroke severity in “actor” patient simulation of right and left stroke syndromes in an experimental setting that evidently differs from a heterogeneous stroke population. Furthermore, because actors were trained to imitate stroke deficits and are familiar with being examined on the NIHSS, our results may overstate the possible agreement. Finally, the distribution of mobile telecommunication services may differ between regions and cities. Thus, the transferability of our results to other regions is not necessarily possible.

In conclusion, remote NIHSS-based evaluation of stroke symptoms in a moving ambulance car was only feasible in only 40% of stroke scenarios and not at an acceptable level for clinical use, at least on the basis of the used technology. Further technical development is needed before telestroke is applicable for prehospital acute stroke management during patient transport.

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