Background and Purpose—ResolutionMD mobile application runs on a Smartphone and affords vascular neurologists access to radiological images of patients with stroke from remote sites in the context of a telemedicine evaluation. Although reliability studies using this technology have been conducted in a controlled environment, this study is the first to incorporate it into a real-world hub and spoke telestroke network. The study objective was to assess the level of agreement of brain CT scan interpretation in a telestroke network between hub vascular neurologists using ResolutionMD, spoke radiologists using a Picture Archiving and Communications System, and independent adjudicators.

Methods—Fifty-three patients with stroke at the spoke hospital consented to receive a telemedicine consultation and participate in a registry. Each CT was evaluated by a hub vascular neurologist, a spoke radiologist, and by blinded telestroke adjudicators, and agreement over clinically important radiological features was calculated.

Results—Agreement (κ and 95% CI) between hub vascular neurologists using ResolutionMD and (1) the spoke radiologist; and (2) independent adjudicators, respectively, were: identification of intracranial hemorrhage 1.0 (0.92–1.0), 1.0 (0.93–1.0), neoplasm 1.0 (0.92–1.0), 1.0 (0.93–1.0), any radiological contraindication to thrombolysis 1.0 (0.92–1.0), 0.85 (0.65–1.0), early ischemic changes 0.62 (0.28–0.96), 0.58 (0.30–0.86), and hyperdense artery sign 0.40 (0.01–0.80), 0.44 (0.06–0.81).

Conclusions—CT head interpretations of telestroke network patients by vascular neurologists using ResolutionMD on Smartphones were in excellent agreement with interpretations by spoke radiologists using a Picture Archiving and Communications System and those of independent telestroke adjudicators using a desktop viewer.

Clinical Trial Registration Information—www.clinicaltrials.gov unique identifier NCT00829361.


Key Words: computed tomography ■ mhealth ■ Smartphone ■ stroke ■ telemedicine ■ teleradiology ■ telestroke

Advances in the management of patients with acute stroke syndromes have made fast acquisition and interpretation of neuroimaging key factors for delivering favorable outcomes. This holds true within the context of a hub-and-spoke telestroke network as well as within stroke centers. A new client–server-based teleradiology system was developed, evaluated, and approved for use.1 The new teleradiology system, based on client–server architecture, enables rapid access to interactive advanced 2-dimensional and 3-dimensional image visualization on current-generation Smartphone and tablet devices (Apple iOS or Google Android) without requiring patient image data to be stored on the device in an effort to generalize use based on the operating system instead of specific devices. A server loads and renders the patient images and transmits to the remote device. This client–server teleradiology system affords vascular neurologists (VNs) rapid and easy access to neuroradiological images of patients exhibiting symptoms and signs of acute stroke from remote sites in the context of a telemedicine evaluation. A retrospective study of CT brain scans of patients with acute stroke were read by 2 neuroradiologists, one on a medical diagnostic workstation and the other on an iOS device,1 reporting that the sensitivity, specificity, and accuracy of detecting intraparenchymal hemorrhage were each 100% using the iOs device with perfect interrater agreement. The sensitivity, specificity, and accuracy of detecting early acute parenchymal ischemic change were 94% to 97%, 100%, and 98% to 99%, respectively, with good interrater agreement. Study weaknesses included its retrospective design and the fact that it was conducted without the pressures and time constraints of a real-world stroke emergency. The authors recommended that generalizing...
conclusions about its clinical use in real-world acute stroke or telestroke should not be made until additional studies are performed. Although the Smartphone client–server teleradiology system appeared promising for management decisions in acute stroke, this study is the first reliability study to be conducted in a live, real-world, hub-and-spoke telestroke network environment.

Our study objective was to assess the level of noncontrast CT brain scan interpretation agreement between hub VNs using Smartphone teleradiology and spoke radiologists using a Picture Archiving and Communication System (PACS) and independent telestroke adjudicators who used a desktop viewing system (QREADs).2

Methods
ResolutionMD (ResMD) mobile delivers a complete telemedicine solution directly to mobile devices, providing instant access to images and reports. It supports Wi-Fi and 3G/4G cellular data networks to access PACS images from a remote location (Figure 1). The ResMD Smartphone telestroke study was conducted in a hub-and-spoke network environment between the hub, Mayo Clinic Hospital, Phoenix, AZ, and a spoke hospital approximately 185 miles away, Yuma Regional Medical Center, Yuma, AZ (Figure 2). Prospective patients who presented to the spoke hospital with symptoms and signs consistent with an acute stroke syndrome within 12 hours of onset consented to receive a telemedicine consultation and participate in the registry, Stroke Telemedicine for Arizona Rural Residents (STARR).3 Details of how the referring spoke emergency physician and nurse activated the telestroke hotline, registered the patient, communicated with hub VNs, set up the telemedicine cart, and participated in the collaborative assessment have been published.4 Every patient with acute stroke received a standard noncontrast CT brain scan as part of their emergency assessment. Each noncontrast CT brain scan was evaluated by one of 5 hub VNs (through ResMD on an Apple iPhone 4), one of 10 participating spoke radiologists through a PACS, and by 2 blinded independent telestroke investigator–adjudicators from compact discs loaded onto a desktop computer viewing system (QREADs).2 Diagnoses and CT features were recorded on case report forms. With knowledge of the clinical syndrome, the spoke radiologists and the telestroke adjudicators independently submitted CT interpretation reports. The study received approval from the Mayo Clinic Institutional Review Board. A description of the STARR hub-and-spoke network, program, registry, and dynamic has been published.3

Statistical Methods
The $\kappa$ statistic and 95% CIs were used to assess agreement of clinically important radiological features on CT among hub VNs who used ResMD, the spoke radiologists on PACS, and the independent adjudicators with QREADs. When the observed agreement and $\kappa$ statistic was 1.0, the lower limit of the 95% CI was estimated from an exact binomial distribution to obtain a better assessment of variability. All analysis was performed using SAS Version 9 (SAS Institute, Inc, Cary, NC).

Results
Sixty-five consecutive patients who exhibited symptoms and signs consistent with a possible acute stroke syndrome within 12 hours of onset consented to study participation. Twelve of the 65 consented subjects could not be enrolled. Three of 12 were swiftly identified as having a severe traumatic intracranial hemorrhage or an aneurysmal subarachnoid hemorrhage and the telestroke consultation was cancelled so as not to interfere with resuscitation, stabilization efforts, and preparation for air ambulance transfer to a neurological critical care unit. For 9 of 12, the referring emergency physician cancelled the telestroke consultation indicating complete resolution of focal neurological symptoms and absence of neurological deficits. Therefore, 53 of...
the consented subjects remained available for study. Of these 53, in 2 instances, the CD of neuroimages was not retrievable by telestroke adjudicators and in 7 instances the specified non-contrast CT study interpretation report form was incomplete; hence, Hub VN ResMD N=53, spoke radiologist PACS N=46, and telestroke adjudicators DICOM N=51. (Note: When the 9 noncontrast CT transcribed source reports were subsequently retrieved, they read either “nil acute” or “no infarction, hemorrhage, mass, edema, or midline shift.”) None of the original 65 consented subjects were lost to follow-up. The 53 analyzed subjects’ diagnoses at the conclusion of the emergency department assessment were: ischemic stroke (eligible for intravenous thrombolysis) in 34% (18 of 53), ischemic stroke (not eligible for thrombolysis) in 43% (23 of 53), intracranial hemorrhage in 6% (3 of 53), transient ischemic attack in 4% (2 of 53), not cerebrovascular disease in 9% (5 of 53), and diagnosis undetermined in 4% (2 of 53).

Table 1 demonstrates agreement (κ and 95% CI) between hub VNs using ResMD and radiologists and independent telestroke adjudicators who used QREADs. Table 2 displays the number of radiological findings identified by each of the reader groups (hub VN ResMD N=53, spoke radiologist PACS N=46, telestroke adjudicators DICOM N=51).

**Discussion**

Mitchell et al described how the Smartphone client–server teleradiology system appeared promising and may have the potential to allow urgent management decisions in acute stroke. However, Mitchell et al’s study was retrospective and conducted in a controlled environment. Our study, in contrast, was conducted in a live operational regional hub and spoke telestroke network by clinical investigators who were actively participating in real-world telemedicine assessments of patients with time-sensitive stroke emergencies. Even under these conditions, ResMD Smartphone teleradiology application performed extremely favorably. The agreement between VNs using ResMD and radiologists and independent telestroke adjudicators using standard PACS and desktop viewers over identification of the most critical radiological features on noncontrast CT brain scans such as intracranial hemorrhage, neoplasm, and any contraindications to thrombolysis was excellent. Not unexpectedly, agreement over identification of more subtle radiological features such as early ischemic changes and hyperdense artery signs was lower than in the Mitchell et al study, moderate and fair, respectively. The study’s main limitation was the small sample size and the resultant wide CIs around κ estimates.

Smartphone applications adapted to telestroke appear to be promising based on recently published research. Takao et al developed a system for rapidly exchanging and communicating patient data, diagnostic images, and clinical management information among members of a stroke team in and out of the hospital through standard handheld communication devices in real time. The authors concluded that the system may become a useful tool for acute stroke management in the disciplines of neurology and neurosurgery. Gonzalez et al and Smith et al reported that a standard real-time cellular video-phone was a feasible, reliable, and timely tool that carried potential for remotely assessing the National Institutes of Health Stroke Scale score for patients presenting with acute stroke to a remote hospital. When coupled together, real-time video-phone neurological examinations and Smartphone teleradiology assessments may offer a VN a single mobile health tool with which to expeditiously conduct full telestroke and teleradiology assessments necessary for a complete virtual stroke consultation in a remote environment.

**Conclusions**

In a telestroke network environment, VNs’ noncontrast CT identification of radiological contraindications to

### Table 1. CT Interpretation Agreement

<table>
<thead>
<tr>
<th>Identification of</th>
<th>Hub VN (N=53)</th>
<th>Spoke Radiologist PACS (N=46)</th>
<th>Telestroke Adjudicators DICOM (N=51)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kappa 95% CI</td>
<td>Kappa 95% CI</td>
<td>Kappa 95% CI</td>
</tr>
<tr>
<td>Intracranial hemorrhage</td>
<td>2/46 (4%) 1.0 0.92–1.0</td>
<td>3/51 (6%) 1.0 0.93–1.0</td>
<td></td>
</tr>
<tr>
<td>Neoplasm</td>
<td>1/46 (2%) 1.0 0.92–1.0</td>
<td>1/51 (2%) 1.0 0.93–1.0</td>
<td></td>
</tr>
<tr>
<td>Any radiological contraindication to thrombolysis</td>
<td>5/46 (11%) 1.0 0.92–1.0</td>
<td>7/51 (14%) 0.85 0.65–1.0</td>
<td></td>
</tr>
<tr>
<td>Early ischemic changes</td>
<td>4/46 (9%) 0.62 0.28–0.96</td>
<td>7/51 (14%) 0.58 0.30–0.86</td>
<td></td>
</tr>
<tr>
<td>Hyperdense artery sign</td>
<td>2/46 (4%) 0.40 0.01–0.80</td>
<td>3/51 (6%) 0.44 0.06–0.81</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2. No. of Radiological Findings Identified by Each Reader

<table>
<thead>
<tr>
<th>Identification of</th>
<th>Hub VN ResMD (N=53)</th>
<th>Spoke Radiologist PACS (N=46)</th>
<th>Telestroke Adjudicators DICOM (N=51)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intracranial hemorrhage</td>
<td>3 (6%) 2 (4%) 3 (6%)</td>
<td>5 (11%) 11 (22%)</td>
<td></td>
</tr>
<tr>
<td>Neoplasm</td>
<td>1 (2%) 1 (2%) 1 (2%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any radiological contraindication to thrombolysis</td>
<td>7 (13%) 5 (11%) 9 (18%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early ischemic changes</td>
<td>10 (19%) 5 (11%) 11 (22%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hyperdense artery sign</td>
<td>7 (13%) 2 (4%) 5 (10%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

VN ResMD vascular neurologist ResolutionMD; PACS, Picture Archiving and Communications System.
thrombolysis of patients with acute stroke with ResMD on a Smartphone was in excellent agreement with those of spoke hospital radiologists and the independent telestroke adjudicators.

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The Arizona Department of Health Services provided a research grant for the Stroke Telemedicine for Arizona Rural Residents (STARR) Registry and Calgary Scientific Inc provided the technology and technical assistance for ResolutionMD mobile implementation.

Disclosures
None.

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Smartphone Teleradiology Application Is Successfully Incorporated Into a Telestroke Network Environment

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