Integration of Real-Time Electronic Health Records and Wireless Technology in a Mobile Stroke Unit

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Background: UCHealth's Mobile Stroke Unit (MSU) at University of Colorado Hospital is an ambulance equipped with a computed tomography (CT) scanner and tele-stroke capabilities that began clinical operation in Aurora, Colorado January 2016. As one of the first MSU's in the United States, it was necessary to design unique and dynamic information technology infrastructure. This includes high-speed cellular connectivity, Health Insurance Portability and Accountability Act compliance, cloud-based and remote access to electronic medical records (EMR), and reliable and rapid image transfer. Here we describe novel technologies incorporated into the MSU. Technological data-handling aspects of the MSU were reviewed. Functions evaluated include wireless connectivity while in transit, EMR access and manipulation in the field, CT with image transfer from the MSU to the hospital's Picture Archiving Communication System (PACS), and video and audio communication for neurological assessment. *Methods/Results:* The MSU wireless system was designed with redundancy to avoid dropped signals during data transfer. Two separate Internet Protocol destinations with split-tunnel architecture are assigned, for videoconferencing and for EMR data transfer. Brain images acquired in the ambulance CT scanner are transferred initially to an onboard laptop, then via Citrix Receiver to the hospital-based PACS server where they can be viewed in PACS or EMR by the stroke neurologist, neuroradiologist, and other providers. PACS and Radiology Information System are 2 of the XenApps utilized by CT technologists on board the MSU. *Discussion/Conclusions:* These technologies will serve as a blueprint for development of similar units elsewhere, and as a framework for improvement in this technology.

Key Words: Stroke—acute stroke treatment—mobile stroke unit (MSU)—electronic health record (EHR)—tPA—health information technology (HIT)
Subject Terms: Ischemic stroke—computed tomography (CT)—rt-PA—thrombolysis—information technology

Introduction

Acute ischemic stroke (AIS), which affects approximately 700,000 individuals per year in the UnitedStates, is the leading neurologic emergency and one of the primary causes of death and disability in the United States.[1] Because there is a brief therapeutic window for thrombolytic intervention for individuals with AIS, 0-3 hours or 3-4.5 hours after symptom onset, with better outcomes associated with earlier treatment, prompt recognition and neurologic assessment for such individuals is critical.[2,3] Since publication of the landmark NINDS rt-PA trial in 1995 and Federal Drug Administration approval of rt-PA

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for treatment of individuals with AIS in 1996, individuals with suspected AIS are treated as having true medical emergencies requiring emergency evaluation and treatment.[4,5] Despite these advances in stroke care processes, the frequency of rt-PA administration remains frustratingly low, with only 2%-5% of stroke patients receiving thrombolytic therapy.[6-8] This has been attributed largely to the amount of time that transpires between symptom onset and arrival at a hospital for thorough stroke evaluation under conventional stroke patient transportation and treatment paradigms. In response, the mobile stroke concept was developed. With an ambulance-mounted computed tomography (CT) scanner, this system aims to reduce transit time and speed AIS evaluation through brain CT scanning in the field for rapid acquisition of neuroimages, and neurologic evaluation via telemedicine. This approach is still in the nascent stage. Results of a research study of this paradigm were first reported in 2003,[9] and by 2016 fewer than 10 centers worldwide utilized mobile stroke units (MSUs). Those which did often broke new ground in multiple technological and operational aspects of mobile stroke care.

Here we report on the technological build and collaboration employed in establishing a MSU that serves 2 major US metropolitan areas and incorporates rapid transmission of brain images and manipulation of electronic medical information from the field to a neuro-vascular specialist for the purpose of evaluation and treatment of acute stroke.

Methods

Onboard Technology

The UCHealth MSU, which began operation in January 2016, operates in 2 separate Colorado cities, Aurora and Colorado Springs, alternating 1 week in Aurora and the next week in Colorado Springs. Both cities offer ample 4G

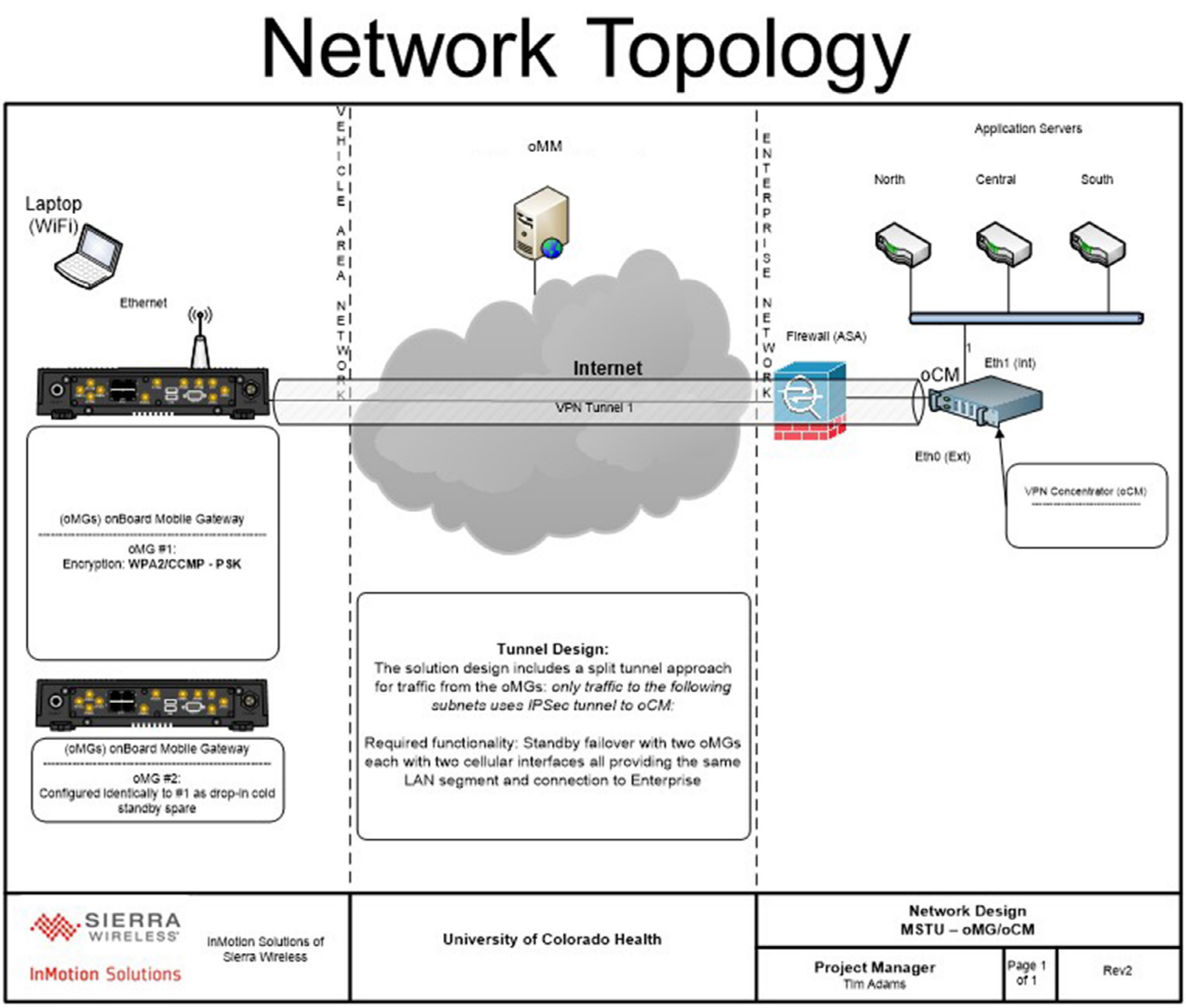

Figure 1. *Onboard technology: 5GHz onboard router (onBoard Mobile Gateway or oMG), and "cold" standby backup router (oMG), able to maintain two simultaneous connections and switch between cellular connections with minimal signal interruption. Network technology: Split-tunnel network with one connection directly to HIPAA-compliant, vendor-hosted, cloud-based Telehealth connection and another VPN-secured, HIPAA-compliant connection to hospital-based EMR and PACS.*

cellular signal (LTE) coverage, allowing a router to be deployed onboard the MSU that leverages each city's cellular network. A key feature of the router chosen is the ability to maintain 2 independent cellular connections. This allows connection to 2 separate cellular providers that both meet the minimum speed and coverage requirements for the MSU's technology needs. If one cellular provider experiences poor coverage, or complete service failure, the router automatically converts to the other cellular provider without crew intervention. The time between failure detection and establishing the secondary carrier connection is consistently less than 10 seconds. Cellular signal strength and GPS data is continuously logged for diagnostic and troubleshooting purposes. Hence, data outages can be analyzed based on carrier signal, geographic circumstances, and other environmental factors to determine the issues contributing to the outage. Because a strong collaborative relationship was created early between the UCHealth MSU and the cellular carriers and because we are able to provide the cell service providers with robust temporal, geographic, and cellular signal strength data, cellular coverage issues are typically resolved quickly.

Applications used onboard the MSU include EPIC − the UCHealth electronic medical record (EMR), point of care testing, and video teleconferencing software (and hardware) provided by InTouch Health. Deploying split-tunnel network architecture, which allows simultaneous access to dissimilar domains through a single connection, allows the MSU to communicate directly with the most appropriate destination, thus minimizing network latency. This prevents applications dependent upon internet sites from having to traverse UCHealth's network first, then "hop" to the internet from the UCHealth network (Fig 1). For example, the videoconferencing application on the MSU utilizes a vendor-hosted, cloud-based environment. Hence, traffic destined for the video teleconferencing vendor's defined IP addresses is routed directly over the internet to the vendor's HIPAA-secure servers. Alternatively, applications that connect to the UCHealth network do so directly over a secure virtual private network to UCHealth's internal network.

Because channel congestion and signal interference are common problems in populated environments, the MSU Wi-Fi network required additional optimization. Typical consumer-grade Wi-Fi routers broadcast very strong signals that reach well beyond the walls of homes and businesses. Placing the MSU Wi-Fi antenna inside the unit, rather than mounting it on the roof, drastically reduces interference from other Wi-Fi sources. In addition, 2.4 GHz spectrum routers are far more common in most public settings than 5 GHz routers, hence, deploying a 5 GHz router and selecting less frequently used channels further improves connectivity. Finally, using hard-wired Ethernet connections whenever possible reduces interference, resulting in more consistent connectivity and an added layer of reliability onboard the MSU.

The decision to transfer a patient to the MSU must be made quickly and with confidence that patient care onboard the MSU will not be compromised by technological problems. Because the UCHealth MSU operates within a defined, but relatively large geographic area, and due to the critical and time-sensitive task of caring for stroke patients on an MSU, the Information Technology (IT) team was challenged to rethink its standard methods of technical support in a healthcare environment, and create an infrastructure that required little immediate intervention from IT support staff in an often volatile setting. Given the unpredictable environmental variables that exist while caring for patients, it is not possible for IT to troubleshoot problems at the moments they arise. With this in mind, an application that continuously pings 3 destinations (the local network gateway on the MSU, the server on the UCHealth network, and an internet-based server) was developed to enable the MSU staff to assess network connectivity while in the field. MSU staff are trained to interpret the output of the continuous pings and judge the MSU's network connectivity strength. If at any time one of the 3 network destinations does not respond or responds with a latency outside a predetermined threshold, additional protocols are executed to improve or re-establish network connections or, if necessary, decline transfer of the patient to the MSU. This ensures that whenever a patient is transferred to the MSU, from a technical standpoint, the patient can be treated on the MSU appropriately. In addition, the MSU staff is trained to capture the application's data output, including data transfer speed, for ongoing IT quality improvement and, especially if a patient is declined due to technical problems, root cause determination.

Image Applications and Transfer

The CT technologist on the MSU, through the use of a Citrix Receiver, has access to multiple XenApps. These applications allow traditional hospital workflow to be mirrored onboard the MSU because the CT technologist is able to fully utilize the electronic functionality necessary to perform and transmit CT images for rapid interpretation and, ultimately, treatment decisions.

A Digital Imaging and Communications in Medicine worklist is available on the MSU and alleviates the need for manual patient information entry into the CT scanner. The worklist is driven by the Radiology Information System which assists the successful image to order reconciliation within the PACS. Worklists are controlled through the use of the Application Entity (AE) Title of the CT scanner. Traveling between 2 major cities requires 2 separate AE Titles to drive the patient information for each hospital region. It is a manual process to change the AE Title each week the MSU changes locations but this has not proven to be too complicated for the CT Technologists to overcome with appropriate training and security rights.

Images that are generated by the MSU CT scanner are electronically pushed to the CT laptop via a static IP address over hardwire. From the CT Laptop the technologist selects the PACS destination by hospital region. The images are then sent wirelessly from the laptop to the internal wireless router on the MSU. Images are then transferred through cellular connectivity to a direct UCHealth virtual private network connection to the UCHealth Network. Hardwire connectivity from the CT laptop to the MSU internal wireless router has been provided to prevent connection loss during image transfer. This configuration also improves transmission speed. Once the images are in PACS they are automatically resolved to an order within Epic without the need of technologist intervention due to the use of the Digital Imaging and Communications in Medicine worklists. It is at this stage that an Image Availability Notification message is sent to the Radiology Information System producing a hyper link within the patient's Epic chart to allow for the consulting stroke neurologist to review the images. Images are also available to reviewing radiologists and populated on the regional hospital list based on the PACS reading list filters and Health Level (HL7) configurations, facilitating rapid neuroradiology consultation with the MSU telehealth provider. Dictations are also pushed automatically to Epic and can be accessed by all healthcare providers. An initial benchmark of 5 minutes from completing the CT image acquisition to complete transmission of the images to PACS was the target; however, with the 4G LTE cellular enhancements deployed images are routinely transferred in less than 1 minute, concurrent with an audio-visual teleconference session.

UCHealth has incorporated in the MSU a secure, cloud-based image sharing platform to increase the operational efficiencies and patient treatment time. CT technologists have access through the PACS application to send images electronically and directly to outside facilities' PACS. As soon as the images are in the UCHealth PACS, images are readily pushed by a CT technologist into the PACS of the destination facility. Having MSU CT images available to internal and external healthcare facilities' PACS before the MSU arrives in the ED allows for receiving departments to initiate protocols before the patient's arrival. UCHealth currently has access to approximately 172 locations through this cloud-based platform. This eliminates the need for external media, which in turn, obviates the need to transfer images from external media and the time it takes for facility personnel to reload the images into their PACS system.

Electronic Medical Record, Epic

When developing the UCHealth telehealth program, it was important to leadership that provider workflow is as similar as possible to their inpatient and ambulatory processes. As such, the telehealth program incorporates Epic as its platform for providing patient care. When developing the MSU processes, it was determined that our current telestroke process would be duplicated which required incorporating Epic into the MSU. Likewise, creating a single Epic encounter allows for continuity of care that is patient centric. As would be the case when practicing in clinic or in the hospital, clinicians are provided access to previous encounter information. Laboratory, radiographic studies, and MSU treatment documentation is shared real-time with the entire treatment team within the same encounter, which follows the patient to the ED when transferred to a UCHealth facility.

During the Epic build an MSU department was created for both regions. Utilizing the hospital system's access center, referred to as the DocLine, a "quick registration" is performed as soon as patient information is available from the field. This creates the encounter that allows order entry, attachment of CT images, and the start of treatment on the MSU. The DocLine, staffed with Registered Nurses (RNs) to assist with all telestroke calls, is able to expedite consults with a neuroradiologist and assist the MSU staff with other events needing intervention with hospital support staff such as IT. Staffing the DocLine with RNs provides the ability to receive and place select orders per an established protocol. A DocLine-specific panel with standing orders to include the CT scan as well as specific point of care testing was created within Epic and is placed by the DocLine RN quickly and independent of a physician verbal order—further expediting patient care.

Once the order is placed a CT tech on the MSU is able to view the order within Epic and execute the study in the same manner as if the patient was physically located in the hospital-based radiology environment. Images are available for review by the telestroke neurologist and neuroradiologist.

MSU workflows were developed to emulate existing clinical processes to ensure that all clinical partners were documenting consistently. Telestroke physician documentation was developed to mirror the current telestroke format with the addition of an MSU-specific order set. This order set streamlines order entry by providing preselected items that are customarily ordered. The inclusion of other more-common orders to include rt-PA administration instructions as well as other medication, allows for quick single-click inclusion at the discretion of the consulting physician. Nursing documentation emulates Epic's ASAP application commonly used in the ED. The build tailored to MSU workflow allows the onboard RN and/or paramedic to follow specific assessment(s), to include continuous vital sign monitoring and the Stroke Scale scoring, NIHSS. An Epic flowsheet entitled "*MSU Run Sheet*" was also created illustrating MSU significant events with discrete data entry of timestamps (Fig 2). This dynamic run sheet is provided to the receiving ED for quick reference of the MSU care events and treatment timeline.

Evolution of the Epic ASAP application has provided the ability to create a Stroke Narrator. Within the Stroke Narrator a tab was created specific for the MSU

Figure 2. *EMR flowsheet with discrete, time-stamped, MSU process and care data.*

documentation tools, providing staff with specific, organized sections which offers cohesive and consistent documentation among the MSU staff.

Upon delivery of the MSU patient to an ED one of 2 actions may be completed by MSU staff. If the patient is brought to an UCHealth facility the MSU staff is able to transfer the patient within Epic to the receiving ED bed for continuous, single encounter, documentation. If the patient is transported to a facility outside of UCHealth, the Epic encounter can be electronically routed from within Epic to the receiving ED for optimal continuation of care via a report that was created within Epic to capture all onboard and provider documentation. The Epic encounter is relayed via fax and includes a patient care report encompassing the clinical assessment notes; treating physician, neuroradiology, and nursing, as well as medication administration, care tasks, and point-of-care testing results. Using Nuance software, CT images are transmitted to the receiving facility.

Results

With a narrow treatment window for AIS, it is critical that treatment is concise, consistent, reliable, and timely. These concepts framed the structure of the UCHealth Mobile Stroke Unit's technical infrastructure. Onboard technology was created to ensure technical reliability necessary for patient care and urgent data transmission. Utilizing a combination of the latest 4G LTE cellular environment, a Wi-Fi antenna placed inside the MSU, and a router with split-tunnel architecture, has created the ability to orchestrate patient care with simultaneous videoconferencing, CT image collection with rapid transfer, as well as real-time EMR documentation. Establishing the ability to share images and onboard patient documentation with nonsystem facilities also supports collaborative efforts in the treatment of stroke within the communities served by the MSU.

Optimizing EMR – Epic – allows for the creation of a dynamic, electronic flowsheet, specific to MSU processes, that delivers critical timestamps of care conducted in the field. This is more efficiant and maintains more continuity compared to the paper chart utilized on most MSUs as well as in the conventional EMS approach. In addition, this mirrors inpatient and ED processes that are well known to the MSU physicians and clinical staff, and anecdotally, provides improved user satisfaction and patient care consistency. Integration of the EMR also allows for continuity of patient care when the patient is transferred to an in-system facility yet also provides thorough treatment information to nonsystem receiving facilities. A single encounter depicts prehospital care that seamlessly transfers to inpatient care; thus enhancing a patient-centric continuum of care.

It is anticipated that the MSU approach will result in substaintial improvement in thrombolysis rates and reduction in times from symptom onset to treatment. The UCHealth MSU is participating in an ongoing, multicenter, efficacy trial of MSUs; **BE**nefits of **S**troke **T**reatment Delivered Using a **M**obile **S**troke **U**nit (BEST-MSU), results of these parameters, and cost for this approach, will be published upon completion of this trial.

Discussion

AIS remains the leading cause of adult disability in the nation with tremendous direct and indirect consequences that impact those inflicted with this condition. The advancement of stroke treatment has included piloting the concept of mobilizing clinicians and new technology to bring early stroke treatment directly to the patient, even when incorporated in conventional ambulances.[10-12] In a further development, mobile stroke ambulances have been outfitted with a CT scanner, and the use of cell phone technology, allowing for rapid, orchestrated efforts to decrease the time to treatment of stroke victims within the MSU operating communities.[13] Careful detail to redundant and reliable technical infrastructure is imperative for the successful operation of these units.[14] Utilizing consistent workflows familiar to providers and staff as well as the use of 1 EMR greatly improves the continuum of care for the patient. Ongoing assessment of advancements in technology in these focused areas will be required to continue to improve the operation of MSUs throughout the world, ultimately improving the outcome of stroke patients by decreasing or eliminating the level of disabilities incurred within the patient population.

Continuing Challenges. In spite of the best efforts to ensure network connectivity, failures will occur due to a variety of causes: onboard equipment failure, cellular carrier outages, geographic areas with poor, or no, cellular coverage (a.k.a. "dead" zones), cellular network congestion, and failure of either the cellular carrier or UCHealth to connect to the internet.

Conclusions

The mobile stroke concept is an important new development in the care of acute stroke. Innovative and unique technology infrastructures were developed for the MSU at our institution to accommodate wireless communication challenges, rapid image transfer, and clear audio and visual communication between the field crew, patients, and the teleneurologist. These unique and innovative technologies will serve as a blueprint for development of similar units elsewhere, and as a framework for improvement in this technology.

Disclosures

None.

Conflict of Interest

The authors have no conflicts of interest to disclose.

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