Remotely Supported Prehospital Ultrasound: Real-time Communication for Diagnosis in Remote and Rural Communities

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Abstract. We have created a system that aims to facilitate prehospital assessment of remote and rural patients using remotely supported ultrasound (US) and a novel communications device. Paramedics can function as remotely supported US operators, guided and advised by hospital-based specialists regarding diagnosis and treatment options. Novel communication technology can link these users in areas with low communications coverage by connecting to multiple cellular networks and/or satellites to stream live US and video images, plus two-way audio. A demonstrator system was used in locations around the Scottish Highlands to stream images to remote reviewers for image interpretation, as well as sending audio and video to allow mobile telestroke assessments while in transit. Connections with live US and audio-visual transmission were successful, with appropriate views provided in 94% scans. All telestroke assessments were completed successfully. This prehospital support US system could facilitate early diagnosis and streamlining of treatment pathways for remote and emergency patients. It could be particularly applicable and useful in rural areas worldwide with poor communications infrastructure and extensive transport times.

1 Introduction

Prehospital diagnosis can save time on arrival at hospital, streamlining patient care, and if early treatment can be given, it can potentially save lives and help improve patient outcomes. This is particularly true for patients who live a considerable distance from major centres of care, such as in the remote Scottish Highlands. Ambulances are currently limited in their diagnostic imaging capacity; however, providing imaging facilities is not enough: users would have to be trained in the use of the technology and image interpretation. One solution would be to send experts out as part of the ambulance team, and this option is used in some countries, particularly in major cities where ambulances are extremely busy and distances to hospital are relatively short. However, in remote and rural areas it is not feasible to staff ambulances with specialists and so diagnosis often must wait until the patient has travelled the distance to the nearest hospital, often being passed from smaller hospitals to larger ones that can provide the required level of care.

We are proposing a remotely supported diagnostic system, where experts in ultrasonography support novice scanners in the prehospital situation using robust communication links. Ultrasound users in the field can receive guidance on the

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recording of images and their interpretation from hospital-based experts through the use of cellular and satellite networks to transmit live images and data, even in areas with variable bandwidth availability. This means that remote ultrasound users need only basic training in how to use the equipment, and diagnosis can be performed by the same people who would be consulted upon the patient's arrival at hospital. This could potentially save time and help streamline the patient's care pathway, because even if treatment cannot be given in the ambulance, the hospital can be alerted to the patient's needs and prepare for their arrival.

Ultrasound (US) is routinely used to assess emergency trauma patients, where it can help locate bleeding within the body using the Focussed Assessment using Sonography for Trauma (FAST) scans, and we think it could also be useful in less routine scans, such as transcranial imaging to look for bleeding in the brain in stroke or traumatic brain injury. In stroke in particular it is vital to diagnose the aetiology (blood vessel blockage versus bleeding) because early intervention with 'clot-busting' (thrombolytic) treatment can significantly reduce disability and lower mortality [1]. However, thrombolysis must not be given to patients with a haemorrhagic stroke because it can worsen outcomes.

We suggest that US could be used to gather early diagnostic information in stroke and other conditions in situations where access to computed tomography is limited and/or delayed through remoteness. There is already a modest evidence for the use of portable ultrasound in the prehospital assessment of stroke patients [2]. The International Pre-hospital Stroke Project has demonstrated that Transcranial Colour-Coded Sonography can be used to identify occlusion in the middle cerebral arteries [3,4]. There is also limited evidence that b-mode (2D greyscale) transcranial ultrasound can be used to identify and rule out haemorrhagic stroke. Mäurer et al demonstrated that ultrasound detected 94.3% of haemorrhages detected by CT, and correctly confirmed the absence of haemorrhage in 95% of cases (n=133) where brain could be visualised [5]. More recently, Kukulska-Pawluczuk et al showed transcranial ultrasound successfully identified brain haemorrhage in 34/39 cases up to 12 hours after CT [6].

Attempts have been made to use a portable CT scanner for prehospital diagnosis of stroke: the PHANTOM-S study trialed a stroke emergency ambulance in urban Berlin (restricted to an area up to 16 minutes from base), which contained a CT scanner, a point-of-care laboratory, telemedicine link, neurologist, radiology technician and paramedic [7]. The study showed that this service could reduce time to thrombolysis by 25 minutes; however, this is likely only to be beneficial in a small-radius, urban area with a large number of potential patients: it would not be cost-effective in rural locations.

We have created a remotely supported prehospital US imaging system, transmitting ultrasound video, plus standard audio/video (AV) in real time, and this paper reports on the initial field testing. Telestroke, the remote assessment of potential stroke patients over a telephone or video link, has been successfully employed in many places worldwide, eg [8]. However, it is usually performed from a static base such as a primary care facility or patient's home. We also used our remote support system to attempt telestroke assessments while on the move, as this would save time and could help provide a more efficient patient pathway.

2 Methods

2.1 US scanning

Ten healthy volunteers without previous US experience received approximately 30 minutes of basic training with the US machine and 2-5 MHz probe (Sonix Tablet, Analogic Corporation, USA) focused on the operation of the machine and techniques to perform the required scans. They were asked to perform three scans that form part of a routine trauma assessment: Morison's pouch to visualise free fluid around the liver and kidneys; the aorta, looking for any enlargement indicative of an aneurysm; and the lung, looking for signs of pneumothorax. Volunteers also attempted to image the brain, looking for the third ventricle which represented the midline of the brain, following the procedure described in Stolz et al. [9]. These scans were repeated in the ambulance with a clinical expert using the US machine to provide comparison data.

All US scanning was performed in an ambulance parked at 16 different sites around the Highlands. Live US video streams, plus AV from a fixed camera, were transmitted via an Omni-Hub™ communications system and bandwidth management device (Tactical Wireless, UK) using bandwidth from a combination of 2G and 3G cellular networks. Two trials were transmitted via satellite. Images were transmitted to one of four participating clinical assessors in Inverness for review and were given a rating for their quality and diagnostic utility on a five-point scale from 1 = poor to 5 = good. Data transfer rates and any equipment or connectivity problems were also recorded.

2.2 Telestroke assessments

The second part of the study involved performing remote stroke assessments in transit in a moving vehicle [10]. A telestroke checklist for clinical use has been created by NHS Highland stroke specialists, incorporating the ROSIER (Recognition of Stroke in the Emergency Room) Score, exclusion criteria for thrombolysis, Modified Rankin Scale, and National Institutes of Health Stroke Scale (NIHSS). This is used to decide whether a patient is a candidate for thrombolysis. In this study, volunteers used a 'script' providing details about a suspected stroke patient's condition to allow them to play the role of a patient and/or responding paramedic for this assessment. There was a pool of scripts describing symptoms of thrombolysable stroke, those with contraindications to thrombolysis, and those with a non-stroke condition (e.g., epilepsy, risk of non-compressible hemorrhage).

The assessments were performed by hospital experts based on details provided by the volunteers using the AV transmission while the vehicle moved between the static test sites used for US scanning. Some assessments were performed while the vehicle was parked, for comparison purposes.

Ethical approval for the study was provided by the North of Scotland National Research Ethics Service committee (ref: 14/NS/0087).

3 Results

3.1 US scanning

Of the 16 sites where static transmission was attempted (see Fig. 1), at only one was there was not enough signal and the attempt was abandoned. At all other sites US and AV were successfully transmitted.

Reviewers' ratings of the images are summarized in Table 1, and show that they found the transmitted images suitable for diagnosis in the majority of cases when cellular networks were used, although the communications quality (e.g., stability, reliability) was not always good. Overall, 94% of the thoracic images were recorded and transmitted successfully, as were 67% of the brain midline images.

Table 1: reviewer ratings of the transmitted ultrasound images

Median rating (range) (Scale: 1 = worst; 5 = best)	Cellular network (n=21)	Satellite network (n=2)
Communications adequacy for diagnosis	4 (2–5)	3 (3–3)
Communications quality	2 (1–5)	3.5 (3–4)

Novice scanners did take slightly longer than experts to complete the scans: 3.5 minutes versus 1 minute for experts for the thorax scans and 5.7 minutes versus 3 minutes for the brain midline scan.

3.2 Telestroke assessments

Nineteen mobile and four stationary telestroke assessments were performed; none were abandoned due to connectivity problems and all were correctly categorized in their thrombolysable status. The mean time to complete an assessment was 11 minutes while mobile (range 1–31 minutes) and 10 minutes while stationary (range 4–16 minutes), which was not a statistically significant difference. (It should be noted that assessments of non-thrombolysable patient cases often took much less time to complete because as soon as a contraindication to thrombolysis was revealed, the assessment would stop; this helps account for the wide range of assessment times). The quality of the communications was rated lower by the experts during mobile assessments (at 3 out of a maximum score of 5) compared with during the stationary trials (at 5 out of 5). Both types of assessment received high ratings (at 5 out of 5) from experts asked whether the AV system allowed adequate diagnosis.

Occasional breaks in transmission were experienced in 47% of the tests, but connection was re-established quickly and only minor delays were reported: for example, several tests reported total delays of 2–3 minutes during the assessment.

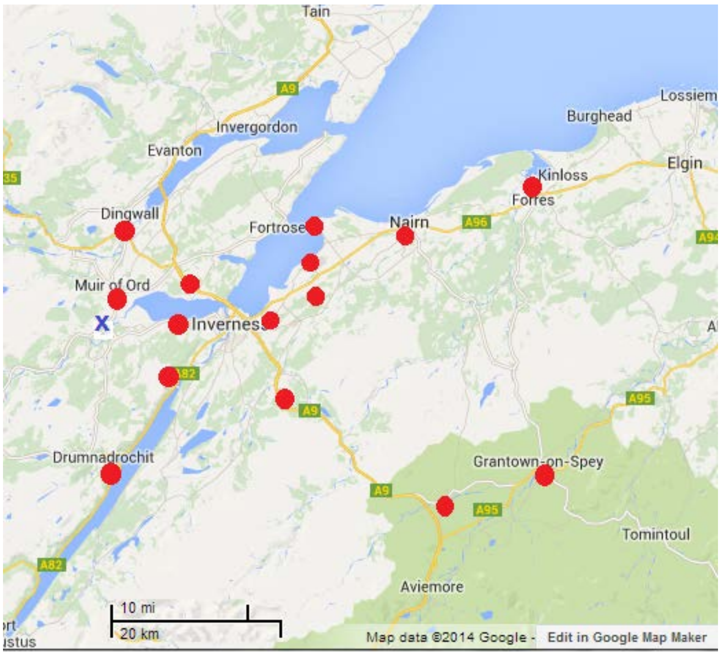

Fig. 1: Locations of the field test scans and transmissions. The blue cross indicates the unsuccessful transmission site

3.3 Transmission details

Transmission rates ranged from 22–1900 Kbps, with a mean of approximately 1250 Kbps. Higher rated AV quality (rated 4 out of 5, or 5 out of 5) was associated with a higher mean upload rate (1021 Kbps, range: 336–839), compared with AV rated 1 out of 5, or 2 out of 5 (553 Kbps, range: 447–1657).

The mean transmission latency or delay was 300 ms (114 ms with cellular networks and 2072 ms with satellite), which was not considered to be a limitation by participants at either end of the test.

4 Conclusion

This study shows that remotely supported prehospital US is possible even in the variable connectivity that is characteristic of the Scottish Highlands, and has the potential to be used in rural emergency care. The value of ultrasound is being able to deliver repeated imaging swiftly and without ionizing radiation. Our tests have also shown that it is feasible to perform telestroke assessments while mobile in rural locations – even when moving between signal areas – and this could be undertaken while a patient is in transit to a hospital, requiring no additional delays to perform and saving time on arrival. Using such a checklist assessment with US imaging results, it could potentially be possible to treat suitable patients with thrombolytic drugs in the ambulance.

Our results come from tests with healthy volunteers rather than patients and so it is difficult to compare them with those found in the existing literature on US for diagnosis of stroke, but we believe our image recording and transmission rate demonstrates the feasibility of remotely supported prehospital US. It should be noted that most previous studies using US to investigate haemorrhage were conducted some time ago with older ultrasound equipment. It is possible that with improved modern scanners, plus software and potentially probe optimisation, that prehospital US scanning for haemorrhage could be both viable and worthwhile.

Our study showed that despite relatively poor quality of communications, evidenced by the low ratings received for the cellular network transmission, images thought to be of diagnostic relevance did arrive with the hospital-based clinical reviewers in a high percentage of cases. This could offer hope for rural and remote areas where communications availability is known to be substandard.

The success of our mobile telestroke testing is also encouraging. There is already a body of evidence supporting telestroke assessment and thrombolysis rates achieved via such systems have been shown to match rates achieved via on-site expert assessment with comparable patient outcomes [8]. In Yperzeele et al.'s review of prehospital stroke care three generations of telestroke technology were described [11]: utilising communication over fixed landline; then the internet but only for patients who had already arrived at hospital; the third generation moves telestroke into the prehospital situation, but only a very limited amount of research has so far been conducted in this arena and the American Stroke Association advocates further research be performed [12].

The information transmitted in both of these initial tests could help accelerate patients' path to appropriate treatment on their arrival at a centre of care and could be simply incorporated into patient care pathways in both rural and urban areas, saving time and potentially improving outcomes by reducing the time to treatment.

This sort of technology does bring with it many areas of contention, just one of which is the legal implications: does the paramedic located with the patient have legal responsibility for their care, or does the advising remote expert? What if something goes wrong and a connection to the experts cannot be made or breaks down mid-assessment? Does the addition of remote support empower prehospital care staff, or take away from their status? How will it affect the staffing required in hospital to ensure support is available? These and many other questions must be considered.

System optimization is ongoing and the whole process should be tested with real patients, and this will be the next step for the project. This will require considerable discussion and negotiation with the hospital and ambulance service to put appropriate protocols in place to cover various eventualities and ensure patients are not harmed or disadvantaged in any way. It should also be noted that this feasibility study was not powered for statistical analysis, so the results are at increased risk of incurring a type 1 error and being overly positive.

In conclusion, we believe that this remotely supported imaging and assessment system could facilitate early diagnosis and streamline care pathways for patients, particularly in areas worldwide which have poor communications infrastructure and extensive transport times to centres of care.

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