ORIGINAL RESEARCH

Training novice users to assess stroke aetiology in remote settings using transcranial ultrasound: pilot study

AUTHORS

Daria Antipova[1] MSc, PhD Student *

Leila Eadie[2] PhD, Research Fellow

Ashish Stephen MacAden[3] MD, PhD, Consultant in Stroke and Rehabilitation Medicine

Philip Wilson[4] DPhil, FRCGP, Director, Centre for Rural Health, p.wilson@abdn.ac.uk

CORRESPONDENCE

*Dr Daria Antipova dariantipova@gmail.com

AFFILIATIONS

[1, 2, 4] Centre for Rural Health, Institute of Applied Health Sciences, University of Aberdeen, Inverness, Scotland IV2 3JH, UK

[3] Raigmore Hospital, NHS Highland, Inverness, Scotland IV2 3UJ, UK

ABSTRACT:

Introduction: Emergency care delivery to patients in remote and rural areas is limited by diagnostic restrictions and long transport times to major centres of care. People with suspected acute stroke living long distances from a hospital are unlikely to receive time-critical reperfusion therapy for these reasons. Basic brain imaging assessing blood flow in the major intracranial arteries could facilitate such care in remote settings. A 3-hour training package for novice transcranial ultrasound users has been piloted on a small group of volunteers to investigate whether they could acquire transcranial ultrasound images and video clips to

potentially allow remote interpretation and optimise pre-hospital management of acute stroke.
Methods: A pilot training project was set up in a university setting in Inverness, Scotland. Volunteer clinicians and students of nursing or medicine with no practical experience in transcranial ultrasound were recruited. Participants received three 1-hour training sessions combining theoretical aspects and hands-on practice on healthy volunteers provided by a qualified neurologist with more than 2 years of experience in transcranial ultrasound. Transcranial greyscale and colour-coded duplex sonography was performed to

visualise midline structures and major intracranial vessels, and to measure blood flow velocity in the middle cerebral artery, followed by an unsupervised assessment. Qualitative analysis of the anonymised feedback from participants on the training experience and its potential application was also performed.

Results: A total of 11 volunteers were recruited in the current pilot study. The average time to complete transcranial ultrasound assessment was approximately 40 minutes. The brain midline and cerebral peduncles were correctly labelled by 64% (7/11) and 91% (10/11) of volunteers, respectively. Participants demonstrated a good performance in detecting major intracranial vessels. The correct labelling rate for the middle cerebral artery was 73% (8/11), and 64% (7/11) for the anterior and posterior cerebral arteries. There was agreement between the trainer and the participants on

rating the quality of scans as assessed using a visual analogue scale. All participants gave positive feedback on the provided training and time allocated for each session. Generally, volunteers thought that operating the ultrasound machine and the probe simultaneously was difficult. It was also suggested that further follow-up training, with possible supervision, would be useful to retain the acquired skills.

Conclusions: Transcranial ultrasound scans of a quality to allow expert interpretation can be acquired by inexperienced transcranial ultrasound operators after receiving a brief training. This could potentially be used by medical staff working in remote and rural areas to facilitate acute care for stroke patients, but further work with a larger sample is needed.

FULL ARTICLE:

Introduction

Patients suspected of having had an acute stroke require rapid assessment with brain imaging to guide further management. Reperfusion therapy with intravenous thrombolysis and mechanical thrombectomy are optimal treatments for the most common type of stroke, acute brain ischaemia, but both must be delivered within hours of symptom onset. However, only 10% of patients actually receive thrombolysis[1] due to various pre-hospital and intra-hospital delays[2]. Thrombectomy can currently only be provided in specialised centres with dedicated neurointerventional facilities, and correct identification of patients that would benefit from direct transfer would optimise clinical outcomes cost-effectively.

Patients who live in remote and rural areas are at particularly high risk of not receiving reperfusion therapy due to long transport times and lack of opportunities for direct access to diagnostic imaging facilities. As previously demonstrated, clinical assessment of patients in rural areas can be supported by secondary care specialists while en route to the hospital with live transmission of audio and video data. This could potentially facilitate management upon arrival at a healthcare facility and improve outcomes[3-5].

The management of patients suspected of having had an acute stroke would improve if there was a basic imaging tool in place that could be used by rural general practitioners (GPs), paramedics or community nurses to help make treatment decisions. Transcranial ultrasound can be used for assessment of blood flow in the major intracranial vessels in order to detect steno-occlusive lesions[6,7] and to detect intracranial haemorrhage in the central structures, such as the basal ganglia[8], which can also cause midline shift of brain structures[9]. Neurovascular examination with portable transcranial colour-coded duplex sonography (TCCS) is a rapid, relatively inexpensive and non-invasive assessment that can be carried out with technology available in many primary care settings. However, it is important to ensure that transcranial ultrasound operators are adequately trained if their assessment results are to be used to guide further management. Thus, a short training package has been previously proposed by Klinzing et al

(2015) for training inexperienced ultrasound operators to perform TCCS [10].

The authors of the present study hypothesised that novice transcranial ultrasound users could perform a complete transcranial ultrasound assessment through the temporal bone window and acquire a set of images and video clips suitable for expert interpretation after a 3-hour training package. The aim was to investigate whether the inexperienced operators could capture the midline, cerebral peduncles, major brain arteries forming the circle of Willis and calculate blood flow velocity in the middle cerebral artery (MCA). In addition, feedback from participants was collected to assess their perspective on the overall experience after training.

Methods

This pilot training project was executed in a university setting in Inverness, Scotland. Actual field testing was not part of this work.

Participants

Adult (aged 18 years and over) male and female healthy volunteers who were qualified clinicians or students of nursing or medicine with no practical experience in transcranial ultrasound were recruited in May–July 2019.

Training package

Transcranial ultrasound scanning of healthy volunteers was performed through the temporal bone window using a SonoSite M-Turbo® Point-of-Care ultrasound machine and a 1–5 MHz low-frequency phased array transducer. Volunteers were asked to remain in a sitting position throughout the scan. Participants received three 1-hour training sessions combining theoretical aspects and hands-on practice on healthy volunteers. All three training sessions were provided by a single trainer, a qualified neurologist with more than 2 years of experience in transcranial ultrasound. Transcranial greyscale and colour-coded duplex sonography was performed to:

1. visualise the midline structures and the opposite skull bone in the transverse plane using greyscale in order to identify the temporal bone window sufficiently for interpretation of findings
2. make three consecutive measurements of the midline as a distance from the third ventricle to the ipsilateral skull and calculate the midline shift as reported previously[11]. Midline shift in suspected stroke patients might suggest a space-occupying haemorrhagic or ischaemic lesion. It has been reported to be a reliable indicator of intracranial haemorrhage with a significant correlation between haemorrhagic focus volume and midline shift[8,9]
3. visualise the cerebral peduncles to localise the circle of Willis anteriorly
4. visualise the major intracranial arteries comprising the circle of Willis bilaterally using TCCS. MCA was identified as orthograde blood flow at an insonation depth of 40–65 mm and 30–40 mm for proximal (M1) and distal (M2) segment, respectively. The anterior cerebral artery (ACA) was detected as retrograde flow at a 60–75 mm insonation depth. The posterior cerebral artery (PCA) was visualised as orthograde (P1 segment) or retrograde (P2 segment) at 55–75 mm depth[12]
5. calculate the mean blood flow velocity in the MCA as described previously[13].

Training session 1 was aimed at learning steps 1–3, training session 2 at steps 4 and 5, and session 3 at steps 1–5. Participants were given an opportunity to perform scanning on two to three healthy volunteers during all three sessions, including self-scanning.

Quality assessment of acquired images and video clips

Within 1 week of the third training session, participants were asked to perform an unsupervised complete transcranial ultrasound scan (steps 1–5) on a healthy volunteer, being assessed on the basis of the acquired set of images and video clips. The time required to complete scanning was recorded, but the maximum allowed time was 1 hour. The quality of video-recording in the transverse plane was assessed by the trainer using the visual analogue scale (VAS) from 0 to 5, where 0 indicated that the acquired video clip did not allow interpretation and 5 represented a high quality video clip. This part was essential for confirming that the novice operators had achieved the required skill level. A participant's ability to capture the intracranial structures of interest was assessed as correctly labelled, incorrectly labelled or not identified.

Qualitative feedback from participants

As a final step, all participants were asked to anonymously comment on their experience by completing a feedback form and answering multiple-choice and closed questions about the easiest or most challenging part of the training, how confident they felt and how they would rate their overall experience (Appendix 1).

Finally, participants were asked to provide any comments or suggestions, for example if they would like to suggest any changes to the training package.

Data analysis

A narrative synthesis was applied, structured around the assessment results and qualitative feedback from the participants.

Ethics approval

This study was granted ethics approval from the University of Aberdeen's College of Life Sciences and Medicine Ethics Review Board (ID 1669) and was also approved by the National Health Service Highland Research Management (ID 1521).

Results

Eleven volunteers with no prior experience in transcranial ultrasonography were recruited. Time to complete a full transcranial ultrasound assessment ranged from 29 minutes to 47 minutes (median 38 minutes, interquartile range 36.0–43.5 minutes).

Quality assessment of acquired images and video clips

The capture rates for the intracranial structures of interest are presented in Table 1.

Midline was correctly identified and measured in 64% of cases (by 7 participants out of 11), with 36% (4/11) being incorrectly labelled. The majority of participants (91%, 10/11) correctly identified brainstem with only 9% (1/11) incorrect labelling. In 3/11 cases (27%) it was technically difficult for novice ultrasound users to identify the MCA and ACA. The correct labelling rates were 73% (8/11) and 64% (7/11) for the MCA and ACA, respectively. In 1 of 11 cases (9%), the ACA was incorrectly identified based on the blood flow direction. The incorrect labelling rate was the highest for the PCA, at 18% (2/11).

The quality of greyscale ultrasound scans in the transverse plane varied from 0 to 5 on VAS with a mean value ± standard deviation of 3.8±1.6. No participants had insufficient temporal acoustic window.

Table 1: Transcranial ultrasound capture rates for intracranial structures of interest

Structure	Correct labelling (n)	Incorrect labelling (n)	Not identified (n)
Brain midline	7	4	0
Brainstem	10	1	0
Middle cerebral artery	8	0	3
Anterior cerebral artery	7	1	3
Posterior cerebral artery	7	2	2

Qualitative feedback from participants

A total of 82% (9/11) participants rated their experience during the training sessions highly (5 out of 5). One participant commented, 'Excellent. Good content and well explained'. From the volunteers' perspectives, the right amount of time was allocated in order to acquire the new skills; however, the general feedback suggested more practice and follow-up sessions would be needed to maintain the newly acquired skills: 'More practice needed to feel confident about reliably performing a ... TCUS [transcranial ultrasound scan]'; 'More practice would be better (more subjects [healthy volunteers to scan]?)'.

As demonstrated in Figure 1, about 45% of participants (5/11) found greyscale transcranial ultrasound the easiest part of the training, and 36% volunteers (4/11) thought that imaging of the major intracranial vessels using TCCS was the least challenging.

Figure 2 illustrates that 73% of participants (8/11) rated the transcranial ultrasound assessment scanning as the most difficult part. The remaining 27% of volunteers (3/11) said that greyscale transcranial ultrasonography was more complicated.

One of the highlighted challenges for novice users was technical difficulties associated with operation of the ultrasound machine at the same time as maintaining the probe's position ('difficult to use both hands').

Using VAS, 55% of volunteers (6/11) rated their confidence level when performing a complete transcranial ultrasound assessment as 3 out of 5, whereas 45% of inexperienced operators (5/11) rated it as 4 out of 5. Participants' opinions regarding the quality of the acquired images and video clips on a scale from 0 to 5 varied from 2 to 4, with 45% of participants (5/11) rating the quality as 3 (satisfactory, just enough for someone to interpret it) and another 45% rating it as 4. One participant (9%) rated the quality of their images and video clips as 2.

All volunteers thought that this training package could be used for GPs, paramedics and other clinical staff working in remote and rural areas, with one pointing out, 'Maybe could use it on our placement or work place to keep updated with it. Better suited for community nurses, GP etc. as they can do it all the time'.
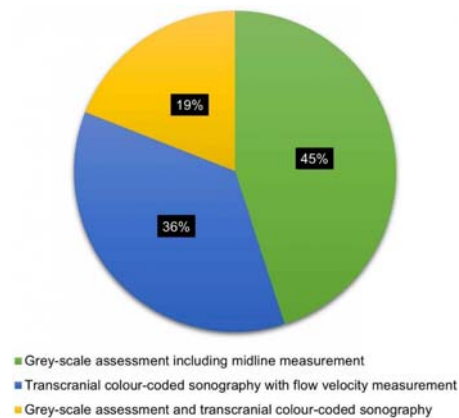

- Grey-scale assessment including midline measurement
- Transcranial colour-coded sonography with flow velocity measurement
- Grey-scale assessment and transcranial colour-coded sonography

Figure 1: Proportional representation of qualitative feedback from participants on the easiest part of training.

- Grey-scale assessment including midline measurement
- Transcranial colour-coded sonography with flow velocity measurement
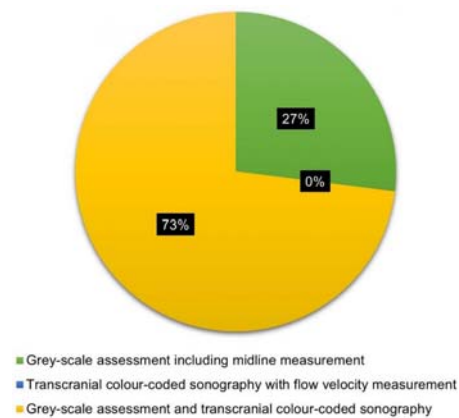- Grey-scale assessment and transcranial colour-coded sonography

Figure 2: Proportional representation of qualitative feedback from participants on the most challenging part of training.

Discussion

As previously demonstrated by this research group, basic transcranial ultrasound examination of patients in rural areas can be performed by inexperienced operators guided and supported by secondary care specialists using live transmission of audio and video data[3-5]. In the present study a brief training package for novice users with a potential application for medical staff working

in remote and rural areas has been proposed. The overall quality of images and video clips acquired by novice operators was demonstrated to be satisfactory to allow expert interpretation. The trainer and the participants gave their images similar quality rating using VAS reaching an agreement. Both midline shift and the brainstem were correctly labelled in the majority of cases. Participants demonstrated good performance in detecting major intracranial vessels. Among the three major intracranial arteries of interest, ACA and MCA were technically more difficult to capture, with the highest rate of non-identification (3/11, 27%). The PCA was incorrectly labelled in a bigger proportion of cases than the ACA and MCA (2/11, 18%).

In a previously published study by Klinzing et al (2015), six inexperienced TCCS operators measured the mean flow velocity in the MCA in 10 healthy volunteers after participating in an introduction session. The introduction covered the basic anatomy of the brain and intracranial vessels as it is visualised using TCCS, technical characteristics required to operate the ultrasound machine and finding the adequate temporal acoustic window. The inexperienced TCCS users then observed one transcranial sonography examination performed by an experienced operator and were given a chance to perform one or two supervised assessments. Thereafter, three operators had active supervision while performing all 10 scans, and the other three participants were supervised only during their first five transcranial examinations. Measurements were compared with those obtained by two TCCS users who completed formal training and had at least 2 years of experience. The results of the present pilot study are in agreement with the findings published by Klinzing et al (2015), which showed that examination of the major brain vessels using transcranial ultrasound can be easily achieved with supervision during initial examinations[10].

Neulen et al (2013) showed that even experienced transcranial Doppler ultrasound users (6 months to 20 years of experience) tend to misinterpret up to 37% of the major intracranial arteries. The accuracy of the study might be particularly limited in case of anatomical or pathological variation of the vessels or repositioning by a space-occupying lesion (large haemorrhage, tumour, etc.)[14]. This limitation might result in misinterpretation of the scans and lead to false management decisions. The auto-pilot software tool (image guidance) for inexperienced transcranial Doppler ultrasound users among medical students resulted in improved accuracy of interpretation of Doppler findings by 27% within a 10-minute limited study[14]. In addition, image guidance assisted in interpretation of transcranial Doppler data in more complex cases, such as anatomical variation of the MCA and insonation through a burr hole after a craniotomy[14]. Future work is required to overcome user dependency, which is currently one of the main barriers to the wide implementation of transcranial ultrasonography as a diagnostic tool.

Another technical limitation of transcranial ultrasonography is inadequate acoustic window, which occurs in 8–29% of the general population[15], or inability to visualise brain structures of interest. Inadequate acoustic window is most frequently detected in women aged over 50 years and in people who are Asian[16]. Temporal

acoustic window was adequate in all healthy volunteers who participated in the present study, which is not surprising and is probably due to their young age.

Participants gave positive feedback on the training materials and time allocated for learning. Transcranial greyscale ultrasonography was rated by 45% of participants (5/11) as technically the easiest part among all training sessions. The complete transcranial assessment containing all the individual parts, such as greyscale ultrasonography and TCCS, was considered the most challenging. This may be because inexperienced operators did not receive any supervision during the final assessment session and probably felt least confident at that time.

In the present study the average time required for a complete examination, including assessment of the intracranial vessels, was approximately 40 minutes. Previously it has been shown that the time to acquire images of midline measurements of sufficient quality increased by approximately 52% in hands of operators who were initially unfamiliar with transcranial ultrasound[5]. Mikulik et al's (2006) bedside study demonstrated that telemedicine-guided transcranial Doppler ultrasound examination performed by a novice ultrasound user led to a substantial increase, of 27 minutes, in assessment time[17].

Endovascular treatment is a minimally invasive and effective reperfusion therapy for patients with acute ischaemic stroke due to large vessel occlusion[1]. Mortality rate in this group of stroke patients can be as high as 80%[18], and shorter time to endovascular reperfusion is associated with better clinical outcome[19,20]. Therefore, the focus of current care has been shifted to consider accurate selection of patients who would benefit from mechanical thrombectomy as it can only be offered in specialised centres with neurointerventional facilities.

In remote and rural areas, non-specialist pre-hospital practitioners, such as GPs and paramedics, currently have to decide whether to transfer a patient with suspected stroke to a local hospital that can only offer intravenous thrombolysis or to arrange longer and costly travel to a regional centre offering mechanical clot retrieval. Travel time between the local and regional hospital should be considered: if the travel time is long (90–120 minutes), the 'drip and ship' model (thrombolysis followed by a transfer for mechanical thrombectomy) would be favoured over the 'mothership' strategy (direct transfer to the endovascular centre)[21].

A number of clinical assessment tools have been proposed to serve this purpose[22] but their diagnostic accuracy is currently insufficient: at least 20% of patients with large vessel occlusion would be incorrectly transferred to a local hospital with no neurointerventional facilities available[23]. Added transcranial ultrasound information on presence or absence of intracranial haemorrhage and blood flow within the major arteries could potentially improve diagnostic performance to allow more accurate triage. According to the literature, sensitivity of transcranial ultrasound in detecting stenosis and occlusion of the major brain vessels ranges from 68% to 100%[24]. It is a relatively inexpensive and widely available diagnostic tool in comparison to

other imaging tests, such as brain CT [25], that might have potential application in countries where there are remote and rural areas with long transport times.

It is likely that potential transcranial ultrasound users in remote and rural areas – such as rural GPs, paramedics and community healthcare professionals – will have infrequent exposure to suspected stroke patients in comparison to medical staff working in urban areas. It would therefore be important to ensure that the acquired knowledge and skills are maintained because even experienced users can get less accurate measurements when using transcranial Doppler ultrasound relatively infrequently[26]. One of the limitations of this pilot work was absence of any follow-up assessment to determine the retention rate of acquired skills, for example, short-term (after 1 week and/or 1 month) and long term (3–6 months after the initial training). This should be incorporated in the study protocol in the future. Further regular follow-up training, with possible supervision, would be required to help novice users build up confidence, improve technical skills and ensure that acquired skills are retained.

Further assessment with a larger sample size is required to support the application of the proposed training model. Future work is needed to validate this training package for stroke patients. It would be important to investigate whether the proposed training can be provided to medical staff working in remote and rural areas to help them make treatment decisions for patients suspected of having had an acute stroke. In pre-hospital settings, initial and follow-up training as well as support during assessment of acute stroke, aided by real-time transmission of images, could be provided remotely by hospital-based experts as reported previously[3-5,27].

Conclusion

This pilot study demonstrated that a brief training package can be used to train inexperienced transcranial ultrasound operators to acquire diagnostic images and video clips that would allow expert interpretation. Positive feedback from the volunteers was provided on the package content and time given to learn this new technique. The developed program could potentially be used for training of remote and rural medical staff and could improve acute care, specifically for suspected stroke patients, by facilitating treatment decisions and triaging patients to the hospital that can offer the most appropriate treatment, such as mechanical thrombectomy. Future research on a larger sample, potentially involving stroke patients, is needed.

REFERENCES:

1 Goyal M, Menon BK, van Zwam WH, Dippel DWJ, Mitchell PJ, Demchuk AM, et al. Endovascular thrombectomy after large-vessel ischaemic stroke: a meta-analysis of individual patient data from five randomised trials. *Lancet* 2016; **387(10029):** 1723-1731. DOI link

2 Reeves MJ, Arora S, Broderick JP, Frankel M, Heinrich JP, Hickenbottom S, et al. Acute stroke care in the US: results from 4 pilot prototypes of the Paul Coverdell National Acute Stroke Registry. *Stroke* 2005; **36(6):** 1232-1240. DOI link, PMid:15890989

3 Eadie L, Regan L, Mort A, Shannon H, Walker J, MacAden A, et al. Telestroke assessment on the move: prehospital streamlining of patient pathways. *Stroke* 2015; **46(2):** e38-e40. DOI link, PMid:25550375

4 Mort A, Eadie L, Regan L, Macaden A, Heaney D, Bouamrane MM, et al. Combining transcranial ultrasound with intelligent communication methods to enhance the remote assessment and management of stroke patients: framework for a technology demonstrator. *Health Informatics Journal* 2016; **22(3):** 691-701. DOI link, PMid:25975807

5 Eadie L, Mulhern J, Regan L, Mort A, Shannon H, Macaden A, et al. Remotely supported prehospital ultrasound: a feasibility study of real-time image transmission and expert guidance to aid diagnosis in remote and rural communities. *Journal of Telemedicine and Telecare* 2018; **24(9):** 616-622. DOI link, PMid:28920524

6 Tsivgoulis G, Sharma VK, Lao AY, Malkoff MD, Alexandrov AV. Validation of transcranial Doppler with computed tomography angiography in acute cerebral ischemia. *Stroke* 2007; **38(4):** 1245-1249. DOI link, PMid:17332465

7 Tsivgoulis G, Sharma VK, Hoover SL, Lao AY, Ardelt AA, Malkoff MD, et al. Applications and advantages of power motion-mode Doppler in acute posterior circulation cerebral ischemia. *Stroke* 2008; **39(4):** 1197-1204. DOI link, PMid:18323502

8 Kukulska-Pawluczuk B, Ksiazkiewicz B, Nowaczewska M. Imaging of spontaneous intracerebral hemorrhages by means of transcranial color-coded sonography. *European Journal of Radiology* 2012; **81(6):** 1253-1258. DOI link, PMid:21435810

9 Tang S-C, Huang S-J, Jeng J-S, Yip P-K. Third ventricle midline shift due to spontaneous supratentorial intracerebral hemorrhage evaluated by transcranial color-coded sonography. *Journal of Ultrasound in Medicine* 2006; **25(2):** 203-209. DOI link, PMid:16439783

10 Klinzing S, Steiger P, Schüpbach RA, Béchir M, Brandi G. Competence for transcranial color-coded Duplex sonography is rapidly acquired. *Minerva Anestesiologica* 2015; **81(3):** 298-304.

11 Stolz E, Gerriets T, Fiss I, Babacan SS, Seidel G, Kaps M. Comparison of transcranial color-coded duplex sonography and cranial CT measurements for determining third ventricle midline shift in space-occupying stroke. *American Journal of Neuroradiology* 1999; **20(8):** 1567-1571.

12 Alexandrov AV, Sloan MA, Wong LKS, Douville C, Razumovsky AY, Koroshetz WJ, et al. Practice standards for transcranial Doppler ultrasound: part I – test performance. *Journal of Neuroimaging* 2007; **17(1):** 11-18. DOI link, PMid:17238867

13 Lee K-J, Jung K-H, Park C-Y, Kim J-M, Lee S-T, Chu K, et al. Increased arterial pulsatility and progression of single subcortical infarction. *European Radiology* 2017; **27(3):** 899-906. DOI link,

PMid:27387877

14 Neulen A, Greke C, Prokesch E, Konig J, Wertheimer D, Giese A. Image guidance to improve reliability and data integrity of transcranial Doppler sonography. *Clinical Neurology and Neurosurgery* 2013; **115(8):** 1382-1388. DOI link, PMid:23347687

15 Marinoni M, Ginanneschi A, Forleo P, Amaducci L. Technical limits in transcranial Doppler recording: inadequate acoustic windows. *Ultrasound in Medicine & Biology* 1997; **23(8):** 1275-1277. DOI link

16 Maeda H, Matsumoto M, Handa N, Hougaku H, Ogawa S, Itoh T, et al. Reactivity of cerebral blood flow to carbon dioxide in various types of ischemic cerebrovascular disease: evaluation by the transcranial Doppler method. *Stroke* 1993; **24(5):** 670-675. DOI link, PMid:8488521

17 Mikulik R, Alexandrov AV, Ribo M, Garami Z, Porche NA, Fulep E, et al. Telemedicine-guided carotid and transcranial ultrasound: a pilot feasibility study. *Stroke* 2006; **37(1):** 229-230. DOI link, PMid:16339460

18 Hacke W, Schwab S, Horn M, Spranger M, De Georgia M, von Kummer R. 'Malignant' middle cerebral artery territory infarction: clinical course and prognostic signs. *Archives of Neurology* 1996; **53(4):** 309-315. DOI link, PMid:8929152

19 Jahan R, Saver JL, Schwamm LH, Fonarow GC, Liang L, Matsouaka RA, et al. Association between time to treatment with endovascular reperfusion therapy and outcomes in patients with acute ischemic stroke treated in clinical practice. *Journal of the American Medical Association* 2019; **322(3):** 252-263. DOI link, PMid:31310296

20 Palesch YY, Yeatts SD, Tomsick TA, Foster LD, Demchuk AM, Khatri P, et al. Twelve-month clinical and quality-of-life outcomes in the Interventional Management of Stroke III Trial. *Stroke* 2015;

46(5): 1321-1327. DOI link, PMid:25858239

21 Holodinsky JK, Williamson TS, Demchuk AM, Zhao H, Zhu L, Francis MJ, et al. Modeling stroke patient transport for all patients with suspected large-vessel occlusion. *JAMA Neurology* 2018; **75(12):** 1477-1486. DOI link, PMid:30193366

22 Antipova D, Eadie L, Macaden A, Wilson P. Diagnostic accuracy of clinical tools for assessment of acute stroke: a systematic review. *BMC Emergency Medicine* 2019; **19(1):** 49. DOI link, PMid:31484499

23 Turc G, Maier B, Naggara O, Seners P, Isabel C, Tisserand M, et al. Clinical scales do not reliably identify acute ischemic stroke patients with large-artery occlusion. *Stroke* 2016; **47(6):** 1466-1472. DOI link, PMid:27125526

24 Antipova D, Eadie L, Macaden AS, Wilson P. Diagnostic value of transcranial ultrasonography for selecting subjects with large vessel occlusion: a systematic review. *The Ultrasound Journal* 2019; **11(1):** 29. DOI link, PMid:31641895

25 Schlachetzki F, Herzberg M, Holscher T, Ertl M, Zimmermann M, Ittner KP, et al. Transcranial ultrasound from diagnosis to early stroke treatment: part 2: prehospital neurosonography in patients with acute stroke: the Regensburg stroke mobile project. *Cerebrovascular Diseases* 2012; **33(3):** 262-271. DOI link, PMid:22261817

26 Shen Q, Stuart J, Venkatesh B, Wallace J, Lipman J. Inter observer variability of the transcranial Doppler ultrasound technique: impact of lack of practice on the accuracy of measurement. *Journal of Clinical Monitoring and Computing* 1999; **15(3-4):** 179-184. DOI link, PMid:12568169

27 Marsh-Feiley G, Eadie L, Wilson P. Telesonography in emergency medicine: a systematic review. *PLoS One* 2018; **13(5):** e0194840. DOI link, PMid:29723198

Appendix I: Participant feedback form

What part did you find the easiest (tick)?
☐ session 1 (grey-scale, midline)
☐ session 2 (Doppler, major intracranial vessels)
☐ session 3 (complete transcranial ultrasound scanning)
What part did you find the most challenging (tick)?
☐ session 1 (grey-scale, midline)
☐ session 2 (Doppler, major intracranial vessels)
☐ session 3 (complete transcranial ultrasound scanning)
Did you have enough time to learn the new skills (tick)?
☐ yes ☐ no
How confident did you feel performing a complete transcranial ultrasound scanning at the final session (circle)?
1 (not at all) 2 3 4 5 (very confident)
How would you rate the quality of images and video clips you collected during the final session (circle)?
1 (poor, an expert is likely to struggle interpreting them)
2
3 (satisfactory, just enough for someone to interpret them)
4
5 (excellent, I am certain an expert would easily interpret them)
How would you rate your overall experience today (circle)?
1 (not at all) 2 3 4 5 (I really enjoyed it)
Do you think this brief programme can be used for training GPs, paramedics etc (tick)?
☐ yes
☐ no
What would you change in the training programme / comments / suggestions?
_____
_____
_____
_____