The reliability of carotid ultrasound in determining the return of pulsatile flow: A pilot study

Biljana Germanoska¹, Matthew Coady¹, Sheyin Ng¹, Gary Fermanis¹ and Matthew Miller²

Ultrasound
2018, Vol. 26(2) 118–126
© The Author(s) 2018
Reprints and permissions:
sagepub.co.uk/journalsPermissions.nav
DOI: 10.1177/1742271X17753467
journals.sagepub.com/home/ult

Abstract

Manual palpation of pulses is unreliable in detecting pulsatile flow in human participants, complicating the assessment of return of spontaneous circulation after cardiac arrest. Ultrasound may offer an alternative. This study's objective was to investigate whether return of pulsatile flow in humans can be reliably assessed by common carotid artery ultrasound. We conducted a single-blinded randomised study of common carotid artery ultrasound using 20 cardiopulmonary bypass patients to model the return of pulsatile flow. Synchronised time-stamped videos of radial artery invasive blood pressure and 10 two-dimensional or 10 colour Doppler ultrasounds were recorded. Three independent reviewers recorded the timestamp where they considered pulsatile flow was first visible on ultrasound. Ultrasound times were compared to the onset of arterial line pulsatile flow and reliability assessed by intraclass correlation coefficient. The median difference between radial artery and ultrasound flow time (interquartile range (range)) was 24 seconds (5–40 (0–93)) for two-dimensional and 5 seconds (2–17 (–28 to 188)) for colour Doppler. The intraclass correlation coefficient for two-dimensional ultrasound was 0.86 (95%CI 0.63–0.96) and 0.32 (95%CI –0.01 to 0.71) for colour Doppler. The median (interquartile range (range)) mean arterial pressure where ultrasound flow occurred for two-dimensional ultrasound was 62 mmHg (49–74 (33–82)) and 56 mmHg (52–73 (43–83)) for colour Doppler. In our pilot study, two-dimensional ultrasound was reliable in detecting the return of pulsatile flow. Colour Doppler detected pulsatile flow earlier and at lower mean arterial pressure but was not reliable, although a larger study is needed to determine colour Doppler's utility.

Keywords

Anaesthesia, blood flow, clinical speciality, clinical speciality, diagnostic imaging, emergency medicine, ultrasound, vascular

Date received: 13 September 2017; accepted: 8 December 2017

Background

Current recommendations for assessment of the return of spontaneous circulation (ROSC) following cardiac arrest include observation for patient movement or spontaneous respirations,^{1,2} both of which may be absent in sedated, comatose or pharmacologically paralysed patients. Healthcare professionals are advised to check the pulse in the presence of an organised rhythm²; however, there is reasonable evidence of the poor accuracy of manual pulse checks in detecting

the presence or absence of a pulse.^{3–6} Using patients who may have pulseless cardiac output (on bypass or on veno-arterial extracorporeal membrane oxygenation or left ventricular assistance device) or pulsatile flow

¹St George Hospital, Kogarah, Australia

²Ambulance Service of New South Wales, Rozelle, Australia

Corresponding author:

Matthew Miller, Ambulance Service of New South Wales, Rozelle, New South Wales 2039, Australia.
Email: mattdotmiller@gmail.com

(off bypass), 45% of participants incorrectly diagnosed absent pulses in patients no longer on bypass, despite systolic pressures greater than 80 mmHg.⁴ Similarly 22% of paediatric patients were misdiagnosed,⁷ including assessments of no pulse in 36% of pulse-present patients. The clinical implications of this include prolongation of rhythm checks, withholding chest compression when a pulse maybe absent or continuing when a pulse has been re-established; all of which may be associated with harm.⁷ In addition, the absence of a means to monitor, in real time, the quality of chest compressions is still a challenge for cardiopulmonary resuscitation (CPR).^{8,9}

Femoral artery ultrasound (US) has been previously reported to identify ROSC in a patient with absent palpable central pulses during CPR.¹⁰ It is possible that extending cardiac US examination in CPR to also visualise central pulses may serve to provide feedback on the quality of chest compressions⁹ and also help to identify pseudo-pulseless electrical activity (defined as ventricular wall motion on US and stable end-tidal carbon dioxide¹¹) or low-flow states.¹² While a recent study has shown that prehospital US of the carotid artery in cardiac arrest is feasible,⁹ to date no study has attempted to explore the relationship between the presence or absence of a pulsation on carotid US to the presence or absence of pulsatile flow.

The primary objective of this pilot study was to investigate whether the return of pulsatile flow in humans can be reliably discriminated from non-pulsatile states by the use of common carotid artery (CCA) US. The secondary objective was to report the range of systolic blood pressure (SBP) and mean arterial pressure (MAP) at which pulsatile flow was first visible on US. To do this, we used cardiopulmonary bypass patients who were coming of bypass, and therefore from non-pulsatile to pulsatile flow. Presence of a pulse on the radial artery line was used as a comparator against which the US images were assessed rather than manual palpation, which is known to be unreliable as outlined above.

Materials and methods

We conducted a single-blinded randomised trial of 20 patients who were undergoing cardiac surgery requiring cardiopulmonary bypass at St George Hospital in Sydney, Australia. Inclusion criteria were all adult (age >18 years) cardiac surgery patients, including valve replacement or coronary artery bypass grafts. Exclusion criteria were previous surgery involving the great blood vessels including aorta or carotid arteries, patients who the cardiac surgeon considers to be inappropriate due to a high surgical risk, patients with an intra-aortic balloon pump and patients with known peripheral vascular disease.

Figure 1. Study procedure for 2D and colour Doppler US patients. ICC: intraclass correlation coefficient; 2D US: two-dimensional ultrasound; US: ultrasound.

After receiving informed consent each participant was randomised to either 2D or colour Doppler US measurement. As the participant was being re-warmed towards the end of the bypass phase of their operation, one investigator (BG) set up two mobile phones (Vodafone models VF695 and VF685; Vodafone, New Zealand) with a camera app that recorded timestamped videos (Timestamp Camera Pro; Yubin Chen, USA¹³). Both phones were mounted on stands; one phone's camera was directed at the anaesthetic monitor to record the patient's haemodynamic information, which included the arterial pressure waveform trace and electrocardiogram. The second phone's camera was directed at the US machine monitor to record the images of the carotid artery. The time on both phones was set to automatically adjust to network-provided time to maintain no difference between monitor and

Table 1. Participant demographics for the total sample and the two ultrasound groups

	Total sample	2D US	Colour Doppler
n	20	10	10
Age (years) (median (IQR (range)))	66 [60–74 (39–84)]	67 [59–71 (39–78)]	67 [60–77 (53–84)]
Sex (m)	18	9	9
BMI (mg kg ⁻²) (median (IQR(range)))	30 [26–33 (20–49)]	31 [29–35 (24–49)]	29 [23–32 (20–39)]
Operation			
CABG	12	8	4
AVR	4	1	3
CABG + AVR	1	0	1
CABG + MV repair	1	0	1
MV replacement	1	0	1
MV repair AVR	1	1	0

AVR: aortic valve replacement; BMI: body mass index (kg/m²); CABG: coronary artery bypass graft; IQR: interquartile range; M: male; MV: mitral valve; 2D US: two-dimensional ultrasound.

US videos timestamps, and audio was not recorded. The videos were in MPEG-4 format and 800 × 480 pixels. The US machines used were a Sonosite M-turbo (linear array probe, 13–6 MHz, Brookvale; New South Wales, Australia) and a Philips iE33 (linear array probe, 11–3 MHz, Philips Healthcare; North Ryde, Australia) depending on availability (as they were shared with the remainder of the operating theatres) and a low frequency linear probe used. To allow an approximation with novice use of US, the machines were left on their default settings with depth being adjusted to bring the image to the centre of the screen. For the 2D US this corresponded to a frame rate of 36–39 Hz, with a depth of 3.5–4.5 cm, frequency at highest and the focal zone set to the middle of the screen. For colour Doppler, the frame rate was between 4.4 and 5 Hz and filter setting to medium or low. Colour Doppler scale was left to the machines default. Lighting in the theatre was standard operating room lighting and was not dimmed.

USs were all performed by one investigator (BG), an advanced trainee in anaesthesia but with no formal US training. The CCA US was obtained by hand, resting the US transducer over the patient's carotid artery, midway between the tragus and sternal notch where the best view could be obtained. The US image was maintained by hand until the patient was completely off bypass. Ten patients had 2D US recorded and 10 had colour Doppler US recorded (Figure 1).

The de-identified US videos were then made available to three reviewers through a shared secure folder. These videos were reviewed on displays with 1920 × 1080 pixel resolution. Each reviewer watched the videos independently and recorded the timestamp at which they considered pulsatile flow to be first present in the carotid artery. For 2D US this was tissue distortion in the artery wall or surrounding tissue, for colour Doppler this was the colour change within the artery. Because of the unknown duration between starting the video and the patients coming off bypass, reviewers were allowed to skip forward in 2 minute blocks to where pulsatile flow was obvious, then skip back and begin watching the video for the first indication of pulsatile flow. Two reviewers were cardiac anaesthetists both of whom have a postgraduate diploma in clinical US (Melbourne, Australia) (MC and SN) and one was a general anaesthetist with experience in prehospital US but no formal training (MM). BG who obtained the US was not involved in reviewing the images. Two of the reviewers (MC and SN) did not have access to the monitor videos. The third reviewer (MM) had access for data extraction but did not view these until after all US videos were assessed.

Once all of the US time data were collected, the monitor videos were reviewed by one investigator (MM). The timestamp at which the first radial arterial wave appeared was recorded for each participant. The difference between this radial artery timestamp and the

Figure 2. Comparison of the three reviewers for the difference between radial artery and US timestamps for pulsatile flow by each 2D US participant. 2D US: two-dimensional ultrasound.

US timestamp was calculated in seconds for each reviewer. For example, if the radial artery timestamp and US timestamp were the same, then a time of 0 seconds was entered. Examples are provided in the supplementary video files 1 and 2. It was this time difference that was used in the statistical analysis. The SBP, MAP and heart rate (HR) were extracted from the radial artery blood pressure on the monitor at the US timestamp of each reviewer.

Statistical analysis

All analysis was performed using the statistical software R (version 3.3.1; R Core Team, Vienna, Austria). The reliability of 2D and colour Doppler US was assessed separately using type-2 intraclass correlation coefficient (ICC). A two-sided p-value of 0.05 was considered significant. SBP, HR and MAP for all reviewers were combined and non-parametric descriptive statistics produced. The relationship between the difference in radial artery and US timestamps, and SBP and MAP was assessed by scatterplot. Post hoc power analyses were planned using the R package ICC.Sample.Size (version 1.0)¹⁴ for a two-sided significance level of 0.05 for three raters and a null hypothesis

of no relationship between raters. A scatterplot of the difference in radial artery to US time against body mass index (BMI) and HR was also produced as post hoc analyses.

Results

CCA US images were recorded for 21 patients, with 20 patients having data for analysis (Figure 1). For the final enrolled patient, the timestamp synchronisation failed when the mobile phone reset itself. This patient's data were removed and a new patient was consented. The demographics for the 20 patients are given in Table 1. No patient reported any adverse effects for the US. The median video length was 7 minutes and 11 seconds (IQR = 5 minutes 40 seconds to 8 minutes 42 seconds, range = 3 minutes 27 seconds to 14 minutes 52 seconds).

Figure 2 shows the relationship between reviewers for each participant for 2D US. The median difference in time between radial artery and 2D US flow was 24 seconds (IQR = 5–40 seconds, range = 0–93 seconds). The ICC for 2D US was 0.86 (95%CI 0.63–0.96). For colour Doppler, the median difference in time between radial artery and US flow was 5 seconds

Figure 3. Comparison of the three reviewers for the difference between radial artery and US timestamps for pulsatile flow by each colour Doppler US participant. US: ultrasound.

(IQR = 2–17 seconds, range = –28 to 188 seconds). The ICC was 0.32 (95%CI –0.01 to 0.71) (Figure 3). There are three potential outliers in the colour Doppler sample (participants 1, 3 and 9). Table 2 presents demographic and haemodynamic data for these patients. All three had heart rates greater than the 75th quantile of participants in our sample when pulsatile flow was seen in colour Doppler US.

Summary statistics for HR, SBP and MAP for the two US methods are presented in Table 3. Scatterplots of the difference between radial artery and US timestamps and HR, SBP and MAP revealed no relationship (Figure 4). When plotted against BMI (Figure 5), there was no relationship for 2D US and BMI. There is a weak negative correlation for BMI and the difference between radial artery and US timestamps for colour Doppler ($r = -0.45$, 95%CI –0.70 to –0.11, $p = 0.01$) but this may be the result of the outliers.

Post hoc power analysis for the 2D US was 0.99. To improve the precision of the 95%CI for an ICC of 0.86 to ± 0.1 , with three reviewers, a sample size of at least 42 would be required.¹⁵ For colour Doppler the power was 0.30 for all 10 participants (as the ICC was 0.3). If the study were to be repeated, in order to demonstrate an improvement in ICC of 0.3, 31 participants would be

needed if three reviewers were to be used (with a power of 0.8, significance level 0.05).

Discussion

Previous research has identified that manual palpation of the pulse is unreliable, and that US of large arteries may be feasible in cardiac arrest situations. We sought to investigate whether US of the CCA could be used to reliably detect the return of pulsatile flow. We found that, while the median time to detection of pulse by colour Doppler may be earlier than 2D US, 2D US was more reliable when assessed by ICC for three independent reviewers.

Previous investigators have looked at estimates of duplex flow velocities of the internal carotid artery in peri-arrest patients;¹² transcranial Doppler,¹⁶ cerebral oximetry¹⁷ and novel automated carotid Doppler monitors have been trialled in animal models of cardiac arrest.^{18,19} However, all of these devices require the availability of extra-equipment and training on use and interpretation. In addition, although hand-held audio Doppler of the radial artery has also been reported in the past,²⁰ correct use of hand-held Doppler devices can be difficult to learn.²¹

Table 2. Demographic and haemodynamic details for the three outliers in the colour Doppler sample. Age ranges have been used and sex removed to anonymise participants

Participant	1	3	9
Age (years)	60–70	60–70	70–80
BMI (kg m ²)	30	20	23
Operation	AVR	AVR	MV replacement
Video length (seconds)	417	433	439
Timestamp difference (radial artery to US) (seconds)			
Reviewer 1	23	188	11
Reviewer 2	36	129	11
Reviewer 3	-28	1	-140
Systolic blood pressure at time of US timestamp (mmHg)			
Reviewer 1	56	94	81
Reviewer 2	60	88	81
Reviewer 3	51	53	64
Mean arterial pressure at time of US timestamp (mmHg)			
Reviewer 1	51	79	67
Reviewer 2	51	79	67
Reviewer 3	46	50	62
Diastolic blood pressure at time of US timestamp (mmHg)			
Reviewer 1	48	65	61
Reviewer 2	47	73	61
Reviewer 3	46	49	61
Heart rate at time of US timestamp (beats per minute)			
Reviewer 1	103	101	85
Reviewer 2	104	143	85
Reviewer 3	103	139	230

AVR: aortic valve replacement; BMI: body mass index; F: female; M: male; MV: mitral valve; US: ultrasound.

Furthermore, all of the devices listed above may be unfamiliar to resuscitation teams outside of the intensive care unit. In contrast, US is becoming increasingly common in resuscitation in critical care and prehospital environments.²² Availability of US in emergency departments varies from greater than 90% in Australia,²³ Denmark²⁴ and Korea²⁵ to 47% in the US.²⁶ In France, the availability had improved from 52 to 71% of ED and 9 to 28% of mobile intensive care stations between 2011 and 2015.²⁷ In addition, the training burden may be low with only 18 images required to learn soft tissue US acquisition and 27 for interpretation reported in one study.²⁸

In our sample, the return of pulsatile flow was detected across a range of SBP and MAP including values less than 60 mmHg where peripheral pulses are unlikely to be palpable.^{20,29} In addition, assessment between reviewers for 2D US showed good reliability. Also, there were no examples of identifying a pulse as present when it was absent in the 2D sample, while for colour Doppler a pulse was reported as present during non-pulsatile flow on four occasions. Despite this, the range between participants was wide, with some identifying US pulsatile flow at the same time as the radial artery pulse, while in other participants the time difference was up to 90 seconds. The scatterplots of US to radial artery timestamp difference to SBP, MAP, HR or BMI suggest that any delay in visualising pulsatile flow was unlikely related to these haemodynamic variables or the patient's weight. Possible causes of this variability include lack of training of the reviewers, as this was a first of kind study, poor elasticity of the carotid arteries and decreasing distension in atherosclerosis making the detection of tissue movement difficult,³⁰ or the quality of US images obtained whether due to movement by the operator or our use of a fixed focal length.

Colour Doppler demonstrated a short median time to detection of pulsatile flow (5 seconds) with a narrower IQR than 2D Doppler (17 seconds versus 40 seconds). Despite this, it appears less reliable. One explanation for the apparent lower reliability for colour Doppler in our study is the small sample size, which would exaggerate the effects of any outlier. The ICC is calculated from the ratio of variability between participants to the total variability (between-reviewer plus between-participant plus random error variability). If there is little variation in the measure between participants (the numerator), then a large variability between reviewers (the denominator) will lead to a lower ICC value.³¹ In our sample, the time difference between radial and US timestamp had an IQR of 15 seconds, indicating low variability between participants. Three reviewer outliers are obvious in Figure 3, participants 1, 3 and 9, with a difference between reviewers of

greater than 100 seconds. This large between-reviewer variability likely explains the low ICC and wide confidence interval.

There are a few potential reasons why the colour Doppler produced the outliers. First, during cardiac bypass there can be transmitted pulses from cardiopulmonary bypass machine pumps that may have appeared as a pulse on the carotid Doppler. Second, movement artefact of the US transducer could appear as flow. Third, as patients come off cardiopulmonary bypass, colour Doppler may detect flow before the appearance of a radial artery waveform, and this may be the reason for some of the negative US pulsatile flow

times we report. Finally, the outliers that we report at higher heart rates may reflect a challenge of the use of colour Doppler in identifying pulses in tachycardia, whether due to movement artefact or screen refresh rate. At a practical level, this does not mean colour Doppler should not be used to detect the return of spontaneous circulation, rather the sample size would need to be larger, or these sources of error addressed in the study design.

There are limitations to our study that warrant discussion. Due to the physical limitations of our operating theatre, in an effort to limit the inconvenience to operating room staff we could only conduct a pilot study and as a result our sample size was small. While the power analysis suggests the sample size for the 2D participants was sufficient, the colour Doppler was underpowered. This limits the generalisability of our findings but has allowed a sample size calculation for subsequent follow-up studies. We used a cell phone camera to capture a video of the US image in order to allow accurate comparisons with the monitor videos by synchronised timestamp with seconds as the smallest unit. While recording the images directly on the US machine may have improved the images, the smallest unit of time displayed is minutes, which is too inaccurate for this study. We recruited cardiopulmonary bypass patients as a model of pulseless activity arrest returning to a pulsatile flow. This was done to allow

Table 3. Summary statistics for systolic blood pressure (SBP), mean arterial pressure (MAP) and heart rate (HR) at the time pulsatile flow was reported on ultrasound. All values are median (IQR [range])

	2D US	Colour Doppler
SBP (mmHg)	75 [57–93 [38–101]]	67 [56–81 [47–94]]
MAP (mmHg)	61 [49–75 [33–81]]	57 [51–73 [43–83]]
HR (BPM)	81 [74–86[63–102]]	80 [74–103 [61–230]]

BPM: beats per minute; 2D US: two-dimensional ultrasound.

Figure 4. Scatterplots of SBP and MAP to the time difference between radial artery pulsatile flow and US pulsatile flow. ● = 2D US participants. ◆ = colour Doppler US participants. HR: heart rate; MAP: mean arterial pressure; SBP: systolic blood pressure; 2D US: two-dimensional ultrasound.

Figure 5. Scatterplots of BMI to the time difference between radial artery pulsatile flow and US pulsatile flow. ● = 2D US participants. ◆ = colour Doppler US participants. BMI: body mass index.

data collection from humans in a controlled environment with established invasive monitoring. These patients also represent those at risk of cardiac arrest in terms of age, comorbidities and atherosclerosis, allowing some generalisation to the population that we were attempting to represent. Eventually CCA US in a large sample of cardiac arrest patients will be needed to validate this method of assessing pulsatile flow. Finally, the pulsations seen on US do not directly equate to cerebral blood flow or cerebral perfusion pressure, important factors in determining neurological outcome in cardiac arrest patients. However, the presence of an arterial line allowed us to correlate the presence of pulsatile flow with a SBP and MAP. Methods for estimating SBP using either b-mode US^{32,33} or tissue Doppler³⁴ have been described that may have a role in the future.

Conclusion

Our pilot study using cardiopulmonary bypass patients to model the return of pulsatile flow demonstrates that 2D US and colour Doppler may offer a reliable method for assessing the return of pulsatile flow in humans across a wide range of SBP and MAP values. Colour Doppler, although estimated as less reliable in our small sample, may be able to detect pulsatile flow at lower blood pressures and earlier than 2D US. Future studies with larger sample sizes are needed, especially to investigate if there is additional utility in assessing chest compression quality during CPR. Any further study will need to address motion artefact in colour Doppler and consider producing training images prior to study commencement for reviewers to practice on.

Acknowledgments

The authors would like to thank Prof Richard Morris and Dr Michael Cooper, Department of Anaesthesia, St George Hospital, Kogarah, Sydney for their assistance in the study design and comments on the draft as well as the cardiothoracic surgeons and cardiac anaesthetists of St George Hospital, Kogarah, Sydney for facilitating the ultrasound examinations in these patients.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Ethics approval

Ethical approval was obtained from the South Eastern Sydney Local Health District ethics committee before commencement (HREC/15/POWH/579) and the study was registered under the Australian New Zealand Clinical Trials Registry (ACTRN12616001591448).

Guarantor

MM

Contributors

MM designed the study and GF assisted with logistical aspects. MM and BG wrote the protocol and BG liaised with the ethics committee. BG recruited participants and performed the measurements while MM, MC and SN reviewed the patient videos. MM did the statistical analysis. All

authors contributed to writing, interpreting data and reviewing the manuscript as a whole.

References

1. Australian and New Zealand Committee on Resuscitation. Guideline 8: cardiopulmonary resuscitation January 2016, <https://www.nzrc.org.nz/assets/Guidelines/BLS/ANZCOR-Guideline-8-CPR-Jan16.pdf> (2016, accessed 10 April 2016).
2. Link MS, Berkow LC, Kudenchuk PJ, et al. Part 7: adult advanced cardiovascular life support: 2015 American heart association guidelines update for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation* 2015; 132: S444–S464.
3. Ochoa FJ, Ramalle-Gomara E, Carpintero JM, et al. Competence of health professionals to check the carotid pulse. *Resuscitation* 1998; 37: 173–175.
4. Dick WF, Eberle B, Wissner G, et al. The carotid pulse check revisited: what if there is no pulse? *Crit Care Med* 2000; 28: N183–N185.
5. Albarran JW, Moule P, Gilchrist M, et al. Comparison of sequential and simultaneous breathing and pulse check by healthcare professionals during simulated scenarios. *Resuscitation* 2006; 68: 243–249.
6. Moule P. Checking the carotid pulse: diagnostic accuracy in students of the healthcare professions. *Resuscitation* 2000; 44: 195–201.
7. Tibballs J and Russell P. Reliability of pulse palpation by healthcare personnel to diagnose paediatric cardiac arrest. *Resuscitation* 2009; 80: 61–64.
8. Babbs CF. We still need a real-time hemodynamic monitor for CPR. *Resuscitation* 2013; 84: 1297–1298.
9. Adedipe AA, Fly DL, Schwitz SD, et al. Carotid Doppler blood flow measurement during cardiopulmonary resuscitation is feasible: a first in man study. *Resuscitation* 2015; 96: 121–125.
10. Miller M, Grant P and Karishnaraj M. Return of spontaneous circulation confirmed by two dimensional ultrasound following pulseless electrical activity arrest. *Anaesthesia Cases*. Epub ahead of print 2015. DOI: 10.21466/ac.ROSCCBT.
11. Prosen G, Krizmaric M, Završnik J, et al. Impact of modified treatment in echocardiographically confirmed pseudo-pulseless electrical activity in out-of-hospital cardiac arrest patients with constant end-tidal carbon dioxide pressure during compression pauses. *J Int Med Res* 2010; 38: 1458–1467.
12. Haas M, Allendorfer J, Walcher F, et al. Focused examination of cerebral blood flow in peri-resuscitation: a new advanced life support compliant concept – an extension of the focused echocardiography evaluation in life support examination. *Crit Ultrasound J* 2010; 2: 1–12.
13. Chen Y. Timestamp camera pro, <http://www.timestampcamera.com/> (2015, accessed 15 February 2015).
14. Rathbone A, Shaw S and Kumbhare D. ICC.sample.size: calculation of sample size and power for ICC, <https://CRAN.R-project.org/package=ICC.Sample.Size> (2016, accessed 10 April 2016).
15. Wolak ME, Fairbairn DJ and Paulsen YR. Guidelines for estimating repeatability. *Methods Ecol Evol* 2011; 3: 129–137.
16. Lewis LM, Stothert JCJ, Gomez CR, et al. A noninvasive method for monitoring cerebral perfusion during cardiopulmonary resuscitation. *J Crit Care* 1994; 9: 169–174.
17. Parnia S, Yang J, Nguyen R, et al. Cerebral oximetry during cardiac arrest: a multicenter study of Neurologic Outcomes and Survival. *Crit Care Med* 2016; 44: 1663–1674.
18. Yu AH, Cohen-Solal E, Raju BI, et al. An automated carotid pulse assessment approach using Doppler ultrasound. *IEEE Trans Biomed Eng* 2008; 55: 1072–1081.
19. Larabee TM, Little CM, Raju BI, et al. A novel hands-free carotid ultrasound detects low-flow cardiac output in a swine model of pulseless electrical activity arrest. *AJEM* 2011; 29: 1141–1146.
20. Schonberger RB, Lampert RJ, Mandel EI, et al. Handheld Doppler to improve pulse checks during resuscitation of putative pulseless electrical activity arrest. *Anesthesiology* 2014; 120: 1042–1045.
21. Chan CPY, Li Y-L, Agarwal N, et al. Learning profiles for non-invasive transcutaneous Doppler ultrasound. *Eur J Emerg Med* 2015; 22: 128–134.
22. Nelson BP and Sanghvi A. Out of hospital point of care ultrasound: current use models and future directions. *Eur J Trauma Emerg Surg* 2016; 42: 139–150.
23. Nagaraj G, Chu M and Dinh M. Emergency clinician performed ultrasound: availability, uses and credentialing in Australian emergency departments. *Emerg Med Australas* 2010; 22: 296–300.
24. Nielsen K, Lauridsen JRM, Laursen CB, et al. Physicians using ultrasound in Danish emergency departments are mostly summoned specialists. *Scand J Trauma Resusc Emerg Med* 2015; 23: 51.
25. Ahn C, Kim C, Kang BS, et al. Variation of availability and frequency of emergency physician-performed ultrasonography between adult and pediatric patients in the academic emergency department in Korea. *Clin Exp Emerg Med* 2015; 2: 16–23.
26. Sanders J, Noble V, Raja A, et al. Access to and use of point-of-care ultrasound in the emergency department. *West J Emerg Med* 2015; 16: 747–752.
27. Bobbia X, Abou-Badra M, Hansel N, et al. Changes in the availability of bedside ultrasound practice in emergency rooms and prehospital settings in France. *Anaesth Crit Care Pain Med*. Epub ahead of print 4 August 2017. DOI: <https://doi.org/10.1016/j.jaccpm.2017.06.008>.
28. Blehar DJ, Barton B and Gaspari RJ. Learning curves in emergency ultrasound education. *Acad Emerg Med* 2015; 22: 574–582.
29. Deakin CD and Low JL. Accuracy of the advanced trauma life support guidelines for predicting systolic blood pressure using carotid, femoral, and radial pulses: observational study. *BMJ* 2000; 321: 673–674.
30. Svedlund S, Eklund C, Robertsson P, et al. Carotid artery longitudinal displacement predicts 1-year cardiovascular outcome in patients with suspected coronary artery disease. *Arterioscler Thromb Vasc Biol* 2011; 31: 1668–1674.
31. Zidan M, Thomas RL and Slovis TL. What you need to know about statistics, part II: reliability of diagnostic and screening tests. *Pediatr Radiol* 2015; 45: 317–328.
32. Bortolin L, Pascaner A and Craiem D. Comparison of central systolic pressure estimates obtained from ultrasound images and applanation tonometry. *J Phys Conf Ser* 2013; 477: 1–7.
33. Graf S, Craiem D and Armentano RL. Non invasive assessment of carotid and femoral arterial pressure using B-mode ultrasound diameter waveforms. In: *Engineering in Medicine and Biology Society (EMBC), annual international conference of the IEEE*, San Diego, California, 28 August–1 September 2012, pp.5610–5613, San Deigo, CA: Institute of Electrical and Electronics Engineers.
34. Haluska BA, Jeffriess L, Mottram PM, et al. A new technique for assessing arterial pressure wave forms and central pressure with tissue Doppler. *Cardiovasc Ultrasound* 2007; 5: 6.