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Clinical paper

Femoral artery Doppler ultrasound is more accurate than manual palpation for pulse detection in cardiac arrest

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Abstract

Objectives: Our primary objective was to assess the accuracy of Doppler ultrasound versus manual palpation in detecting any pulse with an arterial line waveform in cardiac arrest. Secondarily, we sought to determine whether peak systolic velocity (PSV) on Doppler ultrasound could detect a pulse with a systolic blood pressure (SBP) $\geq$ 60 mmHg.

Methods: We conducted a prospective, cross-sectional, diagnostic accuracy study on a convenience sample of adult, Emergency Department (ED) cardiac arrest patients. All patients had a femoral arterial line. During a pulse check, manual pulse detection, PSV and Doppler ultrasound clips, and SBP were recorded. A receiver operator characteristic curve analysis was performed to determine the optimal cut-off of PSV associated with a SBP $\geq$ 60 mmHg. Accuracy of manual palpation and Doppler ultrasound for detection of any pulse and SBP $\geq$ 60 mmHg were compared with McNemar's test.

Results: 54 patients and 213 pulse checks were analysed. Doppler ultrasound demonstrated higher accuracy than manual palpation (95.3% vs. 54.0%; $p < 0.001$) for detection of any pulse. Correlation between PSV and SBP was strong (Spearman correlation coefficient = 0.89; $p < 0.001$). The optimal cut-off value of PSV associated with a SBP $\geq$ 60 mmHg was 20 cm/s (area under the curve = 0.975). To detect SBP $\geq$ 60 mmHg, accuracy of a PSV $\geq$ 20 cm/s was higher than manual palpation (91.4% vs. 66.2%; $p < 0.001$).

Conclusions: Among ED cardiac arrest patients, femoral artery Doppler ultrasound was more accurate than manual palpation for detecting any pulse. When using a PSV $\geq$ 20 cm/s, Doppler ultrasound was also more accurate for detecting a SBP $\geq$ 60 mmHg.

Keywords: Cardiac arrest, Cardiopulmonary resuscitation, Doppler ultrasound, Pulse detection

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Introduction

One of the hallmarks of international guidelines for cardiopulmonary resuscitation (CPR) is two-minute chest compression cycles followed by a rhythm and pulse check.[1–3] Unfortunately, manual palpation of a pulse during cardiac arrest is difficult due to body habitus, environmental stress, time limitations, and assessor experience; thereby limiting the accuracy of manual pulse detection which varies from 63% to 94%.[4–10] Despite these challenges, manual palpation of a pulse remains the primary mode for detection of return of spontaneous circulation (ROSC) in the current cardiac arrest resuscitation algorithms.[1–3]

Arterial Doppler ultrasound may provide a more accurate method for detection of a pulse in cardiac arrest; however, it may also detect blood flow with inadequate blood pressure for manual detection and perfusion. Peak systolic velocity (PSV) on Doppler ultrasound is easy to measure (Figs. 1a–1c) in comparison to other Doppler ultrasound measures of arterial blood flow such as the velocity time integral and flow time.[11–13] In addition, PSV correlates with systolic blood pressure (SBP) in non-cardiac arrest patients[14,15]; so it may also accurately detect adequate blood pressures to stop chest compressions in cardiac arrest patients. Recent studies have demonstrated improved accuracy of pulse detection with ultrasound,[16–18] and similar interruption times to manual palpation.[16,17] However, none of these studies included actual cardiac arrest patients with an arterial line in place as the gold standard for pulse detection.

The primary objective of this study was to assess the accuracy of femoral artery pulsed-wave Doppler ultrasound in comparison to manual palpation to detect any pulse with an arterial line waveform for patients in cardiac arrest. Secondarily, we sought to determine whether peak systolic velocity (PSV) on Doppler ultrasound accurately detects a pulse with an adequate blood pressure needed for perfusion, which we defined as a SBP $\geq$ 60 mmHg. We used accuracy for our primary outcome because it encompasses the importance of both sensitivity, which includes avoiding pronouncing death in a patient with a pulse and changing management strategies once ROSC is established; and specificity because chest compressions should continue when a pulse is not present.

Methods

Study design

This was a prospective, cross-sectional, partially blinded, diagnostic accuracy study performed in a quaternary care Emergency Department (ED) between June 18, 2019 and July 20, 2021. Standards for Reporting Diagnostic Accuracy (STARD) guidelines were followed in the design and reporting of this study.[19] Our healthcare system's Institutional Review Board approved this study with a waiver of informed consent. All research data is available upon request.

Patients

We enrolled a convenience sample of adult patients ($\geq$ 18 years old) with nontraumatic cardiac arrest (both out-of-hospital [OHCA] and in-hospital [IHCA]). Patients were enrolled if they had a femoral arterial line in place and a Doppler ultrasound-trained Emergency Medicine attending physician was available. Patients were excluded if they were a candidate for extracorporeal membrane oxygenation.

Study protocol

Prior to study enrolment, all research personnel participated in a study training session with the Principal Investigator. Training included a 45-minute didactic session on femoral artery pulsed-wave Doppler ultrasound performance and measurement of arterial line blood pressures. There were 18 Emergency Medicine attending physicians with prior training in point-of-care ultrasound who served as research personnel in this study. Mechanical CPR is used for all patients who fit the device in our ED.[20] All patients had an arterial line in place prior to beginning the study, and all treatment decisions were made by the treating team.

Manual palpation of a pulse was performed at the femoral and/or carotid artery by the treating team. The treating team was blinded to the Doppler ultrasound exam; however, they were not blinded to arterial line blood pressure waveforms and measurements. Doppler ultrasound exams were performed using either a 8, 10, or 12-megahertz (MHz) linear transducer on either a Zonare Z.one Pro or Mindray TE7 (Mindray North America, Mahwah, NJ) ultrasound machine in vascular mode settings. Patients were in the supine position for the exam. Prior to a pulse check, the ultrasound machine volume was turned off and the ultrasound transducer was placed in the inguinal canal at 90° to the skin surface to identify the vasculature in transverse orientation. All ultrasounds were performed on the same side and proximal to the femoral arterial catheter. Once the femoral artery was identified the pulsed-wave Doppler function was enabled with the indicator placed in the centre of the artery in short axis, to visualize the arterial tracing (Figs. 1a–1c). The Doppler angle was not adjusted and maintained on the control setting. The scale was adjusted to view the entire peak and trough of the Doppler waveform prior to a pulse check during chest compressions (Fig. 1a). During a pulse check, research personnel simultaneously confirmed and recorded whether the treating team palpated a pulse; the presence or absence of Doppler ultrasound and arterial line waveforms; the highest PSV on Doppler ultrasound; and the highest SBP on the arterial line. Repeated measurements were recorded during subsequent pulse checks until sustained ROSC was achieved or time of death was pronounced. Ultrasound images were stored on Qpath E (Telexy Healthcare Inc., Maple Ridge, BC, Canada). The enrolling ultrasonographer and a second Doppler ultrasound-trained sonographer, who was blinded to any patient information, independently reviewed all stored Doppler ultrasound images to confirm whether a Doppler waveform was present and the measurement of the highest PSV during the pulse check. In the 21 patients with video recordings available, video review of the cardiac arrest resuscitation using our previously published methods[20] confirmed research personnel recordings for whether a pulse was palpated and the highest SBPs obtained during the pulse check, and determined time to arterial line placement.

Outcome measures

The primary outcome of this study was the accuracy of Doppler ultrasound compared with manual palpation for detecting any pulse with an arterial line waveform. Pulse detection by manual palpation (present/absent), Doppler ultrasound (present if waveform was visualized and absent if not visualized), and arterial line (present with waveform and absent with no waveform) were all dichotomous variables. Accuracy was defined as the number of true positive plus true negative pulse checks divided by the total number of pulse checks. The secondary objective of this study

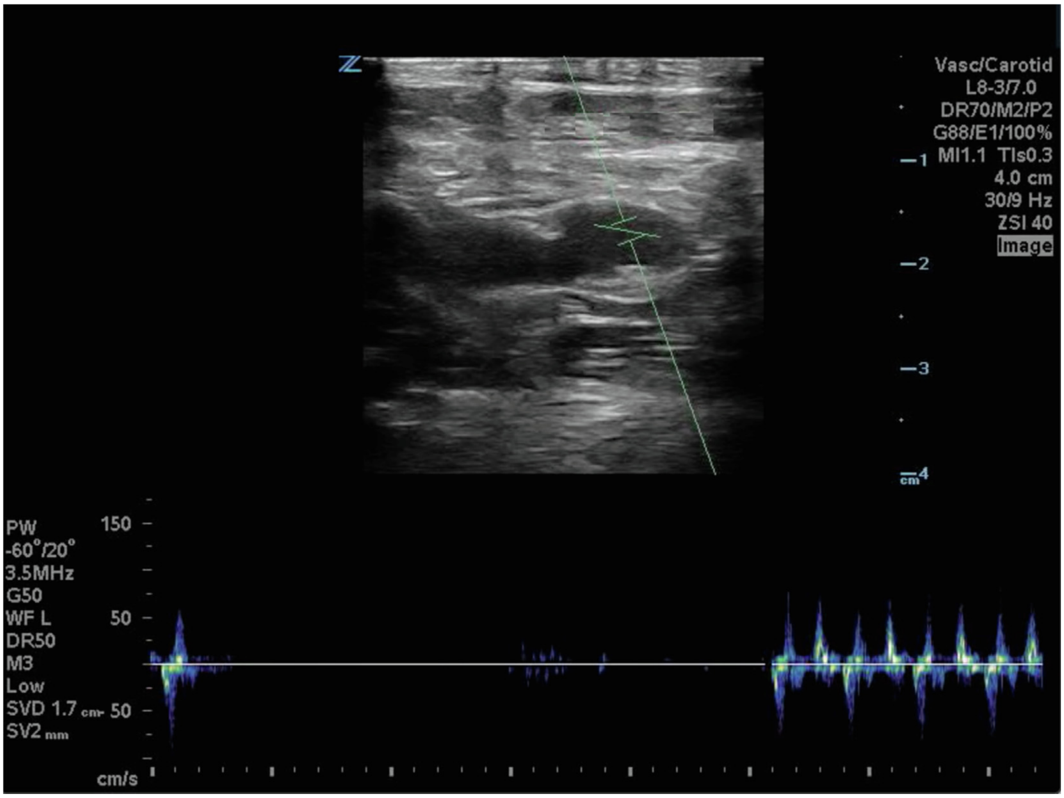

Fig. 1a – Femoral artery Doppler ultrasound waveforms with chest compressions and no Doppler ultrasound blood flow visible at a pulse check.

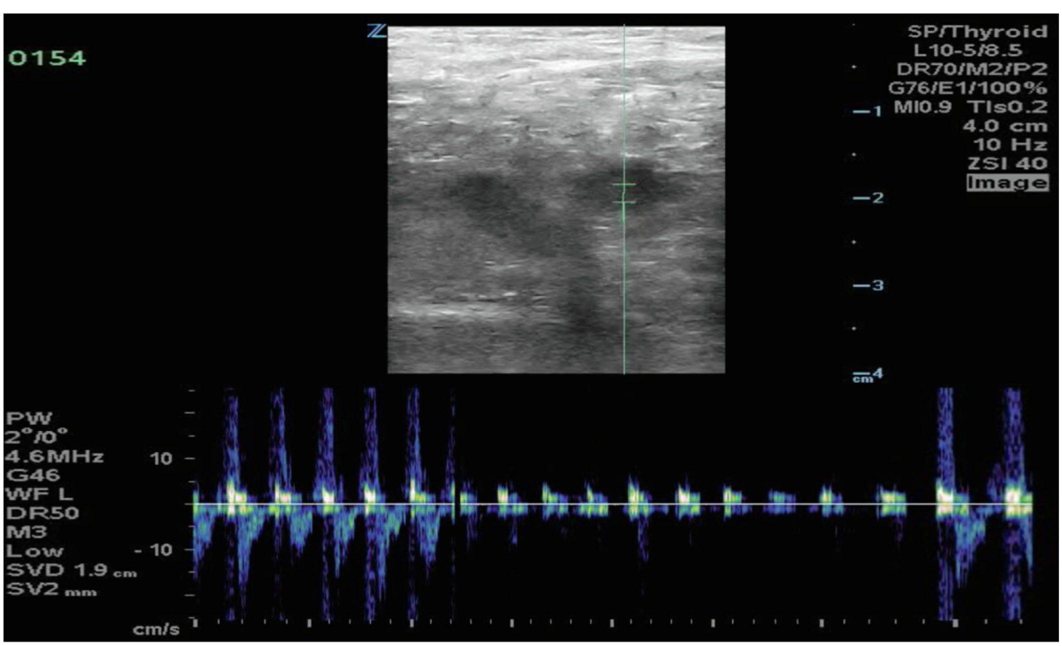

Fig. 1b – Femoral artery Doppler ultrasound waveforms with chest compressions and low blood flow (peak systolic velocity < 10 cm/s) at a pulse check.

was to determine if PSV on Doppler ultrasound could accurately detect a pulse with a SBP $\geq$ 60 mmHg because it should allow for both manual palpation of a pulse[21] and sufficient pressure to stop chest compressions.[22] We then compared the accuracy of the determined PSV cut-off on Doppler ultrasound versus manual palpation.

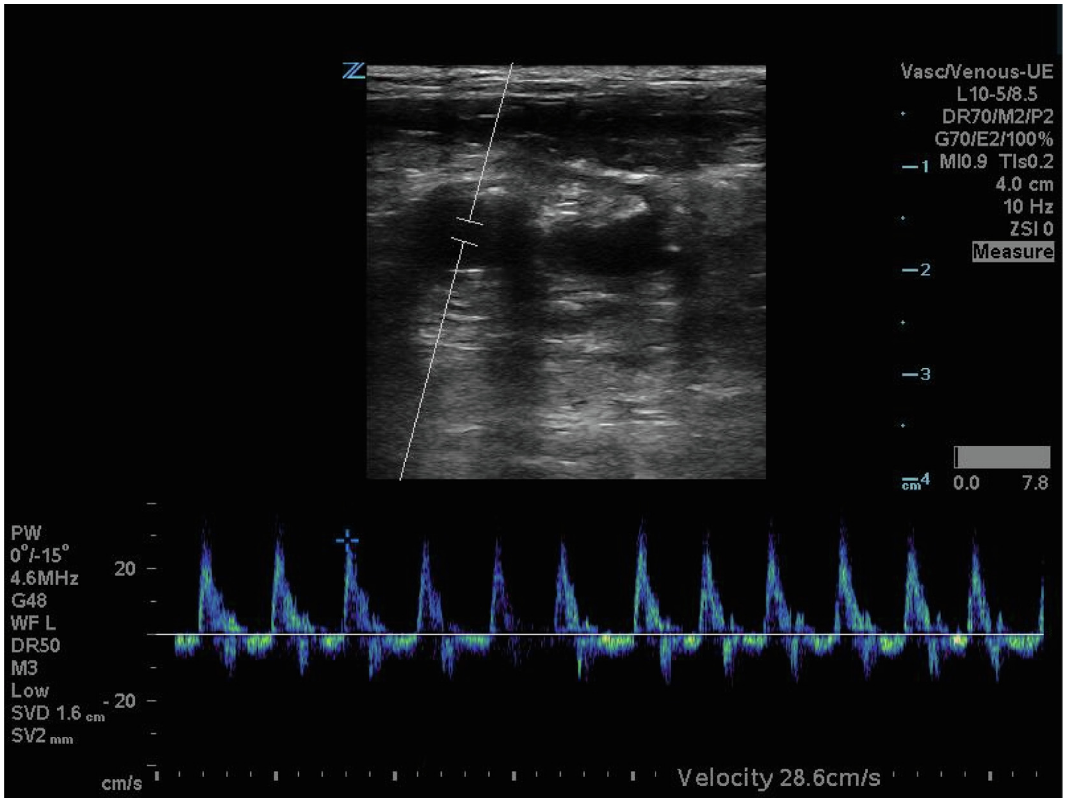

Fig. 1c – Femoral artery Doppler ultrasound waveform visible with high blood flow (peak systolic velocity of 28.6 cm/s) at a pulse check.

Statistical analysis

Statistical analysis was performed by a biostatistician who was not involved in study design or data collection. Descriptive statistics were used to characterize the overall study sample. The correlation between PSV on Doppler ultrasound and arterial line SBP was assessed with a Spearman correlation coefficient. A receiver operator characteristic (ROC) curve analysis was performed to determine the optimal cut-off value of PSV on Doppler ultrasound that is associated with SBP $\geq$ 60 mmHG. Accuracy, sensitivity, and specificity of Doppler ultrasound and manual palpation for detection of any pulse and a pulse with a SBP $\geq$ 60 mmHg were calculated and compared with McNemar's test. Since a patient could have numerous pulse checks, a repeated measures analysis was performed using a mixed-model approach to calculate accuracy, sensitivity, and specificity of the primary outcome. All statistical analyses were performed using SAS 9.4 (SAS Institute, Cary, North Carolina, United States).

We determined that a sample size of 308 pulse checks would be needed to estimate the accuracy of Doppler ultrasound for pulse detection with a width of 10% if the sensitivity of manual palpation was 80%, specificity was 70%, and the prevalence of a pulse was 20%.[23] This study was stopped early after an interim analysis found the sensitivity of manual palpation was lower and the prevalence of a pulse was higher than predicted.

Results

The study flow sheet is provided (Fig. 2). An arterial line was unable to be placed in 11 out of 66 patients (16.7%) despite a Doppler ultrasound-trained physician being available. A total of 54 patients and 213 pulse checks were analysed for the primary outcome detection of any pulse, with a median of 3 pulse checks per patient (interquartile range [IQR]: 2–6 pulse checks) Patient demographics are shown in Table 1. Patients were elderly with a median age 81 years (IQR 66–87 years), predominantly male (67%) and white (63%), largely OHCA (61%), and predominantly non-shockable with asystole representing 28% and PEA 35% of initial ED rhythms.

For the primary outcome (Table 2), Doppler ultrasound demonstrated higher accuracy than manual palpation for detection of any pulse (95.3% vs. 54.0%; $p < 0.001$). These results were nearly identical when controlling for repeated measures (Supplemental Table 1). However, as seen in Table 2, when analysing for the presence of a pulse with SBP $\geq$ 60 mmHg the accuracy of Doppler ultrasound was lower, although still significantly more accurate than manual palpation (77.6% vs. 66.2%; $p = 0.011$). For detection of a pulse with SBP $\geq$ 60 mmHg, the sensitivity of manual palpation was low at 47.4%; however, the specificity of manual palpation was higher than Doppler ultrasound (82.3% vs. 58.4%; $p < 0.001$). As the SBP detection threshold increases from 0 mmHg to 100 mmHg, the accuracy and specificity of Doppler ultrasound decreases while the sensitivity increases; but the accuracy and sensitivity of manual palpation increases while the specificity decreases. (Supplemental Table 2).

PSV on Doppler ultrasound and arterial line SBP were available for 210 pulse checks. As seen in Fig. 3a, there was a strong correlation between PSV and SBP (Spearman correlation coefficient: 0.89; $p < 0.001$). The optimal cut-off value for PSV associated with a SBP $\geq$ 60 mmHG was 20 cm/s (Fig. 3b, area under the receiver operating curve = 0.975). As seen in Table 2, to detect

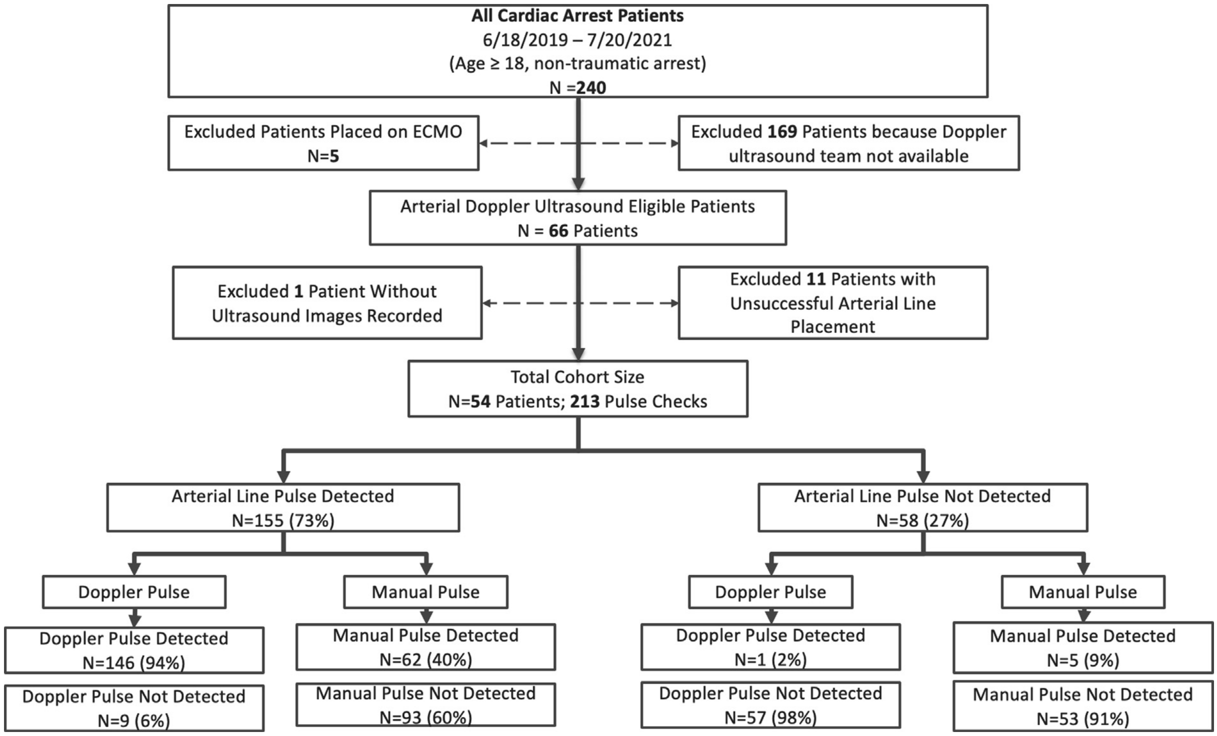

Fig. 2 – Study Flow Chart. ECMO indicates Extracorporeal Membrane Oxygenation; PSV, peak systolic velocity; SBP, systolic blood pressure.

Table 1 – Patient demographics (n = 54 patients).

Age, years	
Median (IQR)	81 (66, 87)
Sex	
Male, *n* (%)	36 (67%)
Female, *n* (%)	18 (33%)
Race	
White, *n* (%)	34 (63%)
Non-White, *n* (%)	20 (37%)
Ethnicity	
Hispanic or Latino, *n* (%)	2 (4%)
Not Hispanic or Latino, *n* (%)	45 (83%)
Unknown/not documented, *n* (%)	7 (13%)
Location of cardiac arrest	
Out-of-hospital, *n* (%)	33 (61%)
In-hospital, *n* (%)	21 (39%)
First ED Cardiac Rhythm	
Asystole, *n* (%)	15 (28%)
Pulseless electrical activity, *n* (%)	19 (35%)
Ventricular fibrillation/tachycardia, *n* (%)	10 (19%)
Unknown/not documented, *n* (%)	10 (19%)
Arterial Line Placement Time (*n* = 24)	
Median seconds (IQR)	208 (136, 382)
Outcomes	
Return of spontaneous circulation, *n* (%)	35 (64%)
Survived to admission, *n* (%)	19 (35%)
Number of Pulse Checks Analysed	
Median (IQR)	3 (2,6)

SBP $\geq$ 60 mmHg the accuracy of PSV $\geq$ 20 cm/s on Doppler ultrasound was higher than manual palpation (91.4% vs. 66.2%; $p < 0.001$).

In Table 3, categorizing Doppler ultrasound flow as no flow (PSV = 0 cm/s), low flow (PSV > 0 and <20 cm/s), and high flow (>20 cm/s) was 86.7% accurate at identifying 3 important groups of cardiac arrest patients: 1) those with no pulse; 2) those with an inadequate pulse (SBP > 0 and <60 mmHg); 3) those with an adequate pulse (SBP $\geq$ 60 mmHg). There was a significant association between the PSV flow categories and the pulse by SBP categories ($p < 0.001$).

Discussion

This study of ED cardiac arrest patients found that femoral artery Doppler ultrasound was more accurate than manual palpation for detection of any pulse on an arterial line. The accuracy of manual palpation of any pulse was poor at 54%. The lower accuracy than prior studies[4–7,9] is likely because of the increased sensitivity of an arterial line to detect any pulsatility, as well as the challenges of detecting a pulse within 10 seconds in actual ED cardiac arrest patients, which has also been seen in prior studies.[5,6,10] In our study, manual palpation at SBP thresholds previously believed to be detectable had very low sensitivity for detecting a pulse ranging from 47.4% with SBP $\geq$ 60 mmHg to 61.5% with SBP $\geq$ 100 mmHg (Table 2, Supplemental Table 2). This study brings into question the current guideline recommendations for manual pulse detection in cardiac arrest, especially in settings where Doppler ultrasound is available.[1–3]

Our study adds to previous studies[16,18] demonstrating arterial Doppler ultrasound has high accuracy for detection of pulsatile blood flow in cardiac arrest patients. Since the specificity of Doppler ultrasound is very high for the detection of any pulsatile blood flow, CPR

Table 2 – Accuracy, sensitivity, and specificity of femoral artery Doppler ultrasound and manual palpation for detecting any pulse and systolic blood pressure (SBP) greater than or equal to 60 mmHg; peak systolic velocity is PSV.

	Doppler Ultrasound	Manual Palpation	*p*-value
For Detecting Any Pulse			
Accuracy	95.3% (91.5–97.7%)	54.0% (47.1–60.8%)	< 0.001
Sensitivity	93.5% (84.4–97.4%)	40.0% (32.3–47.7%)	< 0.001
Specificity	98.3% (94.9–100.0%)	91.4% (82.0–96.2%)	0.103
For Detecting SBP ≥ 60 mmHg			
Accuracy	77.6% (71.4–83.1%)	66.2% (59.4–72.6%)	0.011
Sensitivity	100% (96.3–100%)	47.4% (37.5–57.4%)	< 0.001
Specificity	56.9% (47.4–66.0%)	81.9% (74.9–88.9%)	<0.001
	Doppler Ultrasound PSV ≥ 20 cm/s*	Manual Palpation	
For Detecting SBP ≥ 60 mmHg			
Accuracy	91.4% (86.8–94.5%)	66.2% (59.4–72.6%)	<0.001
Sensitivity	87.6% (81.1–94.2%)	47.4% (37.5–57.4%)	0.006
Specificity	94.7% (90.6–98.8%)	81.9% (74.9–88.9%)	<0.001

* PSV was recorded in 210 of 213 pulse checks.

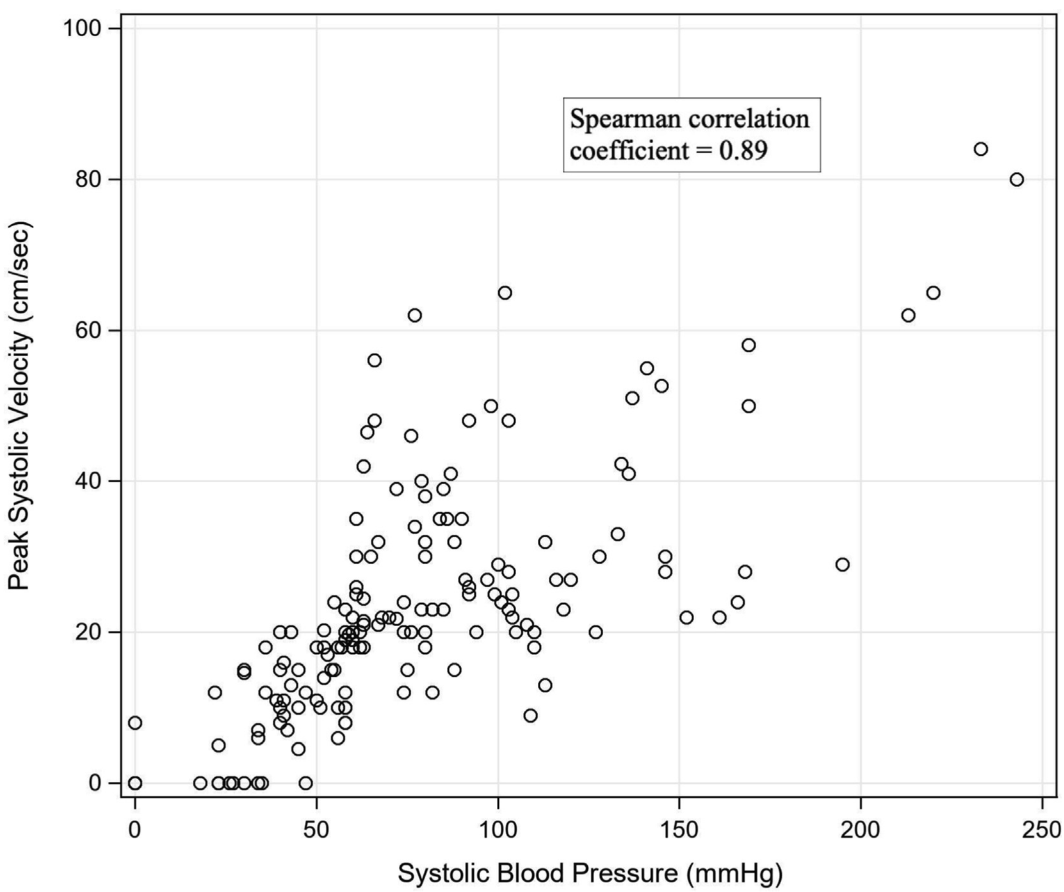

Fig. 3a – Scatterplot of Peak Systolic Velocity (PSV) on Doppler Ultrasound by Arterial Systolic Blood Pressure (SBP) on Femoral Arterial Line with Spearman correlation coefficient.

teams can be confident that patients without a Doppler ultrasound waveform do not have a pulse and should continue chest compressions or pronounce death if appropriate. Unfortunately, the Doppler ultrasound waveform alone is overly sensitive for detecting any pulsatile blood flow, which could lead CPR teams to stop chest compressions at very low blood pressures when chest compressions are still beneficial. Since our study included an arterial line as the gold standard for pulse detection, we were able to assess the

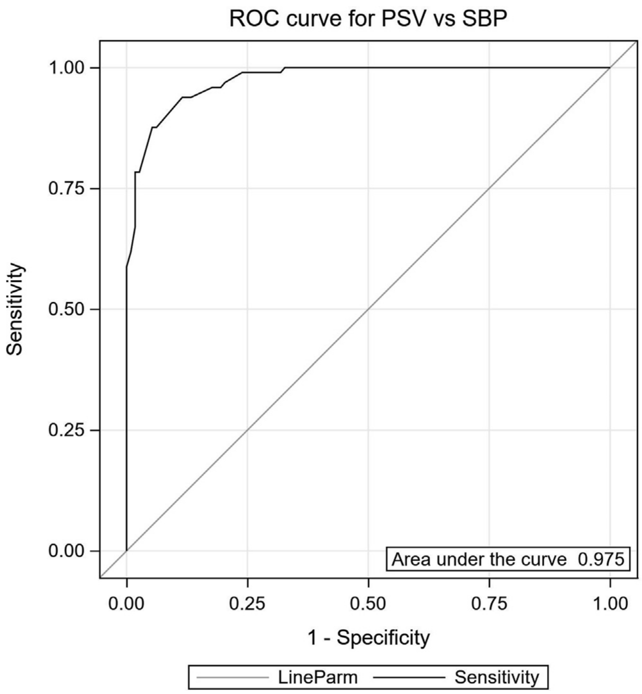

Fig. 3b – Receiver operating characteristic (ROC) curve determining optimal cutoff value for PSV associated with a SBP ≥ 60 mmHG was 20 cm/s (area under the curve = 0.975).

performance of Doppler ultrasound at detecting an adequate blood pressure to stop chest compressions, which we defined as an SBP ≥ 60 mmHg. For detecting a SBP ≥ 60 mmHg, the specificity of Doppler ultrasound was lower than manual palpation; therefore, more patients with a SBP < 60 mmHg would have chest compressions stopped prematurely if Doppler ultrasound waveforms alone were used for pulse detection instead of manual palpation.

Since both the sensitivity of manual palpation and the specificity of Doppler ultrasound were very low for detection of an adequate pulse with SBP ≥ 60, we compared PSV on Doppler ultrasound with femoral artery SBP measurements during a pulse check. We found a strong correlation between PSV and SBP and higher accuracy of PSV ≥ 20 cm/s on Doppler ultrasound to detect a SBP ≥ 60 mmHg than manual palpation. Additionally, both the sensitivity and specificity of PSV ≥ 20 cm/s for detection of a pulse with SBP ≥ 60 mmHg were significantly higher than manual palpation. Therefore, more patients with an adequate pulse were detected and could move to post-resuscitation management, and fewer patients with no pulse or an inadequate pulse would have chest compressions discontinued prematurely if PSV ≥ 20 cm/s on Doppler ultrasound was used instead of manual palpation.

In Table 3 we demonstrate Doppler ultrasound with PSV allows for differentiation of no blood flow, low blood flow, and high blood flow states with high agreement with corresponding SBP categories (no pulse, inadequate pulse, and adequate pulse). Therefore, Doppler ultrasound with PSV can be used to guide cardiac arrest management during a pulse check. Since Doppler ultrasound has very high specificity for detection of any pulse, patients with no Doppler ultrasound waveform need ongoing CPR or a decision on termination of resuscitation. Additionally, since Doppler ultrasound PSV < 20 cm/s detects most patients with SBP < 60 mmHg, a PSV ≥ 20 cm/s should increase confidence that an adequate pulse is present and CPR teams and can take more time to confirm the presence of an adequate pulse (increase time for manual palpation, measure a non-invasive blood pressure, or place an arterial line) and proceed to post-resuscitation care. Doppler ultrasound is less accurate when patients have low blood flow (PSV > 0 and <20 cm/s) or an inadequate pulse (SBP > 0 and <60 mmHg), often referred to as pseudo-PEA, which is the presence of electrical activity and myocardial contractions without a palpable pulse.[24,25]. However, patients with pseudo-PEA likely need a different management strategy that is not well defined by cardiac arrest guidelines.[1–3]

Continuing chest compressions is likely beneficial in patients with pseudo-PEA. In pseudo-PEA animal studies, there were improved outcomes when continuing chest compressions in addition to vasopressors,[26] and improved coronary perfusion pressure with synchronized chest compressions.[27] Additionally, pseudo-PEA patients may benefit from the addition of continuous vasopressors or inotrope infusions to increase the blood pressure to detectable levels.[25,28,29] Pseudo-PEA patients have higher rates of ROSC than PEA patients[28,30,31]; therefore, it is important to identify in order to avoid discontinuing resuscitative efforts prematurely. Prior studies found pseudo-PEA to be present in 19–32% of PEA cardiac arrest patients[16,32,33]; and in our study, 26% of all pulse checks had pseudo-PEA. Detecting pseudo-PEA previously required an arterial line or echocardiography, which can increase chest compression interruptions when done with transthoracic echocardiography.[34–36] Arterial Doppler ultrasound with PSV provides a new opportunity to identify pseudo-PEA.

Table 3 – Pulse Checks with Categorized Doppler ultrasound peak systolic velocity (PSV) versus categorized Pulse by arterial line systolic blood pressure (SBP).

	No Pulse	Inadequate Pulse (SBP > 0 & <60 mmHg)	Adequate Pulse (SBP ≥ 60 mmHg)
No Doppler Flow PSV = 0 cm/s	57	9	0
Low Doppler Flow PSV > 0 & <20 cm/s	1	40	12
High Doppler Flow PSV ≥ 20 cm/s	0	6	85
Number of Pulse Checks	58	55	97

The 2020 AHA guidelines recommend using arterial lines to evaluate for ROSC when available and a rhythm check reveals an organized rhythm (Level of Evidence C, Expert Opinion).[1] Unfortunately, placing an arterial catheter in a cardiac arrest patient is difficult. We were only successful placing an arterial catheter 83.3% of patients, and the median time to placement of the arterial catheter from needle to skin to first arterial waveform detection was 208 seconds from video review analysis, and this excluded arterial line set up time. Additionally, placing and setting up an arterial line diverts clinician's attention from analysing CPR quality and determining the cause of the cardiac arrest. Doppler ultrasound is likely easier and faster to obtain and measure than an arterial line, while providing similar pulse detection times as manual palpation without increasing chest compression interruptions.[16,17] During a pulse check, arterial Doppler ultrasound using PSV may provide similar information to arterial lines without the additional time delays and training required to set up and place an arterial line.

The future of Doppler ultrasound in resuscitation is promising. While Doppler ultrasound is currently available in the hospital setting, ultrasound technology is rapidly expanding with smartphone compatible ultrasound probes, and potentially Doppler ultrasound patches in the future.[13] This could allow for arterial Doppler ultrasound for pulse detection to expand into the pre-hospital setting where the majority of cardiac arrests occur.[37]

Limitations

Our study has several limitations. First, this was a single centre study, with a small number of patients, and due to sample size limitations, we treated repeated measurements for each patient as independent. We performed an analysis accounting for repeated measures, which yielded nearly identical results as treating each measurement as independent (Supplemental Table 1). Second, treating teams were not blinded to the results of the arterial line; however, this should have increased the accuracy of manual pulse detection by the treating team. The treating team was blinded to the Doppler ultrasound findings. Third, study personnel were specifically trained in arterial Doppler ultrasonography. While the training was not long or technically difficult, it may be challenging to obtain similar skills in hospitals with less ultrasound experience or resources. Fourth, Doppler ultrasound was performed in a transverse orientation at 90° to the skin; however, it is commonly obtained in longitudinal orientation for peripheral arterial disease studies.[38,39] Based on our experience we believed longitudinal Doppler ultrasonography would be difficult to perform in cardiac arrest, whereas a transverse orientation is easier for the ultrasonographer. Fifth, carotid palpation was recently found to be more sensitive than femoral palpation of a pulse in cardiac arrest[40]; however, in our study manual palpation was performed at the femoral and/or carotid artery. The location of manual pulse detection was unable to be recorded consistently because both carotid and femoral pulses are often checked simultaneously, and we wanted to limit interference in the treating team's management of the complex cardiac arrest patient. Seventh, we excluded patients when an arterial line was unable to be placed. These excluded patients may have been more likely to have obesity or severe peripheral arterial disease. Patients with severe peripheral arterial disease are also known to have elevated PSV on Doppler ultrasound[41,42]; therefore, we advise caution in interpreting the results of Doppler ultrasound in patients with known advanced peripheral arterial disease. Because of these limitations, especially those surrounding the measurement of PSV, validation of this study is needed.

Conclusions

In this study of ED cardiac arrest patients, femoral artery Doppler ultrasound was more accurate than manual palpation for detecting any pulse, and when using a PSV $\geq$ 20 cm/s, it was also more accurate for detecting a pulse with a SBP $\geq$ 60 mmHg. In settings where Doppler ultrasound is available, femoral artery Doppler ultrasound is an accurate and objective tool to determine the presence of a pulse in cardiac arrest. External validation of this study, particularly the PSV cut-off on Doppler ultrasound, is needed before widespread adoption.

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Conflicts of interest

ALC received funding from the ZOLL Foundation to support this research, and outside this work she receives research funding from Nihon Kohden Corporation. TL receives research funding from Nihon Kohden Corporation outside the submitted work. LBB receives research funding from the National Institutes of Health, United Therapeutics, Philips, ZOLL, and Hewlett-Packard outside the submitted work; he also serves on the scientific advisory boards for: Nihon Kohden Corporation, Philips Medical Systems, and Hewlett-Packard. DMR receives research funding from the ZOLL Foundation and CalciMedica outside the submitted work. All other authors have no conflicts of interest to disclose.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resuscitation.2022.01.030.

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