Echocardiography does not prolong peri-shock pause in cardiopulmonary resuscitation using the COACH-RED protocol with non-expert sonographers in simulated cardiac arrest

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Abstract

Objective: Focused echocardiography during peri-shock pause (PSP) can prognosticate and detect reversible causes in cardiac arrest but minimising interruptions to chest compressions improves outcome. The COACH-RED protocol was adapted from the COACHED protocol to systematically incorporate echocardiography into rhythm check without prolonging PSP beyond the recommended 10s. The primary objective of this study was to test the feasibility of emergency nurses learning to perform all roles in the COACH-RED protocol. PSP duration and change in participant confidence were secondary outcomes.

Methods: After an initial two-hour workshop, five ALS-trained nurses were assessed for the correct use of COACH-RED protocol, without critical error, in three simulated cardiac arrest scenarios of four cycles each. Assessments were repeated on days 7 and 35. On day 35, three COACHED scenarios were also assessed for comparison. Participant roles per scenario and cardiac rhythm per cycle were randomised. Participants completed questionnaires on their confidence levels. Sessions were videotaped for accurate measurement of PSP duration and results tabulated for simple comparison. Statistical analysis was not performed due to small sample size.

Results: There were no critical errors, two minor team-leading errors and two minor echosonography errors. Minor errors occurred in separate scenarios resulting in a 100\% pass rate overall by predetermined criteria. Echocardiographic recordings were 100\% adequate. Overall median PSP was 9.35s for COACH-RED and 6.94s for COACHED. Sub-group analysis of COACH-RED revealed median PSP 10.80s in shockable rhythms and 8.74s (~2s less) in non-shockable rhythms. Mean participant confidence in performing COACH-RED improved from 1.6 to 4.6, on a 5-point scale.

Conclusion: The COACH-RED protocol can be effectively performed by ALS-trained nurses, in all roles of this protocol, including echocardiography, in a simulated environment, after a single training session. Using this protocol, focused echocardiography does not prolong PSP beyond 10s.

Keywords: Advanced cardiac life support, Cardiac arrest, Cardiopulmonary resuscitation, Echocardiography, Education, Nursing, Simulation training

Abbreviations: ALS, Advanced Life Support; ARC, Australian Resuscitation Council; CPR, Cardiopulmonary resuscitation; ED, Emergency Department; IQR, Interquartile Range; PEA, Pulseless Electrical Activity; PSP, Peri-Shock Pause; SAH, Sydney Adventist Hospital; VF, Ventricular Fibrillation; VT, Ventricular Tachycardia.

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Introduction

Bedside ultrasound performed by clinicians has become increasingly widespread over the past 35 years and is now considered a core skill requirement of specialist training by most emergency medicine colleges and societies worldwide.1–7 Echocardiography during a cardiac arrest has been used to identify reversible causes such as cardiac tamponade, hypovolaemia and pulmonary embolus and is increasingly being used as a decision aid for termination of resuscitation since the absence of spontaneous organised cardiac activity on echocardiography has been reported to predict a poor prognosis.8–12 Conversely, the evidence for echocardiography leading to a positive change of outcome in cardiac arrest is lacking, and in recent years some studies have suggested a negative effect through prolongation of pauses in chest compressions.13–16 Studies in animals and humans have shown vastly improved chances of successful defibrillation and survival when pauses in chest compressions are minimised.17–20 To minimise peri-shock pauses (PSP) in compressions, most resuscitation councils now recommend continuing compressions whilst charging the defibrillator. However, there is some variation as to whether this occurs before or after a pause for rhythm assessment.25–30 The Australian Resuscitation Council (ARC) recommends anticipatory charging of the defibrillator before pausing for rhythm assessment, with or without subsequent defibrillation, aiming to keep the PSP less than 10s.34

In New South Wales, Australia, COACHED (Fig. 1) is a commonly used mnemonic algorithm guiding a pause for rhythm check with anticipatory charging.35 Mnemonics and algorithms as cognitive aids have been shown to reduce cognitive load, reduce systematic errors, expedite tasks, establish a common language and allow for team-sharing of a mental model in stressful situations.37–44 To date, only one study has evaluated the COACHED protocol, and its use was found to reduce the pause in compressions from 8s to 6s in a simulated environment.36

The COACH-RED protocol was created to systematically incorporate focused echocardiography into the rhythm check without prolonging the pause in compressions beyond the 10s recommended by the Australian Resuscitation Council (Fig. 1).34,45 The authors video-recorded themselves using the algorithm in a simulated environment and reported the PSP to be well below 10s—6.45s for non-shockable and 8.47s for shockable rhythms.45–47 In Australia, the COACHED protocol is often primarily used by senior nurses in charge of the defibrillator, allowing the team leader (usually a medical doctor) to release some cognitive load during this process whilst maintaining situational awareness.36 The primary aim of this study was to examine the feasibility of teaching nurses to perform each role in the COACH-RED protocol safely and to retain the ability after one then five weeks. Uniquely, whilst every participant was trained in Advanced Life Support (ALS) and COACHED, none had previous formal training in echocardiography or COACH-RED. We hypothesised that using COACH-RED would require a slightly longer PSP compared to COACHED, but not beyond 10s.

Methods

Study design

This was a pilot, prospective simulation study aimed at training a convenience sample of five participants so they could safely perform each role in the COACH-RED protocol (see Figs. 1 and 2).

Fig. 1 – The COACHED and COACH-RED Protocol.
The original author of the COACHED protocol is unknown. The COACH-RED protocol is reproduced here (with some alterations) with permission from Finn et al., 2018.6
Competency was assessed immediately, one week after initial training and again one month later, to check retention of knowledge, skill and confidence. Fig. 3 illustrates the components of the three sessions. The initial session comprised a 45-minute PowerPoint presentation followed by a practical session. The material covered in the presentation included a literature review of the role of focused echocardiography in cardiac arrest, normal subcostal echocardiographic findings and examples of abnormal subcostal echocardiographic findings. Abnormal findings included enlarged right ventricle, cardiac tamponade and lack of spontaneous cardiac activity. The COACH-RED protocol, as depicted in Fig. 1, was then taught and the two videos from the original publication by Finn et al. (2019) were shown to participants.46,47

Each assessment consisted of three scenarios of four cycles each. Participants kept the same role for each scenario, but rhythm varied from one cycle to the next. Participants were given 30 min to practise before each assessment and time was allowed for further training after assessments if required. In addition to COACH-RED, three scenarios of COACHED were also assessed during the final assessment, to compare the two protocols and the difference in PSP duration.

To avoid selection bias, participants were randomly allocated roles for each scenario. An online randomiser programme was used for this purpose.48 Similarly, shockable vs non-shockable rhythms were randomly allocated to individual cycles in advance.

**Setting**

We used identical equipment in all three sessions, which were carried out in the Sim Lab of University of Sydney’s Clinical School located at Sydney Adventist Hospital (SAH), New South Wales, Australia. The study took five weeks to complete from the initial session on 13th November 2019 to the third session on 18th December 2019. The CPR manikin was a Blue Phantom™ 1800-FAST ultrasound phantom (© CAE Healthcare, Florida, USA) allowing for subcostal echocardiographic views. The ultrasound machine was a Philips Sparq (© Philips, Bothell, USA), with standard Cardiac Preset using phased array probe and cine-loop recordings set to 10 s. An adult-sized bag-valve-mask (© Mayo Healthcare, Sydney, Australia) and the ALSi system (© iSimulate, Sydney, Australia) allowed for high-fidelity simulation. Canon EOS 60D (© Canon, Tokyo, Japan) and Nikon D750 (© Nikon, Tokyo, Japan) cameras on tripods were used to video-record sessions from different angles, capturing all participants whilst a GoPro Hero3 (© GoPro Inc, San Mateo, USA) was placed nearer the manikin to record the PSP. None of the participants had used the manikin or ultrasound machine prior to this study.

**Participants**

Inclusion criteria were predefined as healthcare staff of the Emergency Department (ED) at SAH, with at least three years of
experience in the department and up to date with ALS training. Written informed consent was obtained from participants using an opt-in signed consent form explaining the study design, rationale and that sessions would be filmed with recordings potentially published for data transparency. Participants were excluded if they were unable to attend all three sessions.

Data collection and analysis

Questionnaires were used to gather baseline participant characteristics as well as experience and confidence with CPR and focused echocardiography at the start of every session and the end of the final session. Researchers marked participants performance in real-time during assessments using a mark sheet with predefined criteria. Adobe Premiere Pro v14.0 (© Adobe Inc, SanJose, USA) was used to slow down the 60 frames per second GoPro Hero3 footage and measure PSP to an accuracy of 0.016s per frame. Data were tabulated in Excel 365 (© Microsoft Corp, Washington, USA) and simple descriptive statistics used for comparison. As this was a pilot study with small sample size, no statistical analysis was performed.

Ethics

The study was approved by the Adventist Healthcare Limited Human Research Ethics Committee (HREC 2019-036) and received no funding.

Study outcomes

The primary outcome was defined as the correct performance of the COACH-RED protocol by the team. To pass a scenario, participants had to correctly perform COACH-RED in three out of four cycles with at least one satisfactory echocardiographic recording per scenario, and participants were required to pass two out of three scenarios per each assessment. A critical error was defined as anything which could potentially be dangerous for participants, such as defibrillating whilst echosonographer or other touching the manikin or misinterpretation of the rhythm. The correct performance was marked using predefined assessment criteria for each role, in Table 1.

Secondary outcomes were the length of peri-shock pause (PSP) for both COACH-RED and COACHED protocols as well as participant self-reported confidence and feedback.

Results

Participants

Five participants met inclusion criteria and were all ALS-trained nurses. All participants voluntarily consented to participate and attended all three sessions. The participant mean age was 40 (range 32–53) with a 3.2 male to female ratio. Mean experience working in ED was 12 years (range 8–20) and mean time since ALS certification was 7.4 months (range 3–15). All participants were familiar with the COACHED protocol prior to this study, having used it regularly in previous cardiac arrest resuscitations. None had any previous formal training in focused echocardiography or the COACH-RED protocol.

Primary outcomes

Table 2 summarises the results of the COACH-RED and COACHED assessments, grouped into primary and secondary outcomes. Fig. 4 depicts still images from the cine-loop recordings obtained in each cycle. There were only four cycles of incorrect performance; no critical errors and all echocardiographic recordings were satisfactory, resulting in a 100% pass rate for the primary outcome. Two role errors occurred due to the echosonographer not removing the probe promptly when instructed, and two were due to the team leader failing to instruct a shock and resumption of compressions in a shockable rhythm. These errors were in separate COACH-RED scenarios, allowing for the 100% pass rate. There were no errors in the COACHED scenarios.

Secondary outcomes

Peri-Shock pause

Peri-shock pause (PSP) per individual cycle and their averages are shown in Table 2. Of all cycles using COACH-RED, 69% had a PSP of

| Table 1 - COACH-RED Assessment Criteria/Checklist. |
| Role       | Responsibilities                                                                 |
|------------|-----------------------------------------------------------------------------------|
| Airway     | Removes oxygen at appropriate time                                               |
|            | Safe Overall                                                                     |
| CPR        | Hands off chest at appropriate time                                              |
|            | Hands back on chest promptly                                                     |
|            | Safe overall                                                                     |
| Defib      | Performs COACH-RED                                                                |
|            | Charges defibrillator                                                            |
|            | Checks all clear including US probe                                              |
|            | Disarms/Delivers appropriately                                                  |
|            | Safe overall                                                                     |
| Echo       | Prepares machine with correct preset & positioning                                |
|            | Records adequate subcostal image (≥1 from 4 cycles)                              |
|            | Removes probe at appropriate time                                                |
|            | Safe Overall                                                                     |
| Team Leader| Performs COACH-RED                                                                |
|            | Interprets rhythm                                                                |
|            | Instructs disarm/deliver shock appropriately                                     |
|            | Instructs to continue compressions promptly                                      |
less than 10s, with a median of 9.35 (IQR 2.34, Range 6.83–15.36) seconds. There were two outlying COACH-RED cycles with PSP greater than 15s, resulting in a mean PSP greater than 10s for day 0 and day 7. Excluding these, with median values, the averages for all three COACH-RED sessions were below 10s. COACH-RED performance improved during the study period — 83% of cycles had a PSP of lesser than 10s by the third session. The average PSP also improved from the first to the third scenario on each assessment.

With COACHED protocol, 100% of cycles had a PSP less than 10s with a median of 6.94 (IQR 0.615, range of 6.46–8.97) seconds. The difference in median between COACH-RED and COACHED was 2.41s.

Fig. 5 illustrates the discrepancy in PSP for shockable and non-shockable rhythms. Only two of the non-shockable COACH-RED cycles resulted in a PSP greater than 10s compared to nine for shockable rhythms. Shockable rhythms were thus much more likely to

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**Table 2 – Primary & Secondary Outcomes.**

| Assessments | Primary Outcome - Pass? | Secondary Outcome | Pen-Shock Pause (PSP) (seconds) |
|-------------|--------------------------|-------------------|---------------------------------|
|             | Airway | CPR | Defib | Echo | Team Leader | Overall Pass? | PSP | Median PSP       |
|-------------|--------|-----|-------|------|-------------|---------------|-----|-----------------|
| C 0 1 1     | Y      | Y   | Y     | Y    | Y           | Y             | 9.82| 10.48 9.70 9.35 |
| O 2 2       | Y      | Y   | Y     | Y    |             |               | 11.14| (IQR 2.34)      |
| A 3 3       | Y      | Y   | Y     | Y    |             |               | 9.67|                  |
| C 4 4       | Y      | Y   | Y     | N    |             |               | 15.36|                  |
| H 2 1       | Y      | Y   | Y     | Y    | Y           |               | 7.92| 9.89            |
| R 2 2       | Y      | Y   | Y     | Y    |             |               | 9.15|                  |
| E 3 3       | Y      | Y   | Y     | Y    |             |               | 9.35|                  |
| D 4 4       | Y      | Y   | Y     | Y    |             |               | 10.62|                  |
| 7 1 1       | Y      | Y   | Y     | Y    | Y           |               | 9.34| 10.75 9.79      |
| 2 1 2       | Y      | Y   | Y     | Y    |             |               | 10.98|                  |
| 3 1 3       | Y      | Y   | Y     | Y    |             |               | 15.64|                  |
| 4 1 4       | Y      | Y   | Y     | Y    |             |               | 10.52|                  |
| 35 1 1      | Y      | Y   | Y     | Y    | Y           |               | 10.95| 9.66 8.36       |
| 2 2 2       | Y      | Y   | Y     | Y    |             |               | 8.36|                  |
| 3 3 3       | Y      | Y   | Y     | N    |             |               | 11.03|                  |
| 4 4 4       | Y      | Y   | Y     | Y    |             |               | 7.75|                  |
| 2 1 2       | Y      | Y   | Y     | Y    | Y           |               | 8.79| 7.59            |
| 3 1 3       | Y      | Y   | Y     | Y    | Y           |               | 9.13| 8.60            |
| 2 2 2       | Y      | Y   | Y     | Y    |             |               | 7.87|                  |
| 3 3 3       | Y      | Y   | Y     | Y    |             |               | 8.84|                  |
| 4 4 4       | Y      | Y   | Y     | Y    |             |               | 8.35|                  |
| C 35 1 1    | Y      | Y   | Y     | Y    | Y           |               | 7.07| 7.20 6.94       |
| O 2 2       | Y      | Y   | Y     | Y    |             |               | 7.25| (IQR 0.61)      |
| A 3 3       | Y      | Y   | Y     | Y    |             |               | 8.97|                  |
| C 4 4       | Y      | Y   | Y     | Y    |             |               | 7.14|                  |
| H 2 1       | Y      | Y   | Y     | Y    | Y           |               | 6.79| 6.74            |
| E 2 2       | Y      | Y   | Y     | Y    |             |               | 6.46|                  |
| D 3 3       | Y      | Y   | Y     | Y    |             |               | 7.35|                  |
| 3 1 2       | Y      | Y   | Y     | Y    | Y           |               | 6.68|                  |
| 2 2 3       | Y      | Y   | Y     | Y    |             |               | 6.6|                  |
| 3 3 4       | Y      | Y   | Y     | Y    |             |               | 8.86|                  |
| 4 4 4       | Y      | Y   | Y     | Y    |             |               | 6.56|                  |

PSP = Peri-shock pause, IQR = Inter Quartile Range, Defib = Defibrillation, Echo = Echocardiogram.
result in a PSP greater than 10s and all the primary outcome errors and delays beyond 15s occurred in shockable rhythm cycles.

**Confidence**

Fig. 6 depicts the trend in confidence recorded by the participant questionnaire before each session and after the final session. The questionnaire after the final session also asked participants whether they thought COACH-RED should be implemented in their ED and which roles they would be happy to perform. All participants answered yes to the first question and were happy to perform all roles except for one participant who stated they would not feel comfortable in the role of echosonographer yet.

**Experience**

Participants were asked if they had participated in cardiac arrests between sessions. Two participants were involved in a cardiac arrest in the week between the first two sessions and used the COACHED but not the COACH-RED protocol.

**Fig. 4 – Stills from COACH-RED Recordings.**
Fig. 5 – Peri-Shock Pauses for Shockable vs Non-shockable Rhythms.

Fig. 6 – Individual Participant & Mean Confidence.
Discussion

Emergency physicians have been using focused echocardiography during cardiac arrest to identify reversible causes such as hypovolaemia, pulmonary embolus and pericardial effusion since 1985. At least 13 different protocols have been created for this purpose – FATE, Rapid Cardiac Ultrasound, FEER, CAUSE, FEEL, modified FEER, RUSH, PEA, GDE, SESAME, SHoc, CASA and most recently COACH-RED. Most of these protocols have focused on the echocardiographic views and the pathology to identify whereas COACH-RED was created in response to publications in 2017 and 2018 suggesting that ultrasound during a cardiac arrest was associated with prolongation of pauses in chest compressions. The detrimental effect of a pause in chest compressions was theorised over twenty years ago, proven in animal models in 2002 and later supported by computer-based physiological analysis. A pause in chest compressions is currently necessary for evaluation of the cardiac rhythm during cardiac arrest and subsequent defibrillation where appropriate. The total pause (peri-shock pause) can be divided into pre-shock and post-shock pauses. In 2010, a seminal paper showed that defibrillator charging during chest compressions was safe and could reduce the pre-shock pause from 13.3 to 2.6 s. The same study compared charging before rhythm check (anticipatory charging) with charging after rhythm check and found that both pre-shock and post-shock pauses were one or two seconds longer for anticipatory charging but the overall pause in compressions in the 30 s leading up to defibrillation was significantly shorter with anticipatory charging, by 7–10 seconds. It remains unknown whether it is beneficial to have a much shorter overall pause in the 30 s leading up to defibrillation or an extremely short pause directly before defibrillation, and thus resuscitation guidelines differ between Europe, USA and Australasia.

The European Resuscitation Council (ERC) recommend two pauses—one for rhythm assessment and a second for defibrillation, with chest compressions in between while charging the defibrillator. The American Heart Association (AHA) have the same advice as to the ERC for the first rhythm assessment, but if the first assessment finds a shockable rhythm, they recommend anticipatory charging before subsequent rhythm assessments. The Australian & New Zealand Resuscitation Guidelines recommend anticipatory charging, with a peri-shock pause duration less than 10 s, in keeping with the ILCOR guidelines of 2015, which led to the creation of the COACHED and COACH-RED protocols.

In this study, five ALS-trained emergency nurses successfully learned, retained and performed the COACH-RED protocol in a simulated CPR scenario after a single two-hour training session. This is not the first study to use non-expert sonographers, but we believe it to be the first study with nurses performing all roles of ALS, including echocardiography. It is not customary for nurses to team-lead or performs echosonography during resuscitation in Australia, but both roles were successfully performed with 100% adequacy of echocardiographic views recorded. This has implications for small or remote centres with limited emergency staff. Algorithms and mnemonics such as the 4H’s and 4Ts and COACHED already serve as useful memory aids allowing cognitive offloading during stressful scenarios, but in a centre with a single emergency doctor, the ability to step back during a rhythm check run entirely by nursing staff would allow even greater cognitive offloading; however, this was not evaluated by this study.

The COACH-RED protocol resulted in a median peri-shock pause of 9.35 s overall across 36 recorded cycles. To our knowledge, this was much faster than any other cardiac arrest echocardiography protocol in the literature. Outside of the training and assessment sessions, one cardiac arrest resuscitation was attended by two of the participants where COACHED (in the role of Defib & CPR) but not COACH-RED protocol was used. One participant practised an echocardiographic view in a non-arrest scenario, once throughout the five-week period. Centres with a higher burden of cardiac arrests might expect more consistency of results as participants would be more likely to use the protocol regularly.

This study has further reinforced the use of the anticipatory charging COACHED protocol to achieve peri-shock pauses well under 10 s. The COACH-RED protocol was developed from COACHED, so as to be already familiar to emergency staff. We correctly hypothesised that using COACH-RED would require a slightly longer peri-shock pause compared to COACHED, but not beyond 10 s. As expected, the addition of echocardiography increased the PSP on average by two seconds. Notably, most cycles with peri-shock pauses longer than 10 s in this study were in shockable rhythms. Good quality CPR and defibrillation are the most important interventions for shockable rhythms with little role for echocardiography. Most utility for echocardiography in cardiac arrest has been proposed for the non-shockable rhythms. Prognostication studies are most likely to find value in the first and last sonographic images obtained in a cardiac arrest. Given this dichotomy, resuscitation team could use COACH-RED protocol in the first rhythm check and then either COACHED or COACH-RED for subsequent pauses depending on if the rhythm is likely to be shockable or non-shockable, respectively. Results from this study suggested that learning COACH-RED did not lead to any difficulties switching back to COACHED. Future studies could investigate this more specifically.

Limitations

This was a small study of only five participants, limiting any statistical analysis. The positive results may not be extrapolatable to use in real patient resuscitations with higher stress levels, distracting factors and nuances of obtaining echocardiographic views in various body types within a limited time window. Although participants were blinded to the PSP time being recorded, they were aware of assessment taking place, potentially affecting their performance (Hawthorne effect). All participants were ALS trained, had worked in ED for greater than three years and were familiar with COACHED prior to the study, and these results may not apply to other settings. The current study focused solely on obtaining sub-costal echocardiographic views and did not investigate for non-cardiac pathologies such as tension pneumothorax or ruptured abdominal aortic aneurysm. It is hoped that future research will help investigate some of these questions.

Conclusions

The COACH-RED protocol, which allows safe and effective incorporation of echocardiography into cardiopulmonary resuscitation, can be learned, performed and retained by ALS-trained nurses after a single training session. The COACH-RED protocol can be used to keep pauses in chest compressions (peri-shock pauses) under the 10 s, as recommended by the Australian Resuscitation Council. This provides
a foundation for future studies using COACH-RED in ALS training and real-time resuscitations.

Authors contributions

All authors made a substantial contribution to the conception and design of the study, acquisition and analysis of data. Authors BT, BJ and VM drafted the manuscript. Authors BT and VM revised the manuscript. Author BT prepared all figures and tables. Author VM was the project supervisor responsible for the key ideas and the development of the study. All authors approved of the final version submitted for publication.

Conflicts of interest

This study received no funding or grants, and the study authors have no competing interests to declare.

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References

1. Labovitz AJ, Noble VE, Bierig M, Goldstein SA, Jones R, Kort S, et al. Focused cardiac ultrasound in the emergent setting: a consensus statement of the american society of echocardiography and american college of emergency physicians. J Am Soc Echocardiogr. 2010;23:1225–30. doi:http://dx.doi.org/10.1016/j. echo.2010.10.005.

2. Sloan J, Venables H, Atkinson P, Connelly J, Wright J, McLaughlin R, et al. The Royal College Of Emergency Medicine - Core Ultrasound Curriculum. Emerg Med 2009;1–71. . (accessed May 30, 2020) https://www.rcem.ac.uk/docs/Training/1.14.5RCEM-EMUS-booklet.pdf

3. Kendall JL, Bahner DP, Blivas M, Budhran G, Dean AJ, Fox JC, et al. Emergency ultrasound imaging criteria compendium. ACEP Policy Statement 2006;1–55. . (accessed May 30, 2020) https://www.acep.org/patient-care/policy-statements/Emergency-Ultrasound-Imaging-Criteria-Compendium/

4. Atkinson P, Bowra J, Lambert M, Lamprecht H, Noble V, Jarman B. International federation for emergency medicine point of care ultrasound curriculum. Can J Emerg Med 2015;17:161–70. doi:http://dx.doi.org/10.1017/cem.2015.8.

5. Leschyna M, Hatam E, Britton S, Myalik F, Thompson D, Sedran R, et al. Current State of Point-of-care Ultrasound Usage in Canadian Emergency Departments. 2019111; . (accessed http://dx.doi.org/10.7759/cureus.4246.

6. Australasian College for Emergency Medicine. Credentialing for emergency medicine ultrasoundography (Policy P733). AcemOrgAu 2019;1–8. . (accessed May 31, 2020) https://acem.org.au/getmedia/ee68a734-7634-425d-865a-f5e17dcb4e4/f/P733_Credentialing-for-Emergency-Medicine-Ultrasoundography_v1_Aug2019.

7. Australasian College for Emergency Medicine. Provision of focused ultrasound training and governance (Guideline COR742). AcemOrgAu 2020;1–9. . (accessed May 31, 2020) https://acem.org.au/getmedia/0702004f-c669-4646-b5fc-4fa7e7117ba3/COR742_v1_ED_Ultrasound_Training_Governance_Guideline.

8. Mayron R, Gaudio FE, Plummer D, Asinger R, Elsperger J. Echocardiography performed by emergency physicians: impact on diagnosis and therapy. Ann Emerg Med 1988;17:150–4. doi:http://dx. doi.org/10.1016/s0196-0644(88)80021-9.

9. Blivas M, Fox JC. Outcome in cardiac arrest patients found to have cardiac standstill on the bedside emergency department echocardiogram. Acad Emerg Med 2001;8:616–21. doi:http://dx.doi. org/10.1111/j.1553-2712.2001.tb00174.x.

10. Aichinger G, Zechner PM, Prause G, Sacherer F, Wildner G, Anderson CL, et al. Cardiac movement identified on prehospital echocardiography predicts outcome in cardiac arrest patients. Prehospital Emerg Care 2012;16:251–5. doi:http://dx.doi.org/ 10.3109/109903127.2011.640414.

11. Long B, Alerhand S, Malie K, Koyfman A. Echocardiography in cardiac arrest: an emergency medicine review. Am J Emerg Med 2018;36:488–93. doi:http://dx.doi.org/10.1016/j.ajem.2017.12.031.

12. Atkinson PR, Beckitt N, French J, Banerjee A, Fraser J, Lewis D. Does point-of-care ultrasound use impact resuscitation length, rates of intervention, and clinical outcomes during cardiac arrest? A Study from the Sonography in Hypotension and Cardiac Arrest in the Emergency Department (SHoC-ED) Investigators. Cureus 2019;3–11, doi:http://dx.doi.org/10.7759/cureus.4456.

13. Soar J, Callaway CW, Aibiki M, Böttiger BW, Brooks SC, Deakin CD, et al. Part 4: advanced life support. Resuscitation 2015;95:671–120. doi:http://dx.doi.org/10.1016/j.resuscitation.2015.07.042.

14. Huis in’t Veld MA, Allison MG, Bostick DS, Fisher KR, Goloubeva OG, Witting MD, et al. Ultrasound use during cardiopulmonary resuscitation is associated with delays in chest compressions. Resuscitation 2017;119:95–8, doi:http://dx.doi.org/10.1016/j.resuscitation.2017.07.021.

15. Clattenburg EJ, Wroe P, Brown S, Gardner K, Losonczy L, Singh A, et al. Point-of-care ultrasound use in patients with cardiac arrest is associated prolonged cardiopulmonary resuscitation pauses: a prospective cohort study. Resuscitation 2018;122:265–8. doi:http://dx.doi.org/10.1016/j.resuscitation.2017.11.056.

16. Reynolds JC, Issa MS, Nicholson TC, Drennan IR, Berg KM, O’Neill BJ, et al. Prognostication with point-of-care echocardiography during cardiac arrest: a systematic review. Resuscitation 2020;152:56–68, doi:http://dx.doi.org/10.1016/j.resuscitation.2020.05.004.

17. Paradis NA. Coronary perfusion pressure and the return of spontaneous circulation in human cardiopulmonary resuscitation. JAMA J Am Med Assoc 1990;263:1106. doi:http://dx.doi.org/10.1001/ jama.1990.034408064029.

18. Efelesi T, Sunde K, Steen PA. Effects of interrupting precordial compressions on the calculated probability of defibrillation success during out-of-hospital cardiac arrest. Circulation 2002;106:2270–3, doi:http://dx.doi.org/10.1161/01.CIR.0000163962.42586.FE.

19. Cheskes S, Common MR, Byers PA, Zhan C, Morrison LJ. Compressions during defibrillator charging shortens shock pause duration and improves chest compression fraction during shockable out of hospital cardiac arrest. Resuscitation 2014;85:1007–11, doi:http://dx.doi.org/10.1016/j.resuscitation.2014.05.001.

20. Bhani J, Finn JC, Lockey A, Monsieurs K, Frengley R, Iwami T, et al. Part 8: Education, implementation, and teams: 2015 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Circulation 2015;132:S224–268, doi:http://dx.doi.org/10.1161/ CIR.0000000000002277.

21. Yu T, Weil MH, Tang W, Sun S, Klouche K, Povas H, et al. Adverse outcomes of interrupted precordial compression during automated defibrillation. Circulation 2002;106:368–72. doi:http://dx.doi.org/ 10.1161/01.CIR.0000021429.22005.2E.

22. Steen S, Liao Q, Pierre L, Paskevicius A, Sjöberg T. The critical importance of minimal delay between chest compressions and subsequent defibrillation: a haemodynamic explanation. Resuscitation 2003;58:249–58, doi:http://dx.doi.org/10.1016/S0300-9572(03)00265-X.
55. Breitkreutz R, Walcher F, Seeger FH. Focused echocardiographic evaluation in resuscitation management: concept of an advanced life support-conditioned algorithm. Crit Care Med 2007;35:S150–61. doi: http://dx.doi.org/10.1097/01.CCM.0000260626.23848.FC.

56. Hernandez C, Shuler K, Hannan H, Sonyika C, Likourezos A, Marshall J. C.A.U.S.E.: cardiac arrest ultra-sound exam-A better approach to managing patients in primary non-arrhythmicogenic cardiac arrest. Resuscitation 2008;76:198–206. doi: http://dx.doi.org/10.1016/j.resuscitation.2007.06.033.

57. Breitkreutz R, Uddin S, Steiger H, Ilper H, Steche M, Walcher F, et al. Focused echocardiography entry level: new concept of a 1-day training course. Minerva Anestesiol 2009;75:285–92.

58. Prosen G, Križmanić M, Zavrašnik J, Grmec Š. Impact of modified treatment in echocardiographically confirmed pseudopulseless electrical activity in out-of-hospital cardiac arrest patients with constant end-tidal carbon dioxide pressure during compression pauses. J Int Med Res 2010;38:1458–67. doi: http://dx.doi.org/10.1177/14732300103800428.

59. Testa A, Cibinel GA, Portale G, Forte P, Giannuzzi R, Pignataro G, et al. The proposal of an integrated ultrasonographic approach into the ALS algorithm for cardiac arrest: the PEA protocol. Eur Rev Med Pharmacol Sci 2010;14:77–88.

60. Walley PE, Walley KR, Goodgame B, Punjabi V, Sirounis D. A practical approach to goal-directed echocardiography in the critical care setting. Crit Care 2014;18:681. doi: http://dx.doi.org/10.1186/s13054-014-0681-z.

61. Lichtenstein D, Malbrain MLNG. Critical care ultrasound in cardiac arrest. Technological requirements for performing the SESAME-protocol - a holistic approach. Anaesthesiol Intensive Ther 2015;47:471–81. doi: http://dx.doi.org/10.5603/AIT.a2015.0072.

62. Kern KB, Hilwig RW, Berg RA, Ewy GA. Efficacy of chest compression-only BLS CPR in the presence of an occluded airway. Resuscitation 1998;39:179–88. doi: http://dx.doi.org/10.1016/S0300-9572(98)00141-5.

63. Berg RA, Sanders AB, Kern KB, Hilwig RW, Heidenreich JW, Porter ME, et al. Adverse hemodynamic effects of interrupting chest compressions for rescue breathing during cardiopulmonary resuscitation for ventricular fibrillation cardiac arrest. Circulation 2001;104:2465–70. doi: http://dx.doi.org/10.1161/01.CIR.104.2465-2470.

64. Kern KB, Hilwig RW, Berg RA, Sanders AB, Ewy GA. Importance of continuous chest compressions during cardiopulmonary resuscitation: improved outcome during a simulated single lay-rescuer scenario. Circulation 2002;105:645–9. doi: http://dx.doi.org/10.1161/01.CIR.105.645-649.

65. Babbs CF, Kern KB. Optimum compression to ventilation ratios in CPR under realistic, practical conditions: a physiological and mathematical analysis. Resuscitation 2002;54:147–57. doi: http://dx.doi.org/10.1016/S0300-9572(02)00054-0.

66. Edelson DP, Robertson-Dick BJ, Yuen TC, Eilevstjønn J, Walsh D, Bareis CJ, et al. Safety and efficacy of defibrillator charging during ongoing chest compressions: a multi-center study. Resuscitation 2010;81:1521–6. doi: http://dx.doi.org/10.1016/j.resuscitation.2010.07.014.

67. Chou EH, Wang C, Monfort R, Likourezos A, Wolfshohl J, Lu T, et al. Association of ultrasound-related interruption during cardiopulmonary resuscitation with adult cardiac arrest outcomes: a video-reviewed retrospective study. Resuscitation 2020;149:74–80. doi: http://dx.doi.org/10.1016/j.resuscitation.2020.02.004.