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Original Article

Effect of Using Secondary Anterior-Posterior Defibrillator Pad Placement on Pauses in Chest Compressions: A Three-Group Randomized Manikin Simulation Study with Dutch Ambulance Teams

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Abstract

Successful out-of-hospital cardiac arrest (OHCA) management depends on prompt, effective interventions, particularly high-quality chest compressions and early defibrillation. While the European Resuscitation Council (ERC) currently advises sternal-apical pad placement, alternative configurations such as anterior-posterior (AP) are increasingly considered. The practical challenges of combining AP pad placement with mechanical cardiopulmonary resuscitation (mCPR) remain largely uninvestigated. This randomized simulation study examined the effect of AP pad placement on interruptions to chest compressions among 45 Dutch ambulance teams. Participants were divided into three groups: (1) manual compressions with AP pad application, (2) sequential mCPR followed by AP pad placement, and (3) simultaneous mCPR and AP pad application. The main outcome was total duration of chest compression interruptions, while secondary outcomes included ease of use and placement accuracy. Manual AP pad placement required an average of 38.3 ± 13.3 seconds, causing 12.1 ± 6.0 seconds of pauses. Sequential mCPR with AP pad application took 97.7 ± 23.7 seconds, resulting in 51.7 ± 14.0 seconds of compression interruptions. Simultaneous application lasted 70.5 ± 16.1 seconds, with 31.8 ± 12.3 seconds of interruptions. Correct pad placement was rare: 0% sternal, 11% apical, 13% anterior, and 2% posterior. Participants' confidence in their technique did not correspond to accuracy. AP pad placement during ongoing mCPR is challenging and significantly prolongs interruptions in chest compressions. Ambulance crews should carefully evaluate the need for AP pads before initiating mCPR. The study highlights marked variability in pad positioning, emphasizing the necessity for standardized training and clear procedural guidance.

Keywords: Simulation, Paramedics, Ambulance, Shockable arrest, Out-of-hospital cardiac arrest, OHCA, Mechanical chest compression, Resuscitation, Defibrillation

Background

Effective resuscitation of OHCA patients with ventricular fibrillation relies on early, high-quality interventions, which are central to Advanced Life Support (ALS) guidelines [1-4]. Survival outcomes decrease as the duration of ventricular fibrillation increases, making both prompt defibrillation and continuous chest compressions critical [1,5]. Contemporary ALS protocols reinforce these interventions to optimize survival [6,7].

The ERC currently recommends defibrillation pads be placed in a sternal-apical (anterior-lateral) configuration, with the sternal pad positioned to the right of the sternum below the clavicle and the apical pad along the left mid-axillary line, level with the V6 ECG electrode, avoiding breast tissue [7].

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Alternative configurations, including bi-axillary and anterior-posterior (AP) placements, are also described. The AP configuration is gaining interest, either as a secondary "vector change" or as part of dual synchronized external defibrillation (DSED) for refractory ventricular fibrillation [8-11]. In AP placement, the anterior pad lies over the left precordium, while the posterior pad is positioned just below the left scapula, posterior to the heart [7]. Data on accurate placement under realistic prehospital conditions, accounting for factors such as patient clothing and body habitus, are scarce.

In the prehospital environment, limited personnel, fatigue, and patient transport can compromise compression quality [12,13]. Dutch ambulance services frequently implement early mechanical CPR (mCPR) to address these challenges [14]. However, mCPR may obstruct timely application of secondary AP pads [15]. This study investigates how manual versus mechanical chest compressions influence AP pad placement in a simulation setting with ambulance ALS teams.

Methods

Study design

We conducted a randomized, parallel-group simulation study to evaluate how manual versus mechanical CPR affects the placement of secondary anterior-posterior (AP) defibrillator pads among ambulance teams in the Netherlands. Three distinct strategies for AP pad application were tested, with teams allocated equally across the groups (1:1:1). Reporting of this study adheres to the extended CONSORT and STROBE guidelines for simulation research [16], with the full checklist provided in Supplement A.

Participants

Participants were certified EMS professionals with annual Advanced Life Support (ALS) recertification and ongoing mCPR training. In the Dutch ambulance system, teams are authorized to perform all ALS procedures, including defibrillation with both standard sternal-apical and AP pad placements.

Eligible participants were active-duty ambulance personnel holding current ALS certification and competent in operating mCPR devices. Teams consisted of two members: an ambulance nurse (paramedic-level) and an ambulance driver (EMT-level). To maintain authentic team dynamics, participants were paired according to their regular working partnerships.

Simulation procedures

The study employed a simulated OHCA scenario featuring ventricular fibrillation. Teams received a brief overview of the study setup but were not made aware of the study hypothesis. Participants were given a short orientation on the patient monitor and the mCPR device prior to the simulation.

Each session commenced with an ALS-certified researcher (FC) performing compressions on the manikin, without providing ventilations. Ambulance crews were instructed to manage the scenario as they would in real-life OHCA situations, including dealing with the manikin's clothing in a realistic manner.

All teams first performed a rapid rhythm assessment using sternal-apical defibrillator pads. Following this initial step, crews were randomized to one of three AP pad placement strategies **(Figure 1)**, representing different sequences for integrating AP pads with manual or mechanical compressions.

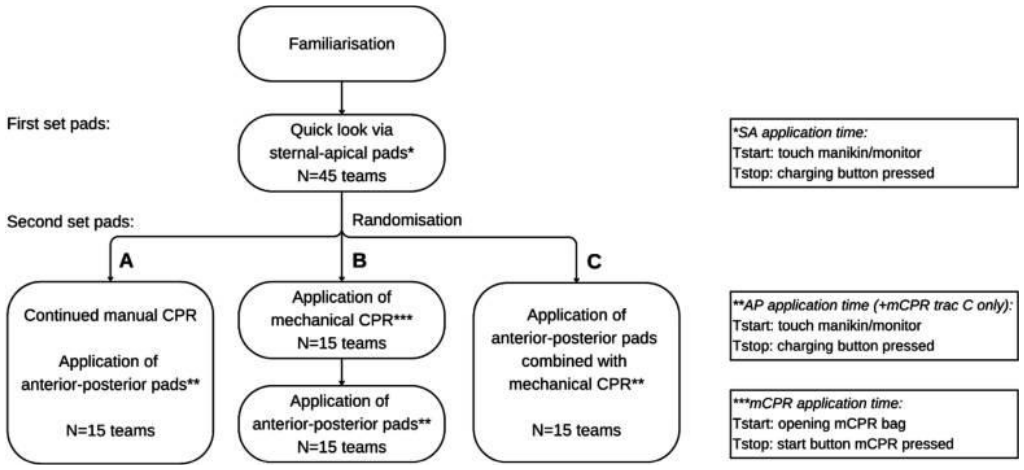

Figure 1. Study Flowchart: Team Allocation, Randomisation, and Intervention Pathways

Group A – Manual Chest Compressions with AP Pad Placement: The BLS researcher performed uninterrupted manual chest compressions while the ambulance personnel positioned the second set of anterior-posterior (AP) defibrillator pads.
Group B – Sequential mCPR and AP Pad Placement: Manual chest compressions were continued until the EMS team set up the mechanical CPR (mCPR) device. After mechanical compressions began, participants were tasked with applying AP pads, causing a brief pause in mCPR.
Group C – Concurrent mCPR and AP Pad Placement: Manual compressions continued until the ambulance crew applied the mCPR device simultaneously with the AP pads.
No immediate debriefing occurred, and participants received no feedback to prevent influencing the performance of subsequent teams.

Outcomes

The primary endpoint was the total time chest compressions were interrupted for AP pad application, measured in seconds. The following predefined intervals were recorded:

- Defibrillator pad application time: from the moment the EMS personnel touched the monitor or manikin until the defibrillator charging button was pressed.
- mCPR setup time: from opening the mCPR kit until mechanical compressions were initiated.

Secondary endpoints included participants' perceived feasibility of each method and the precision of defibrillator pad placement.

Defining optimal pad placement

Two resuscitation experts independently determined the ideal positions for all four defibrillator pads (sternal, apical, anterior, posterior) according to current resuscitation guidelines [7]. Each expert repeated placements twice, at least one week apart. The mean coordinates and angles of the pad placements were calculated to establish a reference standard. A grid was drawn on the manikin, hidden from participants, to allow measurement of placement accuracy [17].
Pads were classified as correctly positioned if the center was within 50 mm of the reference point and the angle was within 45° of the reference; both conditions had to be met.

Sample size

A total of 45 ALS ambulance teams participated, with 15 teams per group. Sample size was calculated in R using the TrialSize package based on the formula by Chow *et al.* [18], assuming a medium effect size (Cohen's $f = 0.25$), $\alpha = 0.05$, and 80% power for a one-way ANOVA, with no expected dropouts.

Randomisation

Teams were assigned via sealed envelopes, each containing a group allocation (A, B, or C). Envelopes were drawn randomly for each team, maintaining allocation concealment until assignment, with 15 teams per group and no crossovers.

Data collection and blinding

High-definition cameras covering the entire resuscitation area, along with a digital clock, were used to capture the primary outcome, allowing precise recording of interruptions in chest compressions. Two independent reviewers (DW, FC) analyzed the video footage, and to maintain data reliability, a randomly selected 20% of recordings was reassessed by a third blinded reviewer (CS). Any disagreement exceeding 5% was resolved through consensus discussion.
Pad placement accuracy, the secondary outcome, was evaluated by a single researcher (DW) who measured each pad's center point relative to the reference and recorded its orientation angle. A second researcher (FC) independently verified these measurements using standardized photographs.
Participants' perceptions of feasibility were collected through a QR-code survey hosted on the Qualtrics platform (Qualtrics™, Provo, UT, USA), which included three demographic questions, four questions on prior experience, and eight Likert-scale items (see supplement B).

Equipment

The REALITi360 Plus monitor (iSimulate, now 3B Scientific, Germany) functioned as both the patient monitor and defibrillator. Its interface was customizable to simulate commonly used ambulance monitors such as Philips, Zoll, Lifepak, Corpuls, and Medtronic. Two sets of self-adhesive defibrillation pads (88 × 132 mm, 1.5 m cables) were used.
Rescue manikins (CrashTest-Service®, fire and extrication department) with realistic human dimensions were employed: 172 cm in length, 102 cm chest circumference, 99 cm abdominal circumference, weighing 90 kg,

dressed in trousers and two upper-body layers. The mechanical CPR (mCPR) device, supplied by the ambulance service, was positioned near the manikin in its original bag.

Statistical analysis
Data were analyzed in IBM SPSS Statistics (Version 28.0.0.0, IBM Corp.). Continuous variables such as time were reported as mean ± SD, while categorical variables like correct pad placement were expressed as counts and percentages. Group comparisons were conducted using independent t-tests (for two groups) or one-way ANOVA (for three or more groups). Spearman's rho was used to assess correlations between variables.

Recruitment
Teams were recruited from multiple ambulance stations to ensure a representative sample, with data collection taking place from May 2024 to January 2025. Only available teams were included, and each team participated only once.

Ethics
All participants were informed about study procedures and provided written consent, with the option to withdraw at any stage. Data were collected anonymously. The METC Oost-Nederland confirmed that the study did not require formal approval under the WMO (2024-17264). All procedures adhered to the Declaration of Helsinki.

Results

In total, 90 participants comprising 45 ambulance teams were enrolled from four Dutch regions. **Table 1** and **Figure 2** summarize team demographics and prior experience with alternative defibrillation strategies.

Table 1. Participants' baseline demographics ($N = 90$)

Gender	N (%)
Male	62 (68.9)
Female	28 (31.1)
Age	
Mean ± SD yrs	42.6 ± 9.9
Background	
Ambulance (registered) nurse	43 (47.8)
Ambulance driver	42 (46.7)
Bachelor Emergency Medicine	4 (4.4)
Physician assistant	1 (1.1)
Clinical experience	
0–5 years	20 (22.2)
6–10 years	19 (21.1)
11–15 years	17 (18.9)
16–20 years	14 (15.6)
>20 years	20 (22.2)

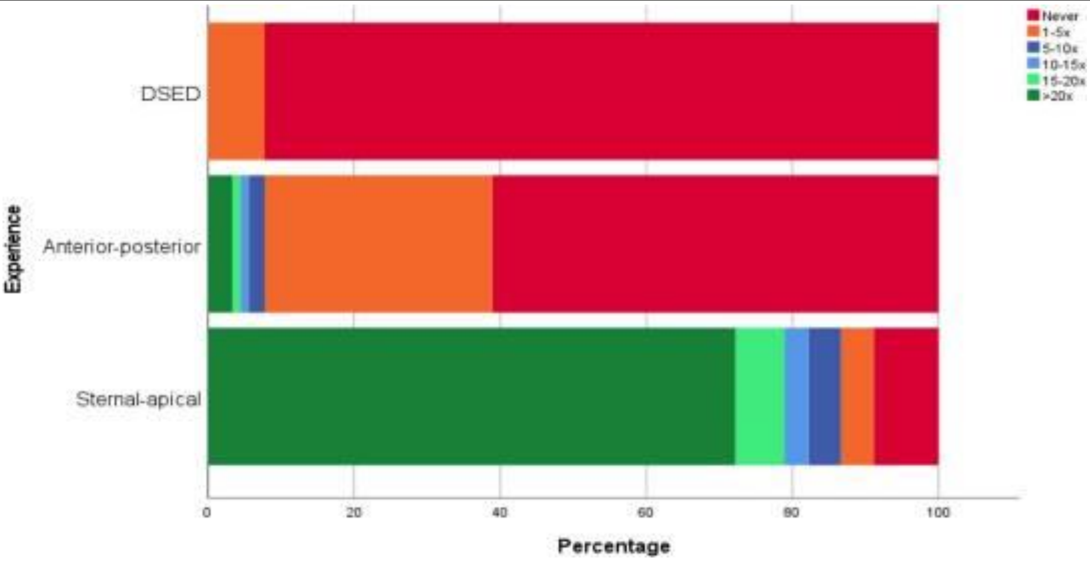

Figure 2. Participants' experience with standard and alternative defibrillation techniques (N = 90)

Among the included ambulance teams, the majority (36 teams, 80%) used the Corpuls3 monitor, while the remaining nine teams (20%) operated the Lifepak15. Mechanical chest compressions were performed using the LUCAS3 device by 28 teams (62.2%), and the CorpulsCPR system was used by 17 teams (37.8%).

The initial rapid assessment in the sternal-apical position took on average 37.5 ± 10.7 seconds, interrupting chest compressions for 5.4 ± 6.0 seconds. In Group A, where AP pads were applied while chest compressions were performed manually, the procedure lasted 38.3 ± 13.3 seconds, with a mean compression interruption of 12.1 ± 6.0 seconds. Applying only mCPR required 57.7 ± 14.0 seconds, causing 21.5 ± 9.0 seconds of interruptions. For Group B, in which AP pads were applied after mCPR was already in place, an additional 40.0 ± 14.0 seconds were needed, resulting in 30.1 ± 15.0 seconds of paused compressions. The simultaneous application of mCPR and AP pads in Group C took 70.5 ± 16.1 seconds on average, with interruptions lasting 31.8 ± 12.3 seconds **(Table 2)**.

Statistical analysis showed a significant difference in total chest compression interruptions between the three approaches (Welch's $F(2, 24.1) = 21.0$, $p < 0.001$). Both Groups B and C had significantly longer interruptions compared with Group A, with increases of 18.1 seconds (95% CI: 7.4–28.7, $p = 0.001$) and 19.7 seconds (95% CI: 10.8–28.7, $p < 0.001$), respectively. Comparing the two mCPR groups directly, Group C experienced shorter overall interruptions than Group B by 19.9 seconds (95% CI: 7.3–32.5, $t(28) = 3.23$, $p = 0.003$).

Table 2. Defibrillation pad application times and BLS interruptions per intervention group

Sternal-apical procedure	**Quick look assessment**			
Number of teams (N)	45 teams			
Procedure time (sec), mean±SD	37.5 ± 10.7			
Number of chest compression interruptions (N), mean±SD	1.4 ± 1.0			
Duration chest compression interruption (sec), mean±SD	5.4 ± 6.0			
Antero-posterior procedure	Group A	Group B	Group C	Significance (p)
Number of teams (N)	15 teams	15 teams	15 teams	
Total procedure time (sec), mean±SD	38.3 ± 13.3	97.7 ± 23.7	70.5 ± 16.1	*P* < 0.001
mCPR application only	N/A	57.7 (14.0)	Combined	N/A
Number of chest compression interruptions (N), mean ± SD	1.7 ± 0.6	2.8 ± 0.8	2.4 ± 0.8	*P* < 0.001
mCPR application only	N/A	1.4 ± 0.5	Combined	N/A
Duration chest compression interruptions (sec), mean±SD	12.1 ± 6.0	51.7 ± 20.4	31.8 ± 12.3	*P* < 0.001
mCPR application only	N/A	21.5 (9.0)	Combined	N/A
Perceived user effects*				
Number of participants (N)	30	30	30	
Feasibility (mean±SD)	8.3 ± 1.3	7.4 ± 2.0	7.7 ± 1.6	*P* = 0.11
Speed (mean±SD)	8.2 ± 1.1	6.9 ± 2.0	7.0 ± 1.9	*P* = 0.003

Patient benefit (mean±SD)	6.5 ± 1.7	6.3 ± 2.2	6.5 ± 1.9	*P* = 0.91
Self-competence (mean±SD)	8.0 ± 2.0	7.7 ± 2.2	7.9 ± 1.9	*P* = 0.80

*11-item Likert scale (0–10).

The precision of defibrillator pad placement according to each anatomical site is presented in **Table 3** and **Figure 3**. Overall, correct positioning was rare: none of the sternal pads (0%) were accurately placed, while 5 apical pads (11%), 6 anterior pads (13%), and 1 posterior pad (2%) met the reference criteria. Most sternal pads were positioned too far laterally (38 pads, 84%) and/or too high on the chest (22 pads, 49%). For apical pads, misplacement was common, with 20 pads (44%) too anterior, 14 pads (31%) too low, and 28 pads (62%) misaligned longitudinally. Nearly half of the anterior pads (21 pads, 47%) were placed too low. Posterior pads also showed frequent errors, with 38 pads (84%) positioned too medially and 27 pads (60%) placed too caudally.

Table 3. Accurateness of defibrillator pad placement in four different positions

Position	Sternal	Apical	Anterior	Posterior
Number of pads applied, N (%)	45 (100 %)	45 (100 %)	45 (100 %)	45 (100 %)
Correct placement, N (%)	0 (0 %)	5 (11 %)	6 (13 %)	1 (2 %)
Angle fault, N (%)	19 (42 %)	28 (62 %)	6 (13 %)	9 (20 %)
Centre point fault, N (%)	44 (98 %)	33 (73 %)	39 (87 %)	43 (96 %)
Too cranial	22 (49 %)	8 (18 %)	10 (22 %)	4 (9 %)
Too caudal	3 (7 %)	14 (31 %)	21 (47 %)	27 (60 %)
Too lateral / posterior	38 (84 %)	1 (2 %)	6 (13 %)	0 (0 %)
Too medial / anterior	1 (2 %)	20 (44 %)	8 (18 %)	38 (84 %)
Distance to reference mean±SD, mm	61.1 ± 20.4	50.3 ± 37.8	58.1 ± 38.4	84.7 ± 55.8
Distance to reference min, mm	23	6	16	9
Distance to reference max, mm	112	203	193	299

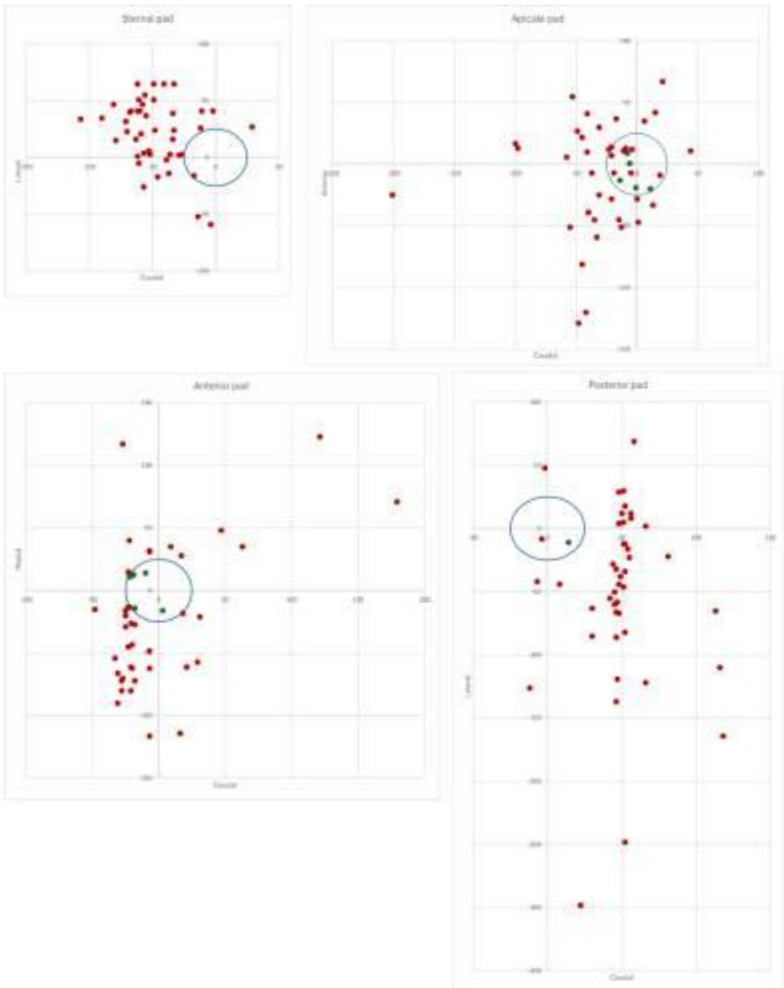

Figure 3. Placement patterns for sternal-apical and anterior-posterior defibrillation pads (N = 45 per position). Legend: The figure displays pad positions in relation to reference points, with measurements

recorded in millimetres. Green markers represent correctly placed pads, whereas red markers denote inaccurate placements, either due to the pad center falling outside the designated reference area or exceeding the recommended angular alignment. (Colour interpretation details are available in the online version of the article.)

Participants evaluated their own confidence in pad placement using a 0–10 scale, where 0 indicated complete uncertainty and 10 indicated full confidence. Mean confidence levels were 8.3 ± 1.3 for sternal-apical pads and 7.3 ± 1.8 for anterior-posterior pads. Despite high self-reported confidence, Spearman correlation analysis indicated no significant association between perceived and actual accuracy, with $\rho = 0.178$ ($p = 0.10$) for sternal-apical pads and $\rho = -0.048$ ($p = 0.66$) for anterior-posterior pads.

The survey also explored participants' familiarity with ambulance service protocols for anterior-posterior pad placement and double sequential defibrillation (DSED) in persistent ventricular fibrillation. A large proportion of respondents reported uncertainty: 61.8% (N = 55) were unaware of anterior-posterior policies, and 68.5% (N = 61) were unsure about DSED regulations. Among those who provided definitive answers, 23.6% (N = 21) confirmed that anterior-posterior placement was permitted, while 14.6% (N = 13) indicated it was not. For DSED, only 7.9% (N = 7) reported it as allowed, whereas 23.6% (N = 21) stated it was prohibited.

Discussion

This study demonstrated substantial variation in interruptions of chest compressions during the placement of secondary anterior-posterior (AP) defibrillation pads. Manual chest compressions were associated with the fewest pauses, while simultaneous application of mechanical CPR (mCPR) and AP pads caused slightly more interruptions. The sequential approach, in contrast, produced the longest delays and the greatest disruption to compressions. Across all strategies, defibrillator pad placement accuracy remained low.

The duration of mCPR application observed here aligns with previous reports [19, 20], although targeted quality improvement initiatives have been shown to shorten these times [20-22]. Our measurements included the preparatory phase for both mCPR and secondary pad placement, reflecting the real-time commitment of ambulance teams. While total procedure time is particularly relevant for primary interventions such as initial rhythm assessments, secondary interventions—like those investigated here—can largely be prepared within a standard 2-minute CPR cycle. Hence, the focus of this study was on interruptions to compressions. The pauses recorded during mCPR use were consistent with real-world data, suggesting that the combination of manikin weight and clothing offered a realistic training scenario [23, 24].

Sternal-apical pad placement was deliberately performed first, in line with Dutch practice for rapid rhythm checks [7], and resulted in fewer interruptions compared with AP positioning. However, the clinical significance of these differences remains unclear; for example, Lupton *et al.* [11] reported higher rates of return of spontaneous circulation with initial AP pad placement in a matched cohort study.

A key insight is that mCPR devices complicate AP pad application. Sequential mCPR and AP pad placement required significant time and led to the longest pauses in chest compressions. The time needed to pause mCPR and place AP pads nearly matched the duration for simultaneous placement, indicating that initiating AP pads after mCPR is considerably more challenging. Therefore, emergency personnel should consider the need for AP pads before starting mechanical compressions and, when possible, apply them beforehand or concurrently.

Consistent with prior studies [17, 25-29], overall pad placement accuracy was low. The combination of realistic manikin weight, clothing, and time pressure likely contributed to this, but these findings should not be interpreted as poor clinical performance or as a reason to delay defibrillation practice. Evidence linking precise pad positioning to patient outcomes remains limited, and further research is required to clarify how deviations affect the transcardiac current and clinical efficacy [30, 31].

These findings emphasize the inherent difficulty of defibrillator pad placement. Key questions include whether energy selection can compensate for misplacement and whether survival could improve with more precise positioning. Observed deviations of 50–85 mm, with extremes nearing 300 mm, represent a notable practical challenge. Despite guidelines emphasizing longitudinal alignment for apical pads [7, 32], almost two-thirds were placed outside the recommended 45-degree angle, underscoring the difficulty of consistent adherence. The extent to which energy settings or waveform adjustments mitigate misplacement remains uncertain. Notably, Esibov *et al.* [33] showed that even minor (<30 mm) misplacements reduce defibrillation success, though waveform design and energy selection can overcome these small errors.

Variability in team performance also highlights the need for improved training. Because instructors themselves show inconsistency, structured 'train-the-trainer' programs and standardized educational materials are necessary for both professionals and lay responders [17, 34]. Some participants reported uncertainty regarding organisational guidance on alternative pad positions, indicating opportunities to strengthen protocol dissemination [17].

Differences were observed in clothing removal strategies, including cutting, tearing, or sliding garments aside. Midline cutting or tearing was most common; while often faster for buttoned shirts, residual fabric along the sides could hinder lateral and posterior pad placement and mCPR device application (e.g., LUCAS3). Additional variability included posterior pad placement methods, with teams either log-rolling patients or having them sit up, as well as differing role assignments for pad placement. Previous studies with lay responders found no consistent side preference for AED pad application, with average apical deviations of 59 mm (left) and 69 mm (right) [28]. Given the overall low placement accuracy and the study design, further analysis of these variables was not feasible.

Limitations

The accuracy of defibrillator pad placement in this study was evaluated using expert consensus guided by current resuscitation recommendations. While expert judgment complements guideline-based criteria, the definition of 'correct' placement remains subject to debate. To improve reliability, a dual-expert repeated measurement method was employed, with placement standards adapted from previous research [17, 25, 27, 32]. The tolerance for center-point placement was relatively strict (50 mm radius), whereas angular allowances were broader, up to 45 degrees. However, evidence on the clinical impact of pad misplacement is limited, which restricts the direct application of these results to patient outcomes.

Ventilations performed by ambulance crews were intentionally excluded to isolate the effect of pad placement on procedural timing and avoid confounding interruptions. This approach mirrors real-world practice, where secondary interventions like alternative pad positions are generally prepared during 2-minute CPR cycles and applied during ventilation pauses to maintain high chest compression fractions.

The presence of a researcher providing high-quality chest compressions may have reduced cognitive load for participants, potentially allowing greater focus on pad placement. While additional crew members are usually available in practice, this setup may have simplified task execution compared with real-world, resource-limited conditions. Similarly, factors such as psychological stress, physical fatigue, simultaneous task demands, and anatomical variability [35] were not represented in this simulation, which could influence performance in actual clinical settings.

Conclusion

This simulation study highlights the considerable difficulty of applying anterior-posterior defibrillator pads during active mCPR. Ambulance teams should evaluate the need for AP pads before initiating mechanical compressions to reduce delays and interruptions. The observed variability in pad placement accuracy emphasizes the importance of standardized guidelines and focused training programs. Future research should investigate strategies to optimize pad placement under real-world conditions, where anatomical differences and operational pressures may further affect outcomes.

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References

1. Holmberg M, Holmberg S, Herlitz J. Incidence, duration and survival of ventricular fibrillation in out-of-hospital cardiac arrest patients in Sweden. Resuscitation. 2000;44:7–17. Available from: http://dx.doi.org/10.1016/S0300-9572(99)00155-0
2. Reynolds JC, Frisch A, Rittenberger JC, Callaway CW. Duration of resuscitation efforts and functional outcome after out-of-hospital cardiac arrest: when should we change to novel therapies? Circulation. 2013;128:2488–94. Available from: http://dx.doi.org/10.1161/CIRCULATIONAHA.113.002408
3. Weisfeldt ML, Becker LB. Resuscitation after cardiac arrest. A 3-phase time-sensitive model. JAMA. 2002;288:3035–8. Available from: http://dx.doi.org/10.1001/jama.288.23.3035
4. Goto Y, Funada A, Maeda T, Goto Y. Time boundaries of the three-phase time-sensitive model for ventricular fibrillation cardiac arrest. Resusc Plus. 2021;6. Available from: http://dx.doi.org/10.1016/j.resplu.2021.100095

5. Holmén J, Hollenberg J, Claesson A, Jiménez Herrera M, Azeli Y, Herlitz J, et al. Survival in ventricular fibrillation with emphasis on the number of defibrillations in relation to other factors at resuscitation. Resuscitation. 2017;113:33–8. Available from: http://dx.doi.org/10.1016/j.resuscitation.2017.01.006
6. Bero M, Sochor M, Wong S, Brady W. Changing the management of refractory ventricular fibrillation: the consideration of earlier utilization of dual sequential defibrillation. Am J Emerg Med. 2020;38:545–8. Available from: http://dx.doi.org/10.1016/j.ajem.2019.05.048
7. Soar J, Böttiger BW, Carli P, Couper K, Deakin CD, Djärv T, et al. European Resuscitation Council guidelines 2021: adult advanced life support. Resuscitation. 2021;161:115–51. Available from: http://dx.doi.org/10.1016/j.resuscitation.2021.02.010
8. Cheskes S, Wudwud A, Turner L, McLeod S, Summers J, Morrison LJ, et al. The impact of double sequential external defibrillation on termination of refractory ventricular fibrillation during out-of-hospital cardiac arrest. Resuscitation. 2019;139:275–81. Available from: http://dx.doi.org/10.1016/j.resuscitation.2019.04.038
9. Cheskes S, Dorian P, Feldman M, McLeod S, Scales DC, Pinto R, et al. Double sequential external defibrillation for refractory ventricular fibrillation: the DOSE VF pilot randomized controlled trial. Resuscitation. 2020;150:178–84. Available from: http://dx.doi.org/10.1016/j.resuscitation.2020.02.010.
10. Cheskes S, Verbeek PR, Drennan IR, et al. Defibrillation strategies for refractory ventricular fibrillation. N Engl J Med. 2022;387:1947–56. Available from: http://dx.doi.org/10.1056/NEJMoa2207304
11. Lupton JR, Newgard CD, Dennis D, Nuttall J, Sahni R, Jui J, et al. Initial defibrillator pad position and outcomes for shockable out-of-hospital cardiac arrest. JAMA Netw Open. 2024;7. Available from: http://dx.doi.org/10.1001/jamanetworkopen.2024.31673
12. San I, Bekgoz B, Ergin M, Usul E. Manual cardiopulmonary resuscitation versus mechanical cardiopulmonary resuscitation: which one is more effective during ambulance transport? Turk J Emerg Med. 2021;21:69–74. Available from: http://dx.doi.org/10.4103/2452-2473.309135
13. Jörgens M, Königer J, Kanz K-G, Birkholz T, Hübner H, Prückner S, et al. Testing mechanical chest compression devices of different design for their suitability for prehospital patient transport – a simulator-based study. BMC Emerg Med. 2021;21:18. Available from: http://dx.doi.org/10.1186/s12873-021-00409-3
14. Liu YK, Chen LF, Huang SW, et al. Early prehospital mechanical cardiopulmonary resuscitation use for out-of-hospital cardiac arrest: an observational study. BMC Emerg Med. 2024;24:198. Available from: http://dx.doi.org/10.1186/s12873-024-01115-6
15. Slagt CS, van Kuijk SM, van Geffen GJ, Mommers L. First results of our local practice guide used during the late phase of resuscitation in patients with refractory VF in out of hospital cardiac arrest. Open Access Emerg Med. 2025;17:203–13. Available from: http://dx.doi.org/10.2147/OAEM.S510483
16. Cheng A, Kessler D, Mackinnon R, Chang TP, Nadkarni VM, Hunt EA, et al. Reporting guidelines for health care simulation research: extensions to the CONSORT and STROBE statements. Simul Healthc. 2016;11:238–48. Available from: http://dx.doi.org/10.1097/SIH.0000000000000150
17. Wulterkens D, Coumou F, Slagt C, Waalewijn RA, Mommers L. Defibrillation pad placement accuracy among advanced life support instructors: a manikin-based observational study examining experience, self-evaluation, and actual performance. Resusc Plus. 2025;22. Available from: http://dx.doi.org/10.1016/j.resplu.2025.100886
18. Chow SC, Shao J, Wang H. Sample size calculations in clinical research. 3rd ed. CRC Press; 2017.
19. Esibov A, Banville I, Chapman F, Boomars R, Box M, Rubertsson S. Mechanical chest compressions improved aspects of CPR in the LINC trial. Resuscitation. 2015;91. Available from: http://dx.doi.org/10.1016/j.resuscitation.2015.02.028
20. Levy M, Yost D, Walker R, Scheunemann E, Mendive S. Abstract 222: optimizing the application of a mechanical chest compression device within a high-performance CPR approach to out-of-hospital cardiac arrest resuscitation. Circulation. 2014;130. Available from: http://dx.doi.org/10.1016/j.resuscitation.2015.04.005
21. Levy M, Kern KB, Yost D, Chapman FW, Hardig BM. Metrics of mechanical chest compression device use in out-of-hospital cardiac arrest. J Am Coll Emerg Physicians Open. 2020;1:1214–21. Available from: http://dx.doi.org/10.1002/emp2.12184
22. Coggins AR, Nottingham C, Byth K, Ho KR, Aulia FA, Murphy M, et al. Randomised controlled trial of simulation-based education for mechanical cardiopulmonary resuscitation training. Emerg Med J. 2019;36:266–72. Available from: http://dx.doi.org/10.1136/emermed-2017-207431
23. Maurin O, Frattini B, Jost D, Galinou N, Alhanati L, Dang Minh P, et al. Hands-off time during automated chest compression device application in out-of-hospital cardiac arrest: a case series report. Prehosp Emerg Care. 2016;20:637–42. Available from: http://dx.doi.org/10.3109/10903127.2016.1142625

24. Yost D, Phillips RH, Gonzales L, Lick CJ, Satterlee P, Levy M, et al. Assessment of CPR interruptions from transthoracic impedance during use of the LUCAS mechanical chest compression system. Resuscitation. 2012;83:961–5. Available from: http://dx.doi.org/10.1016/j.resuscitation.2012.01.019
25. Nurmi J, Rosenberg P, Castrén M. Adherence to guidelines when positioning the defibrillation electrodes. Resuscitation. 2004;61:143–7. Available from: http://dx.doi.org/10.1016/j.resuscitation.2004.01.004
26. Bodtker H, Rosendahl D. Correct AED electrode placement is rarely achieved by laypersons when attaching AED electrodes to a human thorax. Resuscitation. 2018;127:e12–3. Available from: http://dx.doi.org/10.1016/j.resuscitation.2018.04.002
27. Heames RM, Sado D, Deakin CD. Do doctors position defibrillation paddles correctly? Observational study. BMJ. 2001;322:1393–4. Available from: http://dx.doi.org/10.1136/bmj.322.7299.1393
28. Staerk M, Bodtker H, Lauridsen KG, Lofgren B. Automated external defibrillation training on the left or the right side – a randomized simulation study. Open Access Emerg Med. 2017;9:73–9. Available from: http://dx.doi.org/10.2147/OAEM.S140220.
29. Goksu T, Borggrefe M, Haghi D. Inappropriate placement of defibrillator self-adhesive electrode pads with possible fatal outcome. Emerg Med J. 2011;28:158. Available from: http://dx.doi.org/10.1136/emj.2009.082198
30. Pare D, L'Ecuyer JB, Mercier E. Association between pad placement and the return of spontaneous circulation for defibrillation during ventricular fibrillation: a systematic review. J Innov Card Rhythm Manag. 2021;12:4533–5. Available from: http://dx.doi.org/10.19102/icrm.2021.120607
31. Ristagno G, Semeraro F, Raffay V, Stirparo G, Lulic I, Deakin CD, et al. Pad size, orientation, and placement for defibrillation during basic life support: a systematic review. Resusc Plus. 2025;25. Available from: http://dx.doi.org/10.1016/j.resplu.2025.101030
32. Deakin CD, Sado D, Petley GW, Clewlow F. Is the orientation of the apical defibrillation paddle of importance during manual external defibrillation? Resuscitation. 2003;56:15–8. Available from: http://dx.doi.org/10.1016/S0300-9572(02)00290-3
33. Esibov A, Chapman FW, Melnick SB, Sullivan JL, Walcott GP. Minor variations in electrode pad placement impact defibrillation success. Prehosp Emerg Care. 2016;20:292–8. Available from: http://dx.doi.org/10.3109/10903127.2015.1076095
34. Foster AG, Deakin CD. Accuracy of instructional diagrams for automated external defibrillator pad positioning. Resuscitation. 2019;139:282–8. Available from: http://dx.doi.org/10.1016/j.resuscitation.2019.04.034
35. Pagan-Carlo LA, Spencer KT, Robertson CE, Dengler A, Birkett C, Kerber RE. Transthoracic defibrillation: importance of avoiding electrode placement directly on the female breast. J Am Coll Cardiol. 1996;27:449–52. Available from: http://dx.doi.org/10.1016/0735-1097(95)00487-4