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Clinical paper

Accuracy of instructional diagrams for automated external defibrillator pad positioning



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Abstract

Introduction: Correct defibrillation pad positioning optimises the chances of successful defibrillation. AEDs have pictorial representation to guide untrained bystanders in correct pad positioning. There is a wide variation in this pictorial guidance and evidence suggests that correct anatomical pad placement is poor. We reviewed all currently available diagrams and assessed the resultant pad placement achieved by untrained bystanders following these instructions.

Methods: Twenty untrained bystanders were presented with a total of 27 different pad placement diagrams (including one designed by the researchers) in a random sequence and were asked to apply them to the chest of an adult manikin. The lateral/medial and cranial/caudal position in relation to the optimal position recommended by the European Resuscitation Council guidelines was then measured for each pair of pads.

Results: Overall, the sternal pad was placed an average of 6.0 mm cranial to, and 3.2 mm medial to, the optimal position. The apical pad was placed an average of 78.2 mm caudal to, and 59.3 mm medial to, the optimal position. The pad position diagram we designed and assessed outperformed existing diagrams.

Conclusion: All current defibrillation pad diagrams fail to achieve accurate defibrillation pad placement. A clearer, more effective diagram, such as the one we designed, is urgently needed to ensure bystander defibrillation is effective as possible.

Keywords: Defibrillation, Bystander, Automated external defibrillator, Education

Introduction

Out-of-hospital cardiac arrest (OHCA) affects over 350,000 individuals in the United States, and 275,000 individuals in Europe each year. Mortality remains poor with a survival rate of approximately 10%.¹ An intact and effectively functioning chain of survival is vital to optimise the chances of survival, but the key components of this chain are the early rings,² particularly that of bystander CPR and defibrillation. This has been shown to at least double survival rates by filling the therapeutic vacuum that exists while EMS resources are mobilised and transit to scene.³ Survival benefits from public access defibrillation are particularly striking, approaching 60% for the 20% of patients

in a shockable rhythm.³ Community first responders were found to significantly contribute to increased survival following OHCA.⁴ In order to strengthen these links, AEDs have now become a key component of BLS and their benefits have driven public access defibrillator schemes.⁵

Modern AEDs are designed, and indeed encouraged, to be used by those with little or no training and provide visual and audible instructions for those using the device. Correct anatomical positioning of the self-adhesive pads is guided by diagrams on the AED housing or on the pads themselves. On all AEDs, these show antero-lateral positions for adult pad placement. No human studies have evaluated the electrode position as a determinant of ROSC or survival from VF/PVT. However, transmural current during defibrillation is likely to

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be maximal when the electrodes are placed so that the area of the heart that is fibrillating lies directly between them and correct pad positioning is therefore important to optimise the efficacy of defibrillation.⁶ Finite element analysis using the human torso, clinical fluoroscopic studies and animal studies have all demonstrated the importance of correct pad positioning in optimising shock efficacy. Finite element analysis has demonstrated the dependence of spatial distribution of current density magnitude on paddle placement⁷ and the relation between pad placement and the ability to achieve 100% critical mass defibrillation.⁸ Clinical fluoroscopic studies have shown that even small variations in pad position can affect the success of external DC cardioversion and in a swine study, Esibov et al. have also demonstrated that even variations in pad placement of <3 cm can adversely affect defibrillation shock efficacy.⁹

Although the success of resuscitation may depend on the accurate placement of self-adhesive pads, several studies have shown that health care professionals¹⁰ and doctors specifically¹¹ place pads sufficiently inaccurately to jeopardise shock success. The apical pad appears to be particularly susceptible to inaccurate positioning¹² which is likely to have a particularly significant adverse effect on myocardial current density because of the resultant transthoracic current pathways. The inability of health-care professionals to place pads correctly may relate to deficiencies in resuscitation training, but lay members of the public who are attempting to use a public access defibrillator may, because of little if any training, have to rely on pad position diagrams on the AED itself. Lack of clarity in these instructional diagrams not surprisingly also results in significant errors in accurate pad position.¹³ In a study of 18 AED pad position diagrams, the majority failed to provide correct guidance on left apical defibrillation electrode placement, which was misplaced too anteriorly.¹⁴ It is therefore likely that bystander reliance on these diagrams for accurate pad position will limit defibrillation efficacy and hinder the potential benefits of increasingly more frequent bystander public access defibrillation.³

We therefore studied the accuracy of defibrillation electrode placement by untrained lay members of the public to ascertain their interpretation of current diagrams and compared this with an additional diagram we designed aimed at providing clarity for correct pad positioning.

Methods

Study setting

Volunteers were enrolled by personal recruitment from lay members of the local community having been asked if they were willing to participate in a short study of public access defibrillation. Exclusion criteria included previous training in first aid, basic life support, AED use or previously having witnessed an actual resuscitation attempt.

Study methods

Identification of AEDs

All commercially available AEDs were identified through an internet search (July 2017) and a review of AEDs on show at trade displays at the 2017 European Resuscitation Council annual symposium (Freiburg, Germany 2017) and the 2017 Resuscitation Science

Symposium (Anaheim, USA). The defibrillation pad diagrams associated with each type of AED were identified; both those printed on the self-adhesive pads themselves and those printed on the housing of the AED.

Researchers pad position diagram

In addition to identifying manufacturer's diagrams, we also assessed the accuracy of a diagram designed by the research team. This diagram was assessed in exactly the same way and alongside the other 27 other diagrams so the participant could not differentiate between the manufacturers' and researcher's diagram.

Assessment of pad position

An adult Laerdal resuscitation Mannequin (Laerdal UK) placed in a supine position was used for the study. Discrete marks, not identifiable by the study subject, were placed by a researcher to mark the optimal sterno-apical pad positions according to the European Resuscitation Council 2015 guidelines (The right (sternal) electrode placed to the right of the sternum, below the clavicle. The apical paddle placed in the left mid-axillary line, approximately level with the V6 ECG electrode,⁶ which is over the fifth intercostal space.¹⁵)

Each volunteer was presented with the manikin (see below) and shown sequential defibrillation pad instructional diagrams, anonymised with regards to the manufacturer, in a randomised order. They were asked to carefully place each pair of defibrillation pads on the manikin, according to the anatomical position indicated by each diagram. This process was repeated for each placement diagram.

Outcome measure

The position of the centre of each defibrillation pad was marked on the manikin and the distance from the optimal point was measured. (The volunteer was not shown the measuring process or the mark of the optimal point, which was used just for measuring purposes).

Sternal pad

Cranial to the optimal point was recorded as a positive vertical value. Medial to the optimal point was recorded as a positive horizontal value.

Apical pad

Cranial to the optimal point was recorded as a positive vertical value. Lateral to the optimal point was recorded as a positive horizontal value.

Ethics

The study was reviewed and approved by the Faculty of Medicine Ethics Committee, Southampton General Hospital, UK. (ERGO ref: 31936).

Data analysis

Data was analysed using simple descriptive statistics. Positions for the centre of each pad in relation to the optimal position were described using medians and range (mm). Results are shown graphically and were constructed using GraphPad Prism 7.0 for MacOS (GraphPad Software, Inc.).

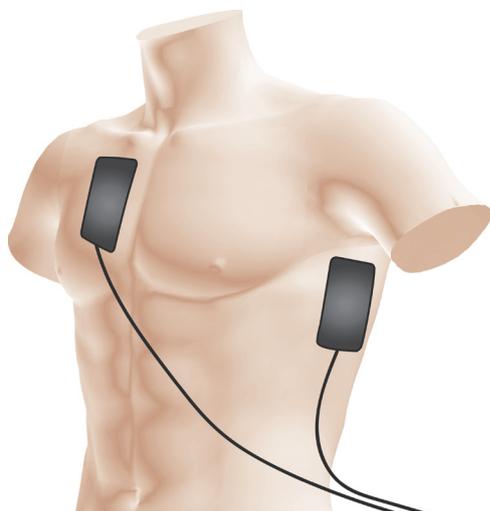


Fig. 1 – Defibrillation pad diagram designed by the researchers.

Results

Volunteers

A total of 20 volunteers were recruited to the study. Of these 40% were male and the median age was 21 years (Range 18–53 years).

Defibrillation pad diagrams

In addition to the researcher's pad placement diagram (Fig. 1), 27 AEDs from a total of 14 manufactures were identified, each with their corresponding defibrillation pad diagrams:

- 1 Philips HeartStart HS1 AED
- 2 Philips HeartStart FR3 AED
- 3 Philips HeartStart FR2 & FR2+ AED
- 4 Zoll AED Plus
- 5 Zoll AED 3
- 6 Zoll AED Pro
- 7 Cardiac Science Powerheart G3 Plus AED
- 8 Cardiac Science Powerheart G5 AED
- 9 CardiAid AED
- 10 Defibtech Lifeline AED
- 11 Defibtech Lifeline View AED
- 12 HeartSine Samaritan AED
- 13 HeartSine Samaritan Pads
- 14 Physio Control LifePak 1000 AED & LifePak CR Plus AED
- 15 Physio Control LifePak CR2 AED
- 16 Mediana HeartOn A15 AED
- 17 Mediana HeartOn A10 AED
- 18 Primedic HeartSave AED
- 19 Schiller FRED Easy & FRED PA-1 Pads
- 20 Schiller FRED PA-1 AED & FRED Easy AED

Table 1 – Median horizontal (lateral/mm) and vertical (cranial/mm) distance from the optimal point (0, 0) and the range of placement according to each of the defibrillation pad diagrams for the sternal electrode pad.

Sternal pad placement

	Horizontal distance (mm)			Vertical distance (mm)		
	Median	Range Min	Range Max	Median	Range Min	Range Max
1	6.4	-16	38	0.0	-22	19
2	-3.2	-32	29	6.4	-19	32
3	-8.0	-35	51	12.7	-16	54
4	-3.3	-19	19	-1.3	-25	38
5	-3.3	-25	22	-4.8	-41	22
6	1.7	-29	32	-15.1	-60	19
7	27.1	-44	57	-4.8	-60	24
8	23.9	-29	48	2.5	-29	19
9	5.6	-22	30	-1.7	-57	21
10	6.4	-29	19	11.2	-6	41
11	8.0	-32	19	-10.4	-70	21
12	27.1	3	51	-11.9	-41	16
13	25.5	-16	38	-11.2	-41	19
14	16.0	-16	44	-0.9	-35	35
15	11.2	-32	29	3.3	-22	19
16	1.7	-25	19	12.7	-10	35
17	-11.2	-54	38	8.0	-32	57
18	-1.7	-48	32	11.2	-18	64
19	2.5	-16	29	16.8	-13	44
20	28.7	-32	54	-6.5	-60	14
21	14.4	-32	41	12.7	-41	44
22	-3.3	-41	127	22.4	-19	48
23	11.2	-14	35	4.8	-13	20
24	-18.3	-54	2	3.3	-35	29
25	1.7	-22	29	7.1	-19	35
26	-8.0	-38	13	14.4	-16	38
27	-3.3	-25	22	9.7	-13	32
28	12.7	-30	25	0.0	-25	25

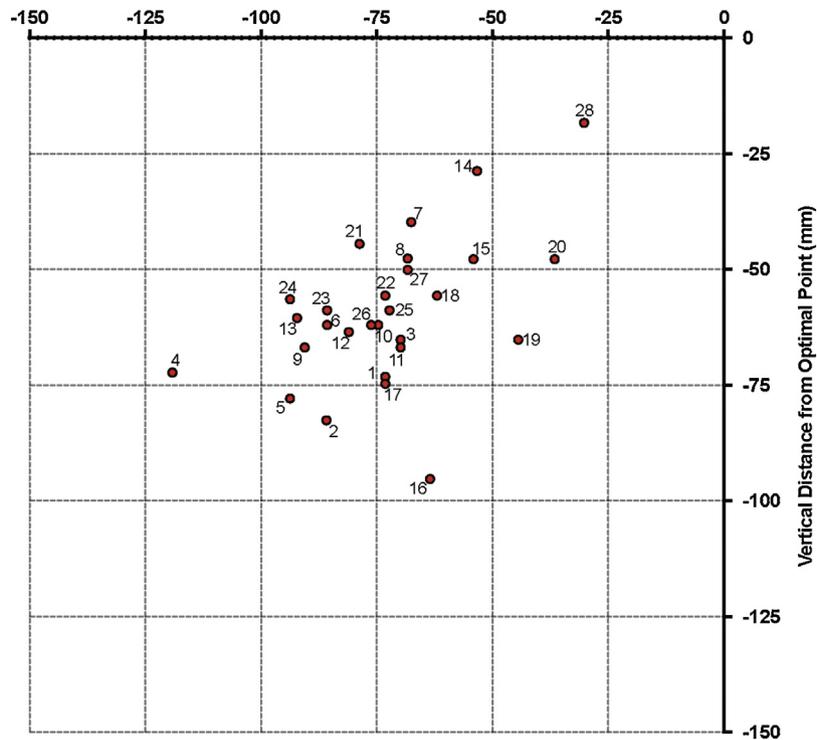


Fig. 2 – Graphical representation of the centre of each defibrillation pad (median) in relation to the optimal position for the apical pad. (Centre of the cross hairs (0, 0) marks the optimal position recommended by the European Resuscitation Council.)

Table 2 – Median horizontal (medial/mm) and vertical (cranial/mm) distance from the optimal point and the range of placement according to each of the defibrillation pad diagrams for the apical electrode pad.

Apical pad placement

	Horizontal distance (mm)			Vertical distance (mm)		
	Median	Range Min	Range Max	Median	Range Min	Range Max
1	-73.2	-114	-19	-73.2	-130	-3
2	-85.9	-146	-29	-82.6	-137	-51
3	-69.9	-118	-16	-65.2	-102	-25
4	-119.1	-140	-51	-72.3	-116	-10
5	-93.7	-124	-6	-77.9	-146	-22
6	-85.7	-121	-3	-62.0	-111	-38
7	-67.6	-105	-19	-39.8	-70	-6
8	-68.3	-102	-10	-47.6	-86	-19
9	-90.6	-130	-38	-66.8	-86	-25
10	-74.7	-111	-29	-62.0	-86	-25
11	-69.9	-111	-25	-66.8	-102	-25
12	-81.0	-109	-10	-63.5	-80	-29
13	-92.2	-111	-48	-60.5	-102	-22
14	-53.3	-108	0	-28.7	-57	-10
15	-54.1	-95	-22	-47.8	-73	-10
16	-63.5	-133	-3	-95.3	-130	-48
17	-73.2	-114	-19	-74.7	-108	-51
18	-62.0	-105	-19	-55.6	-78	-10
19	-44.5	-95	-6	-65.2	-121	-13
20	-36.6	-86	-10	-47.8	-89	-10
21	-78.7	-114	-6	-44.5	-64	-6
22	-73.2	-111	-3	-55.6	-84	-3
23	-85.7	-102	-38	-58.8	-83	-16
24	-93.7	-121	-48	-56.4	-86	-16
25	-72.3	-97	-10	-58.8	-83	-25
26	-76.2	-102	-29	-62.0	-92	-13
27	-68.3	-97	-10	-50.0	-80	-10
28	-30.2	-54	-3	-18.3	-60	0

- 21 CU Medical Systems iPAD SP1 Pads
- 22 CU Medical Systems iPAD SP1 AED
- 23 Prestan AED Trainer
- 24 MS Westfalia AED
- 25 MS Westfalia AED pads
- 26 Corpuls AED pads
- 27 Universal AED Practi Trainer (WNL Products)
- 28 Defibrillation pad diagram designed by the researchers (Fig. 1).

Apical electrode pad placement

Table 1 shows the results for the apical electrodes of all 28 diagrams, showing the median horizontal (lateral) and vertical (cranial) distance from the optimal point (0, 0) and the range of placement according to each of the defibrillation pad diagrams.

The results for the apical electrode pad (median values) are shown graphically in Fig. 2.

Sternal electrode pad placement

Table 2 shows the results for the sternal electrodes of all 28 diagrams, showing the median horizontal (medial) and vertical (cranial) distance from the optimal point and the range of placement according to each of the defibrillation pad diagrams.

The results for the sternal electrode pad (median values) are shown graphically in Fig. 3.

Overall, the apical pad was placed an average of 78.2 mm caudal to, and 59.3 mm medial to, the optimal position. The sternal pad was

placed an average of 6.0 mm cranial to, and 3.2 mm medial to, the optimal position.

The pad position diagram we designed and assessed performed well. Overall, the apical pad was placed an average of 18.3 mm caudal to, and 30.2 mm medial to, the optimal position. The sternal pad was placed an average of 0.0 mm cranial to, and 12.7 mm medial to, the optimal position.

Discussion

The 28 AED diagrams resulted in a wide variation in pad placement, almost all being more than 5 cm from the optimal position. Although concerns about the inaccurate pad placement resulting from defibrillation pad diagrams has been raised before,^{13,16} this is the first study to examine in detail the specific pad positioning resulting from each diagram. The instructional pad placement diagrams on AEDs may often be used by untrained bystanders in a stressful situation and it is therefore imperative that the diagram is clear and accurate in order to maximise the chances of successful defibrillation. Even relatively small deviations from optimal pad position can significantly affect defibrillation shock efficacy and the large deviations occurring as a result of following almost all diagrams significantly exceed the 3 cm threshold at which shock efficacy declines.⁹

Overall, the sternal pad diagrams resulted in reasonably accurate placement of the respective defibrillation pad, with an average of 6.0 mm cranial and 3.2 mm medial error. This suggests that sternal pad placement diagrams are likely to result in reasonably accurate placement and therefore not compromise

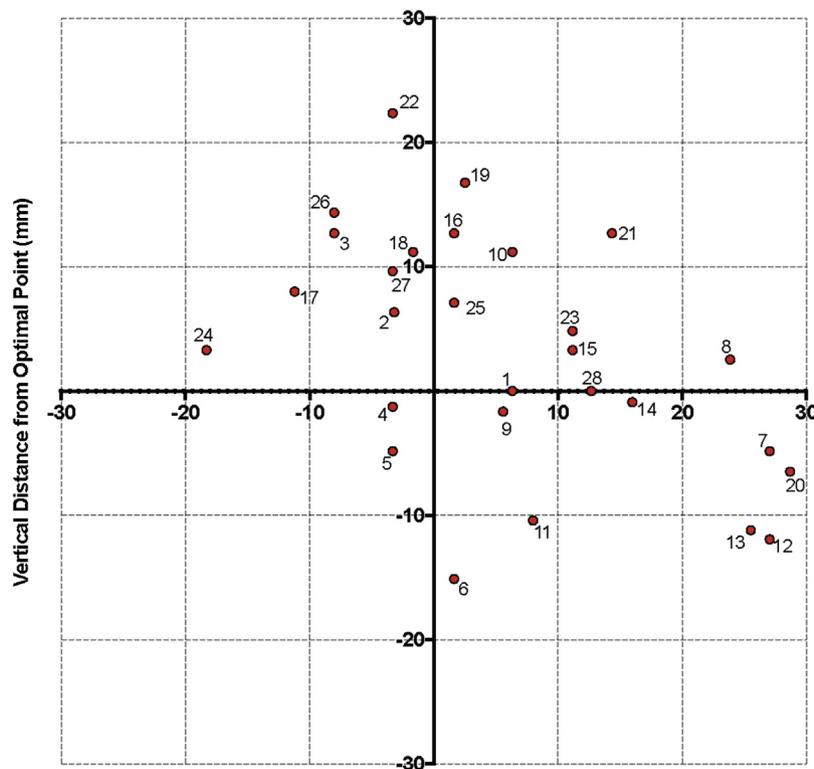


Fig. 3 – Graphical representation of the centre of each defibrillation pad (median) in relation to the optimal position for the sternal pad. (Centre of the cross hairs (0, 0) marks the optimal position recommended by the European Resuscitation Council.)

shock success. However, the apical pads show a much greater variation and overall resulted in very inaccurate placement, with 78.2 mm caudal, and 59.3 mm medial error. All but two of apical pad diagrams resulted in defibrillation pad placement greater than 50 mm from the optimal point except two (the proposed diagram and the Schiller FRED PA-1 AED). This suggests that the existing diagrams are inaccurate in their depiction of the optimal apical pad position and fail to achieve anything even approaching optimal pad positioning. The most accurate pad position diagram was the 3D image designed by the researchers, which significantly outperformed all other apical pad diagrams.

Taken to its logical conclusion, the effectiveness of bystander public access defibrillation may be significantly reduced with such poor pad positioning. There is clearly a need to improve defibrillation pad instructional diagrams, particular that depicting the apical pad which currently performs particularly poorly because of both unclear and inaccurate diagrams. Most of the apical pad diagrams showed the apical pad from a fully anterior view. However, several of the manufacturers' diagrams (Cardiac Science Powerheart G3 Plus AED, Physio Control LifePak 1000 AED & LifePak CR Plus, Physio Control LifePak CR2, Primedic HeartSave AED and MS Westfalia AED) and our proposed diagram were from a rotated antero-lateral view. Five of the six most accurate diagrams depicted an antero-lateral view (including the proposed diagram). This suggests that this type of diagram may be clearer at illustrating the optimal pad placement as more readily shows a clearer mid-axillary placement. An anterior diagram can accurately show the sternal pad placement but clear depiction of the apical pad is limited. This has also been highlighted previously, where errors of pad placement by people were reduced when a side view diagram was visible.¹³ Some anterior diagrams attempted to suggest the location of the section of the pad that was out of view by using arrows (Cardiac Science) or 3D elements (Zoll) but this was still ineffective at displaying an accurate placement. Therefore, it appears that an optimal diagram needs to show placement from an antero-lateral view and this would be supported by the findings that the best performing diagram was a 3D antero-lateral view. A previous study has suggested that colour coding the diagrams may lead to a more accurate pad placement¹⁷ but our test results do not support this, as there was no relationship between the number of colours in the diagram and accuracy of the subsequent pad placement. However, we believe that different colours may assist accurate depiction and appropriate emphasis, influencing overall accuracy.

Conclusion

All current defibrillation pad diagrams fail to achieve relatively accurate defibrillation pad placement by untrained bystanders (or those without recent AED training) to such a significant extent, that defibrillation efficacy is likely to be significantly impaired. We have shown that relatively accurate defibrillation pad placement by untrained bystanders can be achieved by using a 3D antero-lateral diagram. 3D diagrams may also be useful for AED training to emphasise correct pad positioning. There is an urgent need for all defibrillator manufacturers to revise and update their pictorial representation of defibrillation pad positions to ensure that bystanders using their automated external defibrillators (AEDs) apply defibrillation pads more

accurately in order to optimise shock success and therefore patient outcome.

Conflict of interest

None declared.

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REFERENCES

- Berdowski J, Berg RA, Tijssen JG, et al. Global incidences of out-of-hospital cardiac arrest and survival rates: systematic review of 67 prospective studies. *Resuscitation* 2010;81:1479–87, doi:<http://dx.doi.org/10.1016/j.resuscitation.2010.08.006>.
- Deakin CD. The chain of survival: not all links are equal. *Resuscitation* 2018;126:80–2, doi:<http://dx.doi.org/10.1016/j.resuscitation.2018.02.012>.
- Holmberg MJ, Vognsen M, Andersen MS, et al. Bystander automated external defibrillator use and clinical outcomes after out-of-hospital cardiac arrest: a systematic review and meta-analysis. *Resuscitation* 2017;120:77–87, doi:<http://dx.doi.org/10.1016/j.resuscitation.2017.09.003>.
- Pijls RW, Nelemans PJ, Rahel BM, et al. A text message alert system for trained volunteers improves out-of-hospital cardiac arrest survival. *Resuscitation* 2016;105:182–7, doi:<http://dx.doi.org/10.1016/j.resuscitation.2016.06.006>.
- Baekgaard JS, Viereck S, Moller TP, et al. The effects of public access defibrillation on survival after out-of-hospital cardiac arrest: a systematic review of observational studies. *Circulation* 2017;136:954–65, doi:<http://dx.doi.org/10.1161/CIRCULATIONAHA.117.029067>.
- Soar J, Nolan JP, Bottiger BW, et al. European Resuscitation Council Guidelines for Resuscitation 2015: section 3. Adult advanced life support. *Resuscitation* 2015;95:100–47, doi:<http://dx.doi.org/10.1016/j.resuscitation.2015.07.016>.
- Camacho MA, Lehr JL, Eisenberg SR. A three-dimensional finite element model of human transthoracic defibrillation: paddle placement and size. *IEEE Trans Biomed Eng* 1995;42:572–8, doi:<http://dx.doi.org/10.1109/10.387196>.
- Panescu D, Webster JG, Tompkins WJ, et al. Optimization of cardiac defibrillation by three-dimensional finite element modeling of the human thorax. *IEEE Trans Biomed Eng* 1995;42:185–92, doi:<http://dx.doi.org/10.1109/10.341831>.
- Esibov A, Chapman FW, Melnick SB, et al. Minor variations in electrode pad placement impact defibrillation success. *Prehosp Emerg Care* 2016;20:292–8, doi:<http://dx.doi.org/10.3109/10903127.2015.1076095>.
- Nurmi J, Rosenberg P, Castren M. Adherence to guidelines when positioning the defibrillation electrodes. *Resuscitation* 2004;61:143–7, doi:<http://dx.doi.org/10.1016/j.resuscitation.2004.01.004>.
- Heames RM, Sado D, Deakin CD. Do doctors position defibrillation paddles correctly? Observational study. *BMJ* 2001;322:1393–4.
- Staerk M, Bodtker H, Rahbek S, et al. Placement of the left side aed pad is poor: training on the left compared to the right side of a manikin does not improve pad placement. *Circulation* 2015;132:A19582.

13. Nurmi J, Castren M. Layperson positioning of defibrillation electrodes guided by pictorial instructions. *Resuscitation* 2005;64:177–80, doi:<http://dx.doi.org/10.1016/j.resuscitation.2004.08.014>.
14. Bodtker H, Rosendahl D. Automated external defibrillators and defibrillation electrodes from major manufactures depict placement of the left apical defibrillation electrode poorly!. *Resuscitation* 2018;125:e11–2, doi:<http://dx.doi.org/10.1016/j.resuscitation.2018.01.046>.
15. Medani SA, Hensey M, Caples N, et al. Accuracy in precordial ECG lead placement: improving performance through a peer-led educational intervention. *J Electrocardiol* 2018;51:50–4, doi:<http://dx.doi.org/10.1016/j.jelectrocard.2017.04.018>.
16. 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, doi:<http://dx.doi.org/10.1016/j.resuscitation.2018.04.002>.
17. Mosesso Jr. VN, Shapiro AH, Stein K, et al. Effects of AED device features on performance by untrained laypersons. *Resuscitation* 2009;80:1285–9, doi:<http://dx.doi.org/10.1016/j.resuscitation.2009.07.016>.