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Clinical paper

Functionality of registered automated external defibrillators

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Abstract

Aims: Little is known about automated external defibrillator (AED) functionality in real-life settings. We aimed to assess the functionality of all registered AEDs in a geographically selected area and calculate the proportion of historical out-of-hospital cardiac arrests (OHCAs) covered by non-functioning AEDs.

Methods: In this cross-sectional study we inspected all registered and available AEDs on the island of Bornholm in Denmark. We collected information on battery status (determined by AED self-test) and electrode status, as well as AED availability. We identified all historical OHCAs registered with the Danish Cardiac Arrest Registry on Bornholm during 2016–2019 and calculated the proportion of OHCAs covered by an AED (regardless of functionality status) within ≤100, ≤750, and ≤1800 meters and the proportion of OHCAs covered by non-functioning AEDs.

Results: Of 211 registered AEDs, 181 (81.9%) were publicly accessible and functional. The remaining 40 (18.1%) were not functional, primarily due to expired electrodes (42.5%, *n* = 17), obstacles to AED retrieval (20.0%, *n* = 8) or failed self-tests (17.5%, *n* = 7). Of 197 historical OHCAs, non-functional AEDs resulted in an OHCA coverage loss of 5.6%, 4.1% and 1.0 % for ≤100 m, ≤750 m and ≤1800 m, respectively.

Conclusion: Almost one-fifth of all registered and publicly available AEDs were not functional, primarily due to expired electrodes, failed self-tests or obstacles to retrieving AEDs. One in twenty historical OHCA was covered by a non-functional AED. Although general AED functionality was high, this finding underlines the importance of regular AED maintenance.

Keywords: Out-of-hospital cardiac arrest, Automated external defibrillator, Functionality

Introduction

Early defibrillation with an automated external defibrillator (AED) can increase the probability of surviving an out-of-hospital cardiac arrest (OHCA) to more than 50%.[1–3]

Several countries have implemented public access defibrillation programs following recommendations from the European Resuscitation Council and the American Heart Association.[4,5] In Denmark, AED density has increased accordingly from 66 to 611 sold AEDs/100,000 inhabitants from 2007 to 2019.[6] In addition, a national AED network with 21,150 AEDs registered (March 2022) has been established in 2007 to improve resuscitation after OHCAs.[7–10] Approximately 60% of all sold AEDs are registered in this AED network and includes detailed information on AED locations as well as accessibility, and is directly linked to all five emergency medical dispatch centres in Denmark.[8] The Danish AED network collects information upon registration and validates registered information once every year for AEDs accessible less than 24/7 and once every second year for AEDs accessible 24/7.

For AEDs to provide the maximum benefit, they need to be locatable and functional which includes having a functional battery and electrodes. Recognizing this important aspect, guidelines also state the importance of clear and uniform signage to indicate AED location and the fastest way to the AED as well as establishment of teams responsible for monitoring and maintaining the devices.[4] We presume, that if an AED is not continuously serviced, there is an increasing risk of battery or electrode malfunction and that this problem increases the longer the AED has been deployed. Nevertheless, there are no rules or regulations regarding how AED owners should

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maintain their AEDs in Denmark, although maintenance service agreements for AEDs are available for purchase. Data on AED functionality in real-life settings are lacking.

The aim of this study was: (1) to determine the functionality, availability, and reasons for lack of functionality of all registered AEDs in a geographically selected part of Denmark (the island of Bornholm), and (2) to examine the proportion of historical OHCAs that would potentially be covered by non-functioning AEDs.

Methods

Study setting

The Danish Island of Bornholm covers 588 km^2 and has a population of approximately 34,600 (2019), with about 600,000 tourists visiting each year.[11,12] Bornholm was selected due to its past history of community engagement in OHCA resuscitation, which included a mass media campaign to increase awareness and rates of cardiopulmonary resuscitation (CPR) and AED training, widespread CPR educational activities and a structured AED deployment program. Previous studies have found that one third of the population took a CPR course from 2008 to 2010,[13] and that there was a persistent significant increase in the bystander resuscitation attempts BLS from 2010-2013.[14] Furthermore, Bornholm has deployed numerous AEDs from 2008 to 2010, increasing from 9 to 426 AEDs/100,000 inhabitants in two years.[13] In 2019, this number increased to 653 AEDs/100,000 inhabitants.

Study design and population

We conducted a cross-sectional study collecting data on functionality and availability of all registered AEDs located on the Island of Bornholm. All registered AED locations were visited in person, and AEDs were inspected in terms of (1) battery status (determined by AED self-test) (2) electrode status, and (3) availability defined as the AED being accessible, could be opened unhindered and at registered location. In addition, we examined all historical OHCAs (2016–2019) on Bornholm and calculated the proportion of historical OHCAs that theoretically would have been covered by a registered AED within a radius of $\leq$100, $\leq$750, and $\leq$1800 meters, respectively. Furthermore, we calculated the proportion of historical OHCAs covered by a functional and non-functional AED within the three specified distances, given that the AED location and functionality was the same at the time of OHCA occurrence. The study population included all historical OHCAs registered with the Danish Cardiac Arrest Registry. During the study period, a volunteer first-responder program was implemented (1 September 2017) in the Capital Region of Denmark, including Bornholm.[15] Volunteer responders are alerted if an OHCA occurs within 1800 meters (later changed to 5000 meters) and volunteer responders are directed to perform CPR or retrieve an AED and bring it to the OHCA location before emergency medical services' arrival.[15]

The Danish AED Network

The Danish AED Network was established in Copenhagen in 2007.[6] It became nationwide in 2010 and was linked to all five emergency medical dispatch centres across the country in 2011.[6] In the event of an OHCA, the emergency medical dispatcher can identify the nearest accessible AED and guide bystanders to bring the AED to the OHCA location. Registration with the network is voluntary for AED owners, but strongly recommended by the Danish Health Authority and Danish AED vendors.[7] The AED Network includes both private and public AEDs, and information on registered AEDs can be viewed on a smartphone application or a public webpage.[9] Approximately 60% of all AEDs sold in Denmark are registered with the network.[6,10]

Upon registration, the following information is collected from the AED owner: (1) registration date, (2) exact address/coordinates, (3) the type of organization of AED deployment, (4) exact hours of accessibility, (5) the AED's serial number, manufacturer, type, and model, (6) expiration date of electrodes, and (7) contact information for the person responsible for the AED.

AED owners registered in the network receives an email once a year if their AED is not accessible 24/7, and every other year if accessible 24/7. The email requests confirmation that the information given upon registration is still valid. If the AED owner does not respond within 7 days, they will receive another email asking to confirm the information. If they are still not responding the Danish AED Network will try to contact them again by email. If they are not reachable, the AED will be taken off the AED network 1.5 months after the first sent email, and the owner will receive an email that their AED is deactivated.

Data collection

Physical inspection of the AEDs that were accessible 24/7 was carried out on 22 March 2019, and from 22 to 24 May 2019, for all AEDs not accessible 24/7. We used information from the Danish AED Network to localize all the registered AEDs. All AEDs were inspected in person. To be categorized as functional an AED had to meet the following predetermined criteria: (1) the expiration date on the electrodes should not be exceeded, (2) access to the AED should not be hindered, and (3) the AED should have a functional battery (meaning it should pass its self-test). Any device failing to meet one or more of these criteria was marked as non-functional.

Geocoding and analysis of AED coverage of OHCAs on Bornholm

A map was created using geocoded historical OHCAs with complete coordinates in QGIS 3.10.0,[16] and maps from The Danish Map Supply.[17] We identified the proportion of OHCAs covered by an AED within a radius of $\leq$100, $\leq$750, and $\leq$1800 m from the OHCA location, respectively. The three distances chosen were based on the following: For $\leq$100 m, the American Heart Association has previously recommended that AEDs should be placed at a distance requiring $\leq$1.5 min of brisk walking to reach an OHCA location, commonly translated to a straight-line distance of 100 m, which is also the distance used in many AED studies.[8,18,19] For $\leq$750 m, this was the average distance between a volunteer responder, the AED and the OHCA as observed in the Danish volunteer responder program.[15] For $\leq$1800 m, in the current volunteer responder system covering Bornholm, this was the maximum dispatch radius during the study period used between the volunteer responder and the OHCA location.[15]

First, an OHCA was defined as "covered" by an AED if an AED was placed within the specified radii from the historical OHCA. The potential OHCA coverage was estimated by comparing the geographical locations of all historically OHCAs in the study period with the real-life AED functionality examined at two timepoints in 2019. Second, for each historical OHCA potentially covered by an AED, it was determined whether the AED was functional and whether the AED was accessible 24/7. We examined the AED functionality

on a given random day and the outcome of this investigation was used to estimated how many historical OHCA that were covered by a functional/non-functional AED. OHCA coverage was categorized as: (1) coverage by any AED irrespective of functionality, (2) coverage by a functional AED, (3) coverage by a functional AED with 24/7 accessibility, and (4) coverage by a non-functional AED. The proportion of OHCAs covered by an AED was calculated as the number of OHCAs within ≤100 m, ≤750 m and ≤1800 m of an AED, divided by the total number of OHCAs on Bornholm in the period from 2016 to 2019. Loss of OHCA coverage due to lack of AED functionality was calculated as OHCAs covered by any AED subtracted the number of OHCAs covered by a functional AED within the specified radii distances.

Statistical analysis

Categorical variables are presented as proportions and percentages and analysed with the Fisher's exact test. The level of statistical significance was defined as a p-value of <0.05. Statistical analyses were done in SAS version 7.1 (SAS Institute Inc., NC, USA).

Ethics

This study was approved by the Danish Data Protection Agency under the project "Out-of-Hospital Cardiac Arrest in the Capital Region of Denmark" (Ref. no. 2012-58-0004, local ref. no. VD-2018-28, I-Suite no. 6222) and by the National Board of Health (journal no. 3-3013-2721/1 and journal no. 31-1522-14). No ethical approval is required for retrospective registry studies in Denmark.

Results

A total of 226 registered AEDs was identified on Bornholm (=655 AEDs/100,000 inhabitants) in March 2020. Five AEDs were excluded because they were deactivated from the Danish AED Network for unknown reasons.

AED functionality

Of the 221 included AEDs, 181 (81.9%) were accessible and functional. The remaining 40 (18.1%) were non-functional, primarily due to expired electrodes (42.5%, *n* = 17), but also because access to them was hindered (e.g. they were behind locked doors in abandoned buildings) (20.0%, *n* = 8), they failed their self-tests (17.5%, *n* = 7), they were not at the specified location (10.0%, *n* = 4), the AED cabinet could not be opened (7.5%, *n* = 3), or they both failed their self-tests and had expired electrodes (2.5 %, *n* = 1) (Fig. 1). The distribution of functional and non-functional AEDs, as well as their placement, accessibility, time of registration, location, and whether they were placed in an AED cabinet or not are presented in Table 1. We found a significant correlation between AEDs registered before 2016 and poor AED functionality. However, we found no significant correlation between AED functionality and placement, accessibility, type of AED location or use of AED cabinet or not (Table 1).

AED coverage of OHCA

In total, 197 OHCAs occurred on Bornholm from 2016 to 2019, of which 24.9% (*n* = 49) were covered by an AED within ≤100 m, 86.8% (*n* = 171) within ≤750 m, and 93.9% (*n* = 185) within ≤1800 m. The proportion of OHCAs occurring where an AED was non-functional (=AED coverage loss) was 5.6% (*n* = 11) within ≤100 m, 4.1% (*n* = 8) within ≤750 m, and 1.0% (*n* = 2) within ≤1800 m. The combination of limited 24/7 accessibility and non-functional AEDs led to a coverage loss of 11.2% (*n* = 22) within ≤100 m, 6.6% (*n* = 13) within ≤750 m, and 2.5% (*n* = 5) within ≤1800 m (Fig. 2).

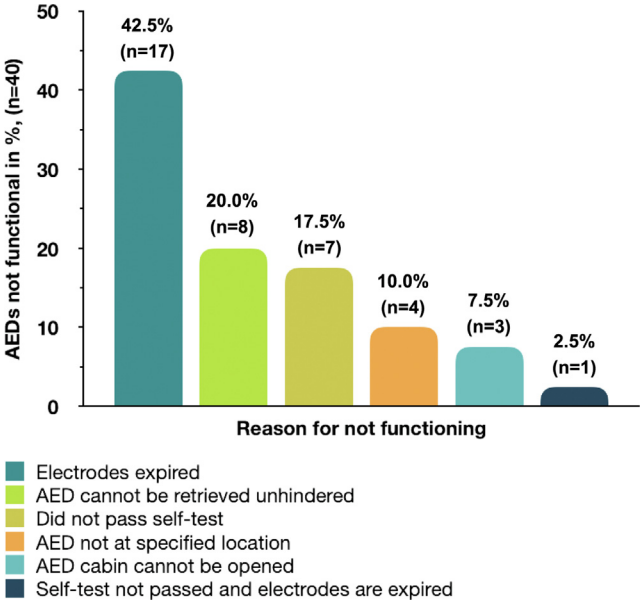

Fig. 1 – Reasons for lack of AED functionality AED, automated external defibrillator.

Discussion

The main finding of this study investigating the functionality of registered AEDs available for public access defibrillation was that almost one-fifth of the AEDs were non-functional. Primary reasons were expired electrodes, hindered access to the AED, or failed AED self-test. The potential AED coverage loss because an AED was non-functional was 5.6% and 4.1% for OHCAs within ≤100 m and ≤750 m, respectively, but only 1% for OHCAs within ≤1800 m. We found a significant correlation between AED lack of functionality and time elapsed since AED deployment. However, we found no significant correlation between lack of AED functionality and AED placement, accessibility, location, or the use of an AED cabinet (Table 1).

The results from this study could provide a basis for a targeted campaign aimed at increasing awareness of AED functionality, including how to check AED functionality, which could potentially improve the loss of AED coverage of OHCA due to non-functional AEDs. This study underlines the importance of continuously servicing AEDs, since many of the non-functional AEDs had an early deployment year. Denmark has currently no rules or regulations regarding how AED owners should maintain their AEDs, but service agreements for such maintenance are available for purchase. One solution could be to make a program like Heart-Safe Zone in Sweden.[20] The program has certain requirements that must be fulfilled, including systematic AED maintenance, registration of the AED in a national registry, and as much onsite visibility and accessibility as possible.[20] Other strategies could be remote monitoring of the AED, such as a GPS in the AED for a more accurate location or Wi-Fi, which is already being used to upload the self-test result to

Table 1 – AED functionality of registered AEDs in the Danish AED Network.

AED functionality	Ready for use, *n* (%)	Not ready for use, *n* (%)	Total, *n* (%)	*P*-values
Total number of registered active AEDs (2007–2019)	*n* = 181 (81.9%)	*n* = 40 (18.1%)	*n* = 221	
Placement				0.05
Indoor	73 (40.3)	23 (57.5)	96 (43.4)	
Outdoor	108 (59.7)	17 (42.5)	125 (56.6)	
Cabin or not				0.15
Cabin	118 (65.2)	15 (37.5)	133 (60.2)	
No cabin	63 (34.8)	15 (37.5)	78 (35.3)	
Unknown*	0 (0.0)	10 (25.0)	10 (4.5)	
Accessible 24/7 or not				0.27
Yes	122 (67.4)	23 (57.5)	145 (65.6)	
No	59 (32.6)	17 (42.5)	76 (34.4)	
Year of AED registration[a,b]				
2007–2010 incl.	93 (51.4)	25 (62.5)	118 (53.4)	0.01
2011–2015 incl.	37 (20.4)	12 (30.0)	49 (22.2)	0.01
2016–2019 incl.	51 (28.2)	3 (7.5)	54 (24.4)	
AED location				
Companies/offices[c]	41 (22.7)	7 (17.5)	48 (21.7)	
School/education facility	25 (13.8)	5 (12.5)	30 (13.6)	1
Attractions/recreational areas	17 (9.4)	8 (20.0)	25 (11.3)	0.13
Residential settings	20 (11.0)	3 (7.5)	23 (10.4)	1
Shopping malls/shops/banks	20 (11.0)	2 (5.0)	22 (10.0)	0.71
Sports facility	13 (7.2)	2 (5.0)	15 (6.8)	1
Other	10 (5.5)	2 (5.0)	12 (5.4)	1
Union/association	7 (3.9)	4 (10.0)	11 (5.0)	0.20
Public building	9 (5.0)	1 (2.5)	10 (4.5)	1
Health clinics	6 (3.3)	1 (2.5)	7 (3.2)	1
Hotels and conference venues	5 (2.8)	2 (5.0)	7 (3.2)	0.32
Church/community centre	6 (3.3)	0 (0.0)	6 (2.7)	0.58
Park/other recreational areas	1 (0.6)	2 (5.0)	3 (1.4)	0.32
Transportation facility	1 (0.6)	1 (2.5)	2 (0.9)	0.30

AED, automated external defibrillator.

* "Unknown" was excluded from the calculation of Fisher's Exact Test for the category "Cabin or not".

[a] 2016–2019 incl. has been used as a reference to calculate *p*-values with Fischer Exact Test for the category "Year of AED registration".

[b] Detailed table for each year can be found in supplement material.

[c] Companies/offices has been used as a reference to calculate *p*-values with Fischer Exact Test for the category "AED location".

a server owned by the manufacturer as part of the service arrangement.

AED functionality has previously been studied on the island of Gotland in Sweden,[21] where a comparison of AED functionality in both registered and unregistered AEDs showed that the battery did not function in 0% ($n = 0$) and 4.3% ($n = 4$) of the cases, respectively. Furthermore, the Swedish study found that electrodes had expired in 19.5% of registered AEDs and 24.7% of unregistered AEDs. In comparison, we found that 3.2% of the registered AEDs did not pass their self-test, and that the electrodes had expired in 7.7% of all the AEDs. Our study only examined registered AEDs, as we had no information on the placement and accessibility of unregistered AEDs. However, the Swedish study only examined public AEDs, whereas we examined both publicly and privately owned AEDs, if they were registered in the Danish AED Network. A study from 2012 analysing data from the Manufacture and User Device Experience database in the United States gathered material from 1150 reviewed cases and found that 2.8% of the AEDs were non-functional, with battery failures (23.2%) and expired electrodes (23.7%) being the most frequent causes.[22]

It is reasonable to assume that more AEDs are deployed on Bornholm than the 226 registered in the Danish AED Network. Based on sales figures from AED vendors in Denmark, the proportion of registered/sold AEDs was 60.8% in Denmark in 2019. If the same proportion of registered/sold AEDs applies to Bornholm, this would potentially mean that there are an additional 150 unregistered AEDs. However, several factors play an important role when it comes to the use of AEDs in OHCA cases. For example, AEDs registered in a structured AED program are used more often than unregistered AEDs.[23] In addition, a previous Danish study showed that the chance of bystander defibrillation tripled and 30-day survival rate doubled when the nearest AED was accessible compared to inaccessible at the time of the OHCA.[6]

All AEDs registered in the Danish AED Network that are not accessible 24/7 are verified (in relation to placement, accessibility, and expiration date of electrodes) every year, and those accessible 24/7 are verified every other year. The indoor AEDs are more likely to be relocated over time, whereas outdoor AEDs are often placed in fixed heating cabinets and therefore rarely relocated. We expected to see a significant difference in the functionality of indoor versus outdoor AEDs but found no significant correlation between functionality and placement indoors or outdoors.

Despite the limitation of assessing a small geographical area such as the Island of Bornholm, our results seems to correlate with estimates on a national level.[6] AEDs have been registered nationwide since 2010, and on the Island of Bornholm, as elsewhere in Denmark, companies/offices and school/education facilities were the most common places to install an AED. However, Bornholm

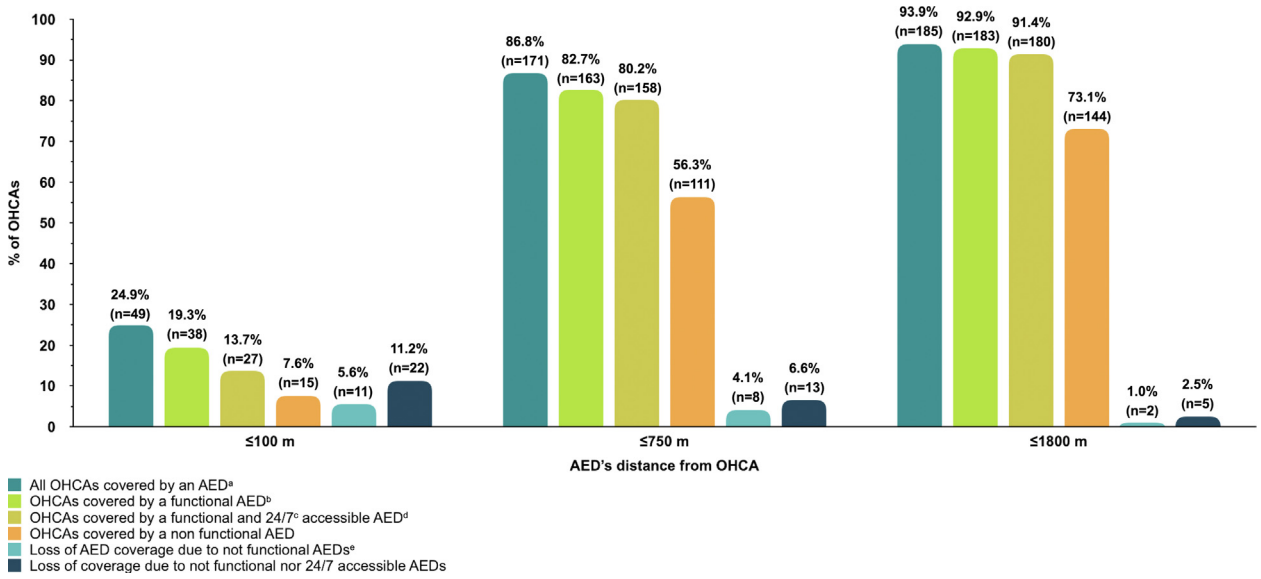

Fig. 2 – AED coverage of historical OHCAs AED, automated external defibrillator. OHCA, out of hospital cardiac arrest. OHCAs with an AED within ≤100 m, ≤750 m and ≤1800 m. Total number of OHCA between 2016–2019 was 197 at Bornholm. [a]Regardless of AED functionality. [b]All OHCAs that had a non-functional AED within their range was removed. [c]Accessible around the clock seven days a week. [d]All the AEDs from (b) that were accessible 24/7. [e]Loss of AED coverage was calculated as "All OHCAs covered by an AED" minus "OHCAs covered by a functional AED".

has been a special focus area for AED deployment and mass education of the residents in CPR.[13] Over the last decade, many AEDs have been deployed on Bornholm (from 6/100,000 inhabitants to 655/100,000 inhabitants between 2007 and 2019). In addition, a huge effort has been made to engage laypersons in CPR and public access defibrillation.[13,14] Accordingly, Bornholm may perform better than the rest of the country in regard to AED functionality.[13,14]

Limitations

The examination of the AEDs and their functionality was only conducted on two given dates, thus providing only a snapshot of the functionality of the deployed AEDs. The devices could potentially have been fixed the next day or have stopped working immediately following the inspection.

This study was limited by its observational nature. Thus, our results regarding the relationships between AED coverage of OHCA, accessibility and functionality were only associations and not casual. We could not determine which AED within the three given ranges (≤100 m, ≤750 m, ≤1800 m) that would be used for bystander defibrillation. Information on AED location and accessibility was only available for AEDs registered in the Danish AED Network and unregistered AEDs were not validated with regards to their location, accessibility, or functionality. This limitation was unlikely to impact our results substantially because unregistered AEDs are not linked to emergency medical dispatch centres, for which reason a person using the volunteer responder app would not be guided to an unregistered AED.

Conclusion

Almost one-fifth of all registered and publicly available AEDs was non-functional, primarily due to expired electrodes, failed self-tests and obstacles to retrieval. This resulted in a loss of AED coverage of historical OHCAs of 5.6%, 4.1% and 1.0% for ≤100 m, ≤750 m and ≤1800 m, respectively. Although general AED functionality was high, this finding underlines the importance of regular AED maintenance.

Conflicts of interest

S. Jespersen, J. Kjoelbye, L. Andelius and F. Folke and C. Hansen have received research grants from The Danish Foundation TrygFonden. F. Folke has furthermore received grants from the Novo Nordisk Foundation (NNF19OC0055142) and an unrestricted research grant from the Laerdal Foundation. TrygFonden, Novo Nordisk and Laerdal has not been involved in planning or conducting the study, interpreting the results, or drafting this manuscript.

CRediT authorship contribution statement

Sofie Seit Jespersen: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing – original draft. **Julie Samsoee Kjoelbye:** Software, Writing – review & editing. **Helle Collatz Christensen:** Writing – review & editing. **Linn Andelius:** Writing – review & editing. **Mads Christian Tofte Gregers:** Writing – review & editing. **Christian Torp-Pedersen:** Writing – review & editing. **Carolina Malta Hansen:** Writing – review & editing. **Fredrik Folke:** Conceptualization, Writing – review & editing, Supervision.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resuscitation.2022.05.013.

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