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Clinical paper

Circumstances, outcome and quality of cardiopulmonary resuscitation by lifeboat crews

Jeroen Seesink[a,*], *Stella A.V. Nieuwenburg*[b], *Theo van der Linden*[c], *Joost J.L.M. Bierens*[c,d]

[a] *Department of Anaesthesiology, Erasmus MC University Medical Centre, Rotterdam, The Netherlands*
[b] *Department of Gastroenterology and Hepatology, Erasmus MC University Medical Centre, Rotterdam, The Netherlands*
[c] *The Royal Dutch Lifeboat Institution (KNRM), Ijmuiden, The Netherlands*
[d] *Research Group Emergency and Disaster Medicine, Vrije Universiteit Brussels, Elsene, Belgium*

Abstract

Background: Little is known regarding circumstances, outcomes and quality of cardiopulmonary resuscitation (CPR) and the use of automated external defibrillators (AEDs) performed by operational lifeboat crews. Our aim is to evaluate circumstances, outcomes and quality of CPR performed by the Royal Dutch Lifeboat Institution (KNRM) in out-of-hospital cardiac arrest (OHCA).

Methods: The internal KNRM database has been used to identify and analyse all OHCA cases between July 2011 and December 2017. A limited set of AED data was available to study the quality of CPR.

Results: In 37 patients the lifeboat crew members have performed CPR, of which 29 (78.4%) occurred under hostile conditions. The median response time to arrive at the location was 15 min. In 11 (29.7%) patients return of spontaneous circulation was achieved at any moment during CPR and 3 (8.1%) patients were still alive after one month. The lifeboat AED was used in 12 patients. Their recordings show a high median compression frequency (120, IQR 111–131) and prolonged median interruption periods (pre-analysis pause 11s (IQR 10–13), post-analysis pause 4s (IQR 3–8), pre-shock pause 24s (IQR 19–26), post-shock pause 6s (IQR 6–11), ventilation pause 6s (IQR 4–8) and other pauses 9s (IQR 4–17)).

Conclusions: Compared to most out-of-hospital resuscitations, resuscitations by lifeboat crews have a low incidence, occur under difficult circumstances and in a younger population. AED's on lifeboats have not contributed to any of the survivals. Analysis of AED information can be used to study the quality of CPR and provide input for improving future training of lifeboat crews.

Keywords: Cardiopulmonary resuscitation, Lifeboats, Automated external defibrillators, Prehospital, Out-of-hospital cardiac arrest, Drowning, First aid and CPR, Quality, Survival

Introduction

The Royal Dutch Lifeboat Institution (KNRM) has a formal governmental task for Search and Rescue (SAR) in the North Sea and most large open waters in the Netherlands. About 900 volunteer lifeboat crew members, distributed over 45 lifeboat stations, are available for Search and Rescue (SAR) missions. Lifeboat crew members respond to many different types of alarm calls, including cardiac arrests. During cardiopulmonary resuscitation (CPR), the crew has to operate under extra-ordinary austere, and sometimes gruesome, circumstances, such as high waves, stormy winds, shaking of the boat, noise, limited space, heavy survival suits, gloves and no direct supervision.

Abbreviations: KNRM, Royal Dutch Lifeboat Institution; SAR, Search and Rescue; CPR, cardiopulmonary resuscitation; AED, automated external defibrillators; OHCA, Out of Hospital Cardiac Arrest; ROSC, return of spontaneous circulation; CCF, chest compression fraction.

* Corresponding author at: Department of Anaesthesiology, Erasmus MC University Medical Centre, 's-Gravendijkwal 230, 3015 CE Rotterdam, The Netherlands.
E-mail address: jeroenseesink@gmail.com (J. Seesink).

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Each KNRM lifeboat has an automated external defibrillators (AED) on board. The use of an AED has been associated with increased survival in Out of Hospital Cardiac Arrest (OHCA) in a large variety of studies were the AED had been used in community programmes and in crowded places such as airports, casino's and airplanes.[1–7] Only very few data is available about the circumstances and outcomes of resuscitation and the use of AEDs on lifeboats.[8–11]

The aim of this study is to evaluate circumstances, patient outcomes and quality of CPR performed by lifeboat crewmembers.

Setting

The KNRM has a structured CPR training programme for all crew members that includes regular instruction and retraining. Over 90% of all crewmembers have a valid CPR and first aid certificate. In 2011, 67 AED's were distributed over the lifeboat stations and lifeboats.

Methods

Data collection for circumstances and outcome of resuscitation

It is by a rigid protocol that the lifeboat's captain produces a structured electronic report after each mission. A separate section in this report has to be completed in missions when first aid and CPR is performed. All reports are stored in an internal electronic database (Central Information System by Xelion BV Delft 2009). A retrospective search was made by the resuscitation coordinator (TL) in the database of the KNRM to collect data from all resuscitations between July 2011 and December 2014 using the terms resuscitation and cardiac arrest. From December 2014 to December 2017 each new resuscitation that has been entered in the database was immediately included. In an additional search, media (KNRM website, KNRM newsletter, internal KNRM newsletter and online newspapers) were searched to identify possible missing reports. The Utstein guidelines for uniform reporting of data of out-of-hospital cardiac arrest[12] and drowning[13] were used to structure the registration of the data with regard to circumstances and outcome. To obtain missing data, regional ambulance services and hospitals have been contacted by telephone and/or email by the medical adviser of the KNRM. If needed, additional data was collected from available press releases and questionnaires that each crewmember has to complete when involved in a resuscitation.

Data collection for quality of resuscitation

All 67 AED's used by the KNRM are Philips Hearthstart FRx. Stored electronic registrations of the AED have been used to assess the quality of the CPR. The Philips Hearthstart FRx registers when the AED is switched on and off, when pads are attached and removed, the start and end of rhythm analysis and if a shock has been delivered. The hardware and software does not provide an accelerometer and usable thoracic impedance analysis to detect breathings. Therefore, the AED does not provide an automatic analysis of relevant CPR quality parameters such as ventilations and compressions. Correspondence with the manufacturer did not lead to any software-based solution. To overcome this limitation, all ECG signal patterns had to be identified manually, and analysed by 2 independent reviewers (JS, SN) by means of a priori established definitions of the ECG signal patterns and CPR quality parameters (Tables 1 and 2). All discrepancies have been discussed with a third independent reviewer (RK) to obtain consensus. To structure the registration of CPR quality, a rationale for measuring and reporting quality of CPR by an international consensus working group has been used.[14]

A maximum period of 15 min was stored in the internal memory of the AED for each resuscitation. In two resuscitations, the duration has been longer than 15 min.

Data processing

All descriptive data was collected and analysed in IBM SPSS Statistics for Windows (Version 22.0, 2013 Armonk, NY: IBM Corp.). All ECG recording data were collected and processed in Microsoft Excel 2013.

Ethical approval

The study protocol has been approved by the Institutional Ethical Committee of Erasmus MC University Medical Centre (MEC-2019-0097).

Results

Circumstances and outcome

In total, 53 resuscitations reports were identified. Sixteen were excluded from the analysis of circumstances and outcome because lifeboat crews were present at the site where resuscitation had been performed, but they were not actively involved (Fig. 1).

Circumstances and outcome of all 37 resuscitations by lifeboat crews are shown in Table 3. Twenty-nine (78.4%) of the resuscitations occurred under unfavourable, or even life-threatening, conditions with waves up to 5 m, water temperatures up to 5 °C, air temperatures up to 4 °C and wind speeds up to 9 Beaufort. In 24 (64.8%), the CPR was situated on board of a lifeboat or another ship. In 27 (73.0%) patients, the lifeboat crew was the first rescue service to arrive on location. Witnessed arrest and bystander CPR before the crew arrived were the case in 13 patients (35.1%) and 15 patients (40.5%), respectively. The median response time from alarm call until arrival of the lifeboat crew on location was 15 min (IQR 9–30). CPR duration varied between 8 and 140 min, with a median of 32 min. In 11 (29.7%) patients return of

Table 1 – The definitions of the ECG signal patterns used in this study.[15–18]

CPR parameter	Definition of the ECG signal pattern
Compressions	Consecutive waveform patterns, characterised by a frequency and duration that is typical for CPR and does not match the pattern of a ventricular contraction.
Chest compression block	A minimum of 5 compressions.
Pause	At least 3 s without chest compressions.
Ventricular contractions	An evident QRS-complex with associated repolarisation
Artefacts	Waveform patterns that does not match the patterns of compressions or ventricular contractions.

Table 2 – The definitions used in this study and results of the CPR quality parameters.

CPR quality parameters	Definition	Median (IQR 25–75%)
Compression parameters		
Duration of compression block	Duration of at least 5 compressions without pauses (seconds).	16 (IQR 14–18)
Number of compressions per block	The total number of compressions during one compression block.	31 (IQR 30–34)
Compression frequency	The average frequency of compressions during one compression block (compressions per minute).	120 (IQR 111–131)
Chest compression fraction (CCF)	The percentage of the total CPR time where compressions are given.	67 (IQR 54–70)
Compression pauses		
Pre-analysis pause	The time between the last chest compression and the AED advise to shock or to continue CPR (seconds).	11 (IQR 10–13)
Post-analysis pause	The time between the advice to continue CPR and the first chest compression (seconds).	4 (IQR 3–8)
Pre-shock pause	The time between the last chest compression and the shock (seconds).	24 (IQR 19–26)
Post-shock pause	The time between the shock and the first chest compression after the shock (seconds).	6 (IQR 6–11)
Ventilation pause	A non-analysis or shock pause of less than 15 s after a chest compression block of 30 ± 10 chest compressions (seconds).	6 (IQR 4–8)
Other pause	All non-analysis or shock pause that not fit the criteria for ventilation pause (seconds).	9 (IQR 4–17)

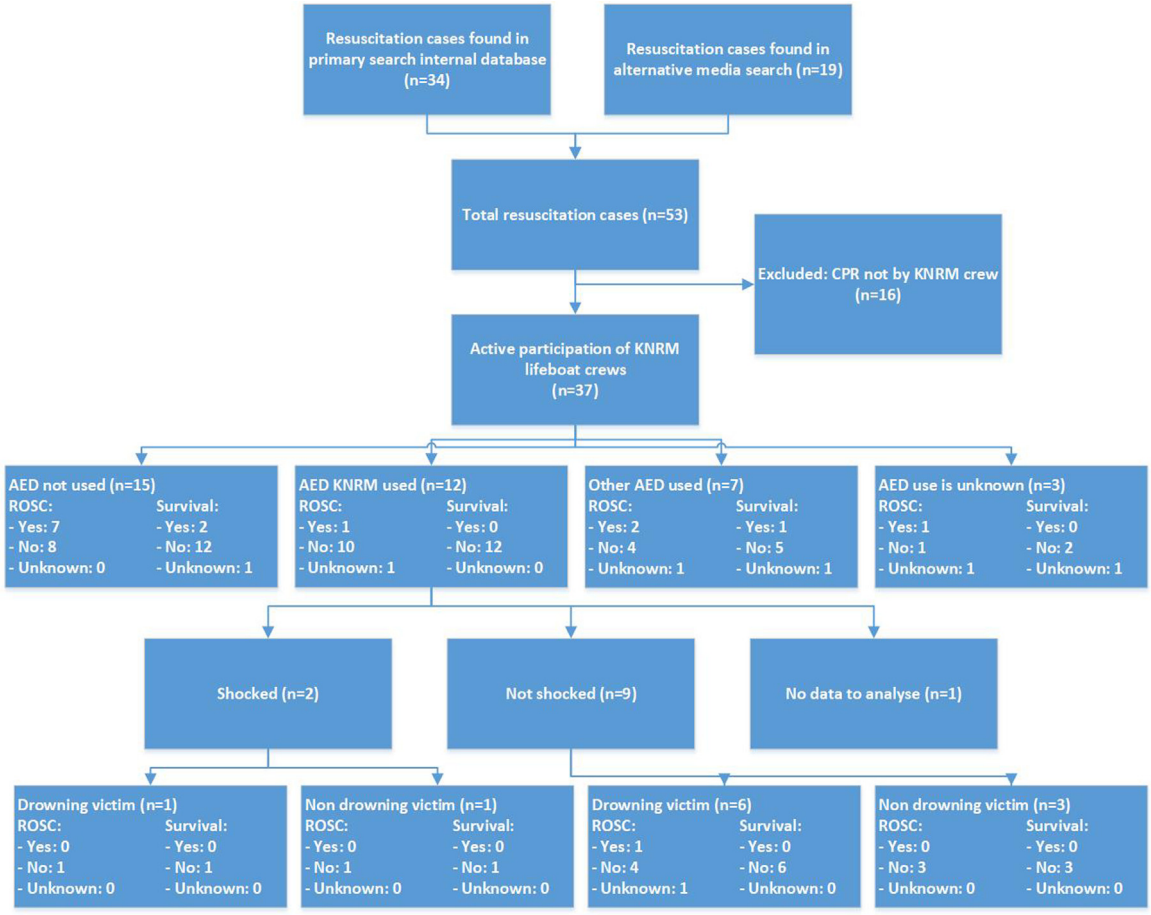

Fig. 1 – Study population and outcome.

spontaneous circulation (ROSC) was achieved at any moment during CPR by the lifeboat crews and 3 (8.1%) patients were still alive after one month. 27 (73.0%) patients had drowned. The age of the patients varied between 11 and 80 years old.

Three patients survived (8.1%). One patient who survived the cardiac arrest was a drowned kite surfer who was resuscitated on the beach. Another patient suffered from a cervical fracture due to a dive in shallow water and subsequently had a cardiac arrest due to drowning. The third patient had a cardiac arrest at home. It happened that a crew was training nearby.

The AED of the lifeboats was used in 12 patients (8 drowning, 4 non-drowning). None of these patients survived (Fig. 1). One shock

Table 3 – Circumstances and outcome of the resuscitations with active participation of lifeboat crews.

	Parameter	*n*	Results
Weather	Wind speed (Bft)	37	Median (IQR 25–75%): 3 (2–4)
	Wave height (m)	28	Median (IQR 25–75%): 0.5 (0–1)
	Water temperature (°C)	22	Median (IQR 25–75%): 16 (11–19)
	Air temperature (°C)	23	Median (IQR 25–75%): 18 (12–21)
	Visibility (miles)	34	Median (IQR 25–75%): 10 (5–10)
	Weather conditions	37	Good/sunny/unknown: 30 (80.1%)
			Fog/rain: 5 (13.5%)
			Glazed frost/snow/bad weather: 1 (2.7%)
			Thunderstorm: 1 (2.7%)
	Weather score (Table 4)	37	Favourable: 8 (21.6%)
			Unfavourable: 25 (67.6%)
			Very unfavourable: 3 (8.1%)
			Life-threatening dangerous: 1 (2.7%)
Patient	Sex	37	Man: 35 (94.6%)
			Woman: 2 (5.4%)
	Age	31	Median (IQR 25–75%): 51 (33–57)
Location	Incident location	37	Inland water: 16 (43.2%)
			North sea: 14 (37.8%)
			Harbour: 5 (13.5%)
			On land: 2 (5.4%)
	CPR location	37	On board of lifeboat: 13 (35.1%)
			On board of vessel/ship: 11 (29.7%)
			Beach: 9 (24.3%)
			Land: 4 (10.8%)
	Location ambulance crew	37	On land when incident on water: 22 (59.5%)
			On board of lifeboat: 8 (21.6%)
			On land when incident on land: 2 (5.4%)
			On board of other vessel: 1 (2.7%)
			Other location: 4 (10.8%)
CPR	Witnessed arrest	37	Yes: 13 (35.1%)
			No: 21 (56.8%)
			Unknown: 3 (8.1%)
	Drowning	37	Yes: 27 (73.0%)
			No: 10 (27.0%)
	Bystander CPR	37	Yes: 15 (40.5%)
			No: 22 (59.5%)
	AED used	37	Yes: 19 (51.4%)
			No: 15 (40.5%)
			Unknown: 3 (8.1%)
	Lifeboat is first rescue service on location	37	Yes: 22 (59.5%)
			No: 10 (27.0%)
			Together with ambulance service: 5 (13.5%)
Time registration (hours)	Alarm call – departure from lifeboat station	36	Median (IQR 25–75%): 0:07 (0:05–0:10)
	Departure from lifeboat station – arrive on site	37	Median (IQR 25–75%): 0:08 (0:04–0:17)
	Alarm call – arrive on site	36	Median (IQR 25–75%): 0:15 (0:09–0:30)
	Event – BLS	24	Median (IQR 25–75%): 0:15 (0:04–0:40)
	Alarm call – AED attachment	15	Median (IQR 25–75%): 0:26 (0:11–1:16)
	Total time BLS	24	Median (IQR 25–75%): 0:32 (0:25–0:45)
Outcome	ROSC[a]	37	Yes: 11 (29.7%)
			No: 24 (64.9%)
			Unknown: 2 (5.4%)
	Survival[b]	37	Yes: 3 (8.1%)
			No: 31 (83.8%)
			Unknown: 3 (8.1%)

[a] Return of spontaneous circulation.
[b] Known survival to 30 days or hospital discharge.

Table 4 – Weather score (as used in reporting on Dutch aquatic incidents by G.J. van der Ploeg). Score: 1–3 = favourable; 4–6 = unfavourable; 7–9 = very unfavourable; >9 = life-threatening dangerous.

Weather score	1	2	3	4
Wind speed (Bft)	0–2	3–5	6–9	>9
Wave height (m)	<0.5	0.5–1.0	1.1–2	>2
Weather circumstances	Good/sunny/unknown	Fog/rain	Glazed frost/snow/bad storm	Thunderstorm

Fig. 2 – Shock given in a non-shockable hearth rhythm.

was delivered to a drowning victim with a non-shockable hearth rhythm. The patient was missing in 6 °C water for more than 1 h before he was found. Eight minutes after attachment of the pads an incorrect shock was given by the AED while during the analysis pause, there was asystole with artefacts on the ECG (Fig. 2). Two shocks were given to a patient with ventricular fibrillation. The lifeboat arrived 11 min after the call for a cardiac arrest. This patient has not achieved ROSC.

The median time between the alarm call and attachment of the AED was 26 min (IQR 11–76). The minimum of zero minutes was reached in a patient who suffered a cerebrovascular accident and turned in resuscitation setting while the lifeboat crew was already on board with the patient. The maximum time to attachment of 115 min was in a patient where a crewmember of a cargo ship was fallen overboard and missing for two hours before he was found. In all three patients that survived the cardiac arrest, the lifeboat was the first to arrive on location at 3, 13 and 22 min after the call.

Quality of resuscitation

Eleven of the 12 AED recordings were available for quality analysis (Table 2). The analysis covered 99 min of CPR, 197 blocks of CPR, 45 rhythm analysis and 3 shocks. The recordings show a high median compression frequency, long median pauses and extreme values for the ranges of compression rate and other pauses. In one patient, only ventilation and analyse pauses were registered and no other pauses, as recommended by the ERC. In one patient no ventilation pause was registered. The median chest compression fraction (CCF) was 67%, ranging from 17 to 83%.

Discussion

Few studies have reported that CPR and the use of AED's is possible on merchant ships and, under experimental settings, in lifeboats.[8–11,19–21] As far as we know, this is the first study that reports the outcome of resuscitation performed by an operational lifeboat service. In this study, the survival after 1 month is 8.1% and no additional effect of the use of AED's on outcome has been found. Moreover, this study shows that an AED can be used for the retrospective evaluation of the quality of CPR, performed by trained lifeboat crewmembers without direct supervision. Similar studies in prehospital settings have demonstrated that this is an effective way of evaluating the quality of CPR.[16,17,22]

CPR duration varied between 8 and 140 min; depending on the moment when ambulance service took over or confirmed the death of the patient. ROSC occurred in 11 (29.7%) resuscitated patients at some moment during the resuscitation and 3 (8.1%) were still alive after one month. This survival rate is within the range of international OHCA studies (Europe: 1.1–30.8%, United States: 3.4–22.0%). However, the survival rate in these aquatic circumstances is below the average Dutch OHCA survival of 22%.[23,24] In all three patients who survived, the lifeboat crew was the first of the responding emergency services arrived on scene. As no shock was given by the lifeboat crew, the AED of the lifeboat did not contribute to survival of any of these three patients. It may be assumed that the absence of a beneficial effect of the AED is related to a relatively long median arrival time of 15 min, with more than 2 h as the maximum response time.[1,3,25–27] Another explanation may be the high percentage (73%) of drowning victims in the study. It is consistently reported that less than 10% of drownings are associated with a shockable rhythm.[25,28–31] The AED is only one factor, whereas the whole rescue chain should work well for a good survival.[32]

A remarkable observation of this study is that several resuscitations occurred under unusual conditions such as waves up to 5 m, wind speeds up to 9 Beaufort, temperatures of air and water below 5 °C, delays up to 2 h and a low incidence of exposure: 37 resuscitation patients in 6 years over 45 lifeboat stations with 900 crew members. Nevertheless, the survival rate of 8.1% in these challenging aquatic circumstances is within the normal international range for OHCA.[23,24] This may be due to the high percentage of drowning victims. Drowning victims may have an increased chance of successful resuscitation in specific conditions as they are generally young and may be affected by the protective effects of hypothermia.[28,29,33,34] In this study population

the median age is 51, but the average temperature of the water is too warm to benefit from rapid hypothermia. In one patient an incorrect shock has been given by the AED while there was asystole with many artefacts on the ECG, possibly also due to the unusual conditions.[8,35,36]

For the KRNM, it is important to monitor the quality of CPR to improve the quality of future crew training. For this reason, the data on CPR quality was of great interest, but collecting this data was only possible by means of a time-consuming manually method. The results of this method provide sufficient preliminary information for suggestions which elements of the lifeboat crew training could be improved. The results show that overall the chest compression frequency is often too high, are interrupted too long and that the chest compressions are not only interrupted for ventilations and AED analysis or shocks. The most pronounced inaccuracy was a median compression frequency of 120 compressions per minute. This resulted in a frequency that was too high in 50% of all compression blocks. Identical findings have been reported in studies that evaluated quality of resuscitation by lifeguards.[9,11,37] The most relevant clinical inaccuracy seems to be the prolonged compression pauses. The overall observation is that too much time is lost by pauses, most of all regarding the non-analysis pauses. Longer compression pauses are associated with a decrease in survival from OHCA.[1,15,16,38] A CCF of 80% is regarded as the standard for a trained rescuer.[1,15,17,18,39,40] However, in this study only in one of the patients a CCF of 80% was reached. In four patients the CCF was below 50% of which one was 17%. In comparison with previous literature, the median pre-shock pause of 24 s is prolonged in the 3 shocks that were given during the study. The median post-shock pause of 6 s is consistent with previous research results.[15,16,38] In all but one patient the median count of compressions per block was about 30, but in one patient the median count was 130 compressions. In this patient no ventilation pauses have been observed, which most likely means that this patient has not been ventilated.[1,29,30,33]

There were some limitations in this study. First of all, the data in the rescue reports have not always been complete. By comparing the data with other available data (press releases, questionnaires, AED data) and by contacting ambulance services and hospitals it was attempted to obtain the maximal completeness and reliability of the data of each rescue.

It was only possible to study the quality of CPR for those patients who had been connected to an AED. There is no reason to believe that this has caused biased insight in the general quality of CPR under the prevailing circumstances.

Another limitation of this study was that a manual analysis of the AED recording data was needed. The AEDs used in this study had no full set of analysis software available, most of all due to the lack of an accelerometer and the lack of an usable automated analysis of the thoracic impedance signal to detect breathing. Automated analysis of the transthoracic impedance signal and use of accelerometers allows an easier and more reliable method to obtain data that reflect the CPR quality. The independent double review of the AED data provided the best possible data. Although many prolonged compression pauses during the CPR have been observed, it was not possible to identify the reasons for these interruptions.

Finally, our study covered a period of 78 months of resuscitation by lifeboat crews. It may be well possible that the use of the AED may result in ROSC and survival in a study over a longer period or with inclusion and analysis of data from other involved rescue organisations in the total of 53 resuscitations, such as fire fighters or police officers. This information is however not available.

Conclusion

The occurrence of resuscitations by lifeboat crews is very low, and these resuscitations occur in more difficult circumstances and in a younger population than in most out-of-hospital resuscitations. The survival of 8.1% (3 out of 37 patients) is within the reported international range for OHCA, but below the relatively high Dutch standard. In this study, the AED's of the lifeboats did not contributed to survival.

Lifeboat crews often provide thoracic compression with too high frequencies and too long interruptions. This information is relevant feed-back to the CPR instructors of the lifeboat crews.

Conflict of interest

Dr. Bierens and Mr. Van der Linden are responsible for the content and structure of the medical training of KNRM lifeboat crews. They receive payment from the KNRM for coordinating the training programme. No other conflict of interest was reported.

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