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Clinical paper

Release velocity ImprovemenT with a new Metronome guiding chest COmpressions: The RITMICO simulation study

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Abstract

Background and trial design: Outcomes of out-of-hospital cardiac arrest vary significantly, often due to the quality of cardiopulmonary resuscitation (CPR) provided. Automated real-time feedback devices have been explored to enhance CPR skills, but few devices currently ensure proper chest recoil. This study aimed to assess whether a double-click metronome could improve chest compressions (CC) metrics and particularly CC release velocity (CCRV) during CPR manikin simulation.

Methods: We developed and tested a double-click metronome for CPR, where the first click signals the compression and the second click marks the end of chest release. We performed a multicenter non-blinded, randomized, controlled trial including volunteers with different levels of CPR expertise. Three CC metrics—depth, rate, and CCRV—were measured using an automated external defibrillator equipped with pads for CPR quality analysis.

Results: 503 volunteers participated in the study, with 54% being male and a mean age of 34 ± 12 years. The median CCRV and CC depth achieved with the double-click metronome were significantly higher compared to the standard metronome (median difference 6 mm/s, IQR-15.2, 28.5, +1.5%, $p < 0.001$; median difference 0.1 cm, +2.5%, IQR −0.1, 0.4, $p < 0.001$). The double-click metronome led to significant improvements in CC depth and CCRV across all volunteer categories, with the greater effect observed in first responders and in non-specialized healthcare personnel.

Conclusions: Compared to a standard metronome, the double-click metronome significantly enhances CPR quality. If further validated in real resuscitations, this new audio prompt could be a valuable tool for integration into devices designed for out-of-hospital cardiac arrest resuscitation, as well as a training tool to improve CPR quality.

Keywords: Out-of-hospital cardiac arrest, Cardiopulmonary resuscitation, Audio prompt, CPR quality

Introduction

Out-of-hospital cardiac arrest (OHCA) is the most frequent cause of death in the industrialized countries.[1,2] Despite advances and development related to cardiopulmonary resuscitation (CPR) in the last 10 years, a high incidence of cardiac arrest is still observed with low rates of survival to hospital discharge. Survival to hospital discharge rates range between 2% and 18%, making cardiac arrest a worldwide health challenge with high rates of morbidity, mortality and associated costs.[3,4]

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Appropriate CPR is imperative to the perfusion of vital organs during a cardiac arrest, improving the chances of achieving return of spontaneous circulation (ROSC), survival from hospital discharge and good neurological outcome.[2] To achieve high quality CPR, the International Liaison Committee on Resuscitation (ILCOR) recommends a manual chest compression (CC) rate of 100–120 min, a CC depth of approximately 5 cm and suggests that people performing manual CPR avoid leaning on the chest between compressions to allow full chest wall recoil.[5,6] However, for this latter metric, ILCOR provides only a weak recommendation, with very-low-certainty evidence.[5,6] Despite advances in training, technology, simulation and dispatch assisted CPR, it has been demonstrated that CPR quality for lay people, basic life support (BLS) and advanced life support (ALS) rescuers is often suboptimal.[4,7] Automated real-time feedback devices have been considered a potential tool to improve acquisition and retention of CPR skills, consequently enhancing the quality of CPR.[8,9] Among these, audio prompts (i.e. metronome) and audio-feedback help to maintain an adequate CC depth and rate and are widely available in automatic external defibrillators (AED).[10–12] However, despite a wide diffusion of tools helping to achieve adequate CC rate and depth, few tools are currently available to guarantee adequate chest recoil. Chest recoil is very important for coronary and brain perfusion.[13–15] In a real-resuscitations study, it was demonstrated how the achievement of a CC release velocity (CCRV) of, at least, 400 mm/sec correlated to a better survival with good neurological outcome.[16]

To provide feedback for both compression and recoil phase of CC, we developed a modified metronome rhythm (double click) which considers both CC frequency and CCRV. The primary aim of this study was to assess if a modified protocol for CC with a double-click metronome improves CPR metrics and particularly CCRV measured by AED. Performance of the double-click metronome was investigated during manikin simulation and compared to that obtained with a standard metronome.

Methods

Description of the double-click metronome

We developed a new double-click metronome in which the first tone gives the rhythm for the compression phase, and is rapidly followed by a second tone, which gives the rhythm for CCRV and corresponds to the end of chest release (audio file 1 in supplemental materials). This modified metronome was compared with a standard metronome (single tone, rate 100 bpm).

Trial design

This is a multicentre non-blinded, randomized, controlled trial involving International EU and non-EU participating centres. The Ethics Committee approved the study (Formal Clarification of Responsibility request number Req-2021-01391), which was conducted in accordance with the Declaration of Helsinki.

Consecutive volunteers, trained in basic life support-defibrillator (BLS-D) were selected for the study participation from 5 different European centres: Ticino Cuore Foundation, Canton Ticino, Switzerland; Fondazione IRCCS, Policlinico San Matteo of Pavia, Italy; University hospital “Policlinico Paolo Giaccone”, Palermo, Italy; University Hospital of Greifswald, Germany; University hospital of Freiburg, Germany. Three different categories of volunteers were included: (1) first responders (including non-professional first responder and on-duty first responder); (2) healthcare personnel (non-critical area) and, (3) specialized healthcare personnel (professional rescuers from ambulance teams and critical care settings). Flowchart of the study protocol is presented in Fig. 1. All volunteers performed 4-min (2 min–10 s pause-2 min) CC simulation protocol guided by both a standard metronome and double-click metronome on a CPR-manikin with medium resistance (45 kg). The order of the two simulations was randomized using a computer-generated sequence. When a volunteer was registered in the online database, the platform automatically assigned the sequence of simulations. Before simulation, participants were briefly trained with an instruction video in their native language. Between the 2 simulations' protocols each volunteer had 10 min of rest. AED original audio prompts were silenced (only external metronome was used to guide subjects). The 3 metrics of CC (depth, rate and CCRV) were assessed via the accelerometer included in an AED (ZOLL Medical A3, Zoll Medical corporation Chelmsford, 269 Mill Road, Chelmsford, MA 01824–4105 U.S.A.) using Q-CPR pads (ZOLL Medical Training CPR Uni-padz, Zoll Medical corporation Chelmsford, 269 Mill Road, Chelmsford, MA 01824-4105 U.S.A.). AED original audio prompts were silenced (only external metronome was used to guide subjects).

Demographic data collection

Age, sex, professional category, number of resuscitations per year, time since last resuscitation, date of last BLS-D course and level of familiarity (1 to 5) with use of a metronome were collected.

Data analysis

Raw data on CC depth, rate and CCRV of each compression were extracted. Standard ranges for CC were considered as follows: compression depth higher than 5 cm, compression rate between 100 and 120 compression per minute (CPM) and CCRV higher than 400 mm/s.

Exclusion criteria included incomplete data and CC with a depth higher than 10 cm or with a CCRV higher than 700 mm/s, supposed to be unrealistic and caused by data acquisition errors. For each simulation, the median value for each of the three metrics was calculated.

Statistical analysis

All analyses were performed using Python 3.10 (Scipy 1.13.1 and Statsmodels 0.14.2 libraries). A one-sided $p < 0.05$ was considered statistically significant. Continuous variables were reported as mean and standard deviation or median and quartiles if skewed. Categorical variables were reported as counts and percent. Volunteer-specific factors (age, sex, professional category, number of resuscitations per year, time since last resuscitation, date of last BLS-D course, level of familiarity (1–5) with use of a metronome and order of simulations) eventually affecting difference between the two protocols (standard versus double-click metronome) were assessed with stepwise regression analysis. A linear stepwise regression was conducted using a combined forward and backward selection procedure. The selection criterion was based on the Akaike Information Criterion (AIC). A p-value threshold of 0.05 was applied.

Comparison between median values of the 3 metrics observed with double-click metronome with respect to standard metronome was computed with one-sided Wilcoxon signed-rank test.

Relationship among metrics was evaluated with Spearman's rank correlation.

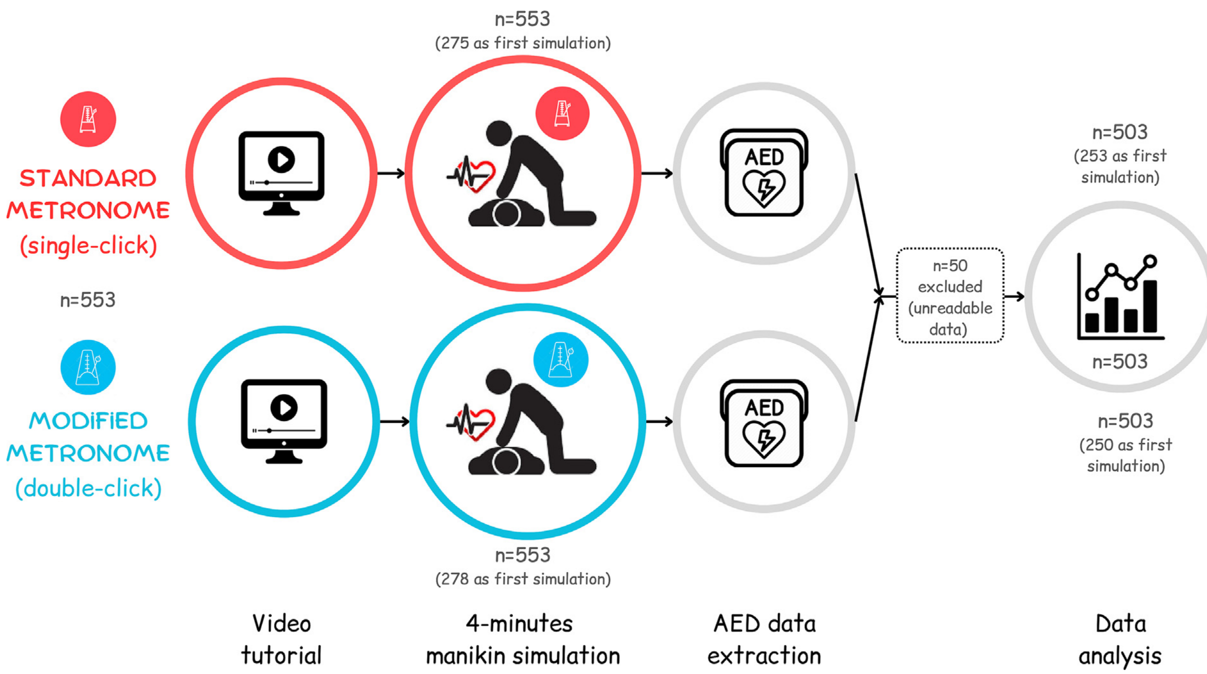

Fig. 1 – Flowchart of the study protocol.

Results

We enrolled 553 volunteers in the study of whom 50 were excluded (9%), due to incomplete or unrealistic data recording in at least one of the two simulations, leading to a final sample of 503 subjects corresponding to 1006 simulations (see Fig. 1). Demographic data were reported in Table 1. 54% of volunteers were males, mean age was 34 ± 12 years old, 42% were specialized healthcare personnel. 48% of volunteers performed 1–6 resuscitations per year and 42% had a recent BLS-D course. 74% of volunteers declared a high level of familiarity with the metronome as feedback tool (see Table 1).

After the stepwise selection, the final model included only the order of the two simulations as predictor of the observed difference in CC depth (β −0.123, p 0.007) and in CC rate (β 1.101, p 0.02).

Comparison of standard versus double-click metronome

The distribution of the median values of the three metrics measured in the two simulations (standard versus double-click protocol) are shown in Table 2 and in Fig. 2. Median CCRV and CC depth obtained with the double-click metronome were significantly higher respect to the standard metronome (median difference 6 mm/s, IQR-15.2, 28.5, +1.5%, p < 0.001; median difference 0.1 cm, +2.5%, IQR −0.1, 0.4, p < 0.001). A slight increase in CC rate was also observed with the double-click metronome respect to the standard one (median difference = 0.01 CPM, IQR −0.3, 1.8, + 0.1%, p < 0.001). With both protocols median CC rate distribution remained in the suggested range for the metric.

When considering the order of simulations, increment in CC rate and release velocity was higher when the order of simulations was standard/double-click protocol (median difference = 8.5 mm/s, IQR −14, 31, +2.2%, p < 0.001 for CCRV; median difference = 0.2 CPM, IQR −0.14, +2.18, +0.2%, p < 0.001 for CC rate) with respect to double-click/standard (median difference = 4 mm/s, IQR −17, 25, +1%, p < 0.05 for CCRV; median difference = 0.0002 CPM, IQR −0.43, +1.35, +0.0002%, p < 0.05 for CC rate). Increment in CC depth instead was found to be higher when the order was double-click/standard (median difference = 0.2 cm, IQR −0.1, 0.5, +3.6%, p < 0.001) with respect to standard/double-click protocol (median difference = 0.1 cm, IQR −0.2, 0.3, +1.5%; p < 0.001).

Results of the two simulations according to volunteers' professional category are reported in Table 3. When comparing the double-click metronome to the standard metronome simulation, CC depth significantly increased across all categories. The greatest increase was observed in first responders (+3.2%), followed by healthcare personnel and specialized healthcare personnel (2.1% and 2.2% respectively). In contrast, CCRV showed a significant increase only in first responders (+1.3%) and healthcare personnel (+2.6%).

Relationship among the 3 metrics

Exploring the relationship among the 3 metrics, a significant positive correlation between CC depth and CCRV was observed (r = 0.75, p < 0.001). Moreover, a significant but weak correlation between CC rate and CCRV was observed (r = 0.2, p < 0.001).

Discussion

To the best of our knowledge, this is the first study to develop and implement a new metronome rhythm specifically designed to guide CPR by focusing on both the chest compression and chest recoil phases. The study's main findings demonstrate that the double-click metronome significantly improves CPR quality compared to a standard metronome, enhancing both chest compression depth and release velocity. Furthermore, this audio prompt is practical and effective across a wide range of providers, with particularly notable performance improvements observed among less specialized rescuers.

Table 1 – Demographic characteristics of study population.

	n = 503
Age (years, mean ± std)	34 ± 12
Sex, *n* (%)	
Female	229 (46)
Male	274 (54)
Professional category, n (%)	
First responder	118 (24)
Healthcare personnel	173 (34)
Specialized healthcare personnel	212 (42)
Mean number of resuscitations per year, *n* (%)	
0	195 (39)
1–6	243 (48)
6–12	41 (8)
>12	24 (5)
Last resuscitation, *n* (%)	
Never	171 (34)
>6 months	146 (29)
4–6 months	70 (14)
<3 months	116 (23)
Time since last BLSD course, *n* (%)	
>2 years	106 (21)
1–2 years	122 (24)
6 months–1 year	67 (13)
<6 months	208 (42)
Familiarity with a metronome, *n* (%)	
1 (none)	7 (1)
2	15 (3)
3	111 (22)
4	217 (43)
5 (a lot)	153 (31)

High-quality CPR is a critical determinant of outcomes for patients experiencing cardiac arrest, yet CPR quality in both prehospital and in-hospital settings is highly variable. Common deficiencies include compressions with insufficient depth or rate, frequent and prolonged interruptions, and incomplete chest recoil.[17–19] CPR quality, a modifiable factor, can be improved through audio-visual feedback tools.[20] However, studies evaluating these tools have yielded mixed results,[21,22] with some showing promising outcomes by demonstrating improvements in ROSC and survival at discharge,[23,24] while others report neutral results regarding survival.[25–27] A recent meta-analysis by Kahsay et al.,[20] assessing the impact of standalone feedback devices on laypersons' CPR quality, found that these tools generally improved compression depth without compromising compression rates. However, they did not enhance chest recoil or hand placement quality. Similarly, Wingen et al.,[12] in a simulation study comparing four app-linked real-time feedback devices among lay volunteers, observed improvements in certain metrics but found that none supported overall adequate CPR performance. In contrast, our study demonstrated a significant improvement in both chest compression (CC) depth and chest compression release velocity (CCRV) with the use of the double-click metronome compared to the standard metronome.

Consistent with other studies,[28] we found a significant positive correlation between CC depth and CCRV, suggesting an interdependence of these metrics. This relationship likely explains why the double-click metronome improved both metrics simultaneously. Additionally, the sequence of simulations emerged as a significant predictor of variations in CC depth and rate. Specifically, CC rate and velocity improved more when the double-click metronome was used during the second simulation. A plausible explanation for this improvement is that the initial simulation with the standard metronome may have served as a training session, better preparing participants for the subsequent simulation. Furthermore, the high level of familiarity reported by volunteers with metronomes as an audio tool for CPR likely facilitated their rapid adaptation to the double-click rhythm, leading to enhanced performance.

Previous studies have also examined factors affecting CPR quality, including methods for reducing rescuer fatigue. In a small simulation study by Dong et al.,[29] different resting methods were tested to improve hands-only CPR quality among lay rescuers by reducing fatigue. Appropriate transient rests were associated with better CC depth and fraction and lower subjectively perceived fatigue. Similarly, Kim et al.[30] analyzed expert CPR providers' ability to maintain adequate CC depth and rate according to different resting pause timings between CC cycles. They didn't find significant differences in CPR performance across the various protocols tested. However, these studies were limited to specific rescuer categories in single-center settings and did not evaluate chest recoil.

In contrast, our study assessed the double-click metronome across various rescuer categories, demonstrating significant CPR quality improvements even among less experienced rescuers. This finding is particularly relevant for first responders, who often perform initial resuscitation during out-of-hospital cardiac arrests. If further studies confirm our findings in real-life resuscitation scenarios, the double-click metronome could become a promising audio prompt for integration into defibrillators and other devices designed for out-of-hospital cardiac arrest resuscitation.

Table 2 – Median and interquartile range (IQR) of the three metrics.

N = 503

	Standard median (IQR)	Double click median (IQR)	Double click – Standard median (IQR), %	*p*-value
CCRV (mm/s)	398 (328, 450)	396 (339, 455)	6.0 (−15.2, 28.5), +1.5%	**<0.001**
CC depth (cm)	6 (5, 7)	7 (5, 7)	0.1 (−0.1, 0.4), +2.5%	**<0.001**
CC rate (CPM)	110 (110, 111)	110 (110, 113)	0.01 (−0.3, 1.8), +0.1%	**<0.001**

Values are reported for both the standard and the double-click metronome protocol and for the difference between the two protocols (double click-standard). CCRV: chest compression release velocity; CC: chest compression; CPM: compressions per minute.

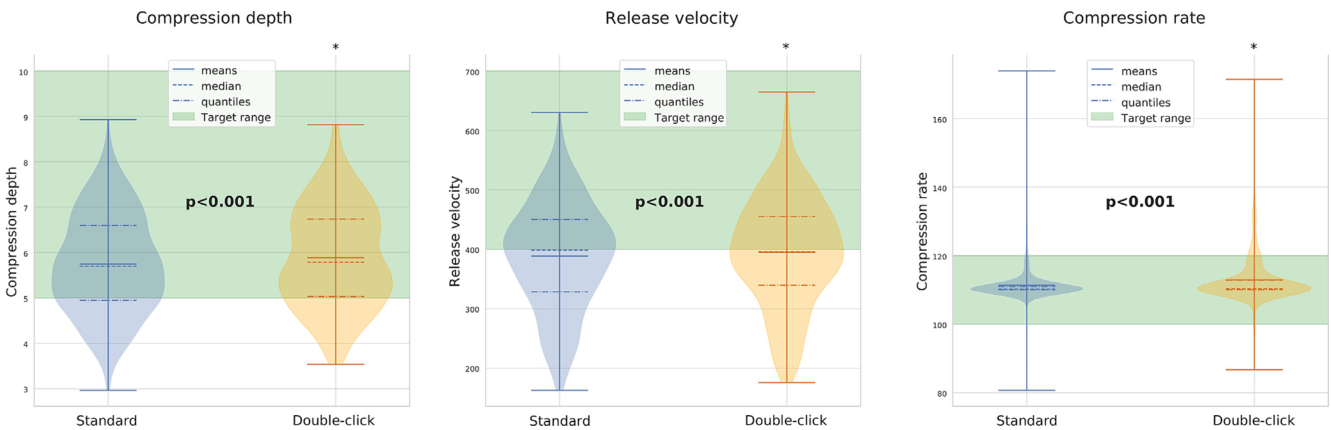

Fig. 2 – Violin plots representing the distribution of the median values of the three parameters (chest release velocity, chest compression depth and rate) resulting with the standard (blue) and the double-click (orange) metronome. In each boxplot the mean, median, 25th and 75th quantiles are reported. The shaded green area represents the valid range for the corresponding metric. An asterisk is reported on top of the orange violin plot if the difference between the double-click and the standard metronome was found to be statistically significant (p < 0.05 with one-sided Wilcoxon signed-ranks test). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 3 – Median and interquartile range (IQR) of the three metrics for each professional category.

First responders (*N* = 118)				
	Standard median (IQR)	Double click median (IQR)	Double click – Standard median (IQR), %	*p*-value
CCRV (mm/s)	400 (324, 459)	410 (352, 470.5)	5 (−19, 31), +1.3%	**<0.05**
CC depth (cm)	6 (5, 7)	6 (5, 7)	0.2 (−0.1, 0.5), +3.2%	**<0.001**
CC rate (CPM)	110.2 (110, 111.1)	110.3 (110, 112.6)	0.06 (−0.25, 1.5), +0.1%	**<0.05**
Healthcare personnel (*N* = 173)				
	Standard median (IQR)	Double click median (IQR)	Double click – Standard median (IQR), %	*p*-value
CCRV (mm/s)	387 (328, 446)	392 (341, 447)	10 (−15, 31), +2.6%	**<0.001**
CC depth (cm)	5 (5, 6)	6 (5, 7)	0.1 (−0.1, 0.5), +2.1%	**<0.001**
CC rate (CPM)	110.2 (110, 111)	110.6 (110.1, 113.4)	0.3 (−0.17, 2.47), +0.3%	**<0.001**
Specialized healthcare personnel (N = 212)				
	Standard median (IQR)	Double click median (IQR)	Double click – Standard median (IQR), %	*p*-value
CCRV (mm/s)	403 (336, 448)	400 (336, 462)	4 (−15, 23), +1.0%	0.082
CC depth (cm)	6 (5, 6)	6 (5, 7)	0.1 (−0.1, 0.3), +2.2%	**<0.001**
CC rate (CPM)	110.2 (110, 111)	110.2 (110, 111.6)	0.06 (−0.28, 1.34), +0.1%	**<0.005**

Values are reported for both the standard and the double-click metronome and for the difference between the two protocols (double click-standard) in terms of median, IQR and percentage. CCRV: chest compression release velocity; CC: chest compression; CPM: compressions per minute.

Limitations

This simulation trial, conducted in a standardized setting using manikins, has several limitations to consider. The CPR duration in our study was restricted to 4 min for each of the two metronome protocols, with a pre-defined pause after the first 2 min. We did not test the potential effects of varying rest pauses on CPR performance.

Participants were provided with a brief training video on the two metronome protocols before starting the simulation. It is likely that users could achieve a higher level of CPR proficiency in real-life scenarios with extended training using the new tool. However, the majority of volunteers expressed a high level of confidence when using the metronome. Additionally, in real-world situations, CPR often needs to be sustained for longer than 4 min before additional rescuers arrive. We did not evaluate the impact of prolonged resuscitation on CPR performance when using the double-click metronome.

Conclusions

The double-click metronome has the potential to significantly enhance CPR quality, particularly improving the performance of a wide range of rescuers, with the most substantial impact on first responders and non-specialized healthcare personnel.

CRediT authorship contribution statement

Maria Luce Caputo: Writing – original draft, Methodology, Conceptualization. **Giuliana Monachino:** Writing – original draft, Methodology, Investigation, Conceptualization. **Ruggero Cresta:** Resources, Data curation, Conceptualization. **Alessia Currao:** Investigation, Data curation. **Enrico Baldi:** Writing – review & editing, Investigation. **Simone Savastano:** Writing – review & editing, Investigation. **Andrea Cortegiani:** Writing – review & editing, Investigation, Conceptualization. **Mariachiara Ippolito:** Data curation. **Sara Accetta:** Project administration, Data curation. **Alessandra Gargano:** Investigation, Data curation. **Camilla Metelmann:** Writing – review & editing, Investigation, Data curation. **Bibiana Metelmann:** Writing – review & editing, Investigation, Data curation. **Carlos Ramon Hölzing:** Data curation. **Julian Ganter:** Writing – review & editing, Investigation, Data curation. **Michael Patrick Müller:** Writing – review & editing, Conceptualization. **Claudio Benvenuti:** Writing – review & editing. **Stefania Tomola:** Investigation, Data curation. **Pierangelo Pinetti:** Investigation, Data curation. **Pier Luigi Ingrassia:** Investigation, Data curation, Conceptualization. **Francesca Dalia Faraci:** Writing – review & editing, Methodology. **Angelo Auricchio:** Writing – review & editing, Methodology.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: "AC is an associate member of the ILCOR Education Implementation and Team (EIT) Task force. MPM is chair of Regions of Lifesavers non-profit first responder organisation, shareholder of SmartResQ Aps, and member of the executive committee of the German Resuscitation Council (GRC). All other authors have no conflict of interest to declare.".

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USE of AI tools statement

During the preparation of this work the authors used *chatGPT* in order to improve language. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Disclosures

AC is an associate member of the ILCOR Education Implementation and Team (EIT) Task force. MPM is chair of Regions of Lifesavers non-profit first responder organisation, shareholder of SmartResQ Aps, and member of the executive committee of the German Resuscitation Council (GRC). All other authors have no conflict of interest to declare.

Appendix A. Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.resplu.2025.100867.

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