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Experimental paper

# Manual versus automatic chest compression devices for cardiopulmonary resuscitation under zero gravity (The MACCC - 0G STUDY)

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## Abstract

**Introduction**: Cardiopulmonary resuscitation (CPR) in microgravity requires specific methods to counteract weightlessness. Automatic chest compression devices (ACCDs) could improve CPR in microgravity. We aimed to compare ACCDs versus manual CPR in microgravity simulated through parabolic flights.

**Methods**: This prospective, open, controlled study compared 3 ACCDs (LUCAS 3©, AUTOPULSE©, EASYPULSE©) to manual CPR during the 66th CNES (Centre National d'Etudes Spatiales) parabolic flights campaign onboard the Novespace Air Zero-G A310 aircraft. Chest compression depths and rates were monitored by a Laerdal© Resusci-Ann-QCPR manikin.

**Results**: The LUCAS 3© device had a median compression depth of 53.0 [53.0–54.0] mm, significantly higher than the EASYPULSE©, AUTOPULSE©, and Manual CPR (Handstand method), measured at 29.0 [26.0–32.0] mm, 29.0 [27.5–30.7] mm and 34.5 [29.6–43.3] mm, respectively ($p$ value < 0.001). Compression rates were 101 [101–101], 100 [100–100] and 80 [80–80] compressions per minute (cpm) for the LUCAS 3©, EASYPULSE©, and AUTOPULSE©, respectively. Manual CPR provided a significantly higher compression rate with 115 [109–123] cpm ($p$ value < 0.001).

**Conclusion**: Only LUCAS 3© provided effective CPR according to international guidelines. ACCDs should implement microgravity CPR algorithms.

**Keywords**: CPR, Microgravity, Parabolic flights, ACCD

## Introduction

Managing cardiac arrest relies on cardiopulmonary resuscitation (CPR) with efficient chest compressions, precisely defined according to current international guidelines as a 50–60 mm compression depth and a 100–120 $\text{min}^{-1}$ compression rate.[1,2] Targeting these parameters is associated with greater survival rate.[3,4]

Microgravity (i.e. the condition in which people or objects appear to be weightless) encountered in spaceflight provides certain physical constraints and studies have found that chest compressions using conventional terrestrial methods failed to provide efficient CPR in such conditions.[5] Adjusted methods have been developed and specific international guidelines have emerged,[6] dividing CPR in Basic and Advanced Life Support (BLS and ALS respectively). For BLS, the Evetts-Russomano[7] and the Reverse Bear Hug[8] methods are considered, while the patient and the rescuer are both pulled towards the medical module of the International Space Station (ISS). Once the patient is strapped on a dedicated medical platform, the Crew Medical Restraint System, CPR can be performed using the Handstand method (HS – CPR), where one pushes their legs on an opposing platform to provide the necessary force with their locked arms above their heads, which improves the compression depth and rate but cannot be performed while moving the patient (see Video in supplemental data 1). However, the proposed methods remain undereffective regarding terrestrial guidelines, and are highly exhausting resulting in an early drop in CPR efficiency.[5,7] Automated Chest Compression Devices (ACCD) are medical devices designed

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to provide mechanical chest compressions with a predefined duty cycle and their benefit have already been demonstrated in case of prolonged resuscitation, improving the return of spontaneous circulation.[9] ACCDs are routinely used on Earth by physicians facing cardiac arrests and are particularly relevant in hostile environments or during refractory (i.e. sustained) cardiac arrests.[10–12] Similarly, the use of ACCDs in microgravity could be a promising option as their performance does not rely on gravity nor the rescuer's physical condition to provide effective CPR. We aimed to compare 3 automatic chest compression devices to manual Handstand cardiopulmonary resuscitation in a prospective, open, controlled manikin study in real conditions of microgravity reproduced by parabolic flights.

## Methods

To promote scientific research in the field of microgravity, the French National Space Agency (CNES) annually supports selected projects and finances parabolic flights performed by Novespace Industries. The study was performed during the 66th Novespace Parabolic Flight Campaign in Merignac, France, organized by the CNES from March 25 to 29th, 2024.

### *Simulating weightlessness*

Parabolic flights took place onboard the Novespace Zero-G A310 Airbus. Thirty parabolas are performed on each flight. Each parabola can be divided into 3 phases: a first phase of hypergravity at 1.8 g lasting 20 s where the plane is accelerated upward to approximately a 45° angle, then a 22-second phase of microgravity at 0 g (simulating weightlessness), and finally another 20-second phase of hypergravity at 1.8 g to pull out the plane to level flight.

### *Manikin and equipment*

CPR was performed on a Resusci-Anne QCPR Laerdal© manikin (Stavanger, Norway) connected to the QCPR Laerdal Skill reporter software. Three automatic chest compression devices were considered for this study: LUCAS 3© (Stryker©, Sweden); Easypulse© (Schiller©, Germany); Autopulse© (Zoll©, USA).

### *Study design and in-flight experimental setup*

This was an open controlled non-randomized manikin study. During the first flight, ten parabolas were dedicated to each ACCD. ACCDs were positioned over the manikin before the parabolas, strictly following the manufacturers' recommendations. Depth of compression and compression rate were recorded during the microgravity phases of the parabola and extracted from the Laerdal Skill reporter software for analysis.

Manual Handstand (HS) CPR was assessed similarly during a second flight by three trained operators (NR, RB and LS). A specific set up was adjusted to perform manual CPR with the current gold-standard Handstand method. The operators were in free floating status once the microgravity phase started, as exposed in supplemental Video data 1. All operators both had previous CPR experience on Earth and had also previously experienced microgravity. The third flight was dedicated to the assessment of the ACCDs' ergonomics. The manikin was initially strapped to the backboard of each ACCD before the parabolas, mimicking a patient in the crew medical restraint system. A team composed of three trained operators was clocked to position the front part of the ACCD to its backboard during the microgravity phases. The adjudication was determined on: i) whether operators were able to position the device or not during each parabola and ii) the time (seconds) required to position the ACCDs. The experimental set up is illustrated in Fig. 2, central illustration.

### *Outcomes*

Compression depth (mm) was considered as primary outcome. Compression rate (cycles per minute, cpm), compression-decompression ratio (automatically extracted for the Laerdal Skill Reporter software), successful placements of ACCDs, and time to position (seconds) ACCDs were considered as secondary outcomes.

### *Statistical analysis*

Quantitative data are presented as median (inter quartile range) and qualitative data as number (percentage). Sample size estimation was not achievable as no data were recorded for ZOLL© Autopulse© and SCHILLER© Easypulse© devices and our report must be considered as a pilot study regarding this statistical analysis. However, we assumed we could highlight a clinically relevant effect based on previous reports mentioned above, considering a 5% alpha, an 80% power, and manual CPR reaching 44 mm compression depth versus 50 mm for LUCAS ACCD, with a 5 mm standard deviation. Comparison between the four groups was performed with a Kruskal-Wallis and Dunn Test for quantitative data and with a Fisher Exact test for qualitative data. A P value <0.05 was considered for statistical significance. The Bonferroni-Holm method was used to counteract the effect of multiple comparisons on alpha risk inflation. Statistics and figures were performed on R, software version 3.2.2 (https://cran.rproject.org/).

## Results

All samples were considered for the final analysis, i.e. 30 measurements for mechanical CPR (10 measurements for each ACCD)

**Table 1 – Primary and secondary outcomes presented as median and inter quartile range, with cpm: compressions per minute; CPR: cardiopulmonary resuscitation.**

| | LUCAS 3© | EASYPULSE© | AUTOPULSE© | Manual CPR | Kruskall-Wallis p value |
|---|---|---|---|---|---|
| Primary outcome | | | | | |
| **Depth (mm)** | 53 [53–54] | 29 [26–32] | 29 [27–30] | 34 [29–43] | < 0.001 |
| Secondary outcomes | | | | | |
| **Compression rate (cpm)** | 101 [101–101] | 100 [100–100] | 80 [80–80] | 115 [109–123] | < 0.001 |
| **Compression-Decompression Ratio** | 1.3 [1.1–1.3] | 1.3 [1.3–1.3] | 1.0 [1.0–1.0] | 0.9 [0.7–1.3] | 0.003 |

and 30 measurements for manual HS-CPR. Primary and secondary outcomes are presented in Table 1. The LUCAS 3© device achieved the highest compression depth with median value of 53 [53–54] mm and significantly outperformed the EASYPULSE©, AUTOPULSE© and Manual CPR, measured at 29 [26–32] mm, 29 [27–30] mm and 34 [29–43] mm, respectively (p value < 0.001). We found no statistical difference between the EASYPULSE©, AUTOPULSE© and manual CPR regarding compression depth. The threshold of 50 mm defined by the European Resuscitation Council was constantly observed with the LUCAS 3© device (100%), while only 10% of manual CPR provided efficient compression depth, and neither the EASYPULSE© (0%) nor the AUTOPULSE© (0%) achieved this milestone outcome (Fig. 1, Panel A). Important variability burdens manual CPR, with the lowest value of 21 mm.

Compression rate was reproducible in all ACCDs and corresponded to the manufacturers' settings, observed at 101 [101–101], 100 [100–100] and 80 [80–80] compression per minute (cpm) for the LUCAS 3©, EASYPULSE©, and AUTOPULSE©, respectively (Fig. 1, Panel B). Manual CPR provided significantly higher compression rates measured at 115 [109–123] cpm (p value < 0.001).

Median compression-decompression ratios were respectively measured at 1.3 [1.1–1.3], and 1.3 [1.3–1.3], 1.0 [1.0–1.0], and 0.9 [0.7–1.3] for the LUCAS 3©, EASYPULSE©, AUTOPULSE©, and manual CPR, respectively.

The mandatory time to position ACCDs was monitored during the third flight. Ten trials were dedicated to each ACCD. In our study, ACCD positioning was fully achieved in 9 (90%), 8 (80%) and 10 (100%) attempts for the LUCAS 3©, EASYPULSE© and AUTOPULSE©, respectively. Operators needed a median time of 13.2 [12.7–13.3], 20.10 [18.8–21.35], and 11.0 [10.00–12.43] seconds to position LUCAS 3©, EASYPULSE© and AUTOPULSE©, respectively. The EASYPULSE© design was associated with significantly longer positioning times compared to the LUCAS 3© and AUTOPULSE© (p < 0.01 with a Kruskall-Wallis and Dunn Test, Table 2 and Supplementary Figure 1).

## Discussion

In zero gravity conditions, only the LUCAS 3© ACCD met the current international guidelines to provide efficient cardiopulmonary resuscitation. Human performance was highly inconsistent, resulting in systematically lower compression depths and higher compression rates, as previously demonstrated.[13,14] Both American and European guidelines recommend a compression depth > 50 mm during CPR but only 10% of participants reached this outcome, suggesting that the current Handstand method developed for advanced life support during cardiac arrest may not be suitable for microgravity.[1,2] The compression-decompression ratio assesses whether CPR induces a diastolic thoracic restriction which might reduce venous return, stroke volume and cardiac output, according to Guyton's law.[15] Although current guidelines support a duty cycle of 50% (i.e. compression-decompression ratio of 1.0), experimental reports found higher values correlated with worst outcomes.[16] Only the EASYPULSE© ACCD provided a significantly higher compression-decompression ratio compared to manual CPR. This might be due to tight strapping of the device around the manikin which altered the compression-decompression ratio. Similarly, the high variability for compression-decompression ratios during manual CPR is partially explained by the microgravity environment, requiring constant hand-foot contact with fixed positions to prevent drifting from the correct CPR position. Regarding the compression rate, all experimental groups provided CPR compression rate in line with current guidelines, excepted the ZOLL© Autopulse© device delivering an 80/min compression rate CPR. Although this might appear underefective, randomized controlled trial comparing 100 and 120 cpm did not find survival benefit for higher compression rates.[17] Epidemiological reports even found high compression rate burden survival, while lower compression rates barely modified outcomes.[4] Trials found similar survival with the LUCAS© or ZOLL© Autopulse©, while the SCHILLER© Easypulse© was associated with reduced return of spontaneous circulation.[9]

In 2020, guidelines for CPR in microgravity were updated by the German Society of Aerospace Medicine (DGLRM) and the European Society of Aerospace Medicine Space Medicine Group (ESAM-SMG), who propose manual CPR as the best chest compression technique.[6] Recent evidence is now available supporting ACCDs in earth resuscitation,[18] and Forti et al. first reported in 2021 a proof-of concept that LUCAS chest compressions could be as effective in 0 g, 1.8 g as in standard 1 g during parabolic flights.[19] Limited crewmembers in current spaceflights, reduced physical conditions, and the inability to provide a "scoop and run" strategy also support the need for novel algorithms integrating ACCDs to manage cardiac arrest in microgravity.

The present project illustrates the benefit expected from ACCDs in hostile environments where performing CPR might be challenging. Our study also provides relevant insights for practical implications as a comparative study between available ACCDs. Differences between ACCD performances could be partly explained. First, prespecified manufacturer settings are major determinants for CPR characteristics. The SCHILLER© Easypulse© clearly underperformed compression depth as its program targets a 35 mm compression depth. Second, the ZOLL© Autopulse© performances, with a circular thoracic compressor design, might have been underestimated by the LAERDAL© manikin, which only assess antero-posterior compression depth. Recent epidemiological analyses reported that both the AUTOPULSE© and the LUCAS© improved return of spontaneous circulation (ROSC) compared to manual chest compressions, while the EASYPULSE© was associated with increased mortality.[9] Koster et al. raised safety concerns regarding AUTOPULSE©-induced life-threatening visceral damage.[20]

On top of the efficiency of each ACCD, our experiment also assessed their ergonomics with time to position the ACCD considered as a relevant surrogate. We found that all devices were suitable for microgravity, although the EASYPULSE© was associated with significantly longer positioning times. As the no-flow period (i.e. total time without CPR) correlates with survival and neurological outcomes, ACCDs achieving the shortest positioning delay could be preferred.[21]

Beyond CPR delivery, ACCDs will have to face new challenges to implement the International Space Station CPR algorithms. First, the ergonomics, assessed by the time to position ACCD in the current issue mainly depends on the device design. The easiest pattern was found with ZOLL© Autopulse© Life bands strapped over the chest. The simple LUCAS© design also allowed a correct positioning in an acceptable timeframe. On the other hand, SCHILLER© design appeared complex and required longer delay for positioning the device. It is suggested that ZOLL© or LUCAS© design should be further considered, while SCHILLER© design is not suitable for

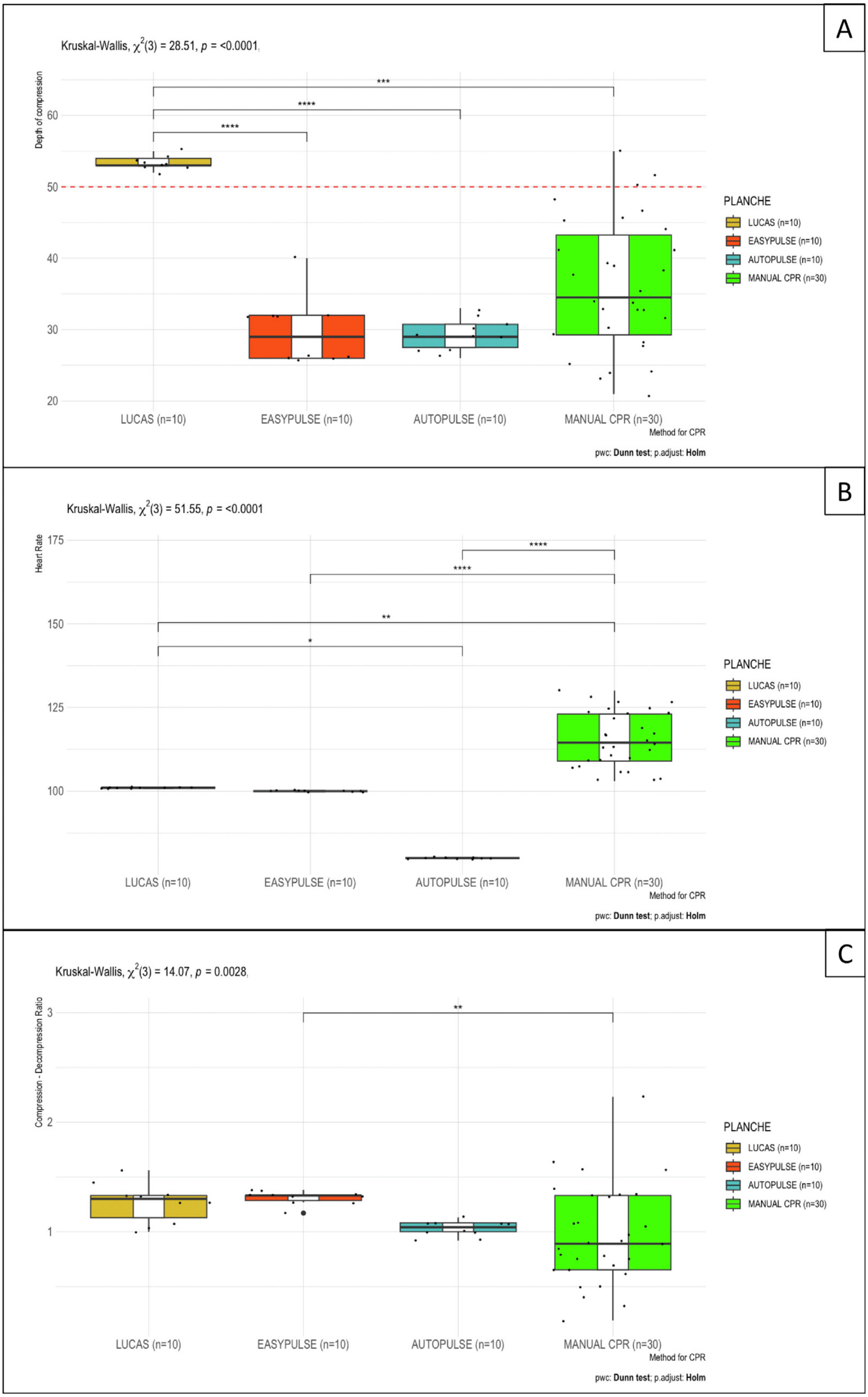

**Fig. 1 – Panel A: Distribution of values for compression depth (mm) with red dotted line representing the target threshold for compression depth (**** for p value < $10^{-5}$, and *** for p values $\langle 10^{-4}$); Panel B: Compression rate provided during Cardiopulmonary resuscitation (* for p value < $10^{-2}$, ** for p value < $10^{-3}$, **** for p value $\langle 10^{-4}$); Panel C: Compression-decompression Ratio during CPR (** for p value $\langle 10^{-2}$). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)**

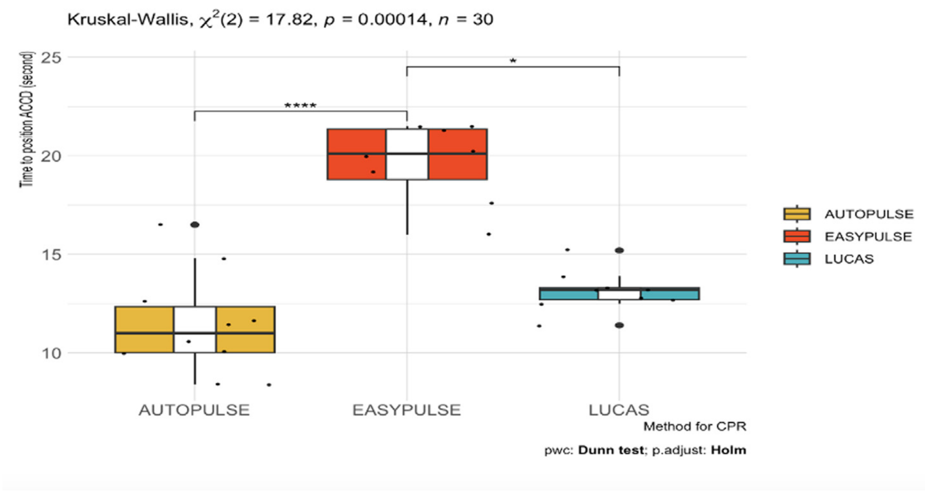

**Fig. 2 – Central Illustration. ACCD: automatic chest compression device; CPR: cardiopulmonary resuscitation.**

**Table 2 – Ergometrics of ACCDs assessed by iteration of successful attempts and time to position the automatic chest compression devices (in seconds), presented as number (percentage) and median (interquartile range).**

| | LUCAS 3© | EASYPULSE© | AUTOPULSE© | p value |
|---|---|---|---|---|
| **Successful attempts** | 9 (90%) | 8 (80%) | 10 (100%) | 0.753 |
| **Time (sec)** | 13.2 [12.7–13.3] | 20.10 [18.8–21.35] | 11.0 [10.00–12.43] | <0.001 |

microgravity environment. Second, vibrations produced by ACCDs should be assessed, as they could interact with the spacecraft structure. Similarly, hanging systems are currently used for treadmills in the ISS to prevent from vibration transmissions and ISS orbit deviation. Finally, reducing the weight of the ACCD is a major concern to reduce the cost of putting into orbit the device.

Our study also has limitations. First, the 22-second microgravity bouts are very short and unable to mimic prolonged CPR, not allowing the detrimental involvement of muscular exhaustion which is a major determinant for resuscitation quality. Second, our results merely provide information regarding the quality of chest compressions but cannot predict whether ACCDs could efficiently improve survival in cardiac arrest in microgravity. Third, the non-randomized design might suggest bias. The experimental set up did not allow randomization and implied serial measurements for ACCDs and manual CPR monitoring. However, this must be confronted to the highly reproducibility of CPR outcomes measurements with ACCDs, suggesting the experimental conditions were highly reproducible. Also, gravitational monitoring was performed during the procedure and pilots were able to reproduce a Zero Gravity environment averaging 0 ± 0.01 g (data not shown). Finally, ACCD benefits beyond CPR effectiveness were not studied in the present issue. Their use (i) reduces mental workload, (ii) absolves crewmembers of the chest compression responsibility (as mental health remains a major concern during spaceflight), (iii) may be easily implemented in an untrained rescuer population, expected in the upcoming era of space tourism exposing a vulnerable population.[22]

In conclusion, manual CPR remains undereffective under Zero Gravity and ACCDs, especially the LUCAS III© device (i.e., the only experimental group reproducing CPR matching with international guidelines), should be considered in emergency procedures to manage cardiac arrest in microgravity.

## Authors contribution

NR and ML designed the study. NR, LS, BP, SZ, RB, BS and ML performed the experiment. NR and ML wrote the manuscript. LS, BP, SZ, RB, BS, BC, and BL provided substantial contribution to the manuscript.

## Author/Funding disclosures

None of the authors received contribution from industry for this study at time of submission and publication. Automatic Chest compression devices were provided by industrials, respectively Stryker©, Zoll©, and Schiller© for LUCAS 3©, Autopulse© and Easypulse©.

## Ethical approval statement

We conducted a manikin study. According to the French Law, Ethical approval was waved.

## CRediT authorship contribution statement

**Nathan Reynette:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Luc Sagnières:** Writing – review & editing, Visualization, Validation, Project administration, Data curation, Conceptualization. **Benjamin Pequignot:** Writing – review & editing, Data curation. **Bruno Levy:** Writing – review & editing. **Stephane Zuily:** Writing – review & editing, Resources, Data curation. **Bruno Chenuel:** Writing – review & editing. **Ron Birnbaum:** Data curation. **Baptiste Sandoz:** Writing – review & editing, Validation, Software, Resources, Methodology, Formal analysis, Data curation, Conceptualization. **Mickael Lescroart:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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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.2024.110385.

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