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Quality of chest compressions during cardiopulmonary resuscitation performed by physicians: do we need to use mechanical chest compression devices? A multicenter, randomized, crossover study

Jakość kompresji klatki piersiowej podczas resuscytacji krążeniowo-oddechowej prowadzonej przez lekarzy: czy potrzebujemy mechanicznej kompresji klatki piersiowej? Badanie wieloośrodkowe, randomizowane, krzyżowe

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Keywords

cardiopulmonary resuscitation, chest compressions, quality, mechanical devices, physician

Słowa kluczowe

resuscytacja krążeniowo-oddechowa, kompresja klatki piersiowej, jakość, urządzenia mechaniczne, lekarz

Summary

Introduction. The quality of cardiopulmonary resuscitation is an important element influencing the return of spontaneous circulation. Guidelines for cardiopulmonary resuscitation put a great emphasis on high quality chest compression.

Aim. The aim of the study was to assess the quality of chest compressions performed with and without the Lifeline ARM mechanical chest compression device during simulated cardiopulmonary resuscitation performed by physicians.

Material and methods. The randomized cross-over simulation study involved 75 physicians. They performed 2-min cardiopulmonary resuscitation cycles, with and without the use of the Lifeline ARM mechanical chest compression system, in 4 scenarios: (A) manual chest compressions with a standard cycle of 30 compressions: 2 rescue breaths; (B) continuous chest compressions; (C) resuscitation with the Lifeline ARM in cycles of 30 chest compressions: 2 rescue breaths; (D) resuscitation with the Lifeline ARM with continuous chest compressions.

A randomized cross-over controlled simulation study was performed, whose protocol was approved by the Institutional Review Board of the Polish Society of Disaster Medicine (approval No.: 23/09/2017.IRB).

Results. The depth of chest compressions with different test scenarios varied and amounted to 44 mm (IQR: 38-46) for scenario A, 47 mm (IQR: 43-48) for scenario B, 51 mm (IQR: 50-52) for scenario C, and 51 mm (IQR: 50-53) for scenario D. The frequency of chest compressions during research scenarios varied and amounted to 129 (124-133) vs. 125 (119-128) vs. 101 (100-101) vs. 101 (100-101) CPM (Scenario A, B, C, D, respectively). The percent of chest compressions with incomplete release varied and amounted to 71% (IQR: 55-79) for scenario A, 63% (IQR: 51-69) for scenario B, 0% (IQR: 0-1) for scenarios C and D.

Conclusions. The quality of manual chest compressions performed by physicians during simulated adult resuscitation is lower than that of chest compressions with the Lifeline ARM device with reference to the median chest compression rate, median chest compression depth, and percent of chest compressions with incomplete release.

Conflict of interest
Konflikt interesów

None
Brak konfliktu interesów

Streszczenie

Wstęp. Prowadzenie wysokiej jakości resuscytacji krążeniowo-oddechowej stanowi istotny element wpływający na powrót spontanicznego krążenia. Wytyczne resuscytacji krążeniowo-oddechowej kładą duży nacisk na wysokiej jakości kompresję klatki piersiowej.

Cel pracy. Celem pracy było określenie jakości kompresji klatki piersiowej wykonywanej z systemem i bez systemu kompresji klatki piersiowej LifeLine ARM podczas symulowanej resuscytacji krążeniowo-oddechowej wykonywanej przez lekarzy.

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Materiał i metody. W randomizowanym, krzyżowym badaniu symulacyjnym udział wzięło 75 lekarzy. Uczestnicy wykonywali 2-min cykl resuscytacji, z systemem i bez systemu mechanicznej kompresji klatki piersiowej LifeLine ARM. Cykle wykonywane były w 4 scenariuszach: (A) manualna kompresja w standardowym cyklu 30 uciśnięć klatki piersiowej do 2 oddechów ratowniczych, (B) manualna ciągła kompresja klatki piersiowej, (C) resuscytacja z wykorzystaniem LifeLine ARM w cyklu 30 uciśnięć klatki piersiowej do 2 oddechów ratowniczych, (D) resuscytacja z wykorzystaniem LifeLine ARM w cyklu kompresji ciągłej. Protokół randomizowany, krzyżowy badania został zaakceptowany przez Radę Programową Polskiego Towarzystwa Medycyny Katastrof.

Wyniki. Głębokość kompresji klatki piersiowej w przypadku badanych scenariuszy była zróżnicowana i wynosiła odpowiednio: 44 mm (IQR: 38-46) dla scenariusza A, 47 mm (IQR: 43-48) dla scenariusza B, 51 mm (IQR: 50-52) dla scenariusza C oraz 51 mm (IQR: 50-53) dla scenariusza D. Częstotliwość uciśnięć klatki piersiowej w poszczególnych scenariuszach wynosiła odpowiednio: 129 (124-133), 125 (119-128), 101 (100-101), 101 (100-101), odpowiednio dla scenariuszy A, B, C i D. Odsetek niepełnej relaksacji klatki piersiowej wynosił 71% (IQR: 55-79) dla scenariusza A, 63% (IQR: 51-69) dla scenariusza B, 0% (IQT: 0-1) dla scenariuszy C i D.

Wnioski. Jakość manualnej kompresji klatki piersiowej wykonywanej przez lekarzy podczas symulowanej resuscytacji osoby dorosłej jest mniejsza aniżeli w przypadku zastosowania systemu kompresji klatki piersiowej LifeLine ARM, odpowiednio w odniesieniu do mediany częstości kompresji klatki piersiowej, głębokości kompresji oraz stopnia relaksacji klatki piersiowej.

INTRODUCTION

Sudden cardiac arrest is among the most serious health problems in both Europe and the United States and remains associated with very high mortality and morbidity (1, 2). As indicated by Atwood et al. (3), as well as by Luc et al. (4), there are approximately 420,000 out-of-hospital cardiac arrests occurring in the United States and 275,000 in Europe each year. The survival rate of patients with sudden cardiac arrest is low and varies with regard to whether the cardiac arrest occurred in the pre-hospital or hospital setting. A study by Luc et al. (5) included 84,625 hospitalized patients with cardiac arrest; a short-term patient survival to discharge from hospital was only 22.3%. Ofoma et al. (5) indicated the survival rate of patients with in-hospital cardiac arrest of 18.6%, and also demonstrated that the survival was significantly lower in those who arrested during off-hours compared with on-hours (16.8 vs. 20.6%).

In pre-hospital cardiac arrest, the patients' survival rate is lower, and, as indicated in studies performed by Nakanishi et al. (6) and Lindner et al. (7), the average survival rate for discharging people from pre-hospital cardiac arrest equals 3-25%. This is related to the fact that pre-hospital cardiac arrest often leads to a delay in the initiation of basic life support procedures, and advanced life support procedures are usually implemented only after the arrival of the emergency medical team, in contrast to in-hospital settings, where they are started nearly immediately after cardiac arrest occurrence (8).

The ability to perform cardiopulmonary resuscitation is among the basic skills that should be possessed by medical personnel, including physicians, nurses, and paramedics (9). The process of developing and implementing recommendations for resuscitation dates back to the 1950s (10); however, during the latest decades, guidelines for cardiopulmonary resuscitation are issued every 5 years by the European Resuscitation Council (ERC) and the American Heart Association (AHA) (11, 12). The current resuscitation guidelines for both children and adults emphasize minimizing interruptions in chest compressions as a key factor affecting resuscitation effectiveness and thus the return of spontaneous circulation (11, 12). According to the current guidelines, high-quality chest compressions are characterized by an appropriate frequency of 100-120 compressions per minute (CPM), a corresponding compression depth of 50-60 mm, as well as complete chest relaxation after each compression. Performing chest compressions in this way determines the most effective perfusion pressure and increases the chances for the return of spontaneous circulation.

According to many studies, though, the quality of resuscitation – even performed by medical personnel – is often insufficient (13). Paramedics perform chest compressions exceeding the recommended maximum rate and not reaching the recommendation for chest compression depth.

There are several types of medical equipment supporting cardiopulmonary resuscitation quality, starting from resuscitation feedback devices (14), to mechanical chest compression devices (15). Although the current guidelines do not recommend the routine use of mechanical chest compression systems during cardiopulmonary resuscitation, the systems application is allowed in situations of prolonged cardiopulmonary resuscitation, inability to perform high quality chest compressions, or patient transport.

An example of such a device is the Lifeline ARM (ARM; Defibtech, Guilford, CT, USA) mechanical chest compression device. It has been designed to perform chest compressions owing to the movements of the piston that compress the chest, so it is possible to standardize the compressions parameters in accordance with the current guidelines for adult resuscitation (12, 16). The device is equipped with an intuitive control panel, enabling to carry out cardiopulmonary resuscitation in

two modes: standard 30 chest compressions: 2 rescue breaths, or continuous chest compressions without interruptions for rescue breaths (fig. 1a, b).

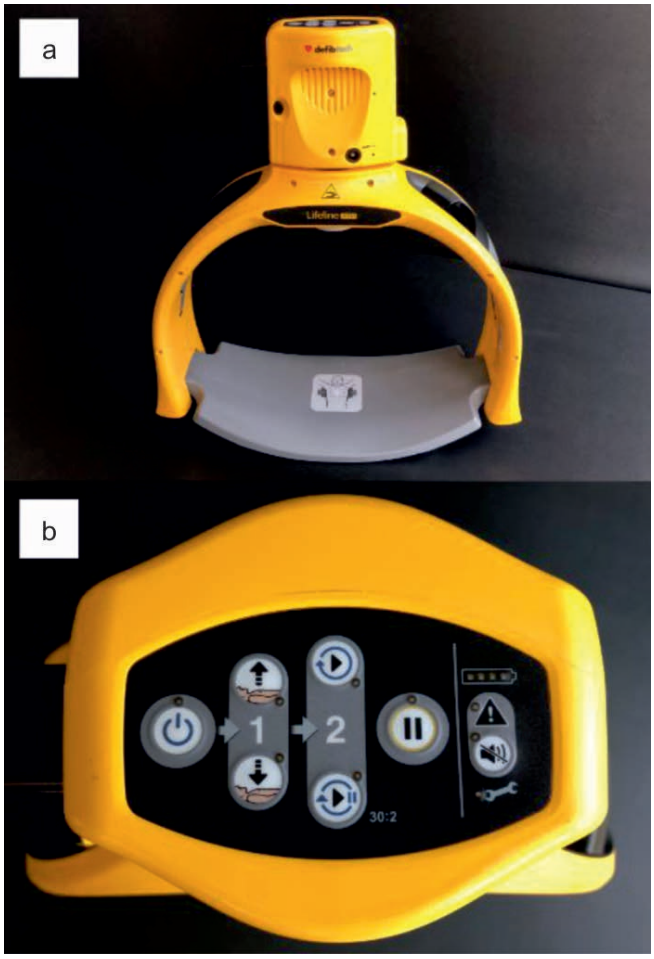

Fig. 1a, b. Lifeline ARM: (a) the mechanical chest compression device; (b) the control panel

AIM

The aim of the study was to assess the quality of chest compressions performed with and without the Lifeline ARM mechanical chest compression device during simulated cardiopulmonary resuscitation performed by physicians.

MATERIAL AND METHODS

Study design and selection of participants

A randomized cross-over controlled simulation study was performed, whose protocol was approved by the Institutional Review Board of the Polish Society of Disaster Medicine (approval No.: 23/09/2017.IRB). The study was carried out in Warsaw, Poznan, and Wroclaw, between October 2017 and May 2018, among physicians participating in basic life support courses based on the AHA 2015 resuscitation guidelines.

After obtaining a voluntary written informed consent from each participant, 77 physicians were qualified for the study. Among the inclusion criteria, there was practicing the medical profession and voluntary participation in the study. The exclusion criteria consisted of specialization in anesthesiology or emergency medicine, as well as pain in the wrist or back. The total of 75 participants completed the survey; 2 withdrew during the study course because of wrist pain.

Cardiopulmonary resuscitation training

Before the start of the study, all participants successfully completed training in basic life support procedures conducted by accredited AHA instructors. After the training, physicians were instructed on the use of the Lifeline ARM mechanical chest compression system. Then, they had 5 minutes to familiarize with the device.

Simulation scenarios

In order to simulate a patient with cardiac arrest requiring cardiopulmonary resuscitation, an adult SimMan 3G simulator (Laerdal, Stavanger, Norway) was used. During the study, the participants performed cardiopulmonary resuscitation in teams consisting of 2 persons. One was responsible for replacement breaths and the other applied chest compressions; after the end of a 2-minute cycle, the roles changed. Then, each participant had a 20-minute break before performing resuscitation based on a different scenario.

The study participants performed cardiopulmonary resuscitation based on 4 scenarios:

a) Scenario A – cardiopulmonary resuscitation with manual chest compressions with a standard cycle of 30 compressions: 2 rescue breaths.
b) Scenario B – cardiopulmonary resuscitation with continuous chest compressions. For this purpose, an independent instructor performed endotracheal intubation allowing for asynchronous resuscitation.
c) Scenario C – cardiopulmonary resuscitation performed with the Lifeline ARM chest compression system in cycles of 30 chest compressions: 2 rescue breaths.
d) Scenario D – cardiopulmonary resuscitation performed with the Lifeline ARM mechanical chest compression system for continuous chest compressions. For this purpose, as in scenario B, the simulator was intubated, allowing continuous chest compressions without interruptions for rescue breaths.

During all scenarios, the simulator was placed on a flat floor in a well-lit room.

The order of the study participants and the research scenarios was random. The physicians were divided into 4 groups with the use of the Research Randomizer program (randomizer.org). The randomization procedure is shown in detail in figure 2.

Data collection and measure quality of chest compression

During the study, only the data concerning the quality of chest compressions automatically recorded by the software controlling the simulator were analyzed.

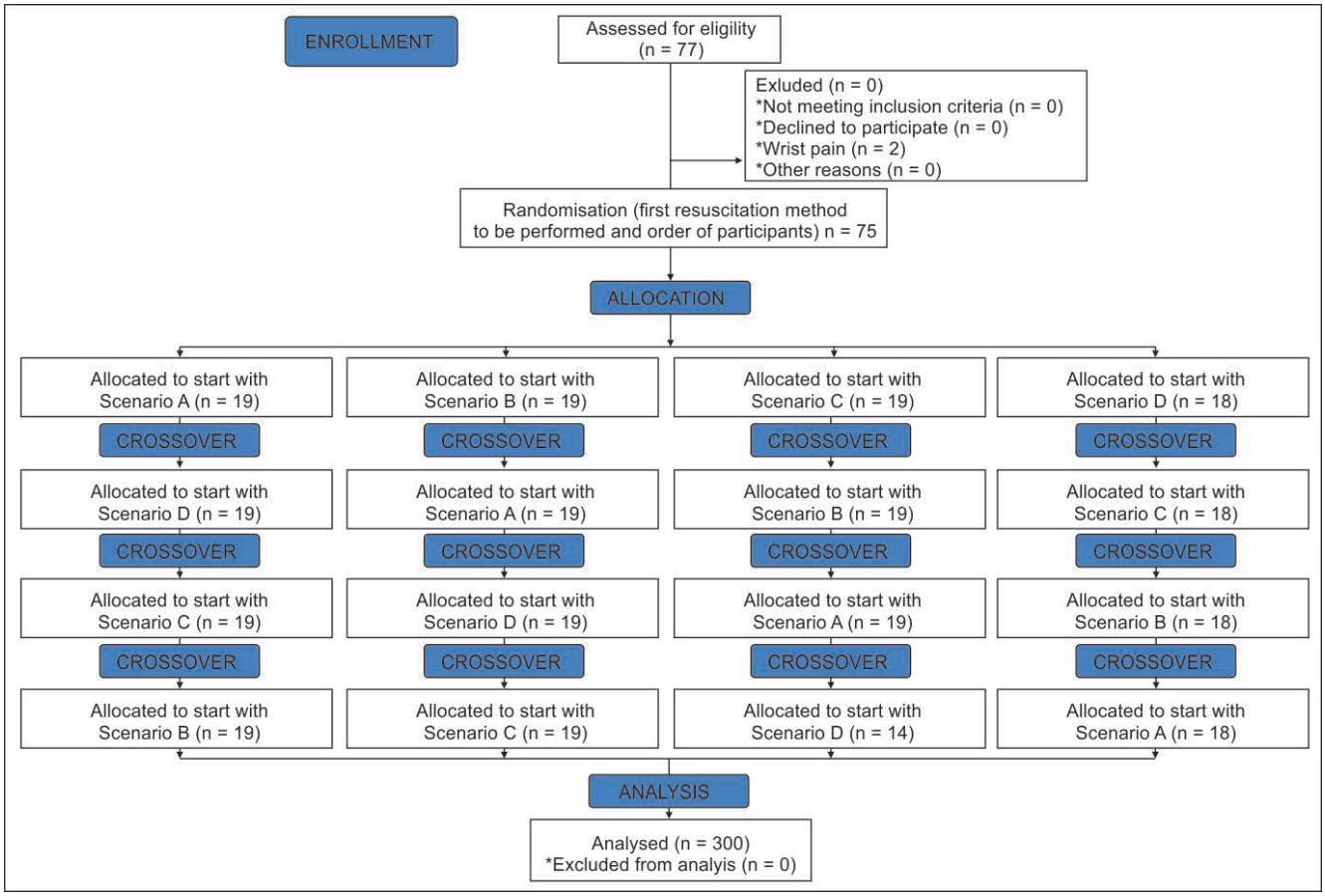

Fig. 2. Randomization flow chart

The primary outcome of the trial was chest compression depth. The appropriate depth was defined as 50-60 mm, and the appropriate chest compression rate as 100-120 CPM, in accordance with the AHA guidelines (16). We also evaluated the no-flow time. In addition, after performing the resuscitation scenarios, the study participants were asked for their self-assessment of the rescuer's fatigue. The assessment was provided in a 100-point visual analog scale (VAS), where 1 meant no fatigue, and 100 stood for extreme fatigue. The participants were also asked to indicate their attitudes towards the use of mechanical chest compression systems during real resuscitation activities.

Statistical analysis

On the basis of previous studies, we calculated the necessary sample size as at least 54 participants using G*Power 3.1 (two-tailed t-test; Cohen's d – 0.8; alpha error – 0.05; power – 0.95). In order to increase the power of the study, we decided to qualify 75 participants.

All statistical analyses were carried out with the Statistica 13.0EN package (StatSoft, Tulsa, OK, USA). The homogeneity between groups was assessed by the Kolmogorov-Smirnov test. The data were compared across groups with the chi-square test for categorical variables and Student's t-test for continuous variables. The two-tailed value of $p < 0.05$ was considered statistically significant. Data are presented as absolute numbers and percentages or as medians and interquartile ranges (IQR).

RESULTS

Baseline characteristics

The total of 75 physicians completed the study, with the median age of 32.5 years (IQR: 31-43) and the median work experience of 7 years (IQR: 5-12). All participants declared clinical experience in the field of adult cardiopulmonary resuscitation.

Quality of chest compressions

The full data of quality parameters for chest compressions during various test scenarios is presented in table 1.

The depth of chest compressions in the different test scenarios varied and amounted to 44 mm (IQR: 38-46) for scenario A, 47 mm (IQR: 43-48) for scenario B, 51 mm (IQR: 50-52) for scenario C, and 51 mm (IQR: 50-53) for scenario D. There were statistically significant differences in the compression depth during resuscitation between scenarios A and B ($p = 0.047$), A and C ($p < 0.001$), A and D ($p < 0.001$), B and C ($p < 0.001$), and B and D ($p < 0.001$) (fig. 3).

The frequency of chest compressions during research scenarios varied and amounted to 129 (124-133) vs. 125 (119-128) vs. 101 (100-101) vs. 101 (100-101) CPM (Scenario A, B, C, D, respectively) (fig. 4).

The percent of chest compressions with incomplete release in the test scenarios varied and amounted to

Tab. 1. Chest compression quality variables

Measurement	Scenario A	Scenario B	Scenario C	Scenario D	p-value
Median chest compression rate (bmp) (goal range, 100-120)	129 [124-133]	125 [119-128]	101 [100-101]	101 [100-101]	Scenario A vs. scenario B: 0.038 Scenario A vs. scenario C: < 0.001 Scenario A vs. scenario D: < 0.001 Scenario B vs. scenario C: < 0.001 Scenario B vs. scenario D: < 0.001 Others: NS
Chest compressions with a rate within the goal range (%)	12 [5-21]	21 [16-25]	100 [99-100]	100 [99-100]	Scenario A vs. scenario B: 0.012 Scenario A vs. scenario C: < 0.001 Scenario A vs. scenario D: < 0.001 Scenario B vs. scenario C: < 0.001 Scenario B vs. scenario D: < 0.001 Others: NS
Median chest compression depth (mm) (target range, 50-60)	44 [38-46]	47 [43-48]	51 [50-52]	51 [50-53]	Scenario A vs. scenario B: 0.047 Scenario A vs. scenario C: < 0.001 Scenario A vs. scenario D: < 0.001 Scenario B vs. scenario C: < 0.001 Scenario B vs. scenario D: < 0.001 Others: NS
% of shallow chest compressions	85 [73-85]	54 [41-79]	0 [0-2]	0 [0-1]	Scenario A vs. scenario B: 0.023 Scenario A vs. scenario C: < 0.001 Scenario A vs. scenario D: < 0.001 Scenario B vs. scenario C: < 0.001 Scenario B vs. scenario D: < 0.001 Others: NS
% of chest compressions with incomplete release	71 [55-79]	63 [51-69]	0 [0-1]	0 [0-1]	Scenario A vs. scenario B: 0.019 Scenario A vs. scenario C: < 0.001 Scenario A vs. scenario D: < 0.001 Scenario B vs. scenario C: < 0.001 Scenario B vs. scenario D: < 0.001 Others: NS
No-flow time (s)	7 [7-9]	0 [0-1]	3 [3-4]	0 [0-0]	Scenario A vs. scenario B: < 0.001 Scenario A vs. scenario C: < 0.001 Scenario A vs. scenario D: < 0.001 Scenario B vs. scenario C: < 0.001 Others: NS
% of correct hand (piston) placement	87 [78-93]	91 [75-98]	98 [98-100]	99 [98-100]	Scenario A vs. scenario C: < 0.001 Scenario A vs. scenario D: < 0.001 Scenario B vs. scenario C: 0.002 Scenario B vs. scenario D: 0.002 Others: NS

71% (IQR: 55-79) for scenario A, 63% (IQR: 51-69) for scenario B, and 0% (IQR: 0-1) for scenarios C and D. There were statistically significant differences in the percent of chest compressions with incomplete release between scenarios A and B ($p = 0.019$), A and C ($p < 0.001$), A and D ($p < 0.001$), B and C ($p < 0.001$), and B and D ($p < 0.001$) (fig. 3).

Self-assessment

While assessing the degree of fatigue during chest compressions in individual study scenarios using the VAS scale, the study participants indicated that resuscitation with the Lifeline ARM mechanical chest compression device was the least tiring (11 points (IQR: 8-15) for both scenario C and scenario D). In scenario A, the level of fatigue according to the study participants was 46 points (IQR: 34-49), while in scenario D – 52 points (IQR: 37-55). There were statistically significant differences ($p < 0.001$) between the following scenarios: A and C, A and D, B and C, and B and D. The total of 72 participants (96%) declared that they would routinely use mechanical chest compressions during resuscitation procedures.

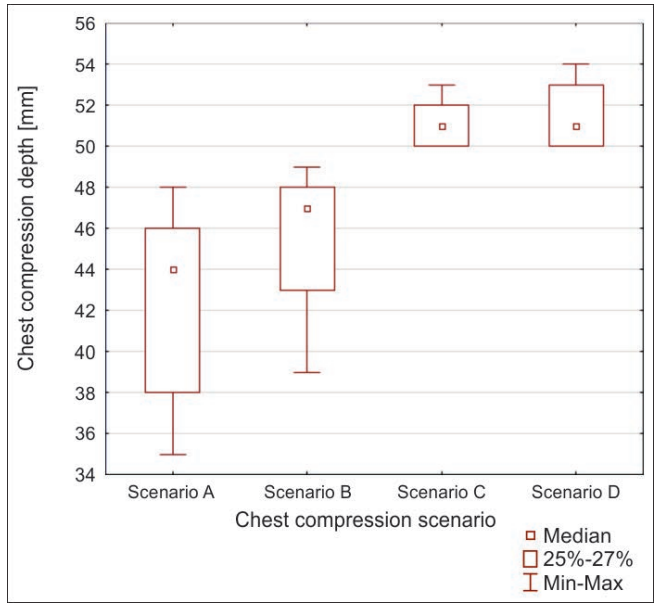

Fig. 3. Median chest compression depth

DISCUSSION

To our knowledge, this is the first randomized crossover trial to indicate the difference in chest compres-

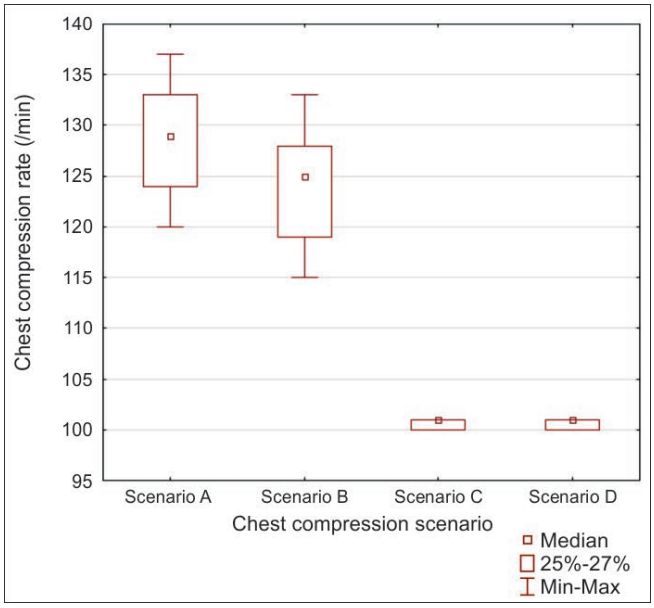

Fig. 4. Median chest compression rate

sion quality between resuscitation with and without the Lifeline ARM mechanical chest compression device. The quality of chest compressions is one of the basic factors determining the effectiveness of cardiopulmonary resuscitation (17).

Chest compressions performed with the appropriate depth are among the key elements enabling appropriate perfusion pressure and thus affecting the chance for spontaneous circulation return (16, 18).

In our own study, the median depth in the case of basic life support resuscitation ranged from 44 to 49 mm, depending on whether the chest compressions were carried out with interruptions for rescue breaths or continuously. Correspondingly, if a mechanical chest compression system was used, the chest compression depth equaled 51 mm.

A too small depth of chest compressions performed manually is also indicated by Chen et al. (19). In their study, healthcare workers were able to perform chest compressions to the depth of 49.3 mm. The problem of too shallow chest compressions refers to cardiopulmonary resuscitation in adults, children, and newborns (16, 20).

Mayrand et al. indicate that the rescuer arm position relative to the patient's chest and step stool utilization during resuscitation are modifiable factors facilitating improved chest compression depth (21). Therefore, sometimes the best solution is to perform cardiopulmonary resuscitation when the patient is located on a flat hard floor – as in the case of research. Considering mechanical chest compression devices, also Lampe et al. revealed that deeper chest compressions performed with a mechanical device resulted in improving several hemodynamic parameters (22). Other authors came to similar conclusions, pointing at the advantage of applying mechanical chest compression devices over manual chest compressions, especially in the case of personnel inexperienced in cardiopulmonary resuscitation, or during patient transport (23, 24).

Another important parameter affecting the quality of chest compressions and thus also of resuscitation itself is the frequency of chest compressions. The current guidelines for cardiopulmonary resuscitation (16) recommend that the chest is compressed at 100-120 CPM.

In the study, the frequency of chest compressions varied between the manual and mechanical method. Physicians performing manual chest compressions had a tendency to compress the chest too quickly as compared with the AHA and ERC guidelines (11, 16).

A similar tendency was also observed by Iskrzycki et al. (25), Ladny et al. (26), or other authors (27, 28). Field et al. pointed out that chest compressions above 120 CPM statistically significantly affected the reduction of the chest compression depth (29).

In the case of a mechanical chest compression system, the compression frequency is pre-programmed on the basis of the current guidelines, so there is no risk of too slow or too rapid chest compressions (30, 31).

Full chest release is another parameter confirming the optimal perfusion pressure during chest compressions. In the presented study, in manual chest compressions, complete chest relaxation was observed in 29-37% of cases, only depending on the technique of chest compressions.

This result is definitely insufficient. As emphasized by Aufderheide et al. (32), full chest decompression improves the hemodynamic conditions during resuscitation, creating a negative pressure in the chest, and thus draws venous blood back to the heart, providing cardiac preload prior to the next chest compression phase. Other authors came to similar observations (33-35).

During the study, apart from investigating the impact of using the mechanical chest compression system on the quality of chest compressions, two methods of cardiopulmonary resuscitation were also evaluated. The first is resuscitation based on the scheme of 30 chest compressions and 2 rescue breaths, the other consists in performing continuous chest compressions, without interruptions.

The second method is possible to apply owing to the protection of the airways with an endotracheal tube or a supraglottic airway device (36). In our study, better chest compressions were obtained with the continuous pattern than in the 30:2 scheme. Continuous chest compressions during resuscitation cycles are also in line with the resuscitation trends, with the resuscitation guidelines emphasizing the need to minimize interruptions in chest compressions.

The use of continuous chest compressions is additionally supported by Ewy and Zuercher (18), who demonstrated that initial bystander administration of continuous chest compressions without assisted ventilations resulted in a significantly better 24-hour post-resuscitation neurologically normal survival as compared with the standard 30:2 technique. An important method to reduce interruptions in chest compressions, even when using the 30:2 scheme, may be mechanical chest compressions, which, after 30 compressions, stop

only for 3-5 seconds, during which the rescuer should perform 2 rescue breaths; then the device immediately performs 30 consecutive chest compressions. Studies carried out by Tranberg et al. (37) showed that the LUCAS-2 mechanical chest compression device improved cardiopulmonary resuscitation quality by significantly reducing the no-flow fraction and by increasing the quality of chest compression compared with manual cardiopulmonary resuscitation during out-of-hospital cardiac arrest resuscitation. Putzer et al. (38) came to similar conclusions in their research.

The use of mechanical chest compressions, as mentioned above in the introduction, is crucial in the case of prolonged cardiopulmonary resuscitation or during the patient transport. Thanks to the standardization of compressions, we have the confidence to perform chest compressions in accordance with the recommendations of the resuscitation guidelines (11). In manual chest compressions, the rescuer's fatigue may impede the quality of the resuscitation activities, while patient transport may expose the resuscitating person to potential injuries related to the movement of the ambulance. In the presented study, the participants maintained that the use of mechanical chest compression systems was associated only with slight fatigue, in contrast to manual chest compressions. Also, in other studies, participants pointed to the advantage of mechanical chest compression systems (24, 25) or resuscitation feedback devices (14) over manual chest compressions, especially in prolonged resuscitation.

The study has both limitations and strengths. The former includes, among others, the medical simulation center settings. However, this choice of methodology was dictated by the fact that cross-over randomized studies are unethical in real-life resuscitation settings and may lead to reduced chances of patient survival; in turn, simulation studies allow full standardization of the performed procedures throughout the entire study (39, 40). Limiting the study group to physicians only was also deliberate; physicians relatively often face the need to perform resuscitation activities and it is important for them to find the most effective method of resuscitation. In our study the participants performed only 2-min cardiopulmonary resuscitation cycles. Taking into account the rescuer fatigue during manual chest compression increasing in time in prolonged resuscitation this factor could impede the results. The advantages of the study are a large research group, the use of advanced adult patient simulators, as well as a randomized, cross-over design.

Future directions. In our study we have found that basic chest compression quality parameters are superior to manual chest compression and it can suggest wider use of mechanical chest compression systems. Our results suggest also that the quality of manual chest compression should be more strictly monitored including real-time audiovisual feedback.

CONCLUSIONS

The quality of manual chest compressions performed by physicians during simulated adult resuscitation is lower compared with mechanical chest compressions with the use of the Lifeline ARM mechanical chest compression device when one considers the median chest compression rate, median chest compression depth, and percent of chest compressions with incomplete release. The participants assessed the chest compressions with the use of the mechanical chest compression device Lifeline ARM as the least tiring; 96% declared that they would routinely use mechanical chest compressions during resuscitation procedures.

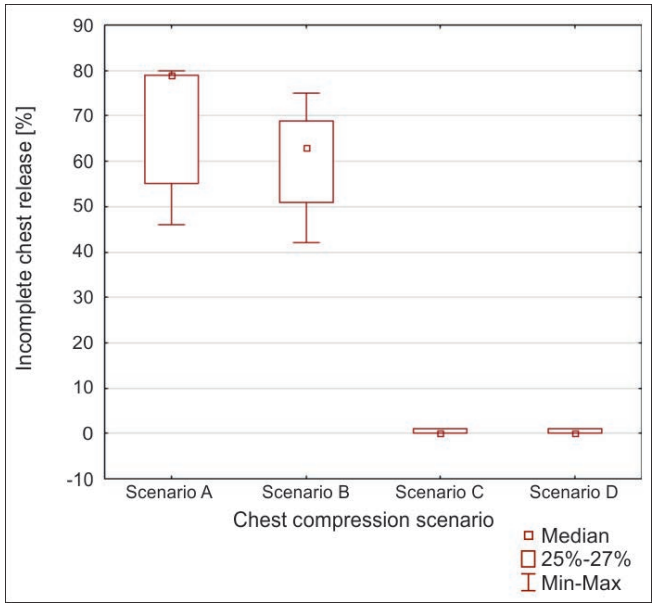

Fig. 5. Incomplete chest recoil

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