Effect of a dynamic mattress on chest compression quality during cardiopulmonary resuscitation

- **Manuscript type:** original research paper
- **Key words:** basic life support; chest compressions; cardiopulmonary resuscitation; dynamic mattress; alternating air mattress
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- **Funding statement:** No funding
- **Conflict of interest disclosure:** The authors of this manuscript declare no relationships with any companies whose products or services may be related to the subject matter of the article.
- **Ethics approval statement:** As this is a manikin-based trial, the approval of the study by a medical ethics review committee was waived due to the observational nature of the study and lack of patient involvement.
- **Patient consent statement:** All participants gave written informed consent. Participation was on a voluntary basis. Anonymity was guaranteed and participants were entitled to access the results after data processing.
- **Trial registering:** The study was registered at ISRCTN.com (ISRCTN61041099)
- **Author contributions:** T. Torsy and W. Deswarte equally contributed to the conception and design of the research; T. Torsy and W. Deswarte contributed to the acquisition and analysis of the data; T. Torsy, W. Deswarte, M. Karlberg-Traav and D. Beeckman contributed to the interpretation of the data; and T. Torsy drafted the manuscript. All authors critically revised the manuscript, agree to be fully accountable for ensuring the integrity and accuracy of the work, and read and approved the final manuscript.

This is the author manuscript accepted for publication and has undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1002/acp.3821

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• **Acknowledgements**: The authors would like to thank the Odisee University College and the TI Sint-Carolus for facilitating this study. They also would like to thank Sarah Steckel and Inge Tency for assisting with the final draft.

**ABSTRACT**

**Aims and objectives**: To examine the effect of an inflated dynamic overlay mattress on chest compression quality during cardiopulmonary resuscitation (CPR) and to explore the predictive effect of healthcare providers’ anthropometric factors, hand positioning and mattress type on chest compression frequency and depth.

**Background**: In-hospital cardiac arrest is a medical emergency that occurs on a regular basis. As patients most at risk for an in-hospital cardiac arrest are usually positioned on a dynamic mattress, it is important to measure the effect of mattress compressibility on chest compression quality during CPR. High-quality CPR is essential for patient survival and good neurological outcome.

**Design**: Manikin-based single-blinded randomised controlled trial.

**Methods**: Nursing students (N = 70) were randomised to a control (viscoelastic foam mattress) or intervention group (inflated dynamic overlay mattress on top of a viscoelastic foam mattress) and had to perform chest compressions over a 2-minute period. Compression rate, depth and hand positioning were registered. The 2015 European Resuscitation Council (ERC) guidelines were used as a reference.

**Results**: The mean difference in chest compression depth between control and intervention group was 2.86 mm (p = 0.043). Both groups met the guidelines for adequate chest compression quality, as recommended by the ERC. A predictive effect of healthcare providers’ body height and weight, mattress type and hand positioning on compression depth could be demonstrated (p = 0.004).

**Conclusions**: CPR in bedridden patients on a dynamic overlay mattress has a negative effect on the quality of chest compressions. Mean chest compression depth decreases significantly. However, clinical significance of the results may be debatable. Mattress type, body weight and hand positioning appear to be significant predictors for adequate chest compression depth.

**Relevance to clinical practice**: A firm surface under the patient is needed during CPR. Special attention must be paid to correct hand positioning during CPR.

**Keywords**: basic life support; chest compressions; cardiopulmonary resuscitation; dynamic mattress; alternating air mattress
Introduction

Sudden cardiac arrest is a major concern for public health as it causes 50% of cardiovascular deaths and even 20% of all natural deaths in Western countries. According to the 2020 EuReCa TWO study commissioned by the European Resuscitation Council (ERC), a total of 37,054 out-of-hospital cardiac arrests were confirmed in Europe during a three-month registration period in 2017. Cardiopulmonary resuscitation (CPR) was initiated in 25,171 of these cases. The overall incidence of out-of-hospital cardiac arrest where CPR was attempted was calculated at 56 per 100,000 population. Compared to out-of-hospital cardiac arrest and other cardiovascular conditions, in-hospital cardiac arrest gets less attention in epidemiological studies. Nevertheless, data suggest an overall incidence of in-hospital cardiac arrest of 1.6 per 1000 hospital admissions, with a survival to discharge of approximately 15–30%.

CPR is considered a mentally and physically stressful task for all healthcare personnel involved. Despite the fact that stress has previously been shown to have adverse effects on overall performance, the question remains to what extent stress affects performance in CPR. Bjørshol et al. (2011) demonstrated no effect on CPR quality of trained, experienced personnel when performing CPR in the presence of socio-emotional stress. However, physical fatigue appears to negatively affect the quality of CPR, resulting in inadequate chest compressions and ventilations.

Background

Achieving and maintaining high-quality CPR is important for patient survival and neurological outcome after a cardiac arrest. In their 2015 resuscitation guidelines, the ERC and the American Heart Association (AHA) emphasized the following key elements for high-quality CPR in adults: minimize interruptions in chest compressions; provide compressions of adequate rate (100–120 compressions per minute) and depth (5–6 centimeters); avoid leaning on the patient between compressions (allow the chest to recoil); avoid excessive ventilation and ensure proper hand positioning.

The quality of chest compressions is affected by the surface under the patient. According to the 2015 ERC guidelines, CPR should be performed on a firm surface whenever possible and air-filled mattresses should be deflated during CPR. Despite the fact that a combination of an inflated dynamic overlay mattress on top of a viscoelastic foam mattress is widely used to prevent pressure ulcers in both in-hospital and out-of-hospital settings, research cannot provide clear, unequivocal evidence to support mattress deflation during CPR. Deflating dynamic mattresses in order to become a firm surface also involves loss of time during CPR. According to Oh et al. (2013), the average time required to deflate an air-filled mattress is approximately 20 seconds. Noordergraaf et al. (2009) noted that patients most at risk for an in-hospital cardiac arrest are usually positioned on a dynamic mattress.

Earlier research showed that CPR performance is adversely affected when performed on a bed compared to the floor. Perkins et al. (2003) concluded that chest compression depth was significantly lower on a mattress (35.2 mm - 39.1 mm) compared to the floor (44.2 mm), regardless of the type of mattress. Mattresses tend to deform...
and move downwards during CPR, thus reducing the efficiency of chest compressions. Mattress compressibility is variable and depends on the type of mattress, the body weight of the patient and whether or not a backboard is used during CPR. Those factors make it difficult to estimate the adequacy of the chest compressions. Therefore, it is important to quantify the effect of mattress compression on the assessment of chest compressions.

The primary aim of this manikin-based simulation study was to investigate the effect of an inflated dynamic overlay mattress on top of a viscoelastic foam mattress versus a viscoelastic foam mattress on the quality of chest compressions on the quality of chest compressions (depth, frequency and hand positioning) during CPR. Secondary, this study aimed to explore the predictive effect of anthropometric factors (healthcare first responder’s body height and weight), hand positioning and mattress type on the depth and frequency of chest compressions.

**Design and methods**

**Study design**

This manikin-based simulation study, designed as a single-blinded randomised controlled trial, examined the effect of an inflated dynamic overlay mattress on the quality of chest compressions during CPR. Chest compression quality parameters that were measured as primary endpoints were compression rate, sternum-to-spine compression depth and hand positioning. Data were collected over a one-week period in September 2020 at Odisee University College (Sint-Niklaas, Belgium). The Consolidated Standards of Reporting Trials (CONSORT) guidelines have been applied for reporting this prospective data analysis.

**Participants**

Students from two in-house nursing education programs participated in the study and had to meet the following criteria: being ≥ 18 years; successfully completed a basic CPR training in the first year of nursing education. Prior to the data collection, a randomisation list (block randomisation; block size of 2; list length of 80 participants and allocation ratio 1:1) was created by an investigator with no clinical involvement in the data collection, using a random number generator (www.randomizer.org). On a first-come, first-served basis and according to the randomization list, the participants were assigned by the data collector to one arm of the two-arm parallel group design just prior to their intervention. Included participants were kept blinded to their allocation while the researcher who collected the data was aware of the participants’ allocated arm. To ensure blinding of the participants, the viscoelastic foam mattress and the dynamic overlay mattress (if present) were covered with a non-translucent white sheet. The pump was non-visible positioned under the bed. None of the participants was informed about the use and evaluation of a dynamic mattress overlay before, during and immediately after the data collection. Participants who spontaneously reported about the presence or absence of a dynamic overlay mattress were registered. Figure 1 shows the progress of the participants through the phases of the study.
Intervention

The dynamic mattress used in this study was an Alpha Response™ overlay mattress (ArjoHuntleigh) placed on top of a viscoelastic foam mattress (Tempur®) in an electrically adjustable bed. The dynamic mattress offered two therapeutic modes: An active (or alternating) mode which periodically redistributes pressure away from vulnerable areas by inflating and deflating the cells beneath the body every 10 minutes; A reactive (or constant lower pressure) mode where the cell pressure is reduced and held constant across the surface in order to lower the pressure exerted on the body. The pump had three settings for the patient body weight range: light (40-70 kilograms), normal (70-120 kilograms) and heavy (120-160 kilograms). The pump was set to maintain air pressure for a patient weighing between 40 and 70 kilograms (kg). A CPR control could be activated to rapidly deflate the mattress.

Weight discs were used to increase the CPR training manikin’s weight (21.5 kilograms), simulating a total weight of 60 kg on the mattress, approximating a realistic scenario. Under the head, arms and legs and aligned with the trunk, 3.5 kg, 7 kg, 10 kg and 18 kg were added respectively to approximate the percentages of total body weight as estimated by Plagenhoef et al. (1983) 15. No weights were placed under the manikin’s back as this could mimic the effect of a backboard during CPR. Participants were asked to perform hands-only (compression-only) cardiopulmonary resuscitation over a 2-minute period.

Measurements

An CPR training manikin Resusci Anne® with Q-CPR® Technology (Laerdal®) and a 30 kg compression spring was used to measure and assess the participants’ chest compression quality in both control and intervention group. A 30 kg force was required to reach 50 mm compression depth. During the intervention, the following metrics were registered using a SimPad® PLUS with SkillReporter™: compression rate, sternum-to-spine compression depth and correct hand positioning. Chest compressions were considered correct if they met the 2015 ERC guidelines for adult basic life support and automated external defibrillation: (1) deliver compressions ‘in the center of the chest’; (2) compress to a depth of at least 50 millimeters (mm) but not more than 60 mm; (3) compress the chest at a rate of 100–120 compressions per minute with as few interruptions as possible; (4) allow the chest to recoil completely after each compression 9. No feedback was provided to the participants during the data collection. Participants were asked to complete a short self-report questionnaire with their age, gender, and anthropometric data (body height and weight). Data collection was coordinated and carried out by one CPR certified final-year undergraduate nursing student at skills lab of the participating nursing schools.

Statistical analysis

Statistical analyses were conducted using SPSS 26.0 (IBM Corporation, Armonk, NY). Categorical variables (e.g., age, gender and outcome variables) were presented using frequencies and percentages. The Shapiro-Wilk test was used to assess the assumption of normality. Mean and standard deviations (SD) were used to present normally distributed continuous variables (e.g., body height, body weight and body mass index (BMI)). A comparison of categorical data between groups was performed using χ² tests. Continuous data were presented
as mean and standard deviation (SD), with comparison between groups as mean difference with 95% confidence interval (CI) and *P* value. Multiple linear regression was used to examine the predictive effect of body height, body weight, hand positioning and mattress type on depth and frequency of chest compressions. Variance inflation factor (VIF) and tolerance were calculated to test multicollinearity.

### Ethical and research approvals

Ethical approval was obtained from the local University College’s Research Ethics Committee in advance of the study (Ref. BPWD1920). The central Review Committee for Medical Ethics from UZ/KU Leuven waived the need for full ethical approval as this is a simulation-based study without patient data collection or involvement of patients. Written consent for participation and use of collected data was obtained from all participants. Participation was on a voluntary basis. Anonymity was guaranteed and participants were entitled to access the results after data processing. Commencement of the study was authorized by the Directors of Nursing Education concerned. The study was registered at ISRCTN.com (ISRCTN61041099).

### Results

#### Patient characteristics

Of the 79 nursing students who volunteered, 9 did not meet the criteria of successfully completed CPR training and were excluded. As a result, a total of 70 nursing students participated in the study. They were evenly distributed over the two study arms and were all included in the data analysis. The majority of the participants (*n* = 42) were between 18 and 21 years old and of female sex (*n* = 53). The 70 participants had a mean body height, body weight and BMI of respectively 170.21 cm (SD = 8.41), 67.70 kg (SD = 11.84) and 23.31 kg/m² (SD = 3.39). All characteristics of the control and intervention group (Table 1) were comparable at baseline (*p* > 0.05). The Shapiro-Wilk test showed that the distribution of body height, body weight and BMI in both groups was normal (all *p* > 0.05). The Shapiro-Wilk test showed that the distribution of body height, body weight and BMI in both groups was normal (all *p* > 0.05).

#### Chest compression quality

Chest compression quality is described in Table 2. The mean difference in chest compression depth between control and intervention group was calculated at 2.86 mm (*p* = 0.043; mean difference [MD], 2.86; 95% confidence interval [CI], 0.107–5.613). Table 3 shows no statistically significant association between allocation group and ERC guidelines conformity for chest compression depth, *χ*² (1, *N* = 70) = 0.612, *p* = 0.434. The mean difference in chest compression frequency between both groups was calculated at 1.51 compressions per minute (*p* = 0.585; mean difference [MD], 1.51; 95% confidence interval [CI], -4.003–7.023). Nevertheless, a statistically significant association between allocation group and ERC guidelines conformity for chest compression frequency approaches, but fails to achieve a customary level of statistical significance, *χ*² (1, *N* = 70) = 2.203, *p* = 0.138 (Table 3). Hand positioning during chest compression showed a mean absolute difference of 3.54% between control and intervention group (*p* = 0.674; mean difference [MD], -3.54; 95% confidence interval [CI], -13.218–20.298). Of all
participants performing CPR on a dynamic mattress overlay, 17.1% (n = 6) spontaneously indicated that it would be better to deflate the mattress during CPR.

**Predictive value of body height, body weight, mattress type and hand positioning**

Variance inflation factor (VIF) and tolerance were calculated to test multicollinearity. There was no mutual multicollinearity between the retained variables in the model: body height (VIF = 1.482; tolerance = 0.675), body weight (VIF = 1.614; tolerance = 0.619), mattress type (VIF = 1.003; tolerance = 0.997) and hand positioning (VIF = 1.113; tolerance = 0.899).

A first multiple linear regression was calculated to predict chest compression depth based on body height, body weight, mattress type and hand positioning. A significant regression equation was found ($F(4, 65) = 4.344, p = 0.004$), with an $R^2$ of 0.211. Participants’ predicted chest compression depth is equal to $39.157 - 2.983$ (dynamic mattress) + $0.024$ (height) + $0.135$ (weight) + $0.060$ (hand positioning), where ‘dynamic mattress’ is coded as 1 = Yes, 0 = No; ‘height’, ‘weight’ and ‘hand positioning’ are coded or measured in cm, in kg and in %, respectively. Participant’s chest compression depth increased 0.135 cm for each kg of weight, 0.024 cm for each cm of height and 0.60 cm for each additional point out of 100. CPR on a dynamic overlay mattress resulted in a 2.983 cm decrease in chest compression depth. Mattress type as well as body weight and hand positioning were significant predictors of chest compression depth. A second multiple linear regression was calculated to predict chest compression frequency, also based on body height, body weight, mattress type and hand positioning. No significant regression equation was found ($F(4, 65) = 1.553, p = 0.197$).

**Discussion**

This randomised manikin-based simulation study demonstrates a negative effect of an inflated dynamic overlay mattress on the quality of chest compressions during CPR. This needs a critical appraisal in the context of the 2015 ERC and AHA guidelines. Chest compression depth is statistically significantly lower in patients lying on a dynamic mattress, compared to those lying on a viscoelastic foam mattress. Overall, mattress type, body weight and hand positioning could be demonstrated as significant predictors for adequate chest compression depth.

As the guidelines recommend, the aim should be a compression depth between 50 and 60 mm. Despite the demonstrated statistically significant difference in compression depth, the control and intervention group both met these 2015 ERC requirements. Therefore, clinical significance of the study results can be questioned. In a real clinical setting, a 2.86 mm difference of compression depth between the control and intervention group ($p = 0.043$; mean difference [MD], 2.86; 95% confidence interval [CI], 0.107–5.613) is unlikely to alter the patient outcome of a resuscitation on a dynamic overlay mattress compared to that on a viscoelastic foam mattress. However, a variety of (anthropometric) factors are related to the depth of chest compressions (e.g., patient size and body weight, chest compliance).

In order to simulate chest compliance, compression springs requiring a 30 kg force to reach 50 mm compression depth were used. According to studies by Tomlinson et al. (2007) and Gruben et al. (1993), a chest compression
depth of 38 mm can be achieved by applying a mean force on the chest of 27.5 kg and 43.9 kg, respectively 16,17. Beesems et al. (2015) calculated the mean force required to reach a 53 mm compression depth at 41.8 kg 18. Our simulation study, in which 30 kg springs were used to achieve a compression of at least 50 mm, is therefore unlikely to reflect reality. Regardless of the compression spring used, the difference between control and intervention group will be statistically significant in any set-up, provided the control and intervention group set-ups are identical. It is questionable whether the results of our study (congruency with the 2015 ERC guidelines in both control and intervention group) would still be the same if stronger compression springs were used.

Our study showed that healthcare provider’s body weight and hand positioning are significant predictors for an adequate chest compression depth. These results are in line with earlier research examining the effect of BMI of participants on the quality of chest compressions: Chest compression depth in CPR is correlated with healthcare providers’ body weight (and therefore often more muscle mass in the torso and/or arms). More specifically, the depth of chest compressions is higher in the overweight people compared to normal weight and underweight people 19–22. To date, most researchers still mainly focused in their research on chest compression depth, rate and the chest compression-ventilation ratio.

Correct hand positioning for chest compression during CPR has not often been a focus of research 23. Our study showed that hand positioning is a statistically significant predictor for chest compression depth. According to the 2015 ERC guidelines, the hand should be placed with the heel in the center of the chest with the other hand on top. Ideally, this instruction should be accompanied by a demonstration of how to place the hands on the lower half of the sternum 9.

A study from Lin et al. (2017) describing the compressibility of different mattress types during CPR, suggests the type of mattress affects adequate chest compression depth. The use of a viscoelastic foam mattress significantly improved mattress compressibility by 11.7 mm compared to a foam ICU mattress 24. No evidence could be found about the compressibility of dynamic overlay mattresses. Therefore, authors emphasize identifying strategies to reduce mattress compressibility during resuscitation events, even though the certainty of evidence is still very low 25.

In case of resuscitation, we also recommend to deflate an air-filled dynamic mattress without any loss of time to create a firm surface during CPR 9. As it takes an average of 20 seconds to deflate an air-filled mattress 12 and the 2015 ERC guidelines suggest not to interrupt chest compressions for more than 10 seconds 9, authors recommend not interrupting chest compressions while deflating the mattress.

**Limitations**

There are some limitations in this randomised controlled trial. Firstly, the anthropometric data were based on self-reporting. Despite being a common data collection method in epidemiological studies, it can cause response bias, even though participants were asked to report fairly. Secondly, in the absence of stronger, reality-reflecting springs, only 30 kg compression springs were used. Therefore, compliance with the 2015 ERC guidelines regarding
depth of compression in both groups cannot be generalized to a real clinical setting without critical appraisal. The clinical significance of the study results can be debated. Finally, the data collection was performed in a controlled, stress-free setting, eliminating the reality of an actual resuscitation. This is likely to affect the results.

**Implications and recommendations for practice**

Healthcare first responders can improve patient survival and neurological outcome after an in- and/or out-of-hospital cardiac arrest by performing high-quality CPR at the time of the arrest. A firm surface is needed to achieve the correct chest compression depth and frequency. Special attention must be paid to correct hand positioning during CPR.

**Conclusions**

It is commonly argued that performing CPR on patients lying in bed on an inflated dynamic support mattress may have a negative impact on the quality of chest compressions. Despite a statistically significant difference between control and intervention group, this study shows that chest compression depth does not significantly deviate from the parameters recommended in the 2015 ERC and AHA guidelines. It was also shown that compression rate and hand positioning were not affected by mattress type. Consequently, this manikin-based simulation study does not provide evidence to support the deflation of a dynamic overlay mattress for CPR. A variety of factors are related to the depth of chest compressions. In any case, during CPR, specific attention should be paid to the timely initiation of chest compressions so that the benefits of this action clearly outweigh the clinical disadvantages of a late start. Therefore, it is important not losing time when deflating the dynamic overlay mattress to create a firm surface for CPR. Mattress type, body weight and hand positioning appear to be significant predictors for adequate chest compression depth.
What is known about the topic

- Performing high-quality chest compressions as part of CPR is important for patient survival and neurological outcome after cardiac arrest.
- The quality of chest compressions is affected by the surface under the patient.
- Research cannot provide clear, unequivocal evidence to support deflation of a dynamic mattress during CPR.

What this paper adds

- Chest compression depth in patients lying on a dynamic overlay mattress does not clinically significantly deviate from the parameters recommended in the 2015 ERC and AHA guidelines compared to patients lying on a viscoelastic foam mattress.
- Mattress type, body weight and hand positioning appear to be significant predictors for adequate chest compression depth.
References


Figure 1 - CONSORT flowchart.JPG
Table 1: Characteristics of participants (n = 70)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Control group (n = 35)</th>
<th>Intervention group (n = 35)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18 – 21 years, no. (%)†</td>
<td>18 (51.4)</td>
<td>24 (68.6)</td>
</tr>
<tr>
<td>22 – 25 years, no. (%)†</td>
<td>7 (20.0)</td>
<td>4 (11.4)</td>
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<tr>
<td>26 – 29 years, no. (%)†</td>
<td>4 (11.4)</td>
<td>2 (5.7)</td>
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<td>30 – 40 years, no. (%)†</td>
<td>5 (14.3)</td>
<td>4 (11.4)</td>
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<td>&gt;40 years</td>
<td>1 (2.9)</td>
<td>1 (2.9)</td>
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<tr>
<td>Gender</td>
<td></td>
<td></td>
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<tr>
<td>Male, no. (%)†</td>
<td>10 (28.6)</td>
<td>7 (20.0)</td>
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<td>Female, no. (%)†</td>
<td>25 (71.4)</td>
<td>28 (80.0)</td>
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<td>Body height, mean (SD), cm</td>
<td>170.14 (9.48)</td>
<td>170.29 (7.33)</td>
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<tr>
<td>Body weight, mean (SD), kg</td>
<td>68.03 (10.26)</td>
<td>67.37 (13.37)</td>
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<tr>
<td>BMI, mean (SD), kg/m²</td>
<td>23.48 (2.65)</td>
<td>23.15 (4.02)</td>
</tr>
</tbody>
</table>

BMI, body mass index; no., number; SD, standard deviation
†Percentages within group
Table 2: The mean difference and 95% confidence interval of chest compression frequency, depth and hand positioning for CPR on a visco elastic foam mattress (control) versus a dynamic overlay mattress (intervention)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Control group (n = 35)</th>
<th>Intervention group (n = 35)</th>
<th>Between-group differences</th>
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<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean difference</td>
</tr>
<tr>
<td>Frequency, compressions per minute</td>
<td>109.80 (10.40)</td>
<td>108.29 (12.61)</td>
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<td>Depth, mm</td>
<td>57.29 (4.18)</td>
<td>54.43 (7.01)</td>
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<tr>
<td>Hand positioning, %</td>
<td>81.63 (36.47)</td>
<td>85.17 (33.74)</td>
<td>-3.54</td>
</tr>
</tbody>
</table>

CI, confidence interval; SD, standard deviation
Table 3: ERC (2015) conformity for chest compression quality

<table>
<thead>
<tr>
<th>Variables</th>
<th>Control group (n = 35)</th>
<th>Intervention group (n = 35)</th>
<th>P Value</th>
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<tr>
<td>ERC conformity</td>
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<tr>
<td>Frequency</td>
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<td>0.138</td>
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<td>Yes, no. (%)†</td>
<td>25 (71.4)</td>
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<td>No, no. (%)†</td>
<td>10 (28.6)</td>
<td>16 (45.7)</td>
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<tr>
<td>Depth</td>
<td></td>
<td></td>
<td>0.434</td>
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<td>Yes, no. (%)†</td>
<td>26 (74.3)</td>
<td>23 (65.7)</td>
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<tr>
<td>No, no. (%)†</td>
<td>9 (25.7)</td>
<td>12 (34.3)</td>
<td></td>
</tr>
</tbody>
</table>

ERC, European Resuscitation Council; no., number
†Percentages within group
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- **Funding statement:** No funding
- **Conflict of interest disclosure:** The authors of this manuscript declare no relationships with any companies whose products or services may be related to the subject matter of the article.
- **Ethics approval statement:** As this is a manikin-based trial, the approval of the study by a medical ethics review committee was waived due to the observational nature of the study and lack of patient involvement.
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- **Trial registering:** The study was registered at ISRCTN.com (ISRCTN61041099)
- **Author contributions:** T. Torsy and W. Deswarte equally contributed to the conception and design of the research; T. Torsy and W. Deswarte contributed to the acquisition and analysis of the data; T. Torsy, W. Deswarte, M. Karlsberg-Traav and D. Beeckman contributed to the interpretation of the data; and T. Torsy drafted the manuscript. All authors critically revised the manuscript, agree to be fully accountable for ensuring the integrity and accuracy of the work, and read and approved the final manuscript.
- **Acknowledgements:** The authors would like to thank the Odisee University College and the TI Sint-Carolus for facilitating this study. They also would like to thank Sarah Steckel and Inge Tency for assisting with the final draft.