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Comparison of manual versus mechanical chest compression with $ETCO_2$ value in-hospital cardiac arrest: A prospective observational study

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Abstract

Aim: The aim of this study was to compare the effectiveness of manual versus mechanical chest compression by using continuous end-tidal carbon dioxide ($ETCO_2$) monitoring in-hospital cardiac arrest patients.

Methods: The study included 90 patients meeting the inclusion criteria. Forty-seven (52.2%) patients were male and 43 (47.8%) were female. A prospective observational study of patients who experienced cardiac arrest while being monitored at the emergency department (ED) was conducted at the ED of a tertiary university hospital between April 2018 and September 2019. Demographics, electrocardiography (ECG) rhythm, cardiopulmonary resuscitation (CPR) technique (manual or automatic), laboratory data, the time to return of spontaneous circulation (ROSC), length of stay in the ED, hospitalization, and mortality were compared according to CPR type. Forty-four (48%) patients underwent manual CPR, and 46 (52%) patients underwent automatic CPR.

Results: The 15th-minute and 20th-minute oxygen saturation (SaO_2) levels, and the 10th-, 15th-, and 20th-minute $ETCO_2$ levels showed a significant difference between the automatic CPR and manual CPR with all three variables being higher in the automatic CPR group (p=0.013, p=0.002, p=0.037, p=0.002, p<0.001, respectively). The causes of cardiopulmonary arrest, consultations, POCUS results, post-CPR lifetime, treatment types and neurological conditions were similar in both of the groups. Exitus was more frequent in the manual CPR device group (p=0,013).

Conclusion: Mechanical Chest Compression provides more high-quality CPR than manual Chest Compression in-hospital cardiac arrest, and mid-resuscitation $ETCO_2$ values equal to or greater than 20 mmHg appear to be a good predictor of ROSC.

Keywords: Cardiopulmonary resuscitation, mechanical chest compression, in-hospital cardiac arrest, $ETCO_2$, CPR, mortality

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Introduction

Long-term survival and good neurological outcomes are highly dependent on well-performed CPR among patients suffering cardiac arrest, and substantially prolonged CPR durations are typically needed to obtain a ROSC (1). As defined by the European Resuscitation Council and the American Heart Association, a high-quality CPR involves chest compressions numbering 100 to 120 per minute that are forceful enough to depress the sternum for at least 5 cm from baseline or one-third of the anteroposterior chest diameter. This degree of cardiopulmonary support is typically able to re-establish systemic circulation, thereby providing adequate coronary and cerebral perfusion (2, 3). Nevertheless, even highly entrained CPR deliverers experience difficulty to perform highly effective CPR for a long time. Mechanical Chest Compression devices are able to negate the fatigue of healthcare staff delivering CPR and thus administer highly efficient CPR, particularly for patients who had cardiac arrest under unsuitable conditions. These devices have, therefore been recommended by CPR guidelines to be used by a trained CPR team. In accordance, The United States Food and Drug Administration has approved two such devices to deliver high-quality CPR: AutoPulse (Zoll Medical Corporation, Chelmsford, MA, USA) and LUCAS (Physio-Control/Jolife AB, Lund, Sweden) (4).

End-tidal carbon dioxide ($ETCO_2$) is measured at end-expiration and refers to the partial carbon dioxide (PCO_2) pressure in exhaled air. Capnography refers to the technique of uninterrupted, non-invasive determination of PCO_2 in exhaled air, while the waveform created during such continuous measurement is termed a capnogram (5).

$ETCO_2$ is a non-invasive indicator of CPR efficacy by acting as a surrogate marker of effective circulation during CPR effort; it thus provides an estimate of the quality of chest compressions during CPR while it also gives an early idea about the likelihood of ROSC and ultimate resuscitation success. Hence, it can reliably be used as a variable to determine the difference between manual and mechanical chest compressions (6).

Mechanical chest compression devices have the potential to help maintain high-quality CPR, but despite their increasing use, little evidence exists for their effectiveness. Studies comparing manual and automatic CPR in cardiac arrest have mostly been performed on out-of-hospital cases or on animal/manikin models (7-12). There are few studies in the literature comparing manual and automatic CPR in in-hospital cardiac arrest (13).

In this study, our primary aim was to investigate the effectiveness of automatic CPR even under adequate conditions in the hospital (sufficiently trained doctor, allied health personnel, and medical device support), and the secondary goal is to compare the effectiveness through continuous $ETCO_2$ monitoring.

Materials and Methods

The present study was a prospective observational study of patients who experienced cardiac arrest while being monitored at the ED of the University of Health Sciences, Antalya Training and Research Hospital between April 2018 and September 2019. The study was approved by the Clinical Research Ethics Committee of the hospital with the decision number of 6/9 and on the date 22.03.2018. Written informed consent form was obtained from all the relatives of participants.

The demographic information (age, sex) of the patients, vital signs (pulse rate, blood pressure, oxygen saturation (SaO_2), electrocardiography (ECG) rhythm (shockable, non-shockable rhythm), CPR technique (manual or automatic), $ETCO_2$ values, procedures performed during clinical follow-up (establishing an airway and intravenous line patency), laboratory data (blood gas, hemogram, and emergency biochemistry), duration of follow-up in the ED, hospitalization status, neurological outcome (survival without sequala, survival with sequala, brain death) and mortality status were recorded on the patient enrollment forms that were standardized before the onset of the study. The study patients were grouped by the time to ROSC during manual or automatic CPR procedure (0. min/5. min/10. min/15. min/20. min/25. min/30. min). The $ETCO_2$ and SaO_2 levels of the individuals were recorded independently at baseline and each subsequent 5-minute intervals. In addition, bedside Point-of-Care Ultrasound (POCUS) was applied to patients with ROSC to investigate possible causes of cardiac arrest (14-16).

The study included 90 patients meeting the inclusion criteria. Forty-seven (52.2%) patients were male and 43 (47.8%) were female. Forty-four (48%) patients underwent manual CPR, and 46 (52%) patients underwent automatic CPR.

The patients aged 18 years or older who had an arrest during ED follow-up were included in this study. Patients under the age of 18 and those who had an arrest due to trauma or drowning were excluded. Patients with witnessed arrest were delivered CPR by a senior emergency physician (having at least two years of emergency medicine training) and other healthcare personnel trained in CPR. Automatic CPR was delivered by emergency medicine physicians who had received at least 4 hours of theoretical and practical training in the Corpuls automatic CPR device. All patients enrolled in the study were delivered advanced cardiac life support. Automatic CPR was delivered by Corpuls piston-driven automatic CPR device. Corpuls automatic CPR device consists of two basic apparatuses, namely an adjustable body and a table. The table on which the device sits can be fixed to the patient's bed, while the height of the body can be adjusted according to the patient's size. The device weighs approximately 5.5 kg. It can perform 80-120 chest compressions per minute at a compression depth of 2-6 cm; it can perform compressions uninterruptedly or is capable of giving an audible warning in every period to allow rhythm control. It can also automatically adjust the distance between its piston and the patient's chest; it starts chest compressions when the green warning lamp on the main head is lit, indicating that the device is at an appropriate distance.

The automated CPR apparatus is positioned in close proximity to the patient monitoring area and is initiated immediately upon identification of cardiac arrest. As this procedure is conducted by practitioners who have undergone prior training, chest compressions are typically initiated within an average of one minute. The patients' initial $ETCO_2$ and oxygen saturation levels were measured after intubation. All patients who underwent automatic CPR were applied chest compressions at a rate of 100-120/min and a depth of 4.5-6 cm. A rhythm check was performed every 2 minutes. $ETCO_2$ levels were measured with a Masimo Emma capnometer device. In all patients, an endotracheal airway was opened, and a capnometer device was placed in the endotracheal tube we used for this airway. This capnometry device had the capability of measuring $ETCO_2$ levels in the range of 0-99 mmHg and displaying the respiratory rate and the respiratory wave graphic on the same screen. A graphical illustration of the study is shown in Figure 1.

Statistical analysis

The statistical analyses were performed by using SPSS software (IBM SPSS Statistics version 26.0, IBM Inc., Armonk, NY, USA).

The normality of the distribution of continuous variables was checked with histograms and the One-Sample Kolmogorov-Smirnov test, with a p-value above 0.05 indicating a normal distribution. Normally distributed continuous variables were expressed as mean ±standard deviation and nominal variables as the number of cases and percentage. Independent variables with normal distribution were compared with Independent samples t-test, while the Chi-square test was used to compare categoric variables. All comparisons were carried out in a two-sided fashion, and a p-value of less than 0.05 was considered statistically significant.

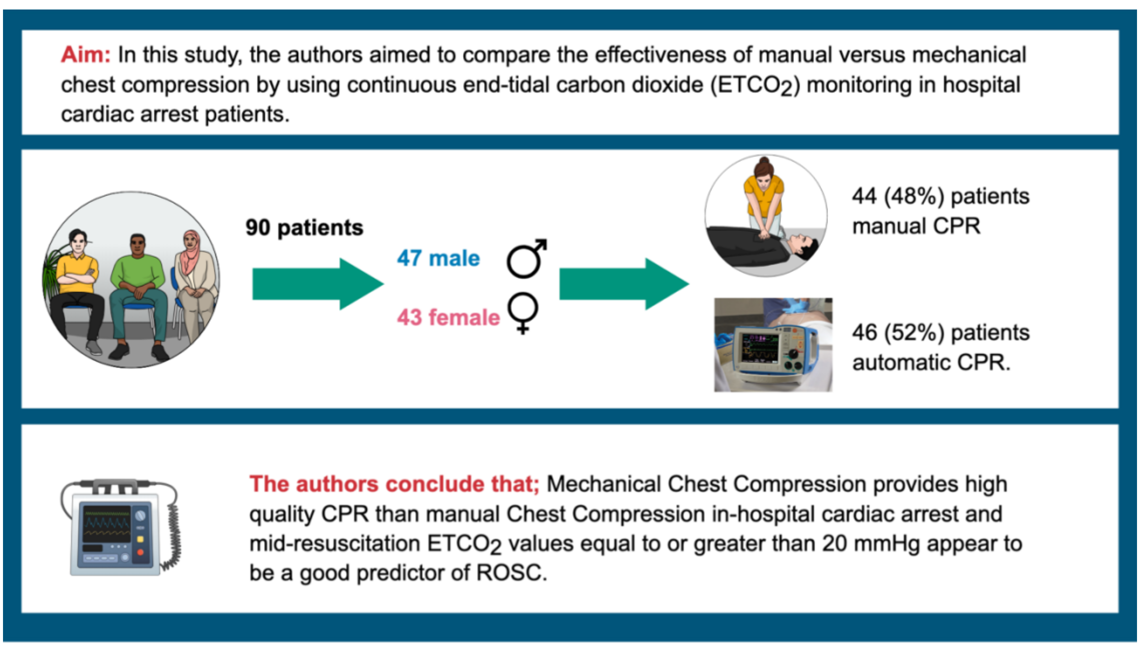

Figure 1. Graphical illustration of the study

Results

The mean age of patients who underwent manual CPR was 70.1±15.8 years; those who underwent automatic CPR had a mean age of 66.8±13.7 years. There was no significant difference between the two groups with respect to mean age and sex distribution. CPR time, cardiac rhythm, and laboratory examinations were similar in both of the groups (Table 1).

The causes of cardiopulmonary arrest, consultations, POCUS results, post-CPR lifetime, treatment types, and neurological conditions were similar in both groups (Table 2). Exitus was more frequent in the manual CPR device group (*p*=0,013).

SO_2 and $ETCO_2$ were similar in both of the groups until the 15th minute and after the 25th minute (Table 3). However, at the 15th and 20th minutes, SO_2 and $ETCO_2$ levels were significantly higher in the automated CPR device group (Table 3 and Figs. 2, 3). In both of the groups, SO_2 levels were increased in the first 10 minutes, but after this point the SO_2 levels decreased. In both of the groups, $ETCO_2$ levels were increasing in the first 5 minutes, but after this point the SPO_2 levels were degreasing (Figs. 2 and 3). In the course of the study, no complications related to the devices were observed in patients who underwent mechanical CPR.

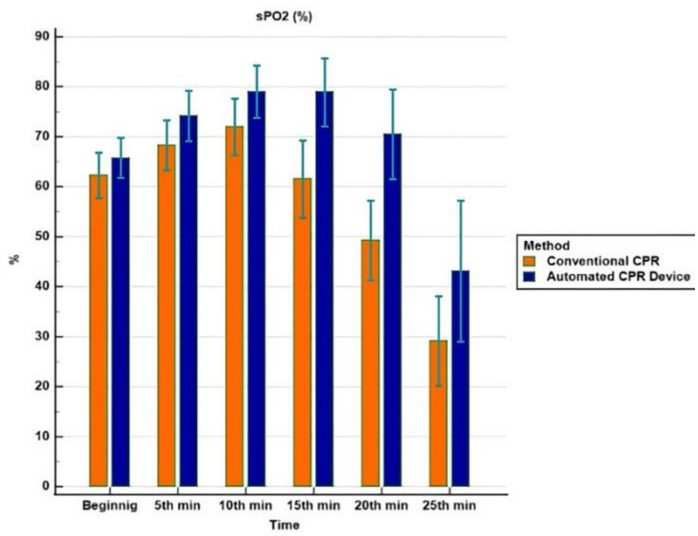

Figure 2. SPO_2 change in time in CPR types.

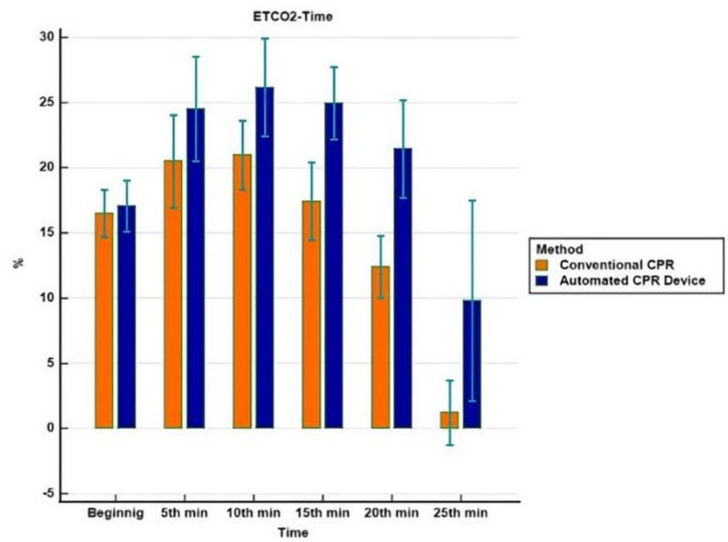

Figure 3. $ETCO_2$ change in time in CPR types.

Table 1. Comparison of CPR type according to age, gender, duration of CPR, rhythm, and biochemical results

	Type of CPR		
	Manual CPR (mean ± SD)	Automatic CPR (mean ± SD)	*p*
Age	70.1±15.8	66.8±13.7	0.283*
Gender n(%)			
Female	24 (54.5%)	19 (41.3%)	0.209 †
Male	20 (45.5%)	27 (58.7%)	
CPR Time (minute)	25.6±7.9	23±7.3	0.117
Cardiac Rhythmn (%)			
Shockable rhythm	7 (15.9%)	9 (19.6%)	0.650 †
Nonshockable rhythm	37 (84.1%)	37 (80.4%)	
Biochemistry			p*
Hematocrit (%)	34.51±8.89	36.77±7.26	0.191
Hemoglobin (mg/dL)	11.77±3.27	12.33±2.6	0.366
White blood cell (x103)	16.69±10.51	17.34±15.13	0.815
Platelet (x103)	286.14±138.04	258.8±164.03	0.396
C-Reactive protein (mg/L)	114.33±106.94	83.13±110.35	0.177
Blood urea nitrogen (mg/dL)	43.2±32.9	38±30.8	0.442
Creatinine (mg/dL)	1.93±1.28	1.86±1.33	0.789
Troponin-I (ng/mL)	158.89±504.88	158.8±305.83	0.999
pH	7.2±0.2	7.2±0.1	0.690
pO_2 (mmHg)	49±10.4	52.2±9.9	0.141
pCO_2 (mmHg)	47.6±10.8	50.3±11.6	0.250
HCO_3 (mEq/L)	17.3±4.5	17.1±4.3	0.843
Lactate (mmol/L)	5.47±4.23	4.9±4.45	0.535
Time of observation at ED (hour)	4.1±3.7	4.2±2.1	0.869

*Student's t-test, † Chi-square test

Table 2. Comparison of clinical characteristics by type of CPR

	Type of CPR n(%)		p*
	Manual CPR	Automatic CPR	
Etiology of CPR			0.263
Unknown	4 (9.1%)	3 (6.5%)	
Acute coronary syndrome	6 (13.6%)	5 (10.9%)	
Cerebrovascular event	9 (20.5%)	9 (19.6%)	
Massive pulmonary embolism	-	1 (2.2%)	
Shock	4 (9.1%)	1 (2.2%)	
Decompensated Heart failure	3 (6.8%)	3 (6.5%)	
Acute respiratory failure	15 (34.1%)	13 (28.3%)	
Other	3 (6.8%)	11 (23.9%)	
Consultation	26 (59.1%)	33 (71.7%)	0.093
Cardiology	18 (40.9%)	19 (41.3%)	
Respiratory disease	2 (4.5%)	2 (4.3%)	
Neurology	2 (4.5%)	2 (4.3%)	
Other	4 (9.1%)	10 (21.7%)	
POCUS			0.657
Decreased EF%	9 (20.5%)	22 (47.8%)	
Pulmonary B lines	4 (11%)	7 (15.2%)	
Survival after CPR			0.356
48 hours	2 (4.5%)	9 (19.6%)	
1 week	1 (2.3%)	6 (13%)	
1 month	-	3 (6.5%)	
6 months	7 (15.9%)	4 (8.7%)	
Therapy			0.501
PTCA + stent	3 (6.8%)	5 (10.9%)	
Anticoagulant Therapy	3 (6.8%)	3 (6.5%)	
Antibiotic therapy	1 (2.3%)	2 (4.3%)	
Bronchodilator therapy	1 (2.3%)	1 (2.2%)	
Other	36 (81.8%)	35 (76.1%)	
Clinical outcome			0.013
Hospitalization	10 (22.7%)	22 (47.8%)	
Exitus	34 (77.3%)	24 (52.2%)	
Neurologic outcome			0.790
Brain death	36 (81.8%)	40 (87%)	
Recovery without sequelae	5 (11.4%)	2 (4.3%)	
Recovery with sequelae	3 (6.8%)	4 (8.7%)	

*Chi-square test, POCUS: Point-care ultrasonography, EF: ejection fraction, PTCA: percutan transvenous coronary angiography

Table 3. Comparison of SO_2 and $ETCO_2$ values according to Type of CPR

	Type of CPR Manual CPR (Mean ± SD)	Automatic CPR (Mean ± SD)	p*
SO_2 (%)			
Beginning	62.3±15	65.3±13.5	0.321
5. minute	68.3±16.3	74.2±16.9	0.098
10. minute	72±18.4	78.7±17.5	0.083
15. minute	61.7±22.9	78±22.3	**0.002**
20. minute	49.7±23.6	69.6±27.1	**0.002**
25. minute	28.6±25.4	41.6±35.6	0.107
30. minute	6.4±14.1	11.8±26.9	0.343
$ETCO_2$ (%)			
Beginning	16.5±5.9	17.2±6.7	0.583
5. minute	20.5±11.5	24.7±13.6	0.117
10. minute	21±8.6	26±12.8	**0.037**
15. minute	17.7±9	24.4±9.2	**0.002**
20. minute	12.7±7.2	21.2±11.5	**<0.001**
25. minute	7.8±7.1	11.6±12.4	0.140
30. minute	2.7±3.3	4.3±9.7	0.409

*Student's t-test

Discussion

Although advances in resuscitation efforts have come a long way, still the survival rates remain low as it depends on high-quality CPR, which means minimizing interruptions in chest compressions, providing compressions of adequate rate and depth, avoiding leaning between compressions, and avoiding excessive ventilation (3). These critical components of high-quality CPR require extreme human physical power, which means fatigue of health care and interruptions impact both myocardial and brain perfusion, which is crucial for favorable neurological survival, so to overcome these manual CPR problems, several mechanical CPR devices were developed (17). These devices maintain a standard chest compression depth and rate without any interruptions, and their effectiveness was validated in many out-of-hospital experimental or human studies (7, 10).

The efficacy of chest compressions during CPR can be monitored by $ETCO_2$ levels, which is an indirect indicator of coronary perfusion pressure and, consequently the possibility of ROSC (6, 18). So it is reasonable to consider using $ETCO_2$ to guide chest compressions in both mechanical devices and manual chest compressions. As far as we know, this study is the first in humans to correlate $ETCO_2$ levels to the CPR technique used. $ETCO_2$ is used as an indirect marker of effective CPR, and our study demonstrated that the mechanical CPR device attained higher $ETCO_2$ levels. Although the use of mechanical CPR devices has not yet been recommended by the available society guidelines, it has been stated that mechanical chest compressions can be given consideration in several special circumstances (issues such as quality, safety, feasibility, and practicability) (10).

Although studies examining out-of-hospital and in-hospital cardiac arrest cases have provided conflicting survival rates, they predominantly indicated that automatic CPR is superior in terms of 30-day survival and hospital discharge of in-hospital cardiac arrest cases, as well as time to ROSC and neurological recovery, which may due largely to a shorter time to start compressions with automatic devices by a larger number of staff highly experienced in in-hospital arrest cases (4-6, 10, 19). A review of the literature reveals a wide range of findings regarding the survival discharge rate from the hospital, with rates varying from 0% to 42%. In large-scale studies, this rate was found to be approximately 20% (20). In-hospital cardiac arrest (IHCA) remains a somewhat neglected issue when compared to out-of-hospital cardiac arrest (OHCA). This issue has been subjected to more frequent analysis in the context of OHCA cases (20). At present, there is no compelling evidence that mechanical chest compressions (CC) have an impact on long-term survival. A review of the literature reveals that the majority of studies were conducted on cases of out-of-hospital cardiac arrest (OHCA) (22). There are few studies evaluating the effectiveness of these devices in IHCA cases; these studies evaluated the importance of chest compression in patients with NEA, whether mechanical chest compression can be a supportive treatment, and the strength of effect between the mechanical CPR method and the conventional method (13, 25-29).

In the meta-analysis conducted by Liu et al., it was concluded that there was no statistically significant difference between manual chest compressions (CC) and the use of the LUCAS device in cases of out-of-hospital cardiac arrest (OHCA) with regard to favorable clinical outcomes (23). In the meta-analysis conducted by Couper et al., it was indicated that the utilization of mechanical CC devices in IHCA cases was associated with enhanced hospital and 30-day survival rates (13). Furthermore, Parnia et al. identified a correlation between mechanical CC and enhanced cerebral oxygenation, though the evidence was limited (24). In a study conducted by Şener et al., it was determined that mechanical CC was not superior to manual CC in terms of ROSC, 30-day survival, and discharge parameters in cardiac arrest patients (21). Nevertheless, mechanical CC appears to be more effective than manual CC in terms of 7-day survival. In this study, the hospital discharge rate was observed to be 9.2%. In our study, the rate of discharge from the hospital was found to be 17.7% in all patients, which is consistent with the findings in the literature.

In the existing literature, the most frequently identified cause of cardiac arrest is cardiac in origin (20). The results of our study indicate that acute coronary syndrome, cerebrovascular accident, and acute respiratory failure were the primary causes (Table 1). The reasons for this situation may include the fact that our hospital is a tertiary care facility where patients with the most critical illnesses in the Mediterranean region are admitted, the intensive admission of elderly home care patients with high comorbidities, and the fact that our hospital is also a stroke center.

The findings of our study indicate that, although the survival rate after 48 hours in patients with ROSC after CPR was higher in the Automatic CPR group than in the Manual CPR group (19.6% and 4.5%, respectively), there was no statistically significant difference between the two groups in terms of neurological outcome (Table 1). However, available studies have not shown that baseline or mid-resuscitation $ETCO_2$ cut-off values consistently predict CPR outcomes (18). Considering that the $ETCO_2$ levels at 10-15-20 minutes were significantly higher and the number of the patients' achieving ROSC was higher with automatic CPR for the same timeframes, we can argue that automatic CPR is more effective in in-hospital cardiac arrest cases. This data may be related to the statistical significance of the automatic piston CPR device with adjustable compression and depth advantage, providing continuity, and in manual application, personnel fatigue and incomplete numerical standardization (19).

Limitations

There are some limitations of our study. As the first limitation, we did not examine the predictive value of pauses associated with deployment. Secondly, we did not take into account the patients' demographic characteristics and comorbidities. Thirdly, we cannot generalize our results to other automatic CPR devices.

Conclusion

According to the results of our study, we found that automatic CPR machine provides high-quality CPR than manual CPR in-hospital cardiac arrest, and mid-resuscitation $ETCO_2$ values equal to or greater than 20 mmHg appear to be a good predictor of ROSC. They may perhaps become a predictor of survival in the upcoming years. Further research is needed to investigate how the predictive performance of $ETCO_2$ for ROSC would be affected by the timing of its measurement during CPR and to determine sensitive and specific cut-off values for determining the efficacy of both manual and mechanical CPR.

Disclosures

Ethical Approval: Ethics committee approval was received for this study from the University of Health Sciences, Antalya Training and Research Hospital Local Ethics Committee, in accordance with the World Medical Association Declaration of Helsinki, with the approval number: 2018-6/9.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – Y.Y.; Design – Y.Y., F.Y.; Supervision – A.Y.; Materials – Y.Y., B.M.S., S.T.; Data collection &/or processing – C.K., S.K.; Analysis and/or interpretation – Y.Y.; Literature search – Y.Y., İ.B., Ö.Z.; Writing – Y.Y.; Critical review – Y.Y., B.M.S, C.K., Ö.Z.

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