Impact of lung compliance on neurological outcome in patients with acute respiratory distress syndrome following out-of-hospital cardiac arrest

June-Sung Kim
Asan Medical Center
Youn-Jung Kim
Asan Medical Center
Muyeol Kim
Asan Medical Center
Seung Mok Ryoo
Asan Medical Center
Chang Hwan Sohn
Asan Medical Center
Shin Ahn
Asan Medical Center
Won Young Kim (wonpia73@naver.com)
Department of Emergency Medicine, University of Ulsan College of Medicine, Asan Medical Center
https://orcid.org/0000-0002-6904-5966

Research

Keywords: cardiac arrest, acute respiratory distress syndrome, mechanical ventilation, ICU management

Posted Date: January 10th, 2020

DOI: https://doi.org/10.21203/rs.2.20594/v1

Abstract

Background

Acute respiratory distress syndrome (ARDS) following cardiac arrest is common and associated with in-hospital mortality. We aimed to investigate whether lung compliance during targeted temperature management is associated with neurological outcome in patients with ARDS after out-of-hospital cardiac arrest (OHCA).

Methods

This observational study was conducted in the emergency intensive care unit from January 2011 to April 2019 using data from a prospective patient registry. Adult patients (age ≥18 years) who survived non-traumatic OHCA and subsequently developed ARDS based on the Berlin definition were included. Mechanical ventilator parameters such as peak inspiratory pressure, tidal volume, minute ventilation, positive end expiratory pressure, and compliance were recorded for 7 days or until death, and categorized as maximum, median, and minimum. The primary outcome was favorable neurological outcome defined as Cerebral Performance Category score 1 or 2 at hospital discharge.

Results

Of 246 OHCA survivors, 119 (48.4%) patients developed ARDS. A favorable neurologic outcome was observed in 23 (19.3%). Patients with favorable outcome had significantly higher lung compliance (38.6 cm H 2 O vs 27.5 cm H 2 O), lower inspiratory pressure (12.0 cm H 2 O vs 16.0 cm H 2 O), and lower peak inspiratory pressure (17.0 cm H 2 O vs 21.0 cm H 2 O) than those with poor neurologic outcome (all P <0.01). In time-dependent cox regression models, all maximum (hazard ratio [HR] 1.05, 95% confidence interval [CI] 1.03-1.08), minimum (HR 1.08, 95% CI 1.04 – 1.12), and median (HR 1.06, 95% CI 1.03-1.10) compliances were independently associated with good neurologic outcome. Median compliance > 31.4 mL/cm H 2 O at day 1 had the highest area under the receiver operating characteristic curve (0.732) with positive predictive value of 90%.

Conclusion

Lung compliance may be an early predictor of neurologic intact survival in patients with ARDS following cardiac arrest.

Introduction

Despite recent advances in prevention and resuscitation, the mortality and morbidity of cardiac arrest (CA) remain high [1–3]. Postcardiac arrest syndrome (PCAS), the major cause of death in CA patients, is characterized by systemic post-arrest ischemia-reperfusion injury with activation of the inflammatory response; its in-hospital mortality is > 50% [4]. PCAS can affect multiple organs. Pulmonary involvement manifests as acute respiratory distress syndrome (ARDS), which often results in poor clinical outcome [5].

The authors postulated that ARDS accelerates ischemic brain injury caused by aggravating the mismatch of supply and demand of oxygen (O_2) and carbon dioxide (CO_2).

Mechanical ventilation is the cornerstone of managing and treating ARDS. However, it can also cause parenchymal lung damage through over-distension and cyclic alveolar opening and closing [6–8]. Lung-protective ventilation utilizing lower tidal volume (V_T) and higher positive end-expiratory pressure (PEEP) has been shown to improve survival in numerous trials [9]. In addition, fluid restriction, use of neuromuscular blocking agents, and prone ventilation reduce mortality in severe ARDS patients [10]. Therefore, discovering accurate prognostic markers of ARDS severity is essential to facilitate risk stratification and apply novel therapeutic interventions to improve outcomes. Since lung compliance correlates with the aerated functional component of the pulmonary system [11], we hypothesized that lung compliance, an easily measured clinical variable, could be an important prognostic marker than V_T or PEEP in patients with ARDS after CA.

This study aims to investigate whether lung compliance during targeted temperature management (TTM) is associated with neurological outcome in patients with ARDS after out-of-hospital cardiac arrest (OHCA).

Material And Methods

Study design and population

This retrospective study used prospectively collected data that were entered into the Asan Medical Center emergency intensive care unit OHCA patient registry from January 2011 to April 2019. Asan Medical Center is a tertiary referral academic center in Seoul, Korea with 2,700 beds and approximately 130,000 Emergency Department patient visitations annually. The study was approved by the institutional research ethics committee; the requirement for informed consent was waived because the study was retrospective in nature.

The OCHA registry consists of all adults (age ≥ 18 years) admitted to the emergency intensive care unit with non-traumatic CA. Patients with the following criteria are excluded from the registry: age < 18 years, presumed traumatic CA, “do not resuscitate” status, transfer to other hospital, and decline proper treatment. This study enrolled patients from the registry who developed ARDS within 48 hours after CA. We identified ARDS patients using the Berlin definition. In brief, we found those who had two consecutive arterial blood gas analysis (ABGA) with partial pressure of arterial oxygen (PaO2)/fraction of inspired oxygen (FiO2) (P/F) ratio < 300 in a mechanically ventilated patient with bilateral radiographic opacities. All chest radiographs were reviewed by radiologists. We excluded patients who received extracorporeal membrane oxygenation (ECMO) during or after cardiopulmonary resuscitation (CPR). Moreover, we exclude the cases of cardiogenic pulmonary edema which were defined as left ventricle ejection fractions below 30% based on transthoracic echocardiography.

Routine post-cardiac arrest care protocol

For all patients, CPR and post-resuscitation care, including coronary intervention and TTM, were administered in accordance with the current Advanced Cardiac Life Support guidelines. TTM consists of three phases: induction, maintenance, and rewarming. TTM was induced with a cooling device with self-adhesive hydrogel coated pads (Arctic Sun Energy Transfer Pads, Medivance Corp, Louisville, CO). The target temperature of 33–36°C was maintained for 24 hours (maintenance phase), and patients were then rewarmed to 36.5°C at a rate of 0.25°C/hr. Temperature was monitored using an esophageal probe and continuous intravenous propofol and opioids (morphine or remifentanil) were administered for sedation and analgesia during TTM. ABGA was performed in all patients just after return of spontaneous circulation (ROSC) and repeated every 2 ± 1 hours. In addition, all patients were mechanically ventilated in pressure-controlled mode and every change of ventilator parameter, such as V_T, PEEP, inspiratory pressure, peak inspiratory pressure (PIP), plateau pressure (P_{plat}), respiratory rate (RR), and minute ventilation was recorded in the electronic medical record by experienced intensive care unit nurses.

Definitions of variables

As part of the protocol, we performed a chest radiograph at least once in a day and obtained ABGA every hour during induction and every 2 hours during the maintenance period. Using the results of ABGA and ventilator parameters, P/F ratio and compliance ($V_T/[P_{plat}-PEEP]$) were calculated. In addition, we categorized the calculated measures, including V_T, minute volume, and compliance as maximum, median, and minimum for 7 days or until death, whichever came first. If there were missing ABGA or ventilator variable data, the means of each variable were filled before the statistical analysis.

We extracted demographic and baseline clinical data from the registry, including age, sex, and underlying diseases. In addition, we gathered other CA data according to the Utstein Style recommendations, including location, witnessed arrest, bystander CPR, duration of CPR, initial documented rhythm, presumed arrest cause, and initial electrocardiography rhythm. The Sequential Organ Failure Assessment (SOFA) score was determined from the initial data on admission. The primary outcome of the study was the association of lung compliance with favorable neurologic outcome at discharge (defined as Cerebral Performance Category (CPC) score of 1 or 2). The CPC score is a well-validated outcome measure for comatose patients after CPR. Other ventilator parameters were compared between ARDS and non-ARDS patients as secondary outcomes.

Statistical analyses

Statistical analyses were performed using SPSS Statistics for Windows version 23 (SPSS Inc., Chicago, Illinois, United States). Continuous variables were expressed as median with interquartile range. Categorical variables were analyzed with the chi-square or Fisher’s exact tests. The normality of distribution was examined using the Kolmogorov-Smirnov test. The Mann-Whitney U test was used for comparisons between the good and poor neurologic outcome groups. To examine the association between ARDS and poor neurologic outcome, we used a Cox regression model with maximum, median, and minimum lung compliances as a time-varying covariate. The diagnostic accuracy of lung compliances was compared by using receiver operating characteristic (ROC) curves and calculating the area under the curve (AUC). In addition, sensitivity, specificity, positive predictive value, negative predictive value, positive likelihood ratio, and negative likelihood ratio were calculated by standard statistical methods. The optimal cut-off value of compliances for neurologic outcome was determined with the Youden index (sensitivity + specificity – 1) from the ROC analysis. $P < 0.05$ was considered significant.

Results

During the study period, a total of 295 registry patients survived CA, and 246 were analyzed after excluding 49 who received ECMO and had cardiogenic pulmonary edema. Among these, 119 patients (48.4%) developed ARDS within 48 hours (20 mild, 48 moderate, 51 severe). Of the 119 patients with ARDS, 23 (19.3%) had a favorable neurologic outcome at discharge.

Baseline characteristics

The baseline characteristics of the study population are presented in Table 1. The median age was 66 years with male predominance (66.4%). Hypertension (47.9%) was the most frequent comorbidity followed by diabetes (37.8%). These did not differ significantly between the good and poor neurologic outcome groups. The favorable neurologic outcome group had a significantly higher proportion of patients with a shockable initial rhythm (64.3% vs 16.0%; $p < 0.001$), presumed cardiac cause (65.2% vs. 41.7%; $p = 0.061$), shorter CPR duration (11.0 vs. 31.5 minutes; $p < 0.001$), and shorter mechanical ventilator duration. Other comorbidities and characteristics of CA did not differ significantly between the two groups.

Table 1
Baseline characteristics of the ARDS patients

Characteristics	Total (n = 119)	Poor outcome (n = 96)	Good outcome (n = 23)	p-value
Age	66.0 (55.0–78.0)	67.0 (55.0–77.0)	66.0 (57.0–80.0)	0.874
Male	79 (66.4)	62 (64.6)	17 (73.9)	0.468
Past history				
Previous ACS	26 (21.8)	18 (18.8)	8 (34.8)	0.525
Previous PCI	17 (14.3)	12 (12.5)	5 (21.7)	0.318
Hypertension	57 (47.9)	49 (51.0)	8 (34.8)	0.173
Diabetes mellitus	45 (37.8)	39 (40.6)	6 (26.1)	0.237
CKD	23 (19.3)	20 (20.8)	3 (13.0)	0.560
Malignancy	12 (10.1)	10 (10.4)	2 (8.7)	1.000
Characteristics of Cardiac arrest				
Witnessed arrest	86 (72.3)	68 (70.8)	18 (78.3)	0.607
Bystander CPR	75 (63.0)	61 (63.5)	14 (60.9)	0.814
Shockable rhythm	22 (23.2)	13 (16.0)	9 (64.3)	< 0.001
Cardiac cause	55 (46.2)	40 (41.7)	15 (65.2)	0.061
Total CPR time (min)	29.0 (14.0–41.0)	31.5 (21.3–43.8)	11.0 (4.0–21.0)	< 0.001
SOFA at admission	12.0 (11.0–15.0)	12.0 (11.0–15.0)	11.5 (10.5–15.0)	0.654
MV duration (day)	7.0 (3.0–9.0)	7.0 (2.0–9.0)	7.0 (5.0–13.0)	0.050

Data are presented as median with interquartile ranges.

Abbreviations: ARDS = acute respiratory distress syndrome; CA = cardiac arrest; MI = myocardial infarction; ACS = acute coronary syndrome; PCI = percutaneous coronary intervention; CKD = chronic kidney disease; LC = liver cirrhosis; CPR = cardiopulmonary resuscitation; MV = mechanical ventilator.

Mechanical ventilator parameters on admission and neurologic outcome

The result of ABGA and mechanical ventilator settings on admission for each patient group are summarized in Table 2. Good neurologic outcome group showed lower $PaCO_2$ level (46.0 mmHg vs 57.0 mmHg; p = 0.005) and higher pH (7.2 vs. 7.0, p = 0.001) than that of poor outcome group. Regarding ventilator settings, patients with good outcome showed significantly lower requirements of inspiratory pressure (12 cm H_2O vs. 16 cm H_2O; $p < 0.001$), PIP (17.0 cm H_2O vs. 21.0 cm H_2O; $p < 0.001$), and respiratory rate (18.0/min vs. 20.0/min; $p = 0.013$). Moreover, compliance was significantly higher in the favorable outcome group (38.6 mL/cm H_2O vs. 27.5 mL/cm H_2O; $p < 0.001$).

Table 2
Comparisons of ABGA and mechanical ventilator parameters on admission in the ARDS patients

Parameters	Total (n = 119)	Poor outcome (n = 96)	Good outcome (n = 23)	p-value
pH	7.0 (6.9–7.2)	7.0 (6.8–7.2)	7.2 (7.0–7.3)	0.001
PaO_2, mmHg	86.0 (68.4–115.8)	86.0 (70.4–115.8)	77.1 (62.5–137.4)	0.287
$PaCO_2$, mmHg	54.0 (40.0–73.0)	57.0 (43.5–76.0)	46.0 (32.6–60.5)	0.005
PEEP, cm H_2O	5.0 (4.0–8.0)	5.0 (4.0–8.0)	5.0 (4.0–7.0)	0.638
Inspiratory pressure, cm H_2O	15.0 (12.0–18.0)	16.0 (14.0–18.0)	12.0 (12.0–13.5)	< 0.001
P_{plat}, cm H_2O	21.0 (17.3–25.8)	21.0 (18.0–22.0)	17.0 (16.0–20.0)	< 0.001
Respiratory rate	20.0 (18.0–22.0)	20.0 (18.0–22.0)	18.0 (15.0–20.0)	0.013
Tidal volume, ml	427.0 (367.0–497.0)	420.0 (360.0–489.5)	458.0 (395.5–545.0)	0.053
Compliance, ml/cm H_2O	29.7 (21.8–36.9)	27.5 (21.6–34.0)	38.6 (33.1–46.2)	< 0.001
Minute ventilation, L/min	8.2 (7.6–10.4)	8.8 (7.7–10.3)	8.8 (6.5–10.7)	0.609

Abbreviations: ABGA = arterial blood gas analysis; ARDS = acute respiratory distress syndrome; PEEP = positive end expiratory pressure; P_{plat} = plateau pressure.

Compliance and good neurologic outcome

Table 3 shows the time-dependent regression model for predicting the neurologic outcome. All of the maximum, median, and minimum lung compliances were independent risk factors for favorable neurologic outcome at discharge. Among these variables, the minimum value was significantly associated with the neurologic outcome (adjusted hazard ratios (HR) 1.08, 95% confidence interval (CI) 1.04–1.12; $p < 0.001$).

Table 3
Univariate and multivariate time-varying cox regression of lung compliance associated with favorable neurologic outcome

Variables	**Univariate**			**Multivariate**		
	HR	**95% CI**	**p-value**	**Adjusted HR**	**95% CI**	**p-value**
Shockable	3.12	1.21–8.03	0.018	2.06	0.73–5.81	0.170
Cardiac cause	1.54	0.05–4.41	0.418			
CPR duration	0.95	0.92–0.99	0.012	0.95	0.90–1.00	0.039
MV duration	1.25	1.10–1.43	< 0.001	1.21	1.11–1.33	< 0.001
Compliance						
Maximum	1.05	1.03–1.06	< 0.001	1.05	1.03–1.08	< 0.001
Minimum	1.06	1.04–1.09	< 0.001	1.08	1.04–1.12	< 0.001
Median	1.05	1.03–1.07	< 0.001	1.06	1.03–1.10	< 0.001

Abbreviations: HR = hazard ratio; CI = confidence interval.

Differences of day-1 compliance for neurologic outcome

Overall trends of maximum, minimum, and median compliances by neurologic outcome group over time are shown in additional file [see Additional file 1]. For all seven compliances, day 1 showed significant large differences between the good and poor outcome groups that decreased over 7 days (Fig. 1). To analyze the diagnostic value of each compliance, ROC curves were calculated (Fig. 2). Median compliance at day 1 had the highest AUC (0.732), followed by maximum (0.702), and minimum (0.629). After calculating the cut-off values for each compliance using the Youden index, sensitivity and specificity were calculated (Table 4). Maximum compliance above 32.5 at day 1 presented the highest specificity (72.0%), positive likelihood ratio (2.48), and positive predictive value (90.4%) than that of other compliances.

Table 4
Performance of compliance to predict good outcomes

	Sensitivity	Specificity	PLR	NLR	PPV	NPV
D1 max > 32.5	69.5	72.0	2.48	0.42	90.4	38.3
D1 min > 28.6	64.9	66.7	1.95	0.53	88.4	32.7
D1 median > 31.4	59.3	66.7	1.78	0.61	90.0	24.5

Abbreviations: D = day; PLR = positive likelihood ratio; NLR = negative likelihood ratio; PPV = positive predictive value; NPV = negative predictive value.

Discussion

In this registry-based study, we found that 19.3% (23/119) of patients who developed ARDS after successful resuscitation from CA had a favorable neurologic outcome. Lung compliance was associated with neurologic intact survival by time-dependent regression analysis and had the highest predictive value for good neurologic outcome at day 1. Our neurologic intact survival rate of ARDS patients is lower than previous studies which reported rates ranging 29.8% – 53.2% [12–14]. This is consistent with a recent finding from Johnson et al [5], who reported 50% mortality among patients who developed ARDS compared with 32% in patients who did not. Even though the clinical impact of ARDS on PCAS patients is not fully known, the occurrence of ARDS after CA may have a negative impact on both survival and recovery of neurologic impairments [15–17]. In addition, the incidence of ARDS following CA has not been well reported; it varies from 5–65% depending on how ARDS is defined [8, 18]. However, it may be common due to the overlap between the pathophysiology of ARDS and PCAS. Lung contusion, ischemia, and exposure to high-dose oxygen during CPR and following reperfusion after CA, a profound systemic inflammatory response, ventilator-associated injuries, secondary infections, and systemic immune reactions could contribute the development of ARDS[19, 20]. Thus, early recognition of ARDS after CPR may allow for prompt initiation of treatment known to improve outcome, such as low tidal volume ventilation, prone positioning, and continuous neuromuscular blockade [21–23].

Although it is well-established to avoid hyperoxemia and hypocapnia, clinical evidence to guide mechanical ventilation strategy in patients with PCAS is limited and inconsistent. Talmor et al. performed a retrospective study using a time-weighted average of V_T and suggested that lower V_T was an independent factor in achieving a good neurologic outcome [24]. To prevent ventilator-induced lung injury, low V_T and optimized PEEP may also be essential in patients with PCAS. However, specific V_T and PEEP settings cannot be recommended because different lung stress or strain levels can be present in patients with the same severity status of ARDS after CA [25]. Therefore, lung compliance calculation and the patient’s ARDS status could be more informative to reflect the degree of lung injury than V_T and PEEP.

In the good neurologic outcome group, we found that lung compliance, whether maximum, minimum, or median, was associated with neurologic outcome at discharge. The compliance difference between groups was dramatic in the first 24 hours after admission and diminished over time. These results imply that the recovery of lung and brain injury is determined in the initial phase, and management of PCAS should focus on the first 24 hours. This study could not confirm whether ventilator settings are simply markers of disease severity or related to prognosis, however, in either case, lung compliance provides more information than V_T and PEEP regarding outcome. Furthermore, strategies to optimize lung compliance may have a role in treatment.

This study had several limitations. First, because of its retrospective design, our results may not be generalized to other circumstances. Second, the diagnosis of ARDS was based on P/F ratio, chest images, and echocardiography, ARDS incidence might be overestimated because hydrostatic pulmonary edema could not be found based on these examinations. However, the Berlin definition allowed some flexibility, including combining cardiogenic pulmonary edema because it is impossible to exclude all pure cardiogenic causes, even when measuring cardiac function through echocardiography. Moreover, some post-cardiac arrest patients can have concomitant ARDS and cardiogenic pulmonary edema. Third, we excluded patients who received ECMO, had a terminal illness, or declined proper management, which may have introduced selection bias. Fourth, we did not consider other confounding factors, such as quality of initial CPR, combined infections, and use of vasopressors that may have influenced the results. Finally, the sedative and neuromuscular blocking agent dosages for each patient and abdominal pressure were not controlled, which could have had an impact on calculated compliance.

Conclusion

Lung compliance may be an early independent predictor of neurologic intact survival in ARDS patients following CA.

List Of Abbreviations

ABGA, arterial blood gas analysis

ARDS, acute respiratory distress syndrome

AUC, area under the curve

CA, cardiac arrest

CI, confidence intervals

CPC, cerebral performance category

CPR, cardiopulmonary resuscitation

ECMO, extracorporeal membrane oxygenation

ED, Emergency Department

FiO_2, fraction of inspired oxygen

HR, hazard ratio

IHCA, in-hospital cardiac arrest

OHCA, out-of-hospital cardiac arrest

PaO_2, partial pressure of arterial oxygen

PCAS, post-cardiac arrest syndrome

PEEP, peak end-expiratory pressure

PIP, peak inspiratory pressure

P_{plat}, plateau pressure

ROC, receiver operating characteristic

ROSC, return of spontaneous circulation

RR, respiratory rate

SOFA, sequential organ failure assessment

TTM, target temperature management

V_T, tidal volume

Declarations

Acknowledgements

None.

Authors' contribution

J.S.K. participated in drafting, data collecting and analyzing. Y.J.K. and M.Y.K. participated in conceptualizing and data collecting. S.M.R., C.H.S. and S.A. read and revised the manuscript. W.Y.K. supervised, read, and approved the final manuscript.

Funding

None.

Availability of data and materials

The datasets generated analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Reviewed and approved by Asan Medical Center IRB with waiver of written consent.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

References

1. Myat A, Song K-J, Rea T. Out-of-hospital cardiac arrest: current concepts. Lancet. 2018;391:970–9.

2. Berdowski J, Berg RA, Tijssen JG, Koster RW. Global incidences of out-of-hospital cardiac arrest and survival rates: Systematic review of 67 prospective studies. Resuscitation. 2010;81:1479–87.

3. Andersen LW, Holmberg MJ, Berg KM, Donnino MW, Granfeldt A. In-hospital cardiac arrest. JAMA. 2019;321:1200–11.

4. Stub D, Bernard S, Duffy SJ, Kaye DM. Post cardiac arrest syndrome. Circulation. 2011;123:1428–35.

5. Johnson NJ, Caldwell E, Carlbom DJ, Gaieski DF, Prekker ME, Rea TD, et al. The acute respiratory distress syndrome after out-of-hospital cardiac arrest: Incidence, risk factors, and outcomes. Resuscitation. 2019;135:37–44.

6. Pierrakos. Acute respiratory distress syndrome: Pathophysiology and therapeutic options. Journal of Clinical Medicine Research. 2012;1–10.

7. Harmon M, van Meenen DM, van der Veen AL, Binnekade JM, Dankiewicz J, Ebner F, et al. Practice of mechanical ventilation in cardiac arrest patients and effects of targeted temperature management_A substudy of the targeted temperature management trial. Resuscitation. 2018;129:29–36.

8. Sutherasan Y, Peñuelas O, Muriel A, Vargas M, Frutos-Vivar F, Brunetti I, et al. Management and outcome of mechanically ventilated patients after cardiac arrest. Crit Care. 2015;19:1–11.

9. Fan E, Brodie D, Slutsky AS. Acute Respiratory Distress Syndrome. JAMA. 2018;319:698–13.

10. Fan E, Sorbo L, Goligher EC, Hodgson CL, Munshi L, Walkey AJ, et al. An official American Thoracic Society/European Society of Intensive Care Medicine/Society of Critical Care Medicine clinical practice guideline: Mechanical ventilation in adult patients with acute respiratory distress syndrome. American Journal of Respiratory and Critical Care Medicine. 2017;195:1253–63.

11. Henderson WR, Chen L, Amato MB, Brochard LJ. Fifty years of research in ARDS. Respiratory mechanics in acute respiratory distress syndrome. American Journal of Respiratory and Critical Care Medicine. 2017;196:822–33.

12. Ryoo S, Jeon S-B, Sohn C, Ahn S, Han C, Lee B, et al. Predicting outcome with diffusion-weighted imaging in cardiac arrest patients receiving hypothermia therapy. Critical Care Medicine. 2015;43:2370–7.

13. Kim Y-J, Ahn S, Sohn C, Seo D-W, Lee Y-S, Lee J, et al. Long-term neurological outcomes in patients after out-of-hospital cardiac arrest. Resuscitation. 2016;101:1–5.

14. Kim Y-J, Kim Y, Lee B, Park Y, Sim M, Kim S, et al. Immediate versus early coronary angiography with targeted temperature management in out-of-hospital cardiac arrest survivors without ST-segment elevation: A propensity score-matched analysis from a multicenter registry. Resuscitation. 2019;135:30–6.

15. Ruemmler R, Ziebart A, Moellmann C, Garcia-Bardon A, Kamuf J, Kuropka F, et al. Ultra-low tidal volume ventilation – A novel and effective ventilation strategy during experimental cardiopulmonary resuscitation. Resuscitation. 2018;132:56–62.

16. Eastwood GM, Tanaka A, Espinoza E, Peck L, Young H, Mårtensson J, et al. Conservative oxygen therapy in mechanically ventilated patients following cardiac arrest: A retrospective nested cohort study. Resuscitation. 2016;101:108–14.

17. Girardis M, Busani S, Damiani E, Donati A, Rinaldi L, Marudi A, et al. Effect of conservative vs conventional oxygen therapy on mortality among patients in an intensive care unit: The Oxygen-ICU Randomized Clinical Trial. JAMA. 2016;316:1583.

18. Elmer J. Exposure to high concentrations of inspired oxygen does not worsen lung injury after cardiac arrest. Crit Care. 2015;19:1–9.

19. Cha K-C, Kim YW, Kim HI, Kim OH, Cha YS, Kim H, et al. Parenchymal lung injuries related to standard cardiopulmonary resuscitation. Am J Emerg Medicine. 2017;35:117–21.

20. Gajic O, Dara SI, Mendez JL, Adesanya AO, Festic E, Caples SM, et al. Ventilator-associated lung injury in patients without acute lung injury at the onset of mechanical ventilation. Crit Care Med. 2004;32:1817–24.

21. Neto A, Nagtzaam L, Schultz MJ. Ventilation with lower tidal volumes for critically ill patients without the acute respiratory distress syndrome. Curr Opin Crit Care. 2014;20:25–32.

22. Guérin C, Reignier J, Richard J-C, Beuret P, Gacouin A, Boulain T, et al. Prone Positioning in Severe Acute Respiratory Distress Syndrome. N Engl J Med. 2013;368:2159–68.

23. Papazian L, Forel J-M, Gacouin A, Penot-Ragon C, Perrin G, Loundou A, et al. Neuromuscular blockers in early acute respiratory distress syndrome. N Engl J Med. 363.

24. Beitler JR, Ghafouri T, Jinadasa SP, Mueller A, Hsu L, Anderson RJ, et al. Favorable neurocognitive outcome with low tidal volume ventilation after cardiac arrest. American Journal of Respiratory and Critical Care Medicine. 2017;195:1198–206.

25. Chiumello D, Carlesso E, Cadringher P, Caironi P, Valenza F, Polli F, et al. Lung stress and strain during mechanical ventilation for acute respiratory distress syndrome. Am J Resp Crit Care. 2008;178:346–55.

Figures

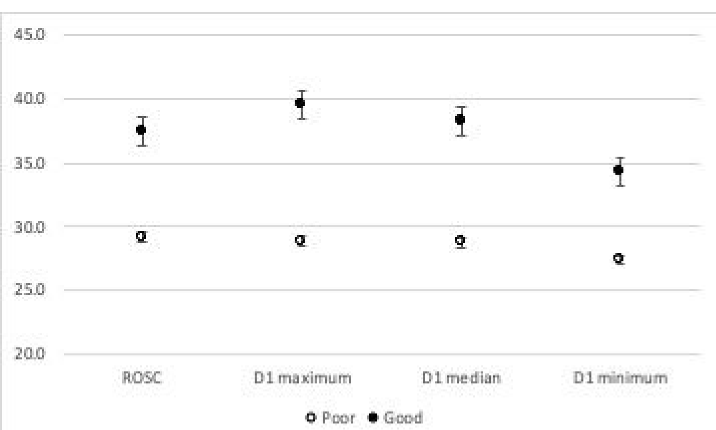

Figure 1

Differences of compliances on day 1 depend on neurologic outcomes

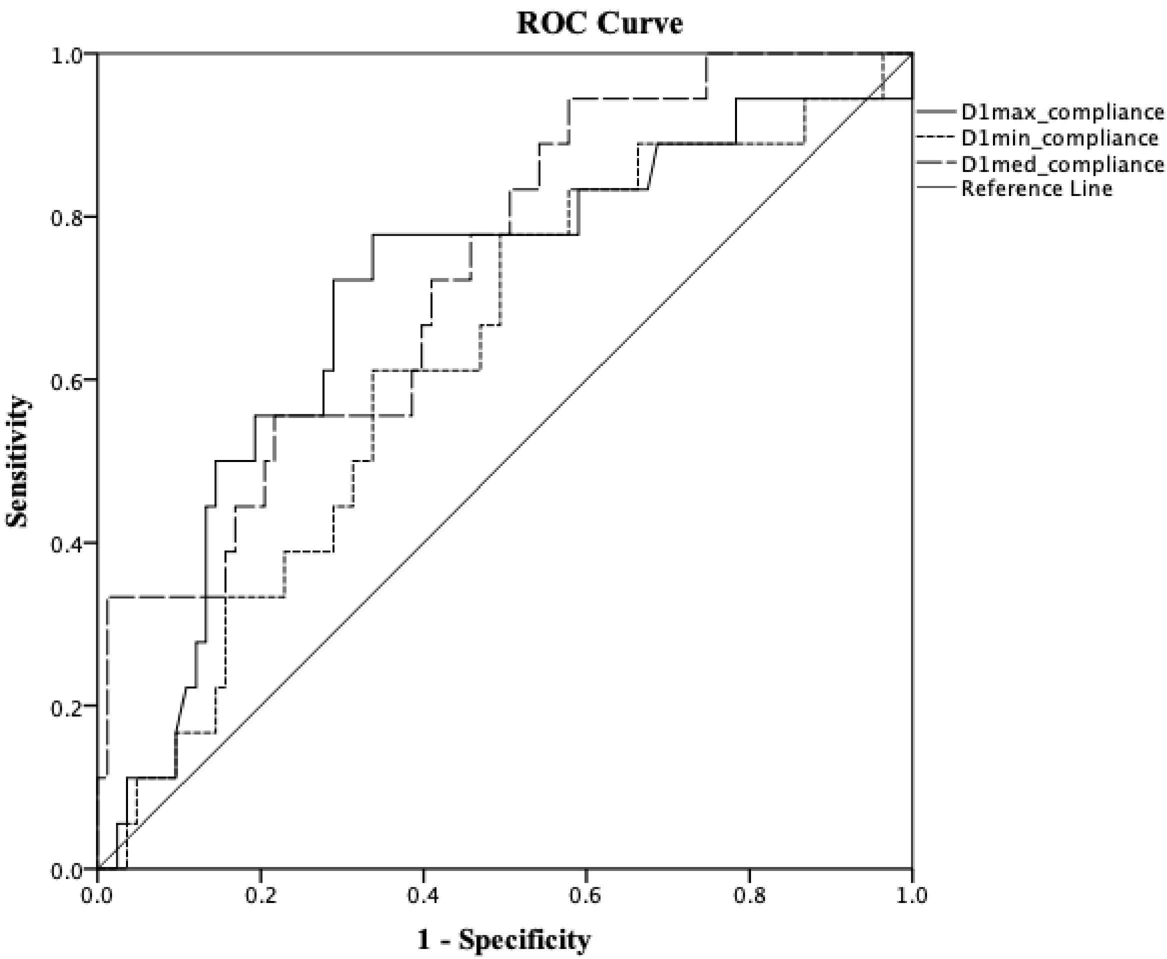

Figure 2

ROC comparisons of maximum, minimum, and median day-1 compliance

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Additionalfile1.pdf