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Clinical paper

Traumatic injuries after manual and automatic mechanical compression during cardiopulmonary resuscitation, a retrospective cohort study

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Abstract

Introduction: Chest compressions during advanced cardiac life support is a life-saving, potential harmful procedure with high incidence of severe and life-threatening injuries. Previous studies suggest a possible correlation between the increased incidence of chest and/or abdominal trauma and the use of automatic mechanical compression devices.

Methods: An observational monocentric retrospective cohort study was conducted including all patients admitted to our Intensive Care Unit suffering from out-of-hospital cardiac arrest (OHCA) in Canton Ticino (Switzerland) from 2012 to 2021. The primary endpoint was to describe any resuscitation-related body injury. The secondary endpoints were to explore possible predictors of cardiopulmonary resuscitation (CPR) related injuries and their association with the 30-day mortality.

Results: We included 335 patients, 287 treated with manual chest compressions, 48 mechanically assisted. 55.5% of all resuscitated patients presented severe, or life-threatening lesions. Skeletal and thoracic injuries were the most frequent lesions followed by abdominal injuries. Mechanical assisted resuscitated patients presented higher risk of bleeding (OR 5.9; 95% CI 2.9–11.6) and increased CPR-related injuries (aOR 6.2; 95% CI 2.5–15.4) compared to standard manual chest compressions. In particular higher number of extra-thoracic and life-threatening lesions were described among the mechanical assisted CPR group. Patients with life-threatening had statistically significant higher mortality at 30-days compared to the severe and lesion's free cohort.

Conclusion: Traumatic lesions occurred frequently after chest compression and their severity was associated with increased 30-day mortality. Mechanical devices, compared to manual chest compression, appear to be more harmful and may play a role in causing body lesions and hemorrhagic events.

Keywords: Out-of-hospital cardiac arrest, Cardiopulmonary resuscitation, Resuscitation complications, Rib fracture, Mechanical cardiopulmonary resuscitation, Traumatic injuries

Introduction

Prompt initiation of high-quality chest compressions is considered one of the most crucial act to enhance survival among resuscitated cardiac arrest victims.[1,2] The requirement for high-quality manual compressions, as described from the European Resuscitation Council and the American Heart Association, can be often difficult to achieve due to limited manpower, fatigue, hands off time, transport limitations and access to the patient, which may lead to sub-optimal cardiopulmonary resuscitation (CPR).[3,4] For this reason automatic mechanical devices can lighten up the rescue team efforts. Mechanical compared to manual chest compression, shortens pauses and increases the chest compression fraction, improving the resuscitation maneuver efficacy.[5] Mechanical assisted resuscitation could be an advantage when patients need to be transferred in the setting of refractory cardiac arrest, in difficult transport situations in case of lack of safety or difficult terrain.[5–7] To meet such needs, the Food and Drug Administration approved two mechanical chest compression devices: AutoPulse™ and LUCAS™.

However, the value for such performing devices do not come without side effects. CPR-associated traumatic injuries can occur and their incidence is source of debate. The introduction of such devices in the clinical practice showed an increase in the rate

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of severe and life-threatening related injuries in post-resuscitation period. In two studies, Khan et al. and Koster et al., concluded that the use of mechanical support devices increased the incidence of lesions compared to manual chest compressions[6,8] and Miller et al. also described a significant greater morbidity and mortality.[9]

For these reasons the current study was designed to investigate the prevalence of CPR related body injuries, along with their potential predictors, and to assess any differences in outcome between manual and automatic mechanical CPR in patients admitted in our centre after out of hospital cardiac arrest (OHCA).

Material and methods

Study design and data source

We conducted a single-center retrospective observational cohort study on patients suffering from cardiogenic OHCA in the region of Canton Ticino - Switzerland (roughly 360,000 inhabitants) and admitted to our Intensive Care Unit, which is the main cardiac receiver centre, in the period from 2012 to 2021.

The local Ethical Committee (Comitato Etico Canton Ticino, Switzerland) approved this study (ID 4079, BASEC 2022-00553) with waiver of informed consent according to Swiss Human Research Act art 34. The study was developed in accordance with the recommendations outlined in the STROBE guidelines.[10]

Study participants and procedures

We screened all patients consecutively admitted to our institute after OHCA and managed either by manual or mechanical CPR with AutoPulse™ or LUCAS™. The exclusion criteria were patients who achieved return of spontaneous circulation (ROSC) without CPR, died before injuries evaluation, post traumatic cardiac arrest, patients with missing data about the first aid intervention and specific refusal to participation to clinical studies and therefore not present in the cardiac arrest research database.

The screened patients were analyzed in two cohort groups: one carried out with manual compression and the other one supported by mechanical assisted device. The patients included into the mechanical cohort group, received in the starting phase resuscitation with manual chest compression and then shifted towards a mechanical device. The decision to use a mechanical device was taken autonomously by the rescue team according to the limiting CPR factors (i.e. fatigue).

The study's primary endpoint was skeletal, thoracic or abdominal lesions after the performed CPR. This was assessed by analyzing the patient's clinical course until death or hospital discharge. Therefore, all the reports from the responsible pre-hospital rescue team and from the interdisciplinary medical staff were exanimated. The obtained images (computed tomography, chest radiography and sonography) were analyzed from the radiology team. For further documentation of possible lesions, we searched for laboratory hematological values, blood gas analysis at entrance and during the hospitalization. In addition, to look for factor associated we considered (i) pre-arrest patient's characteristics (gender, age, frailty), (ii) resuscitation dynamics (first monitored rhythm, CPR device, time from call to ROSC) and (iii) clinical characteristics at admission and during hospital stay (serum pH, hemoglobin course, bleeding, days in ICU, 30-day mortality) were collected.

Study endpoints

The primary endpoint was description of the prevalence of lesions due to cardiopulmonary resuscitation after a cardiac arrest. Two authors blindly and independently assessed the presence and severity of trauma using a pre-specified form according to standard grading for patients in cardiac arrest[11]:

I **Severe**—not life-threatening injury — demands therapy for repair or for alleviation of pain, expected to prolong hospitalization:
  a. Chest musculoskeletal injuries, defined as less than six ribs unilateral or less than four ribs with maximum one bilateral, sternum fracture or spine fracture
  b. Thoracic Injuries such as pneumothorax, minor lung effusions, pericardial effusion
  c. Abdominal Injuries, defined as liver, spleen, suprarenal gland or vessel damage treated conservatively.

II **Life-threatening**—supposed to interfere with cardiovascular or respiratory function needing urgent treatment:
  a. Chest musculoskeletal injuries, defined as either more than six fractured ribs unilateral, more than four broken ribs and at least one bilateral or a flail chest
  b. Thoracic injuries, defined as tension pneumothorax or massive lung effusion (where a drain decompression therapy with a drain was necessary), cardiac tamponade
  c. Abdominal organs major lesions to spleen or liver which require a surgical intervention

The secondary endpoints were the identification of risk factors associated with the development of resuscitation-related injuries, the consequencies of different injuries on the 30-day mortality and the frequency of hemorrhagic events.

Statistical analysis

In order to detect the frequency of severe and life-threatening injuries among OHCA patients the study sample size was calculated. To reach confidence level of 95% with a power of 80%, according to the data available in the literature[9] where an incidence of resuscitation-related damages of about 40% is expected, a minimum sample size of 305 patients was calculated to detect this incidence with an estimation accuracy of ±11%.

To include at least 330 patients, according to local case experiences an incidence of approximately 30 patients per year,[12] information from patients admitted to our center between January 2012 and December 2021 will be searched.

Descriptive statistics were used to determine the distribution of characteristics of the study population. Continuous variables were expressed as mean and standard deviation or median and interquartile range [IQR] values, depending on the normality of the distribution. Qualitative nominal and ordinal variables are presented as absolute values and percentages. Group differences were tested using unpaired *t*-test or Mann–Whitney U test for continuous variables and $\chi 2$ or Fischer's exact test for categorical variables, as appropriate. Odds ratios were calculated to estimate possible associations.

Exploratory univariate analysis were performed to evaluate differences between the cohorts of patients who developed resuscitation-related damage and those without. Secondly, a logistic regression model was used to estimate the association of resuscitation-related injuries with mechanical CPR, adjusted for the relevant risk factors, such as: age > 70 years, CFS pre-frail or frail, time from cardiac arrest to ROSC > 25 min. Finally, a log rank test was conducted to determine if there were differences in the survival distributions for the patients with different type of injuries (no injuries, severe injuries, or life-threatening injuries) after CPR. Pairwise log rank comparisons were conducted to determine which intervention groups had different survival distributions with Bonferroni correction. A $p < 0.05$ was considered statistically significant. Tests were performed using software IBM SPSS® Statistics, version 22.

Results

As presented in the period from 2012-2021, a total of 355 patients were admitted to our ICU after out-of-hospital cardiac arrest: among them 335 met the inclusion criteria and 20 patients were excluded: 12 died before an injury assessment, 5 obtained a ROSC without chest compressions, 2 suffered from a trauma before cardiac arrest and 1 was transferred in another hospital before the clinical evaluation. Mechanical devices were used in 48 patients, while manual chest compression was used for 287 patients. Among the mechanical subgroup, AutoPulse™ was used in 34 patients and LUCAS™ was used in 14 patients (Fig. 1).

The demographic as well as the baseline characteristics between injured and uninjured patients are listed in Table 1. Among the 335 included patients 186 (55.5%) suffered at least from one or more lesions due to cardiopulmonary resuscitation and 149 (44.5%) patients were free from lesions.

A total of 264 body injuries were reported: respectively 233 (88.2%) classified as severe and 31 (11.7%) as life-threatening. Thoracic injuries were the most frequent traumatic lesion with respectively 136 severe and 10 life-threatening, while chest skeletal injuries were respectively 87 severe and 19 life threatening. Abdominal organs suffered from 10 severe and 2 life threatening lesions (Table 2). The graphic representation of the previous results are shown in Fig. 2 accordingly to severity and frequency.

When analyzing the secondary endpoints, the results showed that injured patients appeared to be significantly older (mean age 67 ± 13 *vs* 63 ± 14 years, $p = 0.003$), more frail (Clinical Frailty Scale pre frail/frail in 32.8% *vs* 20.1% with a $p = 0.01$), with longer time to ROSC (ROSC > 25 min. 36.6% *vs* 20.8%, $p = 0.002$) and had a CPR delivered by a mechanical chest compression device (22.6% *vs* 4%, $p < 0.001$). A multivariable logistic regression for predictors of CPR-related injuries (Table 3) confirmed the above listed results. In fact, CPR-related injuries were strongly associated with the use of a mechanical device with a 6.2-fold risk compared with the manual compression group (aOR 6.2; 95% CI 2.5–15.4). Other risk factors that may be associated with CPR related injuries were found to be age over 70 years (aOR 2.3, 95% CI 1.4–3.9) and prolonged time to ROSC (aOR 1.8, 95% CI 1.1–3.0).

Lastly patients resuscitated with mechanical assisted device apparently experienced more frequently blood loss requiring a transfusion of ≥2 units of red blood cell (41.7% *vs* 10.8%; $p = 0.001$) and a 5.9-fold risk of bleeding compared to those who underwent manual compression (OR 5.9; 95%CI 2.9–11.6).

Fig. 3 depicts the survival distribution associated with severity of lesions. There is a statistically significant increase in 30-day mortality in patients suffering from life-threatening injuries compared to severe ($\chi 2(1) = 6.433$, $p = 0.011$) and compared to lesions free cohort ($\chi 2(1) = 14.271$, $p < 0.001$).

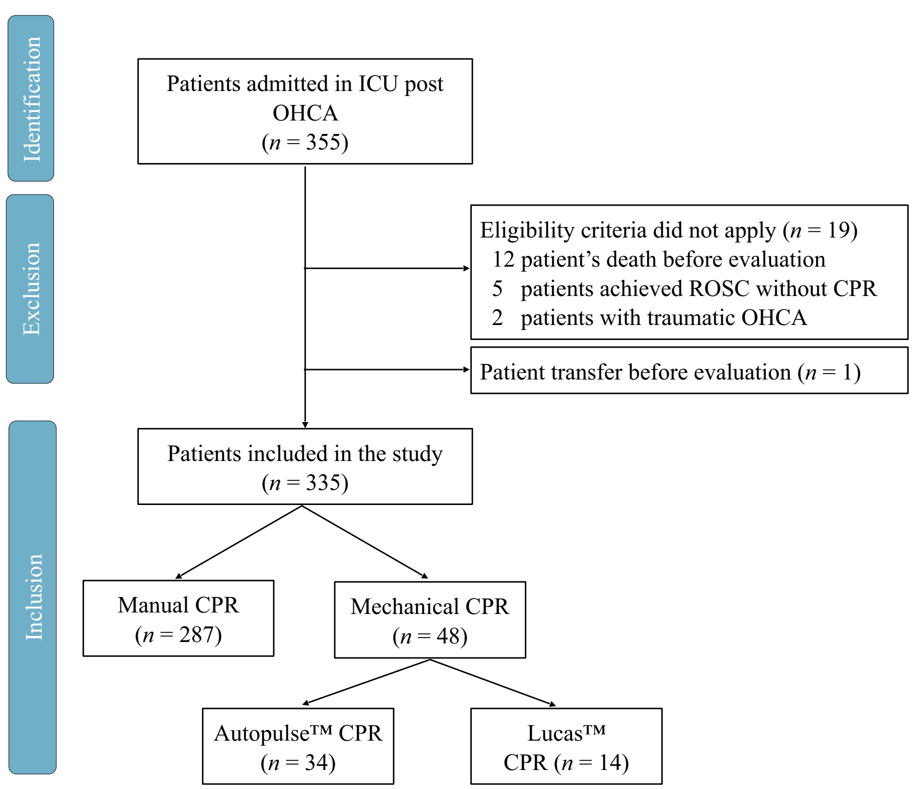

Fig. 1 – Flow diagram of study recruitment. OHCA, Out of Hospital Cardiac Arrest; ROSC Return of Spontaneous Circulation, CPR Cardiopulmonary Resuscitation.

Table 1 – Baseline patient characteristics and outcome.

Variables	All patient (*n* = 335)		Traumatic injuries CPR related				*p*-value
			Yes (*n* = 186)		No (*n* = 149)		
Demographic characteristics							
Gender, males, *n* (%)	271	(80.9)	148	(76.9)	123	(82.6)	0.49
Age, years, mean (±SD)	65	±13	67	±13	63	±14	0.003
CFS Pre-frail or Frail, *n* (%)	91	(27.2)	61	(32.8)	30	(20.1)	0.01
Characteristics of cardiac arrest							
Time from cardiac arrest to ROSC ≥25 min, *n* (%)	99	(29.6)	68	(36.6)	31	(20.8)	0.002
Shockable Rhythms, *n* (%)	270	(80.6)	146	(78.5)	124	(83.2)	0.277
Mechanical CPR, *n* (%)	48	(14.3)	42	(22.6)	6	(4.0)	<0,001
Arterial blood gas values at hospital admission							
Arterial pH, units, mean (±SD)	7.18	±0.17	7.15	±0.17	7.22	±0.16	<0,001
Arterial Lactate level, mmol/L, mean (±SD)	5.31	±3.74	6.13	±3.95	4.27	±3.18	<0,001
Arterial Hb, gr/dl, mean (±SD)	13.7	2.1	13.6	2.4	13.7	1.98	0.726
Hospital course							
Overall ICU length of stay, days, median (IQR)	9	(4–14)	9	(4–15)	9	(4–12)	0.357
In hospital mortality	132	(39.4)	83	(44.6)	49	(32.9)	0.029
Overt bleeding requiring a transfusion of ≥2 units of RBC	51	(15.2)	39	(21.0)	12	(8.1)	<0,001
Lowest Hb, gr/dl, mean (±SD)	12.1	±2.3	11.8	±2.5	12.6	±2.0	0.003

Quantitative variables are presented as mean and standard deviation (SD), otherwise specified. Categorical variables are summarized as frequencies and percentages. ROSC, Return of Spontaneous Circulation; CPR, Cardiopulmonary Resuscitation; IQR, Interquartile Range; Hb, Hemoglobin; RBC, Red Blood Cell; CFS, Clinical Frailty Scale. CFS > 3pt. was categorized as pre-frail or frail.

Table 2 – Distribution of traumatic injuries related to the support by mechanical device during cardiopulmonary resuscitation.

Variables	All patients (*n* = 335)		Mechanical CPR				*p*-value
			Yes (*n* = 48)		No (*n* = 287)		
Severe injuries							
Skeletal Chest Injuries	87	(26.6)	23	(47.9)	64	(22.3)	0.001
Thoracic injuries							
Pneumothorax	15	(4.5)	4	(8.3)	11	(3.8)	0.246
Lung effusion	110	(32.8)	21	(43.8)	89	(31.0)	0.097
Pericardial effusion	11	(3.3)	1	(2.1)	10	(3.5)	0.614
Abdominal Injuries							
Liver injury	4	(1.2)	3	(6.3)	1	(0.3)	0.01
Spleen injury	4	(1.2)	2	(4.2)	2	(0.7)	0.1
Surrenal injury	1	(0.3)	1	(2.1)	0	(0.0)	0.143
Vessel injury	1	(0.3)	1	(2.1)	0	(0.0)	0.143
Life threatening injuries							
Skeletal Chest Injuries	19	(5.7)	8	(16.7)	8	(3.8)	0.002
Thoracic Injuries							
Tension pneumothorax	3	(0.9)	3	(6.3)	0	(0.0)	0.003
Major lung effusion	5	(1.5)	2	(4.2)	3	(1.0)	0.151
Cardiac tamponade	2	(0.6)	0	(0.0)	2	(0.7)	0.734
Abdominal Injuries							
Large liver injury	2	(0.6)	1	(2.1)	1	(0.3)	0.266

Values are presented as frequencies and percentages. Patients can present more than one lesions per category (i.e a patient can present severe skeletal chest injuries, liver injuries and life-threatening tension pneumothorax).

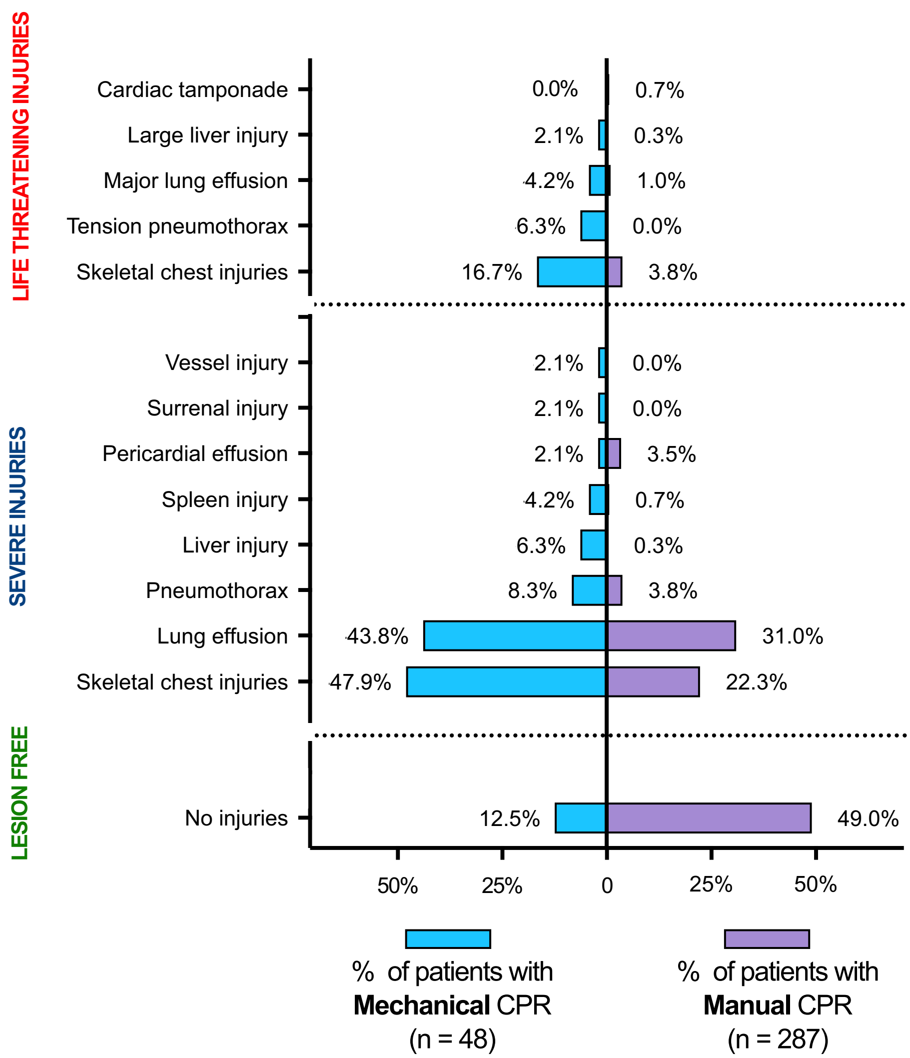

Fig. 2 – Lesions divided into manual vs mechanical CPR. CPR, Cardiopulmonary Resuscitation.

Table 3 – Risk factors CPR-related injuries within a multivariable logistic regression model.

Variables	CPR-related injuries			
	Univariable		Multivariable	
	OR (95%CI)	*p*-value	aOR (95%CI)	*p*-value
Age > 70 years	2.2 (1.4–3.5)	0.001	2.3 (1.4–3.9)	0.002
CFS Pre-frail or Frail	1.9 (1.2–3.2)	0.01	1.3 (0.7–2.3)	0.367
Time from cardiac arrest to ROSC $\geq$ 25 min.	2.2 (1.3–3.6)	0.002	1.8 (1.1–3.0)	0.042
Mechanical CPR	6.9 (2.7–16.7)	0.001	6.2 (2.5–15.4)	0.001

ROSC Return of Spontaneous Circulation; CFS Clinical Frailty Scale; CPR Cardiopulmonary Resuscitation; OR odds ratio; CI confidence interval; aOR adjusted odds ratio.

Discussion

Cardiopulmonary resuscitation is a life-saving technique adopted to maintain organ perfusion during cardiac arrest. Advanced Care Life Support guidelines recommend chest compressions at a rate of 100/min and depth of 50 mm.[12] Accordingly to this target, the rescue team is faced with the challenge to preserve the tissue perfusion avoiding patient's body injuries which may be harmful and potentially life threatening.[6,13]

The present investigation points out that a percentage of 55.5% of resuscitated patients suffer from body injuries, respectively 88.2% severe and 11.7% life-threatening. These results are similar to previous findings showed by Koster et al.[8] and Miller et al.[9]

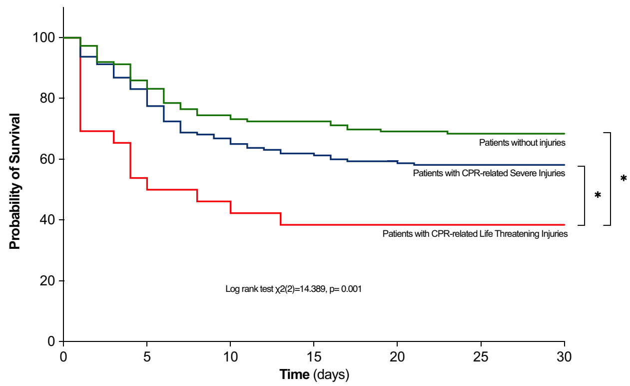

Fig. 3 – Kaplan Meier for survival distribution associated with the severity of lesions. *$p < 0.05$.

There is no surprise that the most frequent site involved was the chest with pneumothorax, lung effusion and skeletal chest fractures, despite the type of chest compression delivered. Supported by the findings from Miller et al.,[9] where musculoskeletal lesions were the most described injuries, our results suggest that severe thoracic injuries were the most frequent lesions after CPR. Interestingly, mechanical CPR seems to play a role in the development of severe and life-threatening extra-thoracic injuries. In fact, we found 12 lesions out of 264 involving the abdominal organs 8 of which were found in mechanical CPR group, opening some thoughts regarding their safety. A possible reason may be owed to misplacement or displacement of the device during CPR or during the transport. Finally, the mechanical equipment does not reassess automatically the initial parameters and the energy delivered during each compression in case of change in the patient position. These findings and concerns about the safety of the mechanical devices were also reported in a previous study conducted by Kosters et al.[8]

In the end, we could state that there is an increased risk of multiple organ injuries when automatic devices are used during CPR. Trauma is obviously correlated with a higher risk of bleeding so that a large portion of patients, who received mechanical CPR, experienced a rise in the amount of red blood cells transfused compared to who underwent manual CPR. This result is not of surprise if one takes also into account that a large number of patients included in the population studied underwent percutaneous revascularization, receiving double anti-platelet therapies in addition to heparin which enhance the hemorrhagic risk. However, the statistically significant difference found in the number of transfusions in the mechanical CPR group compared to the manual CPR, confirms the traumatic effect among the mechanical assisted resuscitated patients.

Enlighted our results, the most reliable finding may be the rising correlation between, the degree of the injury and the final outcome. Noteworthy, when comparing the 30-day-mortality, it appears evident how the magnitude of injury correlates with the mortality rate as depicted in Table 3 by the Kaplan-Meier analysis. It could also indirectly be assumed that a resuscitation supported by a mechanical device does not improve outcome and is associated with a higher 30-day mortality. Hallstrom et al. evidenced in the ASPIRE Trial some concerns about the safety of CPR with use a load-distributing band (Autopulse^{TM}) which appeared to result in lower survival and worse neurological outcomes than traditional manual CPR.[14] Other findings were described from Rubertsson et al. with the LINC trial where no significant difference in survival between patients treated with the mechanical CPR algorithm or those treated with guideline-adherent manual CPR.[15]

In view of our findings, we could state that mechanically assisted CPR had a higher incidence of severe and life-threatening injuries and were associated with an increase in 30-day mortality compared to good quality manual chest compressions. Our results also seemed to be confirmed by the meta-analysis of Ni Zhu et al. In fact, they suggested the use of mechanical devices as part of advanced life support but not as complete replacement of the standard manual CPR mostly because of possible increase in lesions. However, a higher mortality at hospital discharge in the mechanical CPR group was not described.[16] Although the use of assisted devices may be harmful, sometimes the circumstances do not allow other resuscitation methods to deal with OHCA so that, a larger clinical view should be taken into account when clinicians take stock of injuries during the final evaluation after aiming the ROSC.

We suggest that resuscitated patients, in particular those with long ROSC time and mechanical resuscitation, should be taken in charge as a polytrauma and the potentially extra-thoracic injuries screened.

Some limitations have to be addressed. Firstly, this is a single centre retrospective study with low sample size even if it is correctly powered. Secondly, only patients that arrived with a ROSC to the hospital were included in the study and therefore the estimation of the incidence of lesions as well as the impact of the lesions on the survival could be underestimated. Thirdly, every resuscitation attempt started with manual chest compressions and only later the switch on a mechanical assisted device was done, so that some of the lesions attributed to a mechanical device could indeed result from a poor performed manual CPR. Lastly, the time from cardiac arrest to ROSC was included in the multivariate model as proxy of CPR time.

Conclusions

Cardiopulmonary resuscitation is a life-saving technique which leads to body injuries in more than 50% of patients who receive CPR either manually or mechanically. In our setting, those who received a mechanical treatment showed a higher incidence of both severe and life-threatening lesions. Finally, considering the increased number of traumatic and hemorrhagic events, we shall propose to manage OHCA with a prolonged mechanical CPR time as a polytrauma with an extended imaging study scan and/or sonography, aware that more studies should be performed to validate it in clinical practice.

CRediT authorship contribution statement

Thierry Preda: Conceptualization, Methodology, Software, Investigation, Data curation, Writing – original draft. **Matteo Nafi:** Conceptualization, Methodology, Investigation, Writing – original draft, Project administration, Writing – review & editing, Supervision. **Michele Villa:** Methodology, Software, Formal analysis, Data curation, Writing – review & editing, Visualization. **Tiziano Cassina:** Conceptualization, Methodology, Writing – review & editing, Supervision.

Declaration of Competing Interest

All authors declare that they have no known competing financial interests or personal relationships with industry that could have influenced the work reported in this paper.

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