Characteristics of mechanical CPR-related injuries
A case series
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1. **INTRODUCTION**

Cardiopulmonary resuscitation (CPR) has been recognized as a cornerstone in the treatment of cardiac arrest for more than 50 years. CPR is the combination of ventilations and chest compression (CC). Chest compression is regarded as a vital component of CPR and should be initiated immediately upon recognition of cardiac arrest in order to preserve circulation and thereby maintaining vital functions. Mechanical devices for CPR are still more common in the pre- and in-hospital treatment of cardiac arrest and may be employed during transportation of the patient or in circumstances where manual CPR is unfeasible. A shared characteristic for these mechanical devices is their ability to provide rhythmical and automatic chest compressions (CCs) according to international guidelines for CPR. The two most common types of mechanical CPR devices are piston-type and load-distributing bands. In the Region of Southern Denmark, the only device used is a piston-type device LUCAS3™.

Injuries due to manual CPR are well-known and well-described. Mechanical CPR has only recently been implemented in routine use in most European countries. Therefore, studies concerning injuries due to mechanical chest compression (mech-CPR) are sparse, although a few have emerged in recent years. Most of the available studies focus on the skeletal injuries, while few studies systematically describe visceral injuries in autopsy material. An assessment of the severity of these iatrogenic injuries is seldom performed although some case reports have described extensive life-threatening injuries.

The purpose of the forensic autopsy is to establish manner and mode of death, and, if possible, the mechanism of death. In a forensic setting, injuries sustained by CPR gives rise to two types of problems:

The injuries may pose a problem for the forensic pathologist in establishing the manner of death when distinguishing between injuries sustained by CPR and injuries as a result of violence or trauma. Is what we see ‘just’ CPR-related or is this in fact a homicide? On the other hand, if injuries sustained by CPR could be a contributing cause of death, what was the underlying cause of death and which implications does mech-CPR have on establishing the manner of death? Thus, it is imperative to characterize and describe the potential injuries sustained during CPR.

The aim of this case series was to identify and characterize the injury pattern in patients who had received mechanical CPR with focus on the visceral injuries.
2. Method

2.2 Study setting

The Region of Southern Denmark is one of Denmark’s five health regions. The emergency medical service in the region comprises approximately 70 ambulances, three paramedic manned rapid response vehicles, and six physician manned mobile emergency care units (MECUs). On average, a MECU is engaged in 26% of all emergency runs in the region. Odense University Hospital (OUH) serves as a tertiary hospital in the Region of Southern Denmark. Thus, all patients requiring invasive cardiological procedures in the region are referred to this hospital. From September 1st 2015, a piston type CC device was available in all MECUs in the region.

Autopsies in the region are carried out either as a clinical autopsy at the Department of Clinical Pathology, OUH or as a forensic autopsy at the Institute of Forensic Medicine, University of Southern Denmark. The clinical autopsies are requested by the family, the general practitioner or a hospital department. The forensic autopsies are carried out on request by the police. Generally, the autopsy rates in Denmark are low. Of all deaths in 2017, forensic autopsy was performed in 1.9% cases, while pathology autopsy was performed only in 0.9% 14.

2.3 Recruitment

The study period ran from September 1st 2016 to August 31st 2018. The present case series represents a subpopulation of an injury prevalence study carried out by our research group and previously published 15. For details on injury prevalence in manual CPR vs. mech CPR, please refer to this study.

Inclusion criteria:
We prospectively included all patients who had received out-of-hospital mech-CPR with a LUCAS device in the Region of Southern Denmark (RSD) who were subsequently autopsied. Both clinical and forensic autopsies were included. Autopsies were performed only when permission from relatives was given. According to Danish legislation a forensic autopsy can be performed without permission from relatives by court order only. In the present case series, none of the included cases had an autopsy performed following a court order.

Exclusion criteria: Age less than 18, trauma immediately preceding the cardiac arrest, or known pregnancy.
Patients with injuries were included if the autopsy revealed no other plausible etiology of the injuries than CPR. Additionally, all fractures in the thoracic cage were defined as CPR related. Injuries were evaluated according to standard forensic risk assessment. Injuries that would have been fatal and injuries that could have been fatal were classified as potentially life-threatening.

2.4 Properties of LUCAS™3

All patients in our study group were treated with Lund University Cardiopulmonary Assist System (LUCAS2™), which is a battery-driven piston-type device. With a pneumatic cylinder with a suction cup attached on two legs which are mounted on a short stiff back plate, the device provides mechanical compression and decompression at a default rate of 100 compressions per minute with a maximum depth of 52 mm.

2.5 Statistics

Statistical analysis was performed using STATA 15, College Station, Texas, USA. After testing that data were not normal distributed using the Shapiro-Wilk test, percentages were used for categorical data, while the median and quartiles were used for continuous data.

2.1 Ethics

The Danish Patient Safety Authority approved an initial study (Ref. 3-3013-786/1). An extension of the study period was endorsed as a quality assurance study by The Prehospital Organization, The Region of Southern Denmark. Forensic autopsies were performed according to the standard defined in Danish legislation. Hospital autopsies were performed according to the guidelines of the Danish Pathology Society.

3. Results

3.1 Patient characteristics

In two study years, a total number of 169 cases received out-of-hospital, unsuccessful mech-CPR. Of these 169 mortalities, only 50 cases underwent autopsy and were included in this study. Median age for the population was 48 years (interquartile range: 38-62). 18 were female, 32 were male. Median BMI was 26.7 (Quartiles: 24.5-30.5). Overall, 38 (76%) had injuries. In the remaining 12 cases (24%) we found neither skeletal or visceral injuries nor any bruising of the chest. In cases
without injuries, ten patients had had a clinical autopsy performed while two had a forensic autopsy performed. Figure 1 displays causes of death in each group (injuries vs no-injuries). The majority of the patients in the group with no injuries had a cardiac cause of death. In the group with injuries more patients had an unnatural manner of death with more suicides by poisoning as cause of death.

### 3.2 Characteristics of injuries

22 (44%) had a characteristic circular bruising to the chest (see Picture 1). 29 (58%) had skeletal injuries. 11 (22%) had visceral injuries. See Table 2 for the specific visceral injuries. Four patients suffered abdominal injuries. The remaining patients had thoracic injuries only. Four patients had hemothorax with a mean volume of 633 ml. In five cases, the pathologist considered the injuries life-threatening had the patients otherwise survived. These five cases were less than 55 years old and had no known or observed conditions which could explain the extent of injury. Additionally, in none of the patients with visceral injuries anticoagulant therapy was a part of the patient’s regular medication at the time of death. See Table 3 for a detailed overview of the cases with visceral injuries.

### 3.3 Injuries from mech-CPR versus inflicted injury

In case number 5 (See Table 3) only a thorough police investigation ruled out homicide. The case is discussed in detail in an earlier case-report [12]. The preliminary report from the forensic services classified the case as a possible homicide.

In case number 8 (see Table 3) extensive hemorrhage in the musculature of the neck could mimic injuries seen in strangulation cases, and care was taken in this case to exclude strangulation. (see Picture 4)

### 3.4 Injuries from mech-CPR as the cause of death?

In four cases the results of the autopsy were ambiguous and, due to mech-CPR, posed a dilemma for the forensic pathologist.

Case number 7 (See Table 3) 3 was a diver who, according to a witness collapsed in the water at the beginning of descent. He had bilateral pneumothorax and lung contusions, as well as seawater in gastric content at autopsy. The bilateral pneumothorax could have been caused by a failure in the diving equipment and be the immediate cause of death. However, the pneumothorax could also be
the result of mech-CPR. If so, this condition can be considered an obstacle in effective resuscitation and had sinus rhythm been achieved (this is unknown in this case, and therefore speculation) the bilateral pneumothorax due to mech-CPR could be considered as an immediate cause of death. The case was closed as a drowning, and no explanation for the patient’s collapse was established.

Case number 8 (See Table 3) is a case of suicidal overdose with an antihypertensive drug. The patient became unresponsive in a primary hospital setting and an initial echocardiography showed an ejection fraction of 5%. No cardiac tamponade was demonstrated during echocardiography at that point. The patient was transferred to a tertiary hospital while receiving mech-CPR during transport. At arrival at the tertiary hospital, an echocardiography showed pericardial tamponade and further resuscitation was unsuccessful. In this case it is proven that the mech-CPR was in fact the cause of pericardial tamponade due small lacerations of the surface of the heart (see Picture 5). As the cardiac arrest was elicited by intoxication, in this case it could be argued that there were competing causes of death. The case was, however, closed as a suicidal fatal intoxication.

Case number 9 (See Table 3) is a case of dissection and rupture of the aorta with pericardial tamponade. A thorough autopsy and police investigation did not reveal a probable cause for the collapse. It is possible that the dissection of the aorta was responsible for the initial shortness of breath and the rupture responsible for the ensuing collapse. It is also possible that a heart or brain disease (non-structural cardiomyopathy or transitory ischemic attack) led to collapse and that the dissection and rupture was caused by mech-CPR. The case was closed with an unknown cause of death.

Case number 11 (See Table 3) was a case of suicidal overdose with morphine. I.V-naloxone given by emergency services was without effect. Post mortem CT-scan revealed a tension pneumothorax (see Picture 6). There is no other probable explanation for this condition than mech-CPR. As in case number 7, it is possible that this condition was an obstacle to successful resuscitation. The case was closed as a suicidal fatal intoxication.

4. DISCUSSION

It crucial for both forensic and clinical pathologists to be familiar with the patterns of injury caused by mech-CPR, as these devices are becoming more common in pre-hospital care all over the world.
Prevalence of injuries

The topic of injuries related to chest compression in cardiac arrest has been investigated previously. Some studies have systematically described injuries following mech-CPR with LUCAS in autopsy material \textsuperscript{6-11}, while other studies have described injuries as a secondary outcome in patients who survived out-of-hospital cardiac arrest (OHCA) treated with mech-CPR \textsuperscript{2,17,18}. In a previous study including both deceased patients and survivors, we found visceral injuries in 14.3\% of people who underwent mech-CPR, whereas 1.1\% of patients receiving manual-CPR only had visceral injuries \textsuperscript{15}.

The injuries most commonly investigated are skeletal injuries. Visceral injuries are only addressed in six other studies \textsuperscript{6-11}. In studies describing injuries due to CPR detected by autopsy, some researchers have reported a higher risk of rib fractures with mech-CPR \textsuperscript{6-8}, while some report an association between mech-CPR and sternal fractures \textsuperscript{9} or trunk injuries \textsuperscript{11}. The prevalence of visceral injuries following chest compression with LUCAS has also been studied in autopsy materials \textsuperscript{6-10,15}. None of these studies found a difference in visceral injuries observed in patients treated with mech-CPR or manual-CPR. A recent study, however, of 614 deceased patients in whom 113 had received mech-CPR and 511 had received manual CPR found an increased occurrence of visceral lesions in the mech-CPR group \textsuperscript{11}. In this study, the authors compared the prevalence of specific injuries in different studies. In this study, the injuries associated with mech-CPR, both skeletal and visceral injuries, is generally in accordance with the prevalence of previous studies. The prevalence of three or more rib fractures are between 45\% and 68\%. In this study, our prevalence was 54\%. The most frequent visceral injury type in our case series were lung lesions with 10\%. In previous studies were found in 0.0\% to 18.6\% of the patients. Even though the prevalence of injuries varies greatly in previous studies, there is uniform agreement that external chest compression per se may result in injuries to intrathoracic and intraabdominal organs.

Life-threatening injuries

None of the studies mentioned above reported fatal or potentially fatal injuries \textsuperscript{6-10}, though one study argues that some of the more severe injuries could lead to a higher morbidity \textsuperscript{11}. We, on the contrary, found that in five cases the injuries sustained were potentially life-threatening had the patients otherwise survived. The potentially life-threatening injuries in the five cases have different characteristics. In two cases there were pericardial tamponade, and in two cases respiration was
compromised, one due to tension pneumothorax and one due to bilateral pneumothorax. In the last case there were multiple organ injuries with severe hemorrhage. Furthermore, in one of the cases with pericardial tamponade case no. 8, Table 3, a life-saving treatment, Extra Corporal Membrane Oxygenation (ECMO), could not be initiated due to the injuries sustained from mech-CPR.

One explanation for this discrepancy could be the definition of life-threatening injuries. In clinical forensic medicine designating injuries as potentially life-threatening is of course always a hypothetical matter. It is, however, a never-ending theme in courthouses around the globe. The question is approached differently in different countries, but most adhere to the ‘would have or could have’ definition. The types of injury that ‘would have’ led to death are the cases where chances of survival are next to none, like case number 8 with pericardial tamponade due to laceration of the surface of the heart. The cases that ‘could have’ led to death are injuries that in some circumstances are fatal and in some are manageable, like the tension pneumothorax in case number 11. The variation of circumstances in real life is endless and a more precise definition does not make sense.

Another explanation of the discrepancy between the observed number of life-threatening injuries could be duration of the mech-CPR in our study. Several studies both concerning only manual-CPR and manual prior to mech-CPR report no association between the duration of chest compression and the occurrence of injuries. Some researchers have associated the injuries following CPR to peak levels of energy at first compression, thus describing the injuries as occurring within the first minutes of CPR, but this has recently been challenged by four research groups, including our own. Boland et al. investigated injuries detected by diagnostic imaging in cardiac arrest survivors treated with mech-CPR and ascribes a higher prevalence of injuries in the mech-CPR group to an extended period of chest compression. This finding has recently been supported by two studies. The median duration in the present study was 65.9 minutes in the group with injuries and 60.3 in the group with no injuries. This can be compared with the findings in the study by Takayama et al with a mean duration of 45.1 minutes in patients who had sustained injuries, 39.2 in patients without injuries. Boland et al. found 34% of their included cases with a duration of over 20 minutes, while Ondruschka et al. had a mean duration of 72.6 minutes in patients with mechanical CPR.

Forensic autopsy and clinical autopsy
The present case series included injuries found at a clinical autopsy or forensic autopsy. We found that the prevalence of injuries detected during clinical autopsy were significantly lower than that in forensic autopsy ($p = 0.002$). This discrepancy illustrates the different approach to death investigation carried out by the two seemingly familiar fields. While the forensic pathologist primarily deals with manner and mode of death and only secondarily with the cause of death, the clinical pathologist has the cause of death as a primary focus. When the manner of death is already given for the clinical pathologist, he or she might not address signs of trauma.

**Conclusion**

Following cardiac arrest treated with chest compression by a mechanical device, we found five iatrogenic injuries which in itself could have been fatal had the patients survived the incident. In all five cases, the injuries posed a dilemma to the forensic pathologist, with the injuries having a hypothetical influence on both cause and manner of death. Aside from skeletal lesions, lung and heart lesions were the most frequent. Hemorrhage in the thoracic and neck musculature and subcutaneous tissue, was in some cases extensive, mimicking inflicted injury.

We conclude that it is of major importance for the forensic pathologists to be aware of the possible types of injuries that may occur following CPR. Mechanical CPR seems to add to the severity of intrathoracic and intraabdominal lesions and the lesions caused by compressions are both diverse and can be extensive. This awareness may allow the forensic pathologist to be able distinguish between injuries caused by CPR and injuries caused by other trauma, and thereby determining cause of death more accurately.

1. **REFERENCES**


