FORENSIC SIGNIFICANCE OF LESIONS INDUCED BY CARDIOPULMONARY RESUSCITATION

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FORENSIC SIGNIFICANCE OF LESIONS INDUCED BY CARDIOPULMONARY RESUSCITATION (Abstract): Cardiopulmonary resuscitation (CPR) is a lifesaving emergency procedure generating various injuries. At necropsy examination, lesions produced by CPR maneuvers are regularly encountered, unrelated to the primary death cause. The aim of the current study is to examine traumatic injuries observed at forensic necropsy after CPR and to make the differential diagnosis with those induced by violent acts or accidents. The authors performed a retrospective study at the Institute of Forensic Medicine from Iasi, Romania on 49 cases (32 males, 17 females) that benefitted from CPR manoeuvres prior to death. Mean age was 47.3 years, 24 cases (48.98%) presented cardiac arrest secondary to trauma and 41 (83.67%) in an extra-hospital environment. CPR duration reported in 21 cases (42.86%) registered a mean value of 42 minutes. Additional gestures like vein puncture were reported in 25 cases (51.02%) and surgical interventions in 5 cases (10.20%). All intra-thoracic structures can be injured directly or indirectly by chest compressions. Rib fractures are among the most common complications associated with CPR and found in one third of cases. Petechiae on the surface of the heart are observed mostly on the posterior surface. Perivascular haemorrhagic infiltrations can also be noticed and are poorly described in the literature. Intra-abdominal organs are less often the site of complications secondary to resuscitation. In conclusion, injuries produced during CPR may be responsible for important artefacts impeding the understanding of traumatic lesions observed during necropsy and related to the primary death cause. A thorough knowledge of possible aspects is mandatory to the differential diagnosis with other traumatic lesions. Keywords: CARDIOPULMONARY RESUSCITATION, FORENSIC NECROPSY, TRAUMATIC LESIONS, DIFFERENTIAL DIAGNOSIS

INTRODUCTION
Cardiac arrest is an extreme medical emergency, leading to irreversible brain damage and death if proper measures to restore ventilation and blood flow are not taken. Cardiopulmonary resuscitation (CPR) is fundamental for increasing the survival chance of these patients. In the last decade, the interest of forensic pathologists in the study of injuries caused by CPR has augmented due to the emergence of resuscitation guidelines containing specific recommendations concerning the depth of chest compressions, CPR duration, sequence of maneuvers. Even if it is a lifesaving procedure, CPR is an aggressive method causing various lesions especially if technical errors are committed. Necropsy is still considered the gold standard for study of CPR associated lesions despite extensive usage of medical imaging techniques (computed tomography, radiography) in the western world.

At necropsy examination, CPR-related injuries are commonly encountered, unrelated to the primary death cause, and may mislead the forensic examination. One of the objectives of the recommendations made by the European Resuscitation Council is to establish an appropriate balance between the benefit of CPR manoeuvres and the risk of causing harm to the patient (1). An observational study published
in 2013 found a higher incidence of iatrogenic injuries provoked by manual CPR in patients who received chest compressions at a compression depth greater than 6 cm (2). CPR injuries may account for up to 20% of all injuries identified at forensic necropsy (3). Forensic pathologists have to be able to make the differential diagnosis between injuries associated to CPR and those generated by other traumas related to violent acts, accidents, suicide or homicide (4,5).

Although CPR can cause secondary life-threatening lesions, such situations are extremely rare (3). Hemopericardium, hemothorax, hemoperitoneum or other lesions produced during CPR may be responsible for important artefacts impeding the understanding the trauma observed during necropsy (6). In such situations, it is sometimes difficult for the forensic pathologist to determine the exact cause of death, particularly in cases where no other pathology has been identified. It is therefore important, before starting any autopsy, to consult all available data in order to understand discovered lesions. Medical documents rarely contain the exhaustive details of all CPR maneuvers carried out. The reported data may also be erroneous, making it difficult to interpret certain lesions (7,8). It is imperative for the forensic pathologist to search and precisely identify all the lesions secondary to CPR maneuvers in order to determine their possible involvement in the death process but, above all, not to confuse them with the consequences of violent acts causing death.

One of the difficulties encountered by forensic pathologists when performing necropsies is related to the fact that it is not always facile to assert the exact origin of an observed lesion. Sometimes it is difficult to identify all the injuries related to CPR maneuvers, even for rib fractures whose incompleteness may alter findings (9). For example, in a Swedish, multicenter study conducted on 222 autopsies of individuals with non-traumatic cardiac arrest followed by CPR, it was impossible for the 40 forensic pathologists enrolled to affirm whether identified lesions were due to CPR maneuvers in 13.5% of cases (10).

Training of forensic pathology residents should pay particular attention to teaching and displaying all the lesions that can be produced by resuscitation maneuvers. The realization of a lesion mapping together with medical file details would allow forensic pathologists to avoid artifacts and misinterpretations. Thus, it would be easier not to confuse them with injuries induced by other factors such as acts of willful or involuntary violence with completely different legal implications. Initial errors of interpretation are not uncommon. Prahlow and McClain presented the case of an individual presenting a circular wound of 9 mm that was suspected to be the entrance point of a gunshot but was finally found to be secondary to placement of a thoracic drain (11).

The aim of the current study is to examine traumatic injuries observed at forensic necropsy after CPR and to make the differential diagnosis with those induced by violent acts or accidents.

**MATERIAL AND METHODS**

The authors performed a retrospective study at the Institute of Forensic Medicine from Iasi, Romania on 49 cases (32 males and 17 females) that benefited from CPR manoeuvres prior to death and whose necropsies were performed between January 2015-December 2016. Medical and police files provided by the authorities were also analysed in order to interpret necropsy findings. Descriptive statistics (absolute values, means, frequencies) were used to report data.

**RESULTS**

The 49 cases had a mean age of 47.3 years. 24 cases (48.98%) presented cardiac arrest secondary to trauma (car accident, fall from height, traumatic brain injury, strangulation, crushing, stabbing, intoxications). Most cardiac arrests (41 cases - 83.67%) occurred in an extra-hospital environment.

CPR duration was reported in 21 cases (42.86%) and registered a mean value of 42 minutes. Realisation of external cardiac massage was mentioned in the medical files of 26 cases (53.06%) and defibrillation in 7 cases (14.29%). Additional gestures like vein puncture were reported (directly or indirectly) in 20 cases (40.82%), surgical interventions in 5 cases (10.20%), nasogastric tube insertion in one case (2.04%), thoracic drain insertion (for pneumothorax or pleural effusion) in 3 cases (6.12%). Twenty cases (40.82%) were ventilated prior to death with 15 tracheal intubations (30.61%).
At the necropsy examination, no traces of CPR manoeuvres were identified in 4 cases (8.16%). In another 10 cases (20.41%) the presence of a puncture site was the only sign of CPR. These aspects could be explained by the presence of severe trauma that made impossible to identify additional lesions.

Intubation injuries were frequently encountered. Lip lesions (ecchymoses, superficial erosions) were observed in 4 cases (8.16%), dental lesions (fractures, avulsions) in 2 cases (4.08%), upper airways haemorrhagic infiltrates (vocal chords, epiglottis) in 8 cases (16.33%).

In the thoracic region, presternal patched areas and ecchymoses were noted in 7 cases (14.29%). Rib fractures were among the most frequent signs of CPR identified in 16 cases (32.65%) and associated to haemorrhagic infiltrates corresponding to the fracture line. Isolated haemorrhagic infiltrates corresponding to anterior costal arches were observed in 2 cases (4.08%). Subjects that had important thoracic trauma (car accident, crushing, fall from height) with potential of known rib fractures were excluded from the analysis. A single case presented a sternal fracture secondary to cardiac massage. Generally, of the 26 cases with known cardiac massage, 61.54% presented rib fractures.

Intra-thoracic lesions related to cardiac massage were represented by perivascular haemorrhages (7 cases – 14.29%), cardiac petechiae (6 cases – 12.24%, mostly located on the posterior surface – 3 cases), and pulmonary contusion (1 case – 2.04%).

Intra-abdominal organs were less often the site of complications secondary to resuscitation. Only 3 cases presented lesions of the digestive or retroperitoneal structures that could be attributed to CPR manoeuvres (haemorrhagic gastritis – 2 cases, haemorrhagic infiltrate of the retroperitoneum – 1 case).

Cutaneous lesions were visualised in most cases. Even though venous punctures were reported directly or indirectly in the medical files of 20 cases (40.82%), typical lesions were noted in 38 cases (77.55%). Other cutaneous lesions that could be assimilated to CPR manoeuvres were represented by ecchymoses and erosions on the upper limbs due to movement of the body and encountered in 8 cases (16.33%). Traces left by defibrillator paddles were observed in 4 cases (8.16%). Fresh surgical incisions were present in 5 cases (10.20%) and holes made by thoracic drain insertions in 3 cases (6.12%).

Cutaneous lesions and rib fractures are among the most obvious and easy to recognise signs of CPR manoeuvres compared to intrathoracic and intra-abdominal organs lesions that could erroneously be attributed to other trauma related to the primary death cause.

**DISCUSSIONS**

The first elements suggestive for CPR manoeuvres at external examination of the body are represented by lesions of the lips, oral mucosa and teeth but no current criterion makes possible the differential diagnosis with non-resuscitative trauma. The distribution and the particular location of these lesions are important key elements that help differentiating them from those induced by a third-party intervention.

Injuries to the oral mucosa may be induced when securing airways, removing a foreign object or by vomiting (12) and are capable of causing bleeding that can be confused with haemoptysis (4). Lips were injured in 8.1% of cases and teeth in 1.1% of cases studied by Krischer et al. (3). The laryngoscope in particular may remove or fracture the incisors (13).

Ecchymoses and erosions of the scalp, face and neck are currently observed at external examination of patients who have undergone resuscitation (13,14). Even when these wounds are mild and apparent ordinary, they are important for the forensic pathologist who must distinguish them from those caused by an act of violence. For example, the marks left by fingers and nails on the face and neck during resuscitation attempts are located at the base of the mandible, around the mouth and between the larynx and the maxilla, and are parallel to each other while lesions produced during strangulation are irregularly distributed in multiple directions and cover a large area of the neck (12). Ecchymoses of the nose may also be observed as a consequence of mouth-to-mouth manoeuvres or application of a facial mask. Conjunctival petechiae secondary to hypoxia and increased capillary pressure can occur in up to 21% of cases and should be differentiated from those appearing secondary to mechanical asphyxia (15).

Intubation is associated in about one third of the cases with the lesions described above.
and with tracheo-laryngo-pharyngeal injuries. A study of 705 autopsies, published in 1987 by Krischer et al. found them (mucosa lesions, lacerations, retropharyngeal haemorrhage, muscular haemorrhagic infiltrates, tracheal rupture) in 20.4% of cases (3). Severe tracheal lesions could indicate an emergency context.

Other lesions involving cervical and digestive structures (hyoid bone fractures, laryngeal cartilages fractures, oesophageal perforations) have been reported in the literature but were not observed in our series. These are exceptional situations that must be known to forensic pathologists (3). Hyoid bone and thyroid cartilage fractures are often associated with adjacent soft tissue haemorrhage and it is important to distinguish them from lesions produced during strangulation (16). Haemorrhagic infiltrates and fractures occurring in individuals surviving resuscitation for a period of time are more intense than those observed in death by strangulation (17).

Thoracic ecchymoses and erosions are the first elements that suggest the realisation of thoracic compressions as part of CPR. Their frequency is variable up to 2/3 of cases that benefited from manual external cardiac massage (3). These lesions occur most frequently on the anterior surface of the thorax near the sternum. Presternal parchmented areas and ecchymoses appear secondary to electric defibrillation in up to 53.3% of cases (3) especially if the electrodes are in direct contact with the skin (without interposed conduction gel).

Rib fractures are also among the most frequent complications found in about 1/3 of cases (most cases with thoracic compressions) (18). Clinical factors such as age and sex (greater prevalence of osteoporosis in elderly women), or the depth of chest compressions (more than 6 cm) are associated with their appearance (3, 4, 7, 19). The influence of other factors, such as CPR duration, the experience of the person performing cardiac compressions (medical personnel or witness) is still uncertain (13,20). They are practically non-existent in children and infants given the elasticity of the chest wall at these ages (21). Most rib fractures occur between the parasternal and anterior axillary lines and involve the 2nd to the 6th (7th) rib mostly on the left side when hands are correctly applied (21). Fractures of the 1st, 8th and 12th rib are rare same as posterior arch fractures thus imposing the pursuit of other causes (21). Generally, there are encountered 5-8 rib fractures/individual depending on the study (4, 7, 21).

Sternal fractures occur less often compared to rib fractures, Black et al. discovering them in 14% of cases (7). They seem to be related especially to automatic chest compression devices not used in our country.

Perivascular haemorrhagic infiltrations are poorly described in the literature. However, they are part of the frequently observed lesions during necropsy when chest compressions have been applied and mostly involve the ascending aorta, superior vena cava and azygos vein but may extend to the abdominal region in exceptional cases (3).

Petechiae on the surface of the heart, mostly on the posterior surface, are non-specific to the CPR and no macroscopic criterion distinguishes them from those arising from mechanical asphyxia (intentional or criminal) or agony (22). Myocardial lesions (rupture) have also been mentioned in the literature as being related to chest compressions especially in case of increased cardiac pressure like in patients with pulmonary embolism or thinned wall secondary to a myocardial infarction (23). Krischer et al. observed some rare lesions such as endocardial dilaceration, intraventricular haemorrhage, epicardial haemorrhage, subendocardial contusion (3). His bundle and coronary arteries lesions (intimal dilacerations) have been identified in 44% of cases on histological images (24).

All intra-thoracic structures (vessels, pericardium, heart, lungs, diaphragm) can be injured (contusion, rupture, perforation, dilaceration) directly or indirectly by chest compressions. The observed lesions can be directly attributed to CPR only in the absence of trauma. Pulmonary lesions are identified in 13% of cases secondary to gastric content inhalation, emphysema or contusion (3). Pulmonary oedema cannot be directly considered a complication of CPR but a consequence of prolonged manoeuvres. Pneumothorax, haemothorax (azygos vein rupture) and subcutaneous emphysema can also complicate chest compressions (25). Diaphragmatic lesions are rare same as vertebral fractures.

Intra-abdominal organs such as the liver, spleen and stomach are less often the site of complications secondary to resuscitation than the structures mentioned above. However, due to their anatomical location, secondary lesions
(rupture, perforation, dilaceration) may be observed directly related to chest compressions or indirectly related, mainly through bone fractures. An improper hand position could facilitate the occurrence of these type of injuries (13). Krischer et al. identified liver lesions in 2.1% of cases (3) compared to 0.32% in another study (26). Similarly, only 3 cases of post-CPR splenic fracture have been indicated in the literature (27).

Digestive lesions associated with ventilation manoeuvres are most commonly observed in emergency situations where malposition of the intubation tube is frequent and may result in oesophageal intubation. This can lead to oesophageal and gastric lesions, sometimes as far as gastric distension (29.1%) (3), even associated with pneumoperitoneum and subcutaneous emphysema if CPR is continued (28). Signs like cyanosis and abdominal distension indicate a malposition of the tube (6). Such complications can also occur during mouth-to-mouth respirations or when using a facial mask (29). Gastric distension may be complicated by lacerations and bleeding (9-12%) especially in association with chest compressions (4). Gastric ruptures occur rarely and below the gastrooesophageal junction, parallel to the lesser curvature (28).

Ecchymoses, erosions and haemorrhagic infiltrations of the inner side of the upper limbs occurring secondary to body manipulation during resuscitation, are rarely mentioned in the literature, probably due to the lack of repercussions. On the other hand, they have particular forensic implications because of their specific location as they may suggest the intervention of a third party potentially related to the primary cause of death. It is therefore important to find precise anamnestic elements concerning the gestures and manipulations performed during resuscitation manoeuvres.

Puncture sites associated with ecchymoses and underlying haemorrhagic infiltrations are very often a sign of CPR especially if located in specific anatomic regions (cubital fossa, dorsal hand). Nevertheless, no criterion, makes it possible to distinguish these lesions from those provoked by an act causing death (self-injection or administration by a third party of toxic or narcotic drugs). Nearly 80% of these lesions are observed in individuals who have benefited from intensive care manoeuvres. The precise origin of each of these punctures must be strictly checked in order not to omit any malicious intervention by a third party or self-injection (suicide, drug abuse) (3).

Buschmann et al. and Krischer et al. indicate some other potential and rare lesions occurring during CPR such as those involving the recurrent nerves, piriform sinus, vocal cords and arytenoid cartilages (3,6). Hyperextension of the head during CPR may lead to fractures of the cervical spine, or even dilacerations of carotid intima (3,30). Mechanical ventilation is a potential source of pulmonary barotrauma which can be complicated by pneumothorax and subcutaneous emphysema (31).

In common practice, when CPR has been performed, the absence of any other explanation for certain wounds discovered at necropsy sometimes leads to the conclusion that CPR is directly responsible for them. Anamnestic elements detailed in medical or police files are essential and must be exhaustive in order to ensure a certain link between lesions and CPR.

**CONCLUSIONS**

Injuries produced during CPR may be responsible for important artefacts impeding the understanding of traumatic lesions observed during necropsy and related to the primary death cause. A thorough knowledge of possible aspects is mandatory to the differential diagnosis with other traumatic lesions.

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