Penetrating cardiac injuries: literature review and analysis of the forensic approach

Michela Ferrara¹, Benedetta Baldari², Simona Vittorio², Giuseppe Bertozzi¹, Luigi Cipolloni¹,*, Stefania De Simone¹

¹Department of Clinical and Experimental Medicine, Section of Legal Medicine, University of Foggia, 71122 Foggia, Italy
²Department of Anatomical, Histological, Forensic and Orthopedic Sciences, Sapienza University of Rome, 00185 Rome, Italy
*Correspondence: luigi.cipolloni@unifg.it (Luigi Cipolloni)

Abstract

Penetrating cardiac injuries represent an increasingly frequent type of trauma in clinical and autopsy practice. The present study aims to review the specialist literature of the last decade (2010–2020) to assess whether the main features of these lesions have changed compared to previous years. The following characteristics were considered: sex, age, cardiac structure involved, execution or not of surgery and postoperative survival, hemodynamic stability, circumstances and mechanism of production, injury and cause of death. Furthermore, the authors propose a practical appraisal of penetrating heart injury in which death was due to a delay in rescue. In line with the data obtained from the practical case, the review showed that compared to the past, the differences concern especially the mortality rate. This paper highlights that the forensic pathologist who approaches a case of transcardiac injury must consider that the circumstances of death are not always attributable to accidental events, attacks or suicides, but may also be due to clinical malpractice or failure to rescue.

Keywords: Penetrating heart wounds; Transcardiac injuries; Duty to rescue

1. Introduction

Penetrating heart wounds refer to all traumatic cardiac injuries secondary to penetrating action. This kind of trauma is frequently observed in the clinical setting and even more in the autopsy practice, as the injuries are often lethal [1,2]. According to the literature, the leading causes of penetrating cardiac trauma are stab wounds and gunshot wounds, succeeded by accidental impalements [3].

Patients with a penetrating cardiac wound may present varying clinical conditions, ranging from complete hemodynamic stability to cardiac arrest. Physicians must make the diagnosis quickly and promptly start the treatment to reduce mortality [4].

The outcomes of these kind of lesions depend on multiple factors, including mechanism of injury, cardiac site involved, the extent of the damage, hemodynamic stability, the time elapsed since the production of the injury to the diagnosis, and implementation of adequate therapy [4]. Other survival factors are the need for cardiopulmonary resuscitation (CPR) during first aid, cardiovascular-respiratory trauma (CVRS) score at hospitalization, and damage to large intra-pericardial vessels [1].

Pereira et al. [4] found that there has been lower mortality associated with cardiac trauma in recent years, likely due to advances in pre-hospital treatment in local emergency services and shorter transfer times. Therefore, the patient often arrives at the emergency room in an optimal physiological state to receive timely treatment [5]. The long-term outcomes of patients with penetrating heart wounds who have not presented coronary or valvular lesions and who pass the acute phase are optimal, with minimal cardiac morbidity related to the lesion suffered [6].

The present study aims to review the literature on penetrating heart wounds over the past decade (2010 to 2020) to develop a systematic approach to assessing this kind of injury. Studying the progress of diagnostic and therapeutic knowledge of these wounds is essential to clarify all the questions that such cases could have in the forensic field.

2. Materials and methods

Information Sources and Search: For this literature review, PubMed database was questioned. A primary selection was conducted with a search strategy, using the keywords “penetrating cardiac injury” and “transcardiac injury”.

Study Selection and Data Collection Processes: After the initial literature searches conducted, the case reports were selected after the evaluation of the title and abstract, and then potentially relevant case reports were further assessed for eligibility. Full-length articles were preferred; duplicate manuscripts or only-abstract-available texts were excluded.

Eligibility: All case reports in which patients were classified in terms of sex, age, involved cardiac structure, execution or not of surgery and post-operative survival, hemodynamic stability, circumstances and mechanism of production the injury and cause of death in case of decease was selected. Inclusion criteria were: publication date from...
1 January 2010 to 31 December 2020; English language. Moreover, the references of the selected articles were also reviewed. Exclusion criteria were: object migration from other locations [7–9], iatrogenic cardiac trauma caused by medical devices or diagnostic procedures [10–12], cardiac injury following road-chest trauma, non-penetrating trauma [13,14], unrelated events [15], trauma years before [16], aortic pathologies [17].

Results: Following these procedures, 49 case reports were included in the present review.

To validate the effectiveness of the therapeutic improvements in pre-hospital and local emergency service settings, above all related to shorter transfer times, the authors examined a concrete case in which timing of first aid was delayed with unexpected death of the patient.

A 20-years old male was accidentally shot. The accidentally shooter tried to hide what happened, referred to the authorities a minor injury during a joke. The ambulance service arrived about an hour after the accident, and the patient arrived at the emergency room an hour and more than a half later. Pupillary reflexes were present, as were dyspnoea, tachycardia, sweating, and hypotension. Physical examination revealed the presence of a gunshot wound on the right arm without an exit hole. So the physician alerted the helicopter rescue to transport the boy to the nearest surgery center. The death occurred about three and a half hours after the first ambulance call.

3. Results

The results of the literature review are summarized in Table 1 (Ref. [6,18–63]).

3.1 Gender

Of the 49 cases analyzed (mean age 32.13), forty victims were men (mean age 28.1), and nine victims were women (mean age 38.97).

3.2 Damaged cardiac structure

In fourteen cases (30%), the damage concerned the right ventricle, in nine patients (18.3%), the left ventricle, and in four cases (8.1%) both ventricles. In five cases (10.2%), the lesion involved the right ventricle and the interventricular septum. In three patients (6.1%), the damage affected both the interventricular septum and the left ventricle. In two cases (4%), the lesion involved the left anterior descending artery (LAD), while in another two patients, the pulmonary artery. In the remaining cases, the damage involved other cardiac structures, as summarized in Table 1.

3.3 Survival and cause of death

Six subjects (12.2%) — five male and one female — died, including four before being evaluated in the hospital. The leading cause of death was cardiac tamponade. Of the two patients who arrived at the hospital, one underwent surgery and died 14 days after the traumatic event due to respiratory failure resulting from acute respiratory distress syndrome. The other patient did not undergo surgery as there were no traumatic myocardial lesions without a diagnosis of LAD rupture. This misdiagnosis resulted in death within nine days of being injured. The cause of death was cardiac tamponade, in association with infarction of the interventricular septum and of the anterior wall of the left ventricle.

3.4 Means of injury

Based on the collected data, three main categories group the kind of weapons: sharp objects, projectiles, and pointed objects. In 44.9% of cases, the cardiac injury was due to sharp objects, consisting of knives (seven cases), scissors (one case), machete (one case), and circular saw (one case). In the remaining cases, the kind of weapon was unknown. In 44.9% of cases, the object used acted as a projectile. In detail: nail gun (eleven cases), firing bullets (five cases), air pellet gun (two cases), fragments propelled from a lawnmower (two cases), an arrow (two cases). In the remaining 10.2% of cases, pointed objects caused the lesions: a wooden stick (two cases), ice pick (one case), bodkin (one case), stingray barb (one case).

3.5 Circumstances of production of the lesion

Concerning the circumstances of the production of the injury, in 28.6% of cases, the event was accidental. In 16.4% of cases, the lesion resulted from an assault or a fight; in 14.2%, there was a suicide attempt. In the remaining 40.9% of cases, the authors did not specify the scenario.

4. Discussion

As a result of the present literature review, the authors pointed out the following evaluations regarding the characteristics of penetrating cardiac lesions considered by this study and their evolution over the last ten years. Many patients in the analyzed clinical cases were young males, with a mean age of 32.13 years, similar to other studies [64].

The mortality rate in the present study is lower than the analysis previously published [4].

Unlike previous studies, where injuries were mainly caused by stab and gunshot, in the present case series, nail guns are the predominant weapons, followed by knives [65]. According to the literature, the most common causes of death were cardiac tamponade and hemorrhagic shock [66]. The most implicated cardiac structure was the right ventricle, followed by the left ventricle and multiple chamber lesions, in agreement with other studies; this is probably due to the greater exposure of the right heart chamber, considering the cardiac axis rotation [67]. In most cases, the circumstance of production of the injury was accidental, followed by assault and suicide attempt.
| Case report | Sex | Age | Involved cardiac site | Surgery | Survival | Circumstances and mechanism | Cause of death |
|-------------|-----|-----|-----------------------|---------|----------|-----------------------------|----------------|
| Connelly et al. [6] | male | 26 y | anterior right ventricle, ventricular sept, mitral valve | yes | Yes | altercation, knife |  |
| Kulaylat et al. [18] | female | 29 m | anterior right ventricle | yes, hemodynamically stable | Yes | self-inflicted (accidental), pneumatic nail gun |  |
| Cottini et al. [19] | female | 38 y | anterior left ventricle, ventricular sept | yes, hemodynamically unstable, cardiac tamponade | Yes | self-inflicted (suicide attempt), stab wound |  |
| Diez et al. [20] | male | 31 y | both left and right ventricles | yes, cardiac tamponade | Yes | not specified, machete |  |
| Grande et al. [21] | male | 57 y | anterior right ventricle | yes, hemodynamically stable | Yes | self-inflicted (suicide attempt), scissors |  |
| Haghshenas et al. [22] | male | 53 y | right ventricle | yes | Yes | self-inflicted, nail gun |  |
| Leite et al. [23] | male | 18 y | anterior right ventricle | yes, cardiac tamponade | Yes | fight, knife |  |
| Kremer et al. [24] | male | 22 y | right ventricle | yes, hemodynamically stable | Yes | altercation, stab wound |  |
| Gatti et al. [25] | male | 28 y | left ventricle, ventricular sept | yes, cardiac tamponade | Yes | not specified, stab wound |  |
| Claassen et al. [26] | male | 20 y | anterior right ventricle | yes | Yes | not specified, knife |  |
| Claassen et al. [26] | male | 27 y | pulmonic valve | yes, hemodynamically unstable, cardiac tamponade | Yes | not specified, stab wound |  |
| Krishna et al. [27] | male | 16 y | Anterior left ventricle | no | no (dead on arrival at the hospital) |  | cardiogenic shock as a result of cardiac tamponade |
| Zhang et al. [28] | female | 4 y | anterior right ventricle | yes | Yes | self-inflicted (accidental), pneumatic nail gun |  |
| Hsia et al. [29] | female | 54 y | right ventricle | yes, hemodynamically stable | Yes | accidental, wooden knitting needle |  |
| Ochk et al. [30] | male | 38 y | left ventricle | no | no (dead on the scene) | self-inflicted (suicide attempt), crossbow | haemorrhagic shock |
| Oliemy et al. [31] | male | 22 y | atrial septum | yes | Yes | not specified, stab wound |  |
| Barbosa et al. [32] | male | 18 y | right ventricle | yes | Yes | not specified, sharp weapon |  |
| Greenlees et al. [33] | male | 16 y | atrial septum, apex of the left ventricle | yes, hemodynamically stable | Yes | accidental, air pellet gun |  |
| Karigyo et al. [34] | male | 23 y | ventricular apex | yes, hemodynamically unstable | Yes | accidental, sharps from the blade of a grass cutting tool |  |
| Pradhan et al. [35] | female | 56 y | right ventricle | yes, hemodynamically stable | Yes | accidental, impalement on a wooden stick |  |
| Yu et al. [36] | male | 42 y | anterior and posterior left ventricle | yes, cardiac tamponade | Yes | not specified, stab wound |  |
| Enomoto et al. [37] | female | 66 y | atrial septum, septal leaflet, right ventricle, superior vena cava | yes | Yes | attack, stab wound |  |
| Gnassingbé et al. [38] | male | 10 y | left ventricle | yes | Yes | attack, knife |  |
| Case report | Sex | Age | Involved cardiac site | Surgery | Survival | Circumstances and mechanism | Cause of death |
|-------------|-----|-----|------------------------|---------|----------|-----------------------------|---------------|
| Han et al. [39] | male | 31 y | anterior and posterior mitral valve leaflets, ventricular septum | yes, hemodynamically stable | Yes | not specified, stab wound | |
| Branch et al. [40] | female | 40 y | left ventricle | no | no (dead at the hospital 34 minutes from incident) | self-inflicted, shotgun | hemopericardium and subsequent cardiac tamponade |
| Faloye et al. [41] | male | 34 y | anterior right ventricle, ventricular sept, anterior leaflet of the tricuspid valve | yes | no (dead at the hospital 14 days from incident) | not specified, stab wound | respiratory failure |
| Rupprecht et al. [42] | male | 18 y | left ventricle | yes | Yes | accidental, nail gun | |
| Işık et al. [43] | male | 11 y | atrial septum, anterior right ventricle | yes, hemodynamically stable | Yes | not specified, air gun pellet | |
| Kumar et al. [44] | male | 37 y | junction of left atrium and pulmonary veins | no | no (dead on the scene) | attack, bodkin | heart failure due to cardiac tamponade |
| Chen et al. [45] | male | 32 y | LAD coronary artery | yes | Yes | accidental, pneumatic nail gun | |
| Maffei et al. [46] | male | 30 y | lateral left ventricle, right ventricle | yes, hemodynamically stable | Yes | not specified, gunshot | |
| Nwiloh et al. [47] | male | 11 y | right ventricle, ventricular septum | yes | Yes | not specified, arrow | |
| Duric et al. [48] | male | 45 y | right ventricle | yes, hemodynamically stable | Yes | self-inflicted (suicide attempt), knife | |
| Bartoloni et al. [49] | male | 29 y | LAD coronary artery | no | no (dead 9 days after injury) | attack, knife | |
| Michalsen et al. [50] | male | 3 y | right ventricle, interventricular septum | yes | Yes | accidental, pneumatic nail gun | |
| Michalsen et al. [50] | male | 37 y | right ventricle, interventricular septum | yes, hemodynamically stable | Yes | self-inflicted, pneumatic nail gun | |
| Esfahani et al. [51] | male | 6 y | right atrium | yes | Yes | accidental, projectile propelled by a lawnmower | |
| Madani et al. [52] | male | 17 y | pulmonary artery | yes | Yes | accidental, nail gun | |
| Jodati et al. [53] | male | 24 y | right ventricle, interventricular septum, anterior mitral leaflet | yes | Yes | accidental, pneumatic nail gun | |
| Case report                  | Sex     | Age  | Involved cardiac site                                                                 | Surgery                  | Survival | Circumstances and mechanism                  | Cause of death                                      |
|-----------------------------|---------|------|--------------------------------------------------------------------------------------|--------------------------|----------|---------------------------------------------|-----------------------------------------------------|
| Parra et al. [54]           | male    | 81 y | both left and right ventricle, ventricular septum                                     | yes                      | Yes      | accidental, stingray barb                    |                                                      |
| Galante et al. [55]         | male    | 22 y | left ventricle                                                                         | yes, hemodynamically stable | Yes      | not specified, gunshot wound                |                                                      |
| Karigyo et al. [56]         | male    | 40 y | anterior left ventricle, posterior right ventricle                                     | yes                      | Yes      | not specified, firearm projectile           |                                                      |
| Sohala et al. [57]          | male    | 25 y | apex of the left ventricle                                                             | yes                      | Yes      | not specified, stab wound                   |                                                      |
| Garrido et al. [58]         | male    | 54 y | right ventricle                                                                        | yes                      | Yes      | not specified, radial mechanical saw        |                                                      |
| Praeger et al. [59]         | female  | 31 y | anterior right ventricle                                                               | yes                      | Yes      | not specified, stab wound                   |                                                      |
| Prokesch et al. [60]        | male    | 57 y | left ventricle, interventricular sept                                                 | yes, hemodynamically stable | Yes      | self-inflicted (suicide attempt), nail gun   |                                                      |
| Ramponi et al. [61]         | female  | 61 y | right ventricle                                                                        | yes, hemodynamically stable | Yes      | self-inflicted (suicide attempt), knife      |                                                      |
| Panicker et al. [62]        | male    | 70 y | right ventricle, interventricular sept                                                | yes                      | Yes      | accidental, nail gun                        |                                                      |
| ZarainObrador et al. [63]   | male    | 43 y | right atrium, right ventricle                                                          | yes, hemodynamically stable | Yes      | not specified, gunshot wound                |                                                      |
The present study shows that some features of penetrating heart injuries have changed over the past decade. Notably, the mortality rate has decreased, and patient prognosis has improved, likely due to the enhancement of emergency services. Therefore, a careful assessment of the circumstances of death must include a possible failure in the pre-hospital management. The prognosis of patients arriving at the hospital with signs of life in cases of penetrating cardiac wounds is excellent, as described by Kaljusto et al. [68]. The prognosis of nail gun shotwounds patients is better than that of stabbed patients; about half of the patients shot survive if treated promptly. They responded well to cardiac patch and pericardial drainage. Thus, patients with stable hemodynamics and penetrating cardiac wound can survive if treated in the shortest possible time. However, an important limitation of the review presented must be considered: the positive outcome bias, which is inherent in reviews based on series of case reports; to put it another way, linked to the publication of clinical cases based on success stories and not of failed cases.

With the aims to demonstrate that if assistance is provided immediately the chances of survival increased significantly, a concrete case of delayed first aids with death of the patient was examined.

Autopsy findings were:
- a gunshot wound in the middle third of the dorsal side of the right arm (1 × 0.9 cm) with an abrasion along its medial edge;
- 3050 cubic centimeters of blood in the right pleural cavity and 3000 cubic centimeters of blood in the left one;
- an oblique, top-to-bottom, and right-to-left intraparenchymal path across the heart, involving the right atrium, the upper portion of the cardiac septum, and the lower portion of the anterolateral side of the left ventricle (Fig. 1);
- death was due to acute hemorrhagic shock caused by a massive bilateral hemothorax.

Through the clinical and autopsy data, the forensic pathologist and the cardiologist established that the patient developed an hemothorax of approximately 0.5 milliliters/seconds (about 50% of the blood volume) in 1 hour and a half (Table 2).

| Timing         | History                  | Delay | VP |
|----------------|--------------------------|-------|----|
| 23.15–23.30    | Injury                   | 0–15’ | Yes|
| 23.43          | 1st EMS call             | 13’   | Yes|
| 00.06          | 2nd EMS call             | 23’   | Yes|
| 00.16          | Ambulance departure      |       | Yes|
| 00.23.50       | Ambulance arrival on scene | 39’  | Yes|
| 00.45.35       | 1st medical examination  |       | Yes|
| 00.58.13       | Air ambulance call       |       | Yes|
| 01.15.45       | Air ambulance arrival on scene |   | Yes|
| 02.09          | Air ambulance departure  |       | Yes|
| 02.26          | Cardiac arrest           |       | No |
| 03.10          | Death                    | 01.15’–01.30 | No |

Analyzing the events, they concluded that the boy could have reached the hospital in about 30–45 minutes in stable hemodynamic conditions with an immediate rescue. Therefore, the boy would have survived with a high probability.
5. Conclusions

The literature review on penetrating cardiac trauma showed a significantly increasing positive outcome in those patients, essentially due to improved pre-hospital management and the development of therapeutic workup.

A multidisciplinary approach is essential for the forensic pathologist, to integrate the clinical data with the evidence deriving from the site inspection, external examination, and autopsy [69].

The survival rates depend on the means of injury, cardiac site involved, the extent of the damage, the persistence of hemodynamic stability.

When patient dies, it is necessary to analyze the rescue management and its consistency with the improvement of diagnostic and therapeutic methods.

The present study confirms the reduction of patient mortality if first aid is rapid, as recommended by the literature, and also that patients with noticeable vital signs, when promptly assisted, had a high probability of positive outcomes.

In conclusion, the conducted study highlight that forensic pathologists must consider every possible scenario, in addition to those typical of traumatic pathology.

Abbreviations

EMS, emergency medical service; VP, vital parameters.

Author contributions

LC and BB perform autopic examination; GB analyzed the literature; MF writing; SDS review and editing; SV language supervision. All authors have read and agreed to the published version of the manuscript.

Ethics approval and consent to participate

Informed consent were obtained by relatives of the deceased person.

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Conflict of interest

The authors declare no conflict of interest.

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