

Article

SOLVING THE IMPOSSIBLE. PENETRATING CARDIAC INJURIES, A CASE SERIES OF DIAGNOSTIC WORKUP AND MANAGEMENT

Resolviendo lo imposible. Heridas penetrantes cardíacas, serie de casos del abordaje diagnóstico y terapéutico.

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SUMMARY

For a long time, any heart-based injury was an off-limits area for surgeons; a patient with a traumatic cardiac injury was doomed to die. Little more than one hundred years have passed since the first surgical correction of a penetrating cardiac injury and there is still a high rate of mortality, despite the medical advances. We present the case of 6 patients with penetrating cardiac injuries that were repaired at a third level hospital of Mexico, alongside relevant findings on the literature about the topic. From 2019 to 2020, an incidence of 6 patients with penetrating cardiac injuries was present; all men aged 30 years or older. The etiology of 4 (67%) patients was stab wounds and 2 (33%) gunshot wounds. Left anterolateral thoracotomy was used on 5 (83%) patients and midline sternotomy on 1 (17%) patient. 2 (33%) injuries on the left ventricle presented along with coronary arteries injuries. Left ventricle and right atrium injuries presented each 50% of mortality. The mortality was of 33%, 1 patient died due to intraoperative complications and another one due to massive cerebral infarction and polyuric syndrome because of diabetes insipidus. There is a long path ahead of the surgical field on this topic and further to be analyzed. An excellent tool for cardiac tamponade diagnosis due to penetrating cardiac injuries is cardiac ultrasound, therefore it should be used on every hemodynamic unstable patient in the context of PCI. Definitely, time is of the essence, and the survival of patients depends on immediate transport to a hospital and an opportune surgical intervention.

Keywords: heart injuries, thoracic injuries, heart injuries diagnosis, heart injuries surgery

1. Introduction

For a long time, any heart-based injury was an off-limits area for surgeons, as every attempt to correct the defect would be found desperate and unnecessary. Hence, a patient with a traumatic cardiac injury was doomed to die. (Asensio *et al.*, 2009; Flécher, Leguerrier and Nessler, 2020) It was first described on Homer's Iliad, but it was not until year 1895 when Axel Cappelen made the first attempt to correct a cardiac injury by applying stitches; but unfortunately the patient died of sepsis. (Søreide and Søreide, 2006) A year later, Ludwig Rehn performed the first successful repair of a right ventricle injury with sutures. And later on, in 1907 the lethality was reported as high as 60%. (Asensio *et al.*, 2009)

Penetrating cardiac injuries (PCI) can be subdivided in two major groups depending on the mechanism of injury: gunshot wounds (GSW) and stab wounds (SW). PCI's must be suspected in any injury performed on the cardiac box; this is area has been delimited as the one between the sternum superiorly, xiphoid process inferiorly and in between the nipples. It has been described as an area of major heart compromise risk whenever a penetrating injury is performed throughout this breadth. (Kim *et al.*, 2020) However, the heart is approachable from any other chest site, even though the abdomen. A cardiac injury should be suspected whenever a thoracic penetrating injury is present.

The clinical presentation of each group varies depending on many factors, such as the affected structures, the depth of the injury, patient's vital signs, time to hospital arrival, and prompt treatment.

Men are the most affected sex on this type of injury, as on any other traumatic injury. This could be due to the more frequent involvement of men in violent situations, which has been reported in 88-96% of all cases, usually at a young age, between 27-33 years old. (Seamon *et al.*, 2009; Bamous *et al.*, 2016; Stranch, Zarzaur and Savage, 2017; Kim *et al.*, 2020)

SW are different than GSW not only on mechanism, but they also differ on mortality, possible outcomes and complications. (Bamous *et al.*, 2016) GSW tend to have a deeper path, thus affect more structures, and have a worse prognosis. Both ventricles are the most affected areas of the heart,

although there is evidence of higher incidence in right ventricle compared to the left. (Kang *et al.*, 2009; Seamon *et al.*, 2009; Stranch, Zarzaur and Savage, 2017)

Mortality of these injuries goes around 40-90% (Clarke *et al.*, 2011; Kaljusto *et al.*, 2015; Bamous *et al.*, 2016; Morse *et al.*, 2016) and the survival rates have been reported as wide as 3-84% (Tyburski *et al.*, 2000; Kang *et al.*, 2009; Kaljusto *et al.*, 2015).

Little more than one hundred years have passed since the first surgical correction of a PCI and there is still a high rate of mortality, despite the medical advances. The relevance of this topic relies on the fact that there is a long path ahead of the surgical field, and further to be analyzed and discovered. We present the case of 6 PCI that were repaired on our third level hospital, alongside relevant findings on the literature about the topic.

2. Case series report

From 2019 to 2020, an incidence of 6 patients with PCI was present; all men aged 30 years or older. The etiology of 4 (67%) patients was SW and 2 (33%) GSW. All of them presented hypotension at their arrival to the ER. 2 (33%) presented tachycardia, 1 (17%) bradycardia and, 3 (50%) blood pressure between normal parameters. 1 (17%) presented normocytic normochromic anemia. 4 (67%) patients had low- grade acidosis, 1 (17%) moderate-grade and 1 (17%) between normal parameters. They were all admitted during the night shift.

At their arrival, 3 (50%) patients presented Beck's triad. Hypovolemic shock was present in 3 (50%) patients, but only 1 (17%) patient was hemodynamically stable. During the physical examination, 4(67%) patients presented jugular venous distention.

5 (83%) patients showed hemodynamic instability at their arrival, and 4 (67%) of them passed through cardiac evaluation using cardiac ultrasound, which turned out positive in all of them rushing them urgently to an operating room.

The surgical approach used in 5 (83%) of them was a left anterolateral thoracotomy. And 1 (17%) patient was treated with midline sternotomy. Measurement of blood loss was with the necessity of intraoperative blood products transfusion. It was necessary to transfuse more than ten units in 3 (50%) patients, 4 to 6 units in 1 (17%) patient and, 1 to 3 units in 2 (33%) patients.

The location of the PCI was on the left ventricle in 2 (33%) patients, with a 50% rate of mortality; right ventricle in 2 (33%) patients, with 0% mortality; right atrium in 2 (33%) patients, with 50% mortality. Coronary artery lesion was present in 2 (33%) patients, alongside injuries on the left ventricle, and 1 of them died.

Hemostasis was done in 4 (67%) of the patients using a Foley catheter. (Figure 1) And in the other 2 (33%) with digital pressure. The definitive cardiac repairment was with a 3-0, non-absorbable suture, of Prolene material, with a horizontal or vertical mattress stitch. (Figure 2)

We report mortality of 2 (33%) patients, from which 1 (17%) died on the first week of the postoperative due to complications of massive cerebral infarction and polyuric syndrome as a result of diabetes insipidus; the other patient died intraoperatively. The 4 (67%) survivor patients had a mean intrahospital length of stay of 7 days. Among them, the most common complication was pneumonia which was present in 2 of them.

Figure 1.

A Foley catheter is placed inside the injury and the balloon is inflated with a slight traction, thus creating temporary closure of the wound. This helps the surgeon to control the bleeding while getting ready to place a definitive closure.



Figure 2.

Definitive closure of PCI with a vertical mattress stitch using a 3-0 non-absorbable Prolene suture.



3. Discussion

The main mechanism of PCI was SW with an incidence of 67%, which is in accordance with literature, that reports an incidence from 43 to 74%. (Jones *et al.*, 2014; Kaljusto *et al.*, 2015; Stranch, Zarzaur and Savage, 2017; Góes Junior *et al.*, 2019) However, different authors have reported an increase of GSW over SW, which could be best explained for the easy access to guns in different countries. (Campbell *et al.*, 1997; Asensio *et al.*, 2009; Seamon *et al.*, 2015; Morse *et al.*, 2016)

Ventricles were compromised on 67% of the cases, and that may be best explained for its size. They remain the most affected chambers of the heart, around 60-70% (Thorson *et al.*, 2012; Besir, Gokalp and Eygi, 2015; Kaljusto *et al.*, 2015; Seamon *et al.*, 2015). However, the right ventricle is the most affected chamber (Topal, Celik and Eren, 2010; Thorson *et al.*, 2012; Morse *et al.*, 2016; Góes Junior *et al.*, 2019); this can be explained due to the anatomical disposition, as the right ventricle lies just posterior to the sternum, and it is more approachable to SW.(Kang *et al.*, 2009)

Diagnosis

Clinical manifestations

Almost everything related to the initial management relies on the clinical presentation at the patient's arrival to the ER. If the clinical status allows it, a detailed diagnostic workup should be done to rule out any diagnosis that could be missed out in the hurry and that might affect the treatment or prognosis. Not every cardiac injury demands immediate surgical intervention so there is some time that could be spared to make an even more thorough analysis of the injuries.

The clinical presentation depends mainly on the hemodynamic status and the presence or absence of cardiac tamponade, which can be present in 80-90% of the patients with SW. (Ivatury and Rohman, 1992; Embrey, 2007) Contrary to SW, GSW rarely present hemopericardium. Around 65% of the patients arrive to the emergency department with no detectable blood pressure. (Tyburski *et al.*, 2000) We found detectable vital signs in all our patients, although hemodynamic instability in 83%.

The way a PCI manifest also depends on the involved structures. If the pericardium is affected, blood could rapidly accumulate and because it cannot be distended, the pressure rises increasingly, pushing the heart to its center. This causes the blood return to the right side of the heart to decrease, thus declining the blood output. All these events manifest as an increase of frequency and contractility of the heart. However, there could also be an exsanguination caused directly from the wound to the heart. If the cardiac conduction system compromises, it could lead to arrhythmias or even cardiac arrest. Nevertheless, cardiac dysfunction can be the result of single or multiple injuries on different structures, such as blood supply to the heart, the myocardium or its valves. (Kang *et al.*, 2009)

To save time on the initial approach of a PCI, the ER physician must keep in mind all the possible ways a cardiac injury could manifest. As previously stipulated, PCI must always be suspected on penetrating injuries to the thorax or upper abdomen and with concomitant hypotension. (Kang *et al.*, 2009)

The physical examination begins with the inspection at the patient's arrival to the emergency department. The type of injury may provide important information on etiology, whether GSW or SW is being dealt with. The ER physician must first analyze the size and depth of the injury and follow the appropriate Advanced Trauma Life Support recommendations for hemorrhage control if this happens to be present.

A cardiac tamponade is a serious and often lethal complication of penetrating heart injuries and it has the potential to aggravate any underlying problem, so it must be treated as soon as detected. (Bellister, Dennis and Guillamondegui, 2017) The Beck's Triad has been described as three signs found in physical examination that suggest the presence of cardiac tamponade. These are hypotension, jugular venous distention, and muffled heart sounds. However, this triad might not be present on patients with this complication. The triad was present on 50% of the patients, although jugular venous distention was seen on 67%. This indicates that not all the signs may be present for the patient to have a cardiac tamponade. For this reason, it is not a completely reliable finding on the physical examination to rule out a cardiac tamponade. It is a good indicator to suspect cardiac tamponade, but in its absence, a cardiac tamponade cannot be ruled out.

A cardiac tamponade has the potential to cause a decrease of blood output, thus leading to cardiogenic shock. Keeping this in mind, other clinical signs that may be identified on the presence of a cardiac tamponade include signs of shock, such as tachycardia, tachypnoea, hypotension, diaphoresis, and cool extremities with loss of peripheral pulses. (Kang *et al.*, 2009)

Even though physical examination and echocardiography are usually enough to build up a proper diagnosis and lead to adequate decision making on the next step, other studies can give important information to take into consideration. (Long, 2019)

Imaging

Imaging findings of PCI depend on the affected areas. These could be shown as a pericardial tamponade, either with blood or air or as a tension pneumopericardium, which commonly involves adjacent pulmonary affection. These are usually identified with a chest radiograph or Computed Tomography (CT). Hemopericardium on the other hand, is usually not so righteous to detect on a chest radiograph, so an additional CT needs to be ordered. Another fast and reliable option to detect an hemopericardium is with the usage of sonography. PCI may also manifest on imaging as a pericardial rupture, which main concern is herniation. It is also possible, although rare, to detect direct injury on the myocardium during CT imaging. (Mirvis, 2004)

Echocardiography has the characteristic of being dynamic, which allows to assess the motion of cardiac chambers, valves, and left ventricular ejection fraction. Moreover, it can show abnormalities such as pericardial effusion as small as 25 mL, or even cardiac tamponade. (Co *et al.*, 2011) An important advantage is that it can be performed in the ER with a portable ultrasound, thus shortening times and stablishing diagnosis in a more efficient way. The downsides of this modality is that it is operator dependent; and there are some other circumstances that makes it hard to identify all structures, such as obese people, subcutaneous emphysema, or hemopericardium (because of the inward pression that collapses the chambers). (Baker, Almadani and Ball, 2015; Kong *et al.*, 2015; Nicol *et al.*, 2015)

Generally, on stable patients a CT is a good option to analyze the cardiac injury. On the other hand, on unstable patients the Focussed Assessment with Sonography for Trauma (FAST) is the proper way to go due to its accessibility, rapidness, and bedside location. This diagnostic imaging is usually done by surgeons in many parts of the globe, and it is a bedside evaluation. In this case series, FAST further focussed for cardiac imaging showed 100% sensibility, as all the patients evaluated with this modality showed positive findings for free liquid on pericardial sac and were prompted to the OR.

A transthoracic view should be used in everyone whenever possible if the clinical status allows it. It has the disadvantage that if it is taken just after the injury, it could mislead to other diagnosis, due to cardiac oedema, occluding coagulin plugs and non-dilated cardiac chambers. (Thandroyen

and Matisonn, 1981; Sugiyama *et al.*, 2011). If free air is found, as in a pneumothorax or in surgical emphysema, the correct interpretation of the results could be difficult.

Transoesophageal echocardiography is a good alternative when it is not possible to perform a transthoracic view. It has been described as a recommended study to perform intraoperatively, to evaluate repairs. (Reddy and Muckart, 2014) It provides higher definition of the cardiac anatomy, giving the benefit to evaluate in a better way possible any injury missed during the first investigation. It is advantageous to observe cardiac tamponade, shunts, valve injury or coronary artery injuries. (Abou-Leila and Voronov, 2017)

Even though transesophageal echocardiogram can provide useful information, it is not necessary on the initial approach of acute trauma patients, as it is invasive and requires sedation. Besides, there are other imaging studies that can provide the same information, such as multidetector CT, that may demonstrate papillary muscle rupture. (Lee *et al.*, 2009; Co *et al.*, 2011)

Computed Tomography is a reliable exam to perform on stable patients. When talking about penetrating cardiac injuries, Góes Junior *et al.*, (2019) found a sensitivity of 56.5%, specificity of 85.7%, positive predictive value of 65% and negative predictive value of 80.7%. (Góes Junior *et al.*, 2019)

Possible findings that must be ruled out during CT to identify heart injury are pneumopericardium and hemopericardium. However, if a hemopericardium is first identified in an ultrasound, time should not be wasted to perform a CT, for it could worsen the clinical status of the patient. (Plurad *et al.*, 2013)

Furthermore, the CT gives the advantage to evaluate the lungs, searching for signs of lesions, such as looking for hemothorax in the pleural space, or hemomediastinum, pneumomediastinum, or mediastinal hemorrhage. (Plurad *et al.*, 2013; Góes Junior *et al.*, 2019)

It is also effective to detect pericardial or myocardial lacerations, cardiac luxation, path of a projectile, or location of a foreign body. (Hanpeter *et al.*, 2000; Shanmuganathan and Matsumoto, 2006; Raptis, Bhalla and Raptis, 2019) Valvular compromise should be suspected whenever a pulmonary edema develops after a penetrating cardiac injury. (Co *et al.*, 2011)

Nummela *et al.*, (2019) recommend the use of arterial phase whole-body CT as multiple injuries and active bleeding are common. As well as a CT after emergency surgery. (Nummela *et al.*, 2019)

Chest x-rays are usually helpful in giving an overview of the patient state and some life-threatening pathologies that could be missed in the attempt to treat the most serious and obvious injuries. This could include pneumothorax, haemothorax, pneumopericardium, mediastinal hematoma, or displaced heart, pulmonary involvement presenting contusions, etc. (Co *et al.*, 2011; Thorson *et al.*, 2012; Long, 2019) Nonetheless, it is very important to not overestimate the information any chest x-ray offers. Apparently normal x-rays, which are not that rare, in the context of a cardiac wound, could lead to a misdiagnosis. (Kang *et al.*, 2009) For example, it can only show pericardial fluid greater than 200 mL (Co *et al.*, 2011)

If one might not perform a FAST, a subxiphoid pericardial window (SPW) is the best path to take. (Stranch, Zarzaur and Savage, 2017) It consists in a small incision on the pericardium and this procedure must be done under general anesthesia, so it requires an operating room for it to be performed. Having said that, it opens up the way for a thoracotomy to be done if needed. (Thorson *et al.*, 2012) It serves as diagnostic and therapeutic management of the pathology, but it is merely transitory. (Kaljusto *et al.*, 2015)

SPW was the gold standard for many years. (Reis *et al.*, 2012; Karigyo Toshiyuki *et al.*, 2013) Now, even though SPW is getting less used due to the advent of new technologies, it still is the ideal study

whenever a surgeon wants to confirm the results of positive, inconclusive, equivocal, or negative FAST with a significant hemothorax. (Ball *et al.*, 2009) Bamous *et al.*, (2016) suggested that SPW should be performed on stable patients with delayed presentation of traumatic pericardial effusion. (Bamous *et al.*, 2016) Contrastingly, Góes Junior, (2019) showed on his results that SPW should not be used as a screening or routine exam. (Góes Junior *et al.*, 2019)

The result is positive when blood located inside the pericardium sac is evacuated through the incision. Then it is indicated to perform a subsequent approach, such as a medium sternotomy or a left anterolateral thoracotomy, depending on the suspected location of the injuries.

The literature reports a sensitivity of 97% and specificity of 100% either for FAST or SPW. (Uchimura *et al.*, 2010; Co *et al.*, 2011; Hommes *et al.*, 2013; Karigyo Toshiyuki *et al.*, 2013; Kaljusto *et al.*, 2015; Raptis, Bhalla and Raptis, 2019)

Nowadays echography offers some remarkable advantages which allows it to be considered even priorly to SPW, such as its non-invasive nature and easy access. And because of that, it should be available in every trauma center. (Kang *et al.*, 2009; Uchimura *et al.*, 2010; Karigyo Toshiyuki *et al.*, 2013)

Treatment

Usually, PCI demands immediate surgical attention. However, if the patient clinical status allows it, they can be approached through a planned and semi-elective surgery. This come with the advantage of allowing for more studies to be held prior to the intervention, to identify all the possible injuries, and to stablish a thorough plan of action before any intervention in the operating room (OR).

On the other hand, unstable patients with signs of shock, cardiac tamponade, or excessive hemorrhage demand a more aggressive approach, and they must be treated in an OR immediately. If they cannot make it to the OR, an emergency department thoracotomy (EDT) must be performed.

Pre-hospital mortality is as high as 90% (Thorson *et al.*, 2012; Kong *et al.*, 2015; Nicol *et al.*, 2015) In this type of injury, getting to the operating room is imperative. Very little can be done before this vital approach and time should not be wasted in attempts to resuscitate prior to hospital transport, or even any other attempts to maneuver at the encounter site. Immediate surgical intervention can lead to 24-60% of survival rate. (Asensio *et al.*, 1998; Monteiro Tavares Pereira *et al.*, 2013; Kaljusto *et al.*, 2015)

An EDT is often the “Hail Mary” for a surgeon as it is the last resource to save a patient. Only certain patients in the context of PCI would benefit from an EDT. As the western trauma association committee and many other authors have stablished, EDT is indicated on patients with PCI and with refractory shock or on those that required prehospital cardiopulmonary resuscitation no longer than 15 minutes. (Embrey, 2007; Burlew *et al.*, 2012; Abou-Leila and Voronov, 2017; Long, 2019)

Its praxis does not usually have the best outcomes, with surviving rates being reported from 1 to 35%. (Rhee *et al.*, 2000; Seamon *et al.*, 2009; Burlew *et al.*, 2012; van Waes *et al.*, 2012; Rabinovici, 2014; Stranch, Zarzaur and Savage, 2017; Long, 2019) Although if the patient arrives without vital signs on admission, it has a survival rate less than 1% (Burlew *et al.*, 2012; Bamous *et al.*, 2016) Notwithstanding, it is usually the only logical course of action to save a patient’s life.

In the context of an EDT, the most useful approach is to perform a left anterolateral thoracotomy (LAT) to have direct access to the heart. It is the easiest and fastest approach to undermine an injury. (Tun *et al.*, 2017)

However, when the patient is to be treated in an OR, there are two approaches that could be performed on a PCI: a midline sternotomy or a LAT. When an injury on a different place, other than the heart, is suspected (esophageal, descending aorta or the posterior side of the heart) a LAT is the ideal approach as it allows to visualize these structures. (Embrey, 2007)

Midline sternotomy offers a better exposure of the heart, its vessels and bilateral pleural spaces, (Kang *et al.*, 2009; Bamous *et al.*, 2016) It is ideal when the right side of the heart is compromised. (Embrey, 2007) It is also the preferred approach if the patient is stable enough to be transferred into an operating room. (Tun *et al.*, 2017) However, it comes with the disadvantage of sternal wound sepsis risk. (Reddy and Muckart, 2014)

When comparing these two approaches, Besir *et al.*, (2015) reported a mortality of 26.9% for thoracotomies and 14.2% for sternotomies, although no difference in prognosis whatsoever between the two approaches. (Besir, Gokalp and Eygi, 2015) Hence, the approach depends merely on the urgency of the situation and the location of the injuries.

Jones *et al.* (2014) reported on their series that pericardial drainage is a good option to treat patients with cardiac tamponade on the emergency department. The Seldinger technique was used in the subxiphoid location to place a catheter with gravity drainage or continuous aspiration while transporting the patient to the operating room. Results showed a slight decrease on mortality, but the number of patients on their study was too small to consider statistical significance. They also found no complications on the procedure, and no delay on the operative intervention. (Jones *et al.*, 2014)

On unstable patients, a pericardiocentesis could be performed to temporarily relieve the pressure. However, it could take a considerable amount of time that could worsen the patient's prognosis. (Long, 2019)

Whenever the general condition of a patient is stable and the studies performed show no injury whatsoever, it is a general practice to place a chest tube drainage and wait for the patients clinical evolution. (TOMASELLI *et al.*, 2003)

When the heart has an adequate exposure and the surgeon is ready to perform the definite correction, there are some measures that comes in handy. On atrial injuries, the surgeon could perform digital pressure on the injury to control the hemorrhage or place a vascular clamp.

It is a common and creative practice to temporary close the defect by placing a Foley catheter inside the injury, inflate the balloon once inside the cardiac chamber, apply slight traction, being cautious to prevent the injury from becoming larger, and then place a clamp on the catheter just on its way out of the heart, so it can create temporary hemostasis. (Tun *et al.*, 2017)

The direct closure of the injuries must be made with sutures. The ideal type is a non-absorbable pledgeted suture, in a U-fashion way. (Embrey, 2007)

When a coronary artery is compromised, it is important to go underneath the artery when suturing, since direct repair of the wound through sutures or even digital pressure can lead to heart ischemia. Hence, alternative treatment to coronary artery injuries should be taken into consideration These possible courses of action include an intracoronary shunt in primary way, to then proceed with the definitive solution, such as suture of the artery or vein angioplasty. (Embrey, 2007)

Septal injuries closure could lead to failure on the treatment since many of them tend to close on their own after a few days or weeks, hence, such injuries should not be definitely repaired on the initial operation. (Embrey, 2007)

Some other ways to close a cardiac injury have been described, such as fibrin patches. Topical hemostatic agents provide a fibrin rich patch, allowing better clotting formation whenever a suture repair could compromise adjacent arteries. (Butts *et al.*, 2019) So this is a good alternative to take into consideration, and that can be helpful on patients with coagulation disorders. (Chiara *et al.*, 2018)

There has been described an innovative way of closing ventricular septal defects in a percutaneous transcatheter way. (Dehghani *et al.*, 2009; Suh and Kern, 2009) It is a considerable good course of action whenever a surgical approach cannot be performed. (Reddy and Muckart, 2014) But despite that, a valve injury or any other kind of injury is usually present, requiring surgical approach, thus not having a lot of usefulness performing a percutaneous transcatheter closure.

Cardiopulmonary bypass is one of the greatest advents on cardiac surgery. It allows the body to keep its normal perfusion and the surgeon to work with a stable heart and make precise decisions on its repair. The indications to perform a cardiopulmonary bypass include left ventricular injuries that are too large or too dangerous to repair on the beating heart. A proximal coronary artery injury could sustain a great risk of ischemia if direct digital hemostasis or sutures are attempted. Valvular injury is another situation that not only demands surgical correction, but also cardiopulmonary bypass, for it would be almost impossible to repair a moving valve. Any defect on a ventricular septum of considerable size, with or without cardiac shunting, requires a bypass as well. (Abou-Leila and Voronov, 2017; Stranch, Zarzaur and Savage, 2017)

Prognosis

Risk factors for mortality include the presence of cardiac tamponade, extra cardiac associated injuries and right ventricle injury. (Bamous *et al.*, 2016) Tyburski *et al.*, (2000) included the physiologic status at the patient's arrival to the ER. The involvement of multiple chambers or great vessels has also been associated with higher mortality (Tyburski *et al.*, 2000; Morse *et al.*, 2016) The etiology of the PCI plays a fundamental role, as GSW has worse prognosis than SW. (Kaljusto *et al.*, 2015)

Even though the injury is in a principal organ, the causes of death are not usually directly related to the injury itself, but due to the complications that may develop afterwards, such as cardiac tamponade or exsanguination which lead to hypovolemic shock. (Kang *et al.*, 2009; Karigyo Toshiyuki *et al.*, 2013; Kaljusto *et al.*, 2015; de Araújo *et al.*, 2018)

Cardiac tamponade is a feared complication of a penetrating cardiac injury as it is the main cause of death on these patients. It could lead to subendocardial ischemia, malignant arrhythmias or cardiac arrest. (Jones *et al.*, 2014)

Thorson *et al.* found on their series that around 30% of the patients with hemopericardium caused by penetrating trauma on a pericardial window, had a nontherapeutic sternotomy, that means, they had no injury to be repaired. (Thorson *et al.*, 2012) So apparently not every hemopericardium demands a surgical approach, or at least, not all of them has something to be repaired. Be that as it may, it is comprehensible if one does not want to take such risk of not being completely sure of the absence of a potentially mortal injury. It is wise to further analyze each stable patient, for they might not even need a thoracotomy at all.

Cardiac tamponade or exsanguination, on the other hand, demand immediate attention to treat and resolve such complications. Notwithstanding, the possible attempts to treat these are merely transitory for the underlying cardiac injury must be repaired as soon as possible in an operating room.

The literature shows heterogeneous results on mortality among chambers. Tyburski *et al.*, (2000) reported highest rate of survival on injuries on right ventricles, with 60%. (Tyburski *et al.*, 2000)

Stranch *et al.*, found increased risk of death on injuries on right atrium and great vessels. (Stranch, Zarzaur and Savage, 2017) Other authors have found that no difference whatsoever on mortality among chambers (Asensio *et al.*, 1998)

GSW have worst prognosis and higher mortality rates than SW. This difference is mainly explained by the object and the force of impact, (Gunn *et al.*, 2014; Durso, Caban and Munera, 2015; Lichtenberger *et al.*, 2018) and the fact that bullets can affect multiple and deeper structures than sharp objects. Moreover, sharp objects often function as temporary hemostasis, preventing profuse bleeding on the site of injury until the surgical team can approach and correct the defect on a controlled environment. (Nummela *et al.*, 2019)

SW are the most prevalent cause of surgical intervention of PCI (39-81.4%) (Uchimura *et al.*, 2010; Karigyo Toshiyuki *et al.*, 2013; Besir, Gokalp and Eygi, 2015; Khorsandi *et al.*, 2015), even though GSW has been reported as the main etiology of PCI, it often presents higher mortality rate prior to the arrival into the OR. (Albadani and Alabsi, 2013; Kaljusto *et al.*, 2015; Melo *et al.*, 2017; de Araújo *et al.*, 2018)

4. Conclusion

There is still a long road ahead in the surgical field, and further to be improved. Although the data collected is of a small number of patients, the literature supports our findings. In the imaging diagnostic area, great advancements have taken place and that has helped to PCI diagnostic accuracy, thus of better-planned surgeries and different approaches according to the situation. However, PCI still have a high mortality rate, and very little can be done other than correct the defect in an OR. PCI will remain a high mortality injury despite medical advancements because many of them are fatal at the encounter site. Definitively, time is of the essence, and the survival of patients depends on immediate transport to a hospital and an opportune surgical intervention.

5. Ethical aspects

Patients consent to be included in the present study was obtained. It had ethical approval by the board.

6. Conflict of interest

The authors declare there is no conflict of interest

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RESUMEN

Durante mucho tiempo las heridas en el corazón eran un área prohibida para el cirujano. Cualquier persona con herida penetrante cardíaca estaba condenada a morir. Poco más de cien años han transcurrido desde la primera corrección quirúrgica de una herida penetrante cardíaca y sigue habiendo una tasa alta de mortalidad, a pesar de los avances médicos. Se presenta una serie de casos de 6 pacientes con heridas penetrantes cardíacas que fueron reparadas en un hospital de tercer nivel de México, junto con revisión de la literatura. Desde el 2019 al 2020, hubo una incidencia de 6 pacientes con heridas penetrantes cardíacas; todos fueron hombres de 30 años o mayores. La etiología en 4 (67%) casos fueron heridas por arma blanca y 2 (33%) por herida por proyectil de arma de fuego. Se usó el abordaje por toracotomía anterolateral izquierda en 5 (83%) pacientes y esternotomía media en 1 (17%) paciente. Dos (33%) heridas se suscitaron en el ventrículo izquierdo en conjunto con heridas en arterias coronarias. Heridas en el ventrículo izquierdo y atrio derecho presentaron una mortalidad del 50% cada una. La mortalidad total fue de 33%, 1 paciente falleció por complicaciones intraoperatorias y otro más por infarto cerebral masivo y síndrome poliúrico causado por diabetes insípida. Hay un gran camino por recorrer en el ámbito quirúrgico de este tipo de heridas y más por ser analizado. Una herramienta útil para el diagnóstico del taponamiento cardíaco por heridas penetrantes cardíacas es el ultrasonido cardíaco, y, por ende, debe ser usado en todo paciente con inestabilidad hemodinámica en el contexto de una herida penetrante cardíaca. Definitivamente, el tiempo es vida, y la sobrevivencia de estos pacientes depende del transporte inmediato a un hospital y una intervención quirúrgica oportuna.

Palabras clave: heridas cardíacas, heridas torácicas, diagnóstico de heridas cardíacas, cirugía de heridas cardíacas.
