# Role of Fluid Dynamics in Cardiac Blast Effect – A Case Report

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**A B S T R A C T**

***Background*****:** A large variety of injuries is sustained during vehicular accidents. Blunt cardiac injury (BCI) encompasses a wide spectrum of clinical manifestations, ranging from cardiac concussion to cardiac rupture. Apart from the usual blunt injuries, an uncommon type is the compression injuries of the chest. Such compression results not only in direct damage to the solid organs but also results in blast injury of fluid filled organs due to the variations in the intraluminal pressure, in accordance with laws of fluid dynamics.

***Case Report*****:** Here is a rare and interesting case of such nature, in which tangential force over the chest resulted in the massive rise of intraluminal pressure in the ventricles leading to burst of chambers resulting in death.

***Conclusion*****:** In this article, we have tried to explain the various factors resulting in bursting of the fluid filled organs and their relations with fluid dynamics.



▶*Implication for health policy/practice/research/medical education:* Role of Fluid Dynamics in Cardiac Blast Effect – A Case Report

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## 1. Introduction:

The rate of blunt cardiac injury (BCI) in all blunt thoracic trauma patients is approximately 20%; however, in patients with severe thoracic injury or multiple injuries, the rate of BCI may be as high as 76% (1, 2). Blunt cardiac injury encompasses a wide spectrum of clinical manifestations, ranging from asymptomatic myocardial bruise to cardiac rupture and death (3). Severe cases of blunt cardiac trauma causing rupture of cardiac chambers result in immediate death due to tamponade and pump failure. Deceleration injuries, causing the heart to impact against the sternum and vertebrae may cause injury to the myocardium, valvular structures and pericardial attachments. Blunt cardiac injury, most commonly in the setting of an automobile accident, may cause myocardial rupture as a result of cardiac compression between the sternum and the spine, direct impact (sternal trauma), deceleration injury,

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hydraulic effect resulting in rupture, such as that seen during an abrupt abdominal compression which results in a sudden increase in pressure within the right chamber of the heart due to the significant increase in venous pressure that is transmitted to the right atrium or ventricle, or from Blast injury (4). The right heart is the most common site of BCI vowing to their architectural composition. All the chambers of the heart may be involved, but when arranged in decreasing order of frequency, the right ventricle, left ventricle, right atrium, and left atrium are seen (5). Hemodynamics is the study of blood flow and circulation, as it affects the body from a physiological perspective. Much of the human body is composed of fluid and indeed fluid mechanics plays important roles in normal physiological function (1).

In the larger blood vessels of the human body, blood flows through a cylindrical geometry. The flow profile of arterial blood is usually laminar. The transition to turbulence is relatively uncommon and only occurs in high velocity blood flow in complex geometry, such as heart valves and large arterial bifurcations. Certain types of geometry, curvature, changes in diameter, and bifurcations in internal flow systems can impact the dynamics of flow, especially for the human vascular system. Bends and kinks in arteries have a dramatic effect on the alteration of blood flow. Changes in diameter can rapidly increase or decrease flow velocity, impacting the flow profile from sharp parabolas to flattened ones (6-9).

The stress generated by blood against the vessel wall is increased dramatically as the radius of the tube decreases, as well as when the viscosity of the blood increases. The forces exerted by blood at the vessel wall are directly related to waveforms generated in the heart.

In a study of in vitro technique producing myocardial rupture in lamb hearts, which relates tensile strength to a variety of conditions which can prevail in normal and infarcted human hearts showed that there were three separate sites of myocardial rupture which occurred with the frequency of 54% at the papillary muscle, 30% at the inter ventricular septum, and 16% at the free wall of the left ventricle. The distribution and configuration of the experimental ruptures were similar to those usually noted as complications of human myocardial infarction. The mean rupturing pressure noted was 526 mm Hg in normal lamb hearts (10). Intense surfing through the literature blast effect of the heart due to the compression of the great blood vessels at its origin resulting in increased pressure within chambers of the normal heart could not be found. Here we are reporting this rare case of bursting of the lower chambers of the heart due to the sudden, massive increase in pressure within the chambers of the heart as a result of compression of the chest and tried to correlate the effect with the fluid dynamics.

## 2. Case Report:

A 30-year young male was collapsed, when he was compressed in between the van and trailer of a tractor. When the van broke down, the driver of the van (deceased) sought the help of the tractor to tow the van to a nearby garage. Deceased, attached the van to the trailer of the tractor, and before he could move out, the driver of the tractor started moving the vehicle and upon finding the driver of the van still behind the tractor he applied breaks, due to which the deceased (driver of the van) got compressed in between the two vehicles. He was shifted to a nearby hospital where he was declared as brought dead. Postmortem examination was done on the following day.

On postmortem examination, externally a linear, vertically placed parallel abrasions of 3×0.2 cm each, 1 cm apart each other over the front of the chest on its right side (Fig. 1), multiple abrasions of various sizes and shapes over the back of the chest in between the shoulder blades measuring 18x12 cm. On dissection, a horizontally placed fracture of breast bone (sternum) at the level of 3$^{rd}$ and 4$^{th}$ ribs was noted. 1600 ml of fluid blood was present in the left chest cavity (Fig. 2). A horizontally placed contusion of 2×0.2 cm noted over the surface of aorta 3 cm from its origin (corresponding to the fracture of the sternum) (Fig. 3). Multiple cavity deep

**Fig. 1.** External apperance.

**Fig. 2.** Collected blood in chest with intact RIB cage over anterior chest wall.

**Fig. 3.** Contusion over Aorta.

lacerations of the lower left chamber of the heart noted exposing the valve, torn papillary muscles, cordae tendinae to the exterior. Aortic valve showed a tear. Cordae tendinae was intact attached to the valves (Fig. 4). Papillary muscles were torn irregularly. Fracture of the $5^{th}$, $6^{th}$, & $7^{th}$ ribs on the left side, 04 cm away from its origin.

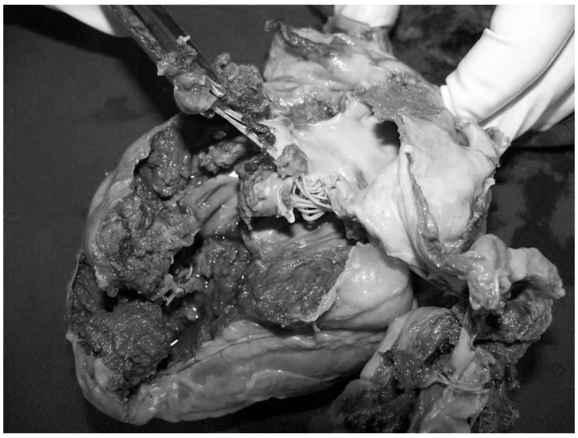

**Fig. 4.** Blast effect of heart.

Right lung was intact and left lung showed contusions around hilum and parenchyma deep lacerations over the back surface corresponding to the fractured ribs. Dissections of other organs were intact and pale.

## 3. Discussion:

It is a known fact that the blunt cardiac injury (BCI) arises from a variety of reasons, like direct impact to the chest; indirect cause like compression of the chest wall in between sternum and the spine; deceleration or torsion causing a tear in the heart at the point of fixation, as seen between the right atrium and vena cava; hydraulic effect resulting in rupture, such as that seen during an abrupt abdominal compression that results in significantly elevated venous pressure that is transmitted to the right atrium or ventricle (11).

Blunt cardiac injury (BCI), ranges from an asymptomatic cardiac concussion to cardiac rupture and death. The basic architectural composition of the right heart makes it vulnerable for rupture and thus most common site of BCI (12, 13). This finding is likely the result of steering wheel–anterior chest wall impact injuries and the anterior location of the right atrium and ventricle within the mediastinum (12, 14). Concurrent injury to more than one chamber has also been documented in more 50% of BCI patients (15).

Much of the human body is composed of fluid and fluid mechanics plays the major role in normal physiological function. The blast injury of the heart due to chest compression (a type of blunt cardiac injury) in cases of road traffic accident with minimal evident external injuries is due to the fluid dynamics. In the larger blood vessels of the human body, blood flows through a cylindrical geometry. The flow profile of arterial blood is usually laminar. The transition to turbulence is relatively uncommon and occurs only in high velocity blood near heart valves and bifurcations of large arteries. Certain types of geometry, curvature, changes in diameter, and bifurcations in internal flow systems can impact the dynamics of flow. Bends and kinks in arteries add a dramatic effect on the alteration of blood flow. Changes in diameter can quickly increase or decrease flow velocity, impact the flow profile (6-9). BCI is usually the result of high velocity impact. In the present case, the chest was compressed with a low velocity force momentarily (for a few seconds). Sudden compression of the aorta near its origin by the impact forced the blood back into the left ventricle forcefully by causing a tear in the aortic valve. Sudden gush of blood into the ventricles, along with the blood coming to the left ventricle from the left atrium, followed by the systole ruptured the lower left chamber forceful enough to give the picture of a blast heart. The result seen can be explained by applying the Pascal's law which states that when there is an increase in pressure at any point in a confined fluid, there is an equal increase at every other point in the container i.e.; an applied force will be distributed throughout a fluid. In study to find the chamber pressure, rate of distention, and ventricular disruption in isolated hearts, the authors conducted in vitro technique for producing myocardial rupture in lamb hearts, which relates tensile strength to a variety of conditions which can prevail in normal and infracted human hearts. They concluded that the mean rupturing pressure was 526 mmHg in normal lamb hearts (10). In another study, the authors tried to find the power of the rat left ventricle wall in experimental uncomplicated myocardial infarction found that normal left ventricular wall could stand the pressure of 1.1×10(5) Pa. During ischemic phase of myocardial infarction, the wall stability in the infarction area increased up to 1.5×10(5) Pa. It diminished during necrotic phase; however, timely started repair processes did not let it drop lower than 1.0×10(5) Pa (16).

Coermann *et al*, and Lundevall put forward a theory to explain the blunt aortic rupture which is due to increase in hydrostatic pressure markedly at impact and the aorta ruptures at its weakest points. Lundevall described a "water hammer" effect in which only 578 g to 660 g of force is necessary to cause aortic disruption. It is estimated that these forces can be generated in a vehicle crashing at 64 kph (40 mph) where deceleration occurs in milliseconds. In cadaver experiments exploring the mechanism of blunt aortic rupture Coermann *et al*, found that intraluminal pressures ranged from 300 g to greater than 1000g (6-9). The pressure required or the force required to rupture the ventricle is not found mentioned in the literature search. Surfing through the literature found that most of the studies undertaken were concerned with the myocardial rupture in the diseased heart.

The incidence of rib fracture and sternal fracture resulting in BCI varies from 18 to 69% and 0 to 60% respectively (1). Rib fractures and sternal fracture in turn result in rupture of the papillary muscles, cardiac free wall, or the ventricular septum depending upon the site of impact, type of the impacting object and the mode of transmission of force within the chest cavity. The anatomical position and the composition of the heart make the involvement of the right ventricle, left ventricle, right atrium, and lastly left atrium (6).

## 4. Conclusion:

In our case, hydraulic effect due to sudden imbalance in fluid dynamics due to abrupt compression of the chest by external force has led to elevated venous pressure resulting in rupture of the heart culminating in hemorrhage, shock and death of the individual. The blast injury of the heart due to chest compression (a type of blunt cardiac injury) in cases of road traffic accident with minimal evident external injuries is due to the fluid dynamics.

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