Radiologic Patterns of Hepatic Injuries following Cardiopulmonary Resuscitation

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Learning objectives

Upon completion of this educational exhibit, the learner should be familiar with the radiological patterns of hepatic injuries following cardiopulmonary resuscitation (CPR). Furthermore, the learner should be able to localize injuries using the Couinaud segmental anatomy and characterize injury severity using the American Association for the Surgery of Trauma (AAST) liver injury scale. Finally, the learner should be to understand the mechanism for these injuries and be aware of the clinical and/or subclinical manifestations.
Background

Closed cardiopulmonary resuscitation (CPR) is the emergency support of the respiratory and circulatory systems. The goal of CPR is to create artificial circulation to the body by manually compressing the heart. As such, CPR is a physically intense procedure as chest compressions are delivered at a rate of 100 per minute with a depth of 5 cm.

Skeletal chest wall injuries are common during CPR along with injuries to the upper airway and pulmonary structures [1]. A literature review found the incidence of CPR-induced skeletal chest wall injuries to be variable with sternal fractures occurring in at least one-fifth, rib fractures in at least one-third, and rib and/or sternal fractures in at least one-third of patients [2].

Although rare, CPR can also lead to intra-abdominal organ injuries [3, 4]. The liver is the most vulnerable abdominal organ to injury because of its size and location. Hepatic injuries can often be subclinical and at times only identified on imaging. Proper diagnosis of these injuries is crucial as hepatic injuries can significantly compromise a patient's hemodynamic stability. For example, case reports have described hepatic lacerations following CPR leading to massive hemorrhage [3]. Additionally, a retrospective analysis found the incidence of major liver injury following CPR to occur in 15 of 2558 patients [4]. Isolated case reports also exist describing rare hepatic injuries due to CPR such as small amounts of gas in the small peripheral intrahepatic vessels [5].

Another study of over 700 patients assessed the complications that arose from administration of CPR and found abdominal complications in 30% of patients. In terms of hepatic injuries, lacerations and/or rupture was observed in 2% of subjects with all other hepatic injuries comprising <1% of complications. The study posited the increased frequency of liver injuries, relative to other abdominal injuries, to its medial location and frequent enlargement in cardiac patients [1].

However, there have only been a limited number of case reports describing radiological evidence of hepatic injury following CPR administration. It is our aim to further address this.
Findings and procedure details

A retrospective series assessing radiological evidence of hepatic injuries following CPR in five patients treated at a Canadian tertiary care center is presented. Institutional review board approval was obtained with informed consent waived.

Cases were collected over a nine-year period using the Picture Archiving and Communication System (PACS). The inclusion criteria was two-fold; the study had to have radiological findings of hepatic injury and CPR had to have been performed prior to imaging. The imaging was reviewed by fellowship trained radiologists.

Injuries were evaluated with multiple parameters. First, the injuries were assessed in terms of the American Association for the Surgery of Trauma (AAST) liver injury scale (Fig. 1). Second, injury location was evaluated in accordance with Couinaud segmental anatomy (Fig. 2). Together the severity and location were used to determine if specific radiological patterns of these injuries exist. Patients were also assessed for radiologic evidence of additional traumatic injuries.

The results are summarized in Figure 3. Imaging records of patients ranging in age from 31-73 (mean age = 53) were reviewed. Three patients had a single injury while two patients had multiple injuries. In total, 8 hepatic injuries were documented. In terms of severity, 5 received an AAST grade III score and 3 received an AAST grade IV score. In terms of location, 3 occurred in segment II, 2 in segments IVa and VI, and 1 in segment VIII. Additional findings included hematoperitoneum, splenic laceration and rib fractures. The multimodality imaging findings from this series are shown in Figures 4-12.
Fig. 1: American Association for the Surgery of Trauma (AAST) liver injury scale.

Fig. 2: Couinaud segmental anatomy of the liver.


![Table](image)

**Fig. 3:** Patient demographics including age and gender as well as details such as severity and anatomical location of injuries.

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Fig. 4: 38-year-old female with drug overdose and prolonged CPR with subsequent drop in hemoglobin. Contiguous axial contrast enhanced CT images through the upper abdomen reveal a subcapsular hematoma involving segment II. Appearances are consistent with an AAST grade IV injury. A small amount of hemorrhage is present around the spleen.

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**Fig. 5:** Contiguous coronal contrast enhanced CT images of the abdomen and pelvis in the patient from Fig. 4 again confirms the presence of an AAST grade IV injury involving segment II of the liver.

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![Image](image_url)

**Fig. 6:** 73-year-old male with prolonged CPR and subsequent decreasing hemoglobin. Contiguous axial contrast enhanced CT images of the abdomen and pelvis reveal a hepatic laceration in segment VI as well as splenic laceration. There is intraperitoneal free fluid. Appearances are consistent with an AAST grade III hepatic injury and grade II splenic injury.

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Fig. 7: Single coronal contrast enhanced CT image of the abdomen and pelvis in the patient from Fig. 6 confirms the presence of an AAST grade III hepatic injury involving segment VI and AAST grade II splenic injury.

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Fig. 8: 31-year-old female with cardiac arrest and CPR in community. Sonographic images reveal a complex cystic lesion with an irregular thick echogenic wall and mobile internal debris. Given the history of CPR, the findings were felt to represent intrahepatic hematomas. Further characterization with MRI was advised.

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Fig. 9: MRI performed to characterize the hepatic lesion seen in Fig. 8. On T2 imaging it demonstrates intermediate to high signal with T2 shading. T1 sequences demonstrate fairly homogeneous signal with some peripheral hyperintense areas. The appearances are in keeping with a hepatic laceration involving segment IVa as well as a large subcapsular hematoma - AAST grade IV score.

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Fig. 10: 64-year-old man admitted with VT post cardiac arrest and subsequent decrease in hemoglobin. Unenhanced axial CT images through the upper abdomen confirm the presence of a linear region of hypoattenuation within segment II of the liver in keeping with an AAST grade III hepatic laceration.

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Fig. 11: Single axial unenhanced CT image from the patient in Fig. 10 through the mid-thorax reveals minimally displaced bilateral anterior rib fractures due to recent CPR administration.

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Fig. 12: 61-year-old male with firm abdomen and decreased hemoglobin post-CPR. Axial contrast enhanced CT image through the upper abdomen reveals AAST grade III injuries including lacerations and subcapsular hematomas involving segments II and VI of the liver.

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Conclusion

The origins of modern CPR can be traced to 1960 when Kouwenhoven published his historic article [6]. CPR can be considered a form of repetitive blunt trauma to the thorax with injuries arising due to direct compression of structures between the sternum and the spine. Studies assessing the position of chest compressions in regards to radiological chest anatomy found that the current recommended depth of chest compressions is approximately one-fifth the anteroposterior diameter of the average adult chest [7]. Furthermore, results yielded significant variation in sternal and thoracic shape within individuals, which may explain why certain patients are more prone to CPR-induced abdominal injuries than others [7]. Research has shown that using the dominant hand as the bottom hand is advantageous to using the non-dominant hand [8].

Radiological studies suggest that the sternum behaves as a hinge during CPR. The superior end of the sternum is relatively immobile at the sternoclavicular joint while there is relatively more allowable movement inferiorly towards the xiphoid process [7]. Compressions focused on the xiphoid process can increase the risk of abdominal injuries and can even cause liver hemorrhage if the xiphoid is fractured and driven into the intra-abdominal cavity. In fact, Kouwenhoven’s original recommendations called for compressions to be focused on the xiphoid process; however, a subsequent study found that hepatic lacerations were occurring in children following CPR and it was suggested that compressions be focused on a more superior point of the sternum [9].

The Organ Injury Scaling Committee of the AAST created a scale to grade severity of hepatic injuries in the late 1980s (Fig. 2). This scale ranges from grade I (least severe) to VI (most severe). Included in a specific grade are details such as presence and depth of hematomas and lacerations [10]. The goal of this scale is to not provide prognostic insight into a patient’s hepatic injury, but to rather clearly define the nature of the liver injury and aid in consequent management. Similar scales exist for other abdominal organs such as the spleen [11]. It should be noted that the AAST scale was originally designed to be used as a surgical scale; however, it is now commonly applied to CT imaging of the liver [12].

We applied the AAST hepatic injury scale to the hepatic injuries in our series. Five injuries received an AAST grade of 3 while three injuries received an AAST grade of 4. The incidence of AAST low grade hepatic injuries is likely underestimated in the literature as these injuries may not have enough clinical significance to warrant abdominal imaging. The AAST uses the term complex hepatic injuries to those injuries receiving a grade of at least 3 and the prognosis for complex injuries is poor. Studies indicate the overall mortality of complex hepatic injuries to be between 60 and 70% [13, 14]. Additionally, while most blunt trauma involving the liver is managed non-operatively, an increased percentage
of complex (AAST Grades 3-5) hepatic injuries must be dealt with angioembolization or surgery in order to improve patient outcome [15].

The Couinaud classification of liver anatomy was published in 1957 [16] and divides the liver into eight functionally independent segments, each with its own vascular inflow, outflow and biliary drainage (Fig. 2). The main divisions in the Couinaud classification is the portal vein which divides the liver into upper and lower segments, the right hepatic vein which divides the liver into anterior and posterior segments, the middle hepatic vein which divides the liver into right and left lobes, and the left hepatic vein which divides the left lobe into a medial and lateral part.

We attempted to categorize the hepatic injuries in our series that occurred following CPR into the Couinaud segment(s) affected. Of the 8 hepatic injuries identified, 3 involved segment II, 2 involved each of segment’s IVa and VI, and a single injury involved segment VIII. It is clear that the majority of injuries are to the left of Cantlie’s line. Cantlie’s line runs from the middle of the gallbladder fossa anteriorly to the inferior vena cava posteriorly. We posit that this is because this region of the liver is more intimate with the midline of the body and as such is more likely to receive transmitted forces from repeated compressions of the sternum. We also see some hepatic injuries in the more lateral Couinaud segments of the liver, which is also plausible as forces can be transmitted through the entire diaphragm as it is in close confines with the lateral aspects of the liver.

In our series, the hepatic injuries seen following the administration of CPR can be attributed to multiple potential causes. First, the fact that these patients underwent CPR raises the question of prior abdominal trauma leading to the CPR event. Second, these patients may have had preexisting conditions causing them to manifest hepatomegaly or they may have had large livers as their normal anatomy. Alternatively, CPR in these patients may have been incorrectly performed with the compressions being more focused in the region of xiphoid process and as such more force being transmitted through the diaphragm to the liver. It has been discussed that complications of CPR such as ruptured liver and spleen may be attributed to improper placement of the hands or compressions that are too vigorously applied. However, it is difficult to evaluate whether these complications are avoidable [1].

Another finding in our series was that of splenic laceration accompanying hepatic laceration in one patient. The premise of splenic lacerations can be considered in the same light as hepatic lacerations, although these are less common due to the smaller size and less direct anatomical relationship of the spleen to the xiphisternal joint [17].

Identification of early hepatic injury following CPR leading to occult intra-abdominal bleeding is challenging to identify. The obvious clinical manifestation is that of
hypotension, but in the post-CPR patient, the development of hypotension is easily attributed to cardiogenic shock. Additionally, signs such as abdominal pain might not be able to be reported by the patient with a decreased level of consciousness due to factors including hypoxia, shock and sedation. Nonetheless, CPR-induced hepatic injuries should remain on the clinical radar of a physician and these patients should undergo imaging to characterize injuries or exploratory laparotomy if the patient becomes hemodynamically unstable.

In summary, we present a case series of hepatic injuries following CPR. The most common pattern was injury to anterior aspects of the liver closest to midline. All injuries scored at least an AAST grade 3 with 40% scoring an AAST grade 4. We postulate that this pattern of hepatic injury is attributed to the compression of the liver between the inferior sternum and spine. There was also radiologic evidence of splenic laceration and rib fracture. Clinicians should be aware that CPR administration can lead to significant hepatic and abdominal injuries. Identification of these injuries is paramount as these injuries can significantly compromise a patient’s hemodynamic stability and be life threatening.
Fig. 1: American Association for the Surgery of Trauma (AAST) liver injury scale.

Fig. 2: Couinaud segmental anatomy of the liver.

References

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