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# Deceleration Impact Experiments and Deceleration Injury Mechanism Analysis on the Thoracic and Abdominal Organs

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**ABSTRACT** *Objective* It takes animal organs as models to study the process and mechanisms of thoracic and abdominal organs deceleration injury to establish a more reasonable basis for the injury assessment. *Methods* New Zealand rabbits were dissected along the cross-section of the chest near the diaphragm as animal models. The chest and organs were exposure. The supine (Group A) and the prone (Group B) positions were designed to be fixed in the crash test platform. The movable platform free fell from fixed height and hit the fixed platform. The high-speed camera was used to record the whole deceleration impact process. After completion of the experiment, the image sequence analysis software was used to analyze the collision process. *Results* The injured areas were all at the impact side. The high-speed camera showed that before ribs squeezing the lung at the hedge side, organs had hit the chest wall at the impact side then compressed. When ribs deformed at the hedge side, they did not compress organs immediately but with a time interval before contact and compression. The deformation of Group A was significantly higher than Group B, but there were no significant differences for the severity of organ damages. *Conclusions* In deceleration injury, the thoracic and abdominal organ damage is mainly due to the inertia impact between organs and the chest wall, while it is of no direct correlation with the compressional deformation. Thus, the AIS injury assessment criteria have serious problems, and it needs to find a new scientific assessment method.

***KEY WORDS*** Injury, Impact, Liver, Deceleration impact, Animal experiment, High speed camera, Forensic science

## 1. INTRODUCTION

When the vehicle encountered obstacles in the process of moving, it could be involved in a sharp slowdown with large probability. For the fighter, it also needs a sharp slowdown process in the moment of landing for various venues. In these deceleration situations, abdomens of occupants inside the aircraft / vehicle may have a powerful contact collision with the machine parts causing organ damage. Therefore, it is necessary to study the biomechanics mechanism of organ injury generated by the deceleration impact.

As a reflection of existing research results in this field, the Injury Severity Score (ISS) is an established medical score to assess trauma severity, and the current damage assessment is using the AIS standard related to ISS [1, 2]. It correlates with mortality, morbidity and hospitalization time after trauma. It is used to define the term major trauma. And the Abbreviated Injury Scale (AIS) is an anatomically based consensus-derived global severity scoring system that classified each injury in every body region according to its relative severity on a six-point ordinal scale: 1 Minor, 2 Moderate, 3 Serious, 4 Severe, 5 Critical, 6 Maximal (currently untreatable).

Early studies have discovered that organs in the chest and abdomen are so fragile and of little elasticity that they are very easily to be injured during the impact [3]. And there have been several preliminary conclusions [4] for these organs injury mechanism: 1) During the deceleration impact, organs encounter more substantial squeeze between the anterior abdominal wall and the spine; 2) Viscous injury: due to over-stretch effects and shear effects caused by the increased fluid pressure in the liver on high load; 3) In sudden deceleration, the liver does the inertia movement that stretch lacerations occurr at the site of attachment of blood vessels and ligaments; 4) Ribs occur stabbed at the end of the fracture.

For organs in case of sudden deceleration, their own injury, which is having nothing to do with the external connection but caused by inertial characteristics, is rarely reported in the previous literature. This paper will preliminary study the mechanical effect caused by its inertia characteristics in organs reducer impact process.

Relations among the AIS, the rib fracture and the chest compression:

Chest Compression → Rib Fracture → AIS

AIS = -3.78 + 0.1956 * Chest Compression (%)

Since it is through the classification assessment to determine the injury level, AIS is mainly based on and developed through the dummy experiments

But the dummy is a frame structure. It is a cavity and supported by a bone structure with no soft issues such as organs inside. So, for this method, it can only assess the inner organ damages by the compression degrees of the thoracic and abdominal wall.

For human body, in traffic accidents, each part is moving at the same speed. But when the vehicle stopped, the body in the vehicle is still moving forward due to the inertia. So different parts of the body have different speeds. When the chest hits the vehicle, organs are still moving forward and then impact with the chest wall. Because of the resistance from the rib profile, the extrusion slows done. Thus, the organ impact with the back should be later than with the chest wall.

For AIS, it does not consider the injury differences between deceleration and acceleration. So, it needs to do experiments to study the real mechanism. It should make clear whether the organ deceleration injury is caused from the chest wall impact by the inertia force or from the back compression by the deformation.

In this research, rabbits are taken as the animal model for observing the injury process. The organ impact properties have also been detected to establish a basis for more reasonable assessment on organ injury.

## 2. MATERIALS & METHODS

Materials：Two groups of New Zealand white rabbits with 9 per group and each weight 2.5 0.1kg (Animal Centre of Daping Hospital); a high-speed camera（PHANTOM V4.3, USA）; and the Biological Impact Device with Free-fall Deceleration Impact Rail [5].

New Zealand white rabbits were anesthetized and then fixed in the experimental platform. After causing them the suffocation death, their abdominal cavities were opened. From the 9th spine, the thoracic cage was cut off and the head was cut. The diaphragm was removed and the lungs were exposed. Placed the chest and organs on the platform of the deceleration device and fix it. Group A: chest plate, back up (Figure 1). Group B: Back plate with chest facing up (Figure 2).

**Fig. 1. Group A: Thoracic cross section (before impact)**

**Fig. 2. Group B: Thoracic cross section (before impact)**

Took out the lungs and heart, took pictures, and observed.

Finally, the image sequence analysis software was used to analyze the injury condition.

## 3. RESULTS

Both groups of lungs collapsed, but no significant changes were seen in the kidneys.

There was bleeding damage on the back panel of Group A (Figure 3). There was bleeding damage on the chest plate of Group B (Figure 4). Both groups were contact injured.

For Group A, as shown in Figure 5, the frames under high-speed camera displayed that, during the deceleration process (the red line on Figure 5), due to the inertia of the organ, it will first collide with the spine, and then it will impact gradually (the point a on Figure 5) with the impact side of the rib wall (the yellow line on Figure 5), and a series of blocked compression motions began. At this time, the front part of the chest (the blue line on Figure 5) was deformed without constricting the organs. Until the deformation speed of the anterior chest synchronously exceeds the obstructed compression velocity of the organ, the organ is subjected to the deformation force of the chest cavity (the point b on Figure 5). The organ was affected by the inertial force (the point a on Figure 5) before the rib compression force (the point b on Figure 5).

For Group B, as shown in Figure 6, the frames under high-speed camera displayed that, during the deceleration process (the red line on Figure 6), due to the inertia of the organ, it will first collide with the front part of the chest, and then it will also impact gradually (the point a on Figure 6) with the impact side of the rib wall (the yellow line on Figure 6), and a series of blocked compression motions began.

**Fig. 3. Group A: After impact**

**Fig. 4. Group B: After impact**

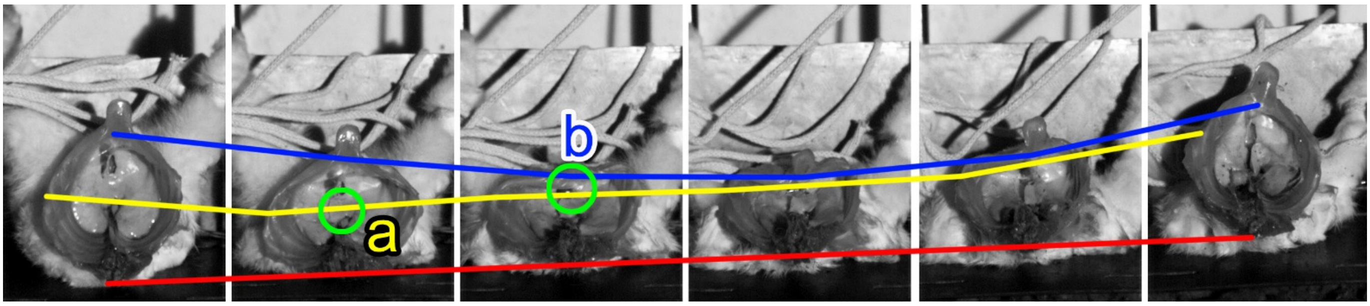


**Fig. 5. Group A: High-speed camera shots during the crash**

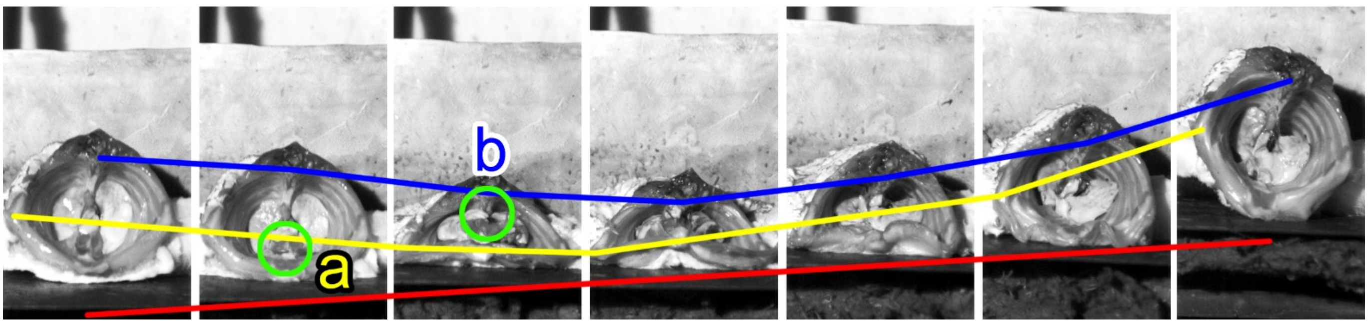


**Fig. 6. Group B: High-speed camera shots during the crash**

At this time, the back of the chest (the blue line on Figure 6) was deformed without constricting the organs. Until the deformation speed of the anterior chest synchronously exceeds the obstructed compression velocity of the organ, the organ is subjected to the deformation force of the back (the point b on Figure 6). The organ was affected by the inertial force (the point a on Figure 5) before the rib compression force (the point b on Figure 6).

According to the high-speed video time series frame diagram, the deformation in Group A was significantly higher than that in Group B, but there was no significant difference in the severity.

## 4. DISCUSSION

The experimental results show that: During the deceleration and impact of the liver, a significant laceration occurred on the opposite side of the impact, and no obvious tearing injury was found on the impact side. Although the severity of the injuries was different due to the individual differences in animal tissues, the results still suggest that the opposite side was subjected to a pronounced tensile stress; and the impact stress on the impact side was relatively weak.

The results of studies on the mechanism of hepatic impact injury have been summarized in the past as crush injury, stretch injury and shear injury caused by increased intrahepatic fluid pressure, traction tears of peripheral blood vessels and ligaments, and stab wounds. [4] The mechanism of stretch injury caused by increased intrahepatic fluid pressure is different from that of this experiment. The former is mainly due to the explosive stretch injury caused by a sudden increase in the pressure of the intrahepatic fluid caused by the impact of the liver in vivo in the presence of liquid filling. In this experiment, the liver was obtained after the animals were sacrificed. There is no liquid filling condition in the liver. Therefore, the tear damage generated in the experiment should not be due to a sudden increase in intrahepatic fluid pressure. In this experiment, the injury mechanism of the liver should be that during the impact, the liver is in the force field due to its own inertia and impact reaction force, and there is only a constraint between the tissue and the tissue in the heel-side tissue, so the opposite side is stretched. Stress can easily cause lacerations. The impact side did not see a significant laceration during the impact. This is due to the fact that the impact-side tissue is not only bound by tissue-tissue constraints, but also because the impact-side tissue is in close contact with the impact contact surface, and the interface between different media can produce a certain amount of friction thus hinders mutual displacement between different media. This boundary condition considerably weakens the stretch effect on the impact side of the liver, so that the tear damage due to stretching can be reduced to a corresponding extent.

In actual traffic accidents, there are two mechanical mechanisms for the tearing of the human liver: The first is due to the sudden increase in intrahepatic fluid pressure during the impact of the impact of the liver bursting tear injury occurs, and its mechanical action is from the inside out; the second is the impact of the heel side of the liver stretched the role of stress caused by its tear damage, and its mechanical action is from outside to inside.

For the dose-effect relationship between impact energy and injury level in liver impact injury, relevant literature [6] has been reported in detail. This experiment focuses on the study of the mechanism of injury in the process of hepatic impact injury. It is expected to help to clarify the mechanical mechanism of liver injury that is common in traffic accident injuries to a certain extent, and to provide some new experimental methods and certain Experimental basis.

The biomechanical mechanism of liver injury is a very broad and complex research direction. The results of the current study are mixed with far-off non-serialized and standardized data such as the impact experiment of human fresh entities, and the injury experiment of anesthetized animals caused by seat belts. The shape, area, impact velocity, and impact mode of the impactor can undergo complex changes, leaving many gaps to be explored. [4] Due to ethical constraints, the liver impact injury experiment cannot obtain sufficient data from human morbidity experiments. Therefore, it is necessary to carry out extensive research on new experimental methods, experimental models, and alternatives.

With the appearance of new experimental instruments and test methods, including the multi-functional small biological impact machine developed by *Prof.* Zhiyong Yin and others [7], as well as the emergence of various biological substitutes or simulants, it provides good conditions for biomechanical research. Biological substitutes have similar organizational structure and mechanical properties to human organs, and also have the ability to reflect different degrees of damage. They can be used under different impact conditions (impact direction, form, impact velocity, loading mode, and some living organisms cannot be achieved. (Conditional) biomechanical studies. These biological substitutes or mimics can provide meaningful suggestions for studying the protective principles of liver injury.

The thoracic frame formed by the ribs and spine is anteriorly soft and hard. Their compression is not the same. If it is squeezed, the injury before and after it should be different. However, the experimental results show that under the opposite placement mode, the deceleration impact of the visceral organs corresponding to the spine parts is the same (all with the same degree of injury on the impact surface). This shows that organ injury is not thoracic compression, but mainly inertial collisions.

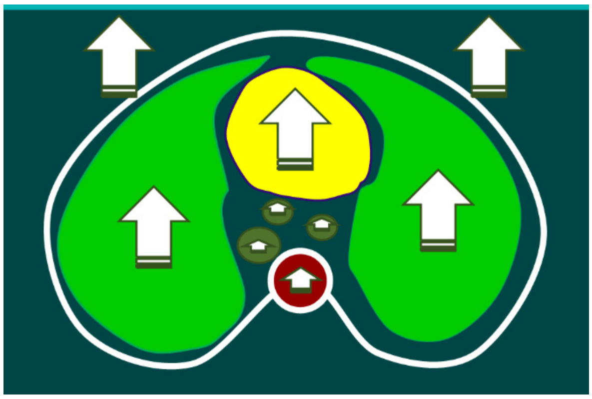

**Fig. 7. Effect of deceleration process on organs (viscera)**

In the case of squeezing deformation, there should be traces of damage on both the upper and lower organs, but in the experiment, there were only traces and no traces. Accelerated injuries are caused by squeezing, such as damage caused by a blow, but the reverse is the opposite (Figure 7), such as damage caused by a car accident. Due to the difference in force of the type of impact, the shape of these two types of injuries is very different.

Inertial injury is only damage to the contact surface. The crush injury is symmetrical, and it should be that both the contact surface and the corresponding surface are damaged.

In previous studies on road traffic injuries, many researchers believed that occupant injury to the thoracic and abdominal organs was caused by external forces acting on the ribs, which in turn caused internal organs to squash and cause injuries. The indicators including chest and abdomen in the assessment of existing vehicle safety performance are still based on the amount of chest compression. The results of this experiment show that the damage to the thoracic organs during deceleration injury is mainly caused by the damage of the organs against the chest wall. Therefore, there are serious problems in the AIS damage assessment criteria and new scientific evaluation methods need to be found.

## 6. CONCLUSIONS

Due to the development of computer technology and the rise of the artificial intelligence wave, some research teams in the academic community are currently working on relevant research through computer modeling, virtual simulation, and intelligent analysis. However, the premise of all virtual technologies is still inseparable from the verification of real data. This experiment has shown that, in the deceleration injury, the thoracic and abdominal organ damage is mainly caused by impact due to the organ inertia, and it is of no direct correlation with the compressional deformation. The conclusion is of great significance for the establishment of a more rational method of chest and abdomen organ damage assessment of injury mechanisms.

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**POSTSCRIPT**

N/A