Intravascular Pressure as a Predictor of Injury Severity in Blunt Hepatic Trauma

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ABSTRACT

The liver is one of the most frequently injured abdominal organs in motor vehicle collisions, and blunt hepatic trauma is associated with a high rate of morbidity and mortality. Early research on blunt hepatic trauma suggests that in high velocity impacts, rapidly increasing internal fluid pressure may play a role in causing hepatic injury. However, this potential mechanism of injury has received little attention in previous biomechanical studies. The aim of the present study is to investigate the relationship between intravascular pressure changes and injury severity in blunt impacts to excised porcine liver specimens. Impact was applied at varying energies using a drop-tower experimental technique. Specimens were instrumented with miniature pressure sensors in the hepatic veins and perfused with normal saline at physiologic temperature and pressures during testing. CT scans of the instrumented specimens were obtained in order to determine the locations of the pressure sensors in a three-dimensional coordinate system. Injury severity scores were assigned according to the Abbreviated Injury Scale (AIS) system. The relationship between peak intravascular pressure and AIS score was analyzed using logistic regression. Results indicate a strong correlation between peak internal pressure and injury severity (Nagelkerke's R^2=.86). The findings of this study could contribute to the development of a finite element model of the human abdomen that could be used to assess the risk of abdominal injury for motor vehicle accident victims.

INTRODUCTION

Field accident studies have shown that the liver is among the most frequently injured abdominal organs in both frontal and side impact collisions (Elhagediab and Rouhana, 1998; Rouhana and Foster, 1985; Bondy, 1980). Clinical studies have reported that blunt hepatic trauma is associated with a high rate of morbidity and mortality (Frey et al., 1973; John et al., 1992). Thus, liver injury is a significant problem in motor vehicle collisions.

Several potential mechanisms of blunt hepatic trauma include stretching of attachment points such as ligaments and vessels during rapid deceleration, laceration from penetration of fractured ribs, compression against the spine or posterior abdominal wall, and rapidly increasing internal fluid pressure leading to excessive tensile or shear strains (Rouhana, 2002; Mays, 1966). Previous studies have analyzed the relationships between several external physical parameters and hepatic injury. Some of these parameters include energy (Mays, 1966), applied pressure (Walfisch et al., 1980), impact force (Talantikite, 1993), velocity (Lau et al., 1981), compression Rouhana et al., 1986), and velocity multiplied by compression (Rouhana et al., 1985). The objective of the present study was to investigate the relationship between internal fluid pressure and liver injury severity in series of blunt impact tests to excised porcine livers in order to better understand the role of rapid increases in internal fluid pressure as a mechanism of injury.

METHODS

A series of impacts tests were conducted on fifteen intact *ex vivo* porcine liver specimens. The conditions for the impact test series are summarized in Table 1. The specimens were acquired from a local meat-processing facility and were harvested immediately after the animal was sacrificed. All specimens were packed in ice until testing began, and all specimens were tested within twelve hours of death.

Table 1: Test Matrix for Porcine Liver Impact Tests

Number of Subjects	Impact Velocity (m/s)	Impact Energy (J)	Nominal Maximum Compression (%)
5	3.0	105	30
5	4.6	250	30
5	6.0	420	30

Prior to the impact event each liver was weighed, photographed, and instrumented with three pressure-measuring catheters in the hepatic veins. A pre-test CT scan was obtained for each specimen in order to determine the locations of the pressure sensors and to evaluate the initial condition of the hepatic vascular system using radio-opaque contrast material. Each liver was perfused with heated saline (32-37 °C) for forty-five to sixty minutes prior to the test.

Drop Tower Design

After specimen preparation was complete, the impact test was conducted using a drop tower experimental technique. The drop tower includes a steel plate with a mass of 24 kg that was released from a predetermined height using an electromagnetic trigger mechanism. High density plastic slip bearings were secured to the sides of the plate to interact with the two guide rails on opposite sides of the tower. An accelerometer was mounted to the steel plate. Compression was limited to 30% of the maximum height of the liver through the use of adjustable-height brake columns. The drop tower design and perfusion system are illustrated in Figure 1.

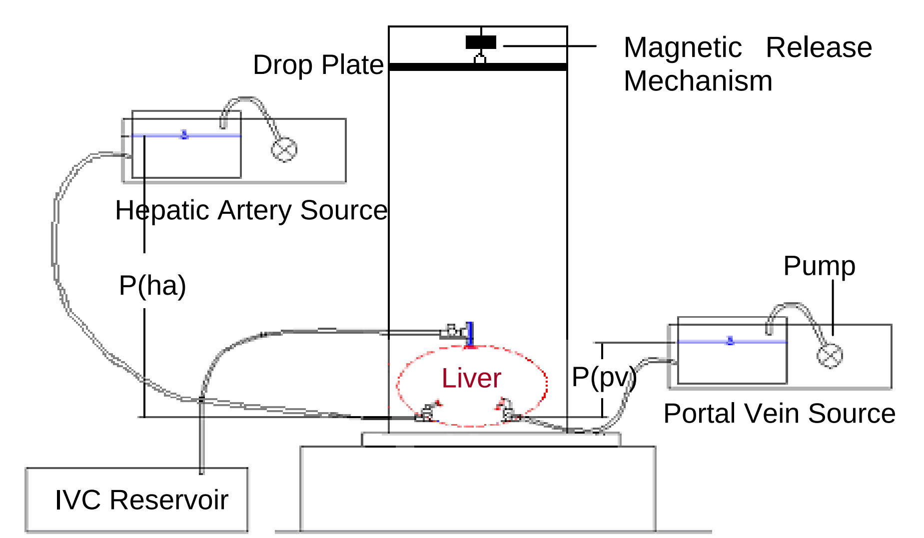

Figure 1: Schematic of Drop Tower Design

Injury Analysis

Following the impact event each specimen was photographed and post-test CT scans were obtained. (CT data will be used for future analysis of intraparenchymal vascular injury.) Visual inspections of each specimen were performed to identify signs of injury. A trauma surgeon assigned injury severity scores according to a modified version of the AIS system (AAAM, 1998). The scoring system for liver injury is summarized in Table 2.

Table 2: Modified AIS Scoring System

AIS 0	No Injury
AIS 2	Superficial Lacerations Subcapsular Hematoma Over ≤ 50% of Surface
AIS 3	Deep Laceration Duct or Vascular Involvement Hematoma Over >50% of Surface or Expanding
AIS 4	Multiple Deep Lacerations "Burst Injury" (Stellate Lacerations, Shattering of Parenchyma)
AIS 5	Parenchymal Disruption of >75% of a Hepatic Lobe Involvement of Retrohepatic Vena Cava or Central Hepatic Veins
AIS 6	Hepatic Avulsion

RESULTS

The data collected in the fifteen tests is presented in Table 3. Impact energies were calculated based on the drop height and mass of the plate. Impact velocities were calculated by integration of the measured acceleration of the plate until the point of impact. Peak pressures were obtained from the pressure-measuring catheters in the hepatic veins.

Table 3: Results from Fifteen Impact Tests

Specimen Number	Impact Energy (J)	Impact Velocity (m/s)	Peak Pressure (kPa)	AIS
PL04	250	4.5	120	3
PL05	105	3	65	0
PL06	250	4.5	134	2
PL07	420	5.8	148	5
PL08	105	3	41	0
PL09	420	5.7	155	4
PL10	105	2.9	49	0
PL11	250	4.6	159	3
PL12	420	5.7	174	5
PL13	105	3	90	0
PL14	250	4.5	103	2
PL15	420	5.8	179	4
PL16	105	2.9	69	2
PL17	250	4.4	87	2
PL18	420	5.4	214	5

Examples of various liver injury severities are illustrated in Figure 2. Figure 2A is a representative image of superficial lacerations. Figure 2B illustrates a deep laceration with vascular involvement. Figure 2C shows an example of parenchymal shattering or burst type injury.

(A) (B) (C)

Figure 2: Illustrations of Varying Liver Injury Severities
(A) AIS 2 Superficial Lacerations
(B) AIS 3 Deep Laceration
(C) AIS 4 Parenchymal Shattering

Statistical Analysis

The relationship between peak pressure and AIS score was analyzed using binary logistic regression. Equation (1) is the expression for the risk function. The calculated regression constants were a = -12.537 and b = 0.10, and the variable x denoted peak pressure measured inside the liver. The plot of the risk function is shown in Figure 3. The fit of the regression model was significant by the log-likelihood test ($p < .05$) and by the Hosmer-Lemeshow test ($p = .902$). The calculated value of Nagelkerke's R^2 was 0.86, indicating a significant association between peak pressure and liver injury.

$$\text{Equation (1): Probability of liver injury (x)} = \frac{e^{a+bx}}{1+e^{a+bx}}$$

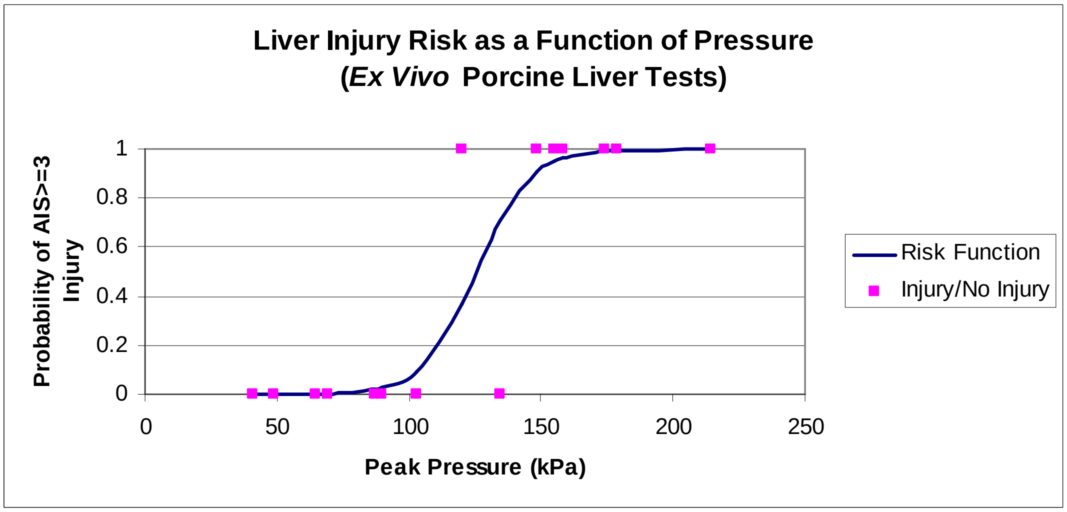

Figure 3: Binary Logistic Regression of Peak Pressure and Liver Injury

CONCLUSIONS

- A well-fitting ($p < .05$) binary logistic regression model was obtained for peak intravascular pressure as a predictor of serious (AIS $\geq$ 3) liver injury in blunt impacts to *ex vivo* porcine livers.
- Peak intravascular pressure was correlated with liver injury (Nagelkerke's $R^2 = .86$).
- A peak intravascular pressure of 126 kPa was associated with a 50% risk of serious liver injury.

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