JOURNAL OF THE MECHANICAL BEHAVIOR OF BIOMEDICAL MATERIALS 4 (2011) 76–84

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/jmbbm

Research paper

Dynamic compressive response of bovine liver tissues

Farhana Pervin[a], *Weinong W. Chen*[a,*], *Tusit Weerasooriya*[b]

[a] *Schools of Aeronautics/Astronautics and Materials Engineering, Purdue University, West Lafayette, IN 47907-2045, United States*
[b] *US Army Research Laboratory, Aberdeen Proving Ground, MD 21005, United States*

ARTICLE INFO

Article history:
Received 12 November 2009
Received in revised form
17 September 2010
Accepted 19 September 2010
Published online 25 September 2010

Keywords:
Kolsky bar
Mechanical response
Liver tissue
Strain rate effect

ABSTRACT

This study aims to experimentally determine the strain rate effects on the compressive stress–strain behavior of bovine liver tissues. Fresh liver tissues were used to make specimens for mechanical loading. Experiments at quasi-static strain rates were conducted at 0.01 and 0.1 s^{-1}. Intermediate-rate experiments were performed at 1, 10, and 100 s^{-1}. High strain rate (1000, 2000, and 3000 s^{-1}) experiments were conducted using a Kolsky bar modified for soft material characterization. A hollow transmission bar with semi-conductor strain gages was used to sense the weak forces from the soft specimens. Quartz-crystal force transducers were used to monitor valid testing conditions on the tissue specimens. The experiment results show that the compressive stress–strain response of the liver tissue is non-linear and highly rate-sensitive, especially when the strain rate is in the Kolsky bar range. The tissue stiffens significantly with increasing strain rate. The responses from liver tissues along and perpendicular to the liver surface were consistent, indicating isotropic behavior.

© 2010 Elsevier Ltd. All rights reserved.

1. Introduction

The human body can be subjected to sudden impact loading such as blasts, falls and traffic accidents. Due to this impact, the human organs and interconnecting tissues are subjected to stress wave loading which subsequently causes damage or injury. Impact-induced damage to liver is a major factor of fatality in accidental crashes and falls. Abdominal organ injuries also appear frequently during defense operations, which have been estimated as high as 20% of all battlefield injuries (Imes, 1945). The liver is the largest internal organ and gland in the human body. Despite its size and relatively protected location, the liver is the most commonly injured intra-abdominal organ. High velocity impacts cause disintegration of the hepatic parenchyma with laceration of vessels and massive intra-peritoneal hemorrhages due to cavitation effects (Uravic, 2003). In deceleration injuries commonly seen in traffic accidents, the liver usually tears between the posterior sector (Couinaud segment VI and VII) and the anterior sector (Couinaud segments V and VIII) of the right lobe. However, crushing tears the central portion of the liver (Couinaud segments IV, V and VIII) (Parks et al., 1999). The mortality and morbidity rates increase with the severity of grade of liver injury (Brammer et al., 2002). With the invention of modern surgery techniques, liver injury related mortality has decreased from 60% before World War II to 10%–20% (Uravic, 2003). However, the prevention of liver injuries still remains a challenge.

Due to the mechanical nature of the cause of damage, it is possible to develop predictive capabilities to pin-point

* *Corresponding author.* Tel.: +1 765 494 1788; fax: +1 765 494 0307.
E-mail address: wchen@purdue.edu (W.W. Chen).

1751-6161/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jmbbm.2010.09.007

impact-induced damage using engineering methods. Numerical simulation is an effective and widely used method in engineering to reveal the details in deformation and strain localization in a structure or material under loading. Such methods may be extended to predict impact-induced damage in highly complex living bodies. To conduct realistic simulations, accurate description of the material response to mechanical loading over a wide rate range must be provided to the numerical codes, which calls for systematic experimentation to obtain the dynamic mechanical behavior of biological tissues. However, such experimental effects have been scarce in the past. This research effort is to determine the compressive mechanical response of the tissues from a fresh bovine liver over a wide range of strain rates.

The strain rate range, in which the liver tissue experiences in impact events, is not well determined yet. In traffic accidents, the well-accepted strain rate range is in the hundreds per second (Brands, 2002). More severe events are expected to produce higher rates of loading. Chafi et al. (2007) studied the brain tissue response to shock loading in TBI studies. In these studies, the loading duration is typically on the order of few hundred microseconds resulting in strain rate of deformation around 1000–3000 s^{-1}. To determine the rate effects in liver tissues in a strain rate range that covers most injury events, we conducted experiments at strain rates from 0.01 to 3000 s^{-1} in this study.

The liver is covered with a connective tissue capsule that branches and extends through the substance of the liver as saptae. Internal organs essentially consist of a functional vascularized internal part (parenchyma) and an external capsule (stroma). The capsule is a thin but tough fibrous supporting connective framework of densely interwoven collagen fibers. The capsule primarily serves the structural integrity of the organ (Carter et al., 2001; Hollenstein et al., 2006). The fibers of connective tissue can be divided into three categories such as collagen, elastic and reticular (Liu and Bilston, 2000). In this study, the liver tissue is treated as a material, which is generally considered homogeneous, isotropic in nature (Carter et al., 2001) and sometimes it has transverse isotropic behavior (Chui et al., 2007).

Recently, the biomechanical properties of liver tissues has been investigated for developing computer simulation programs related to medical application including procedures for treating liver disease (Brouwer et al., 2001; Bruyns and Ottensmeyer, 2002; Brown et al., 2003; Chui et al., 2007). The experiments on liver tissues have been conducted in indentation (Wang et al., 1992; Carter et al., 2001; Kalanovic et al., 2003), in tension (Uehara, 1995; Chui et al., 2007; Gao et al., 2010; Brunon et al., 2010), and compression (Gao et al., 2010; Chui et al., 2007; Sakuma et al., 2003; Nasseri et al., 2003), as well as aspiration experiments (Nava et al., 2004, 2008; Mazza et al., 2007), rotary shear tests (Kalanovic et al., 2003), and oscillatory shear tests (Liu and Bilston, 2000) at lower strain rates and strain levels, pure shear (Gao et al., 2010) and 3D ultrasound imaging (Jordan et al., 2009).

The mechanical behavior of liver tissue may be related to pathology and histology. Thus the quantitative understanding of the mechanical behavior may eventually be related to injury predictions. For example, the impact of fibrosis on elastic properties of the human liver has been evaluated (Mazza et al., 2007; Yeh et al., 2002). The relationship between the fibrosis grade and the elastic modulus has been investigated by an ultrasound elastic imaging technique (Yeh et al., 2002). These results showed that severity of fibrosis has a correlation with the elastic modulus. The mean values of elastic modulus increased with increasing fibrosis grades, in other words, the cirrhotic tissue is harder than the healthy tissue. A quantitative analysis of the correlation between mechanical response and tissue micro-structure of normal and diseased liver has been investigated and a direct proportionality between stiffness index and connective tissue percentage is observed (Mazza et al., 2007). Sparks et al. (2007) studied the relationship between the internal pressure and blunt liver injury. They reported that peak tissue pressure correlates to human liver injury. The mechanical properties of biological tissue may change due to the environmental and physical condition of the tissue and also postmortem time. Ottensmeyer et al. (2004) studied the measurements made with indentation probes on whole porcine livers in-vivo; ex-vivo with a perfusion system that maintains temperature, pressure and hydration; ex-vivo without perfusion; and untreated excised lobes. This study showed a 50% difference in steady-state stiffness between tissues in-vivo and unperfused, but only a 17% difference between in-vivo and perfused tests.

The experimental efforts to determine the mechanical response of liver tissues have been limited to quasi-static loading conditions. The dynamic mechanical response of liver tissue has been much less explored. The stress–strain behavior of pig liver/spleen and human liver were studied by an indentation method at the tip-displacement rates of 3–4 mm/s under both ex-vivo and in-vivo conditions (Carter et al., 2001). The results from ex-vivo experiments showed that the pig spleen is much more compliant than pig liver. The in-vivo human liver indentation test results indicated that the diseased liver had about twice the stiffness of a healthy liver. In a recent work (Saraf et al., 2007); the dynamic response of human tissues from stomach, heart, liver and lung in confined compression and shear with a maximum strain rate of 2900 s^{-1} has been studied. The liver tissues were found to be the stiffest whereas the lung tissues were the softest in terms of shearing response. In terms of bulk response, the stomach tissues were the stiffest, while the lung tissues remained the softest. From a mechanics point of view, the stiffer component will bear higher loads during an impact event and is thus more vulnerable to damage or injuries. The high-rate mechanical response of liver tissues under uniaxial stress loading conditions has not been examined.

In this paper we use a Kolsky bar modified for soft material characterization and an MTS machine to measure the compressive mechanical response of liver tissues under uniaxial stress conditions over a wide range of strain rates to determine the compressive stress–strain behavior and the effect of strain rate on the constitutive behavior. Experiments were conducted at each decade in the strain rate scale from 0.01 to 3000 s^{-1} such that the results form a basis to develop rate-dependent material models in the future. Such models can be input into computer codes to conduct realistic simulations to reveal the details in stress and strain distributions under external loading.

Download English Version:

https://daneshyari.com/en/article/811391

Download Persian Version:

https://daneshyari.com/article/811391

Daneshyari.com