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Nature and etiology of hollow-organ abdominal injuries in frontal crashes

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ABSTRACT

Injuries to the hollow organs of the lower digestive system carry substantial risk of complication due to infection and blood loss, and commonly require invasive abdominal surgery to diagnose and treat. The causes of, and risk factors for, lower abdomen injury in automobile collisions are poorly understood. The goal of this study was to investigate the risk factors and potential mechanisms of hollow-organ, lower abdomen injury in belted automobile occupants in frontal collisions.

A field survey data analysis was performed to examine the relationship between various occupant and collision factors and the risk of moderate or greater severity injury (i.e., Abbreviated Injury Scale, AIS 2+) to the small intestine, large intestine, or mesentery among belted occupants involved in frontal collisions. Descriptive and comparative risk factor analyses were performed with data originating from that National Automotive Sampling System Crashworthiness Data System (NASS-CDS) over the years 2000–2011. Multivariable logistic regression models were developed to describe the effects of these factors on hollow-organ injury risk. Potential injury mechanisms were further investigated through in-depth examination of select cases exhibiting hollow-organ injuries from the Crash Investigation Research and Engineering Network (CIREN).

The inclusion criteria yielded 25,407 individual cases from NASS-CDS, representing a weighted population of 11,373,358 exposed automobile occupants. Within this dataset, 143 cases (weighted frequency: 7962 occupants) exhibited AIS 2+ injury to hollow abdominal organs. Multivariable regression analysis indicated a statistically significant increased risk of moderate or greater severity injuries to the hollow organs of the abdomen with increased in ΔV (odds ratio (OR) 1.07, 95% confidence interval: 1.06–1.09) and age (OR: 1.03, 1.01–1.06). Albeit non-statistically significant, a positive association between BMI and injury risk was observed, especially among obese individuals (OR: 3.55, 0.82–15.2). No association was observed for gender or seated location within the vehicle.

Result: from this study indicate that hollow abdominal organ injury is a universal problem in frontal collisions, not confined to a specific gender or seating location. Examination of CIREN cases suggests these types of injuries are associated with direct loading of the lower abdomen by the lap belt, either through poor initial belt positioning or through a "submarining" type of kinematic where the lap belt slips off of the pelvis and loads into the abdomen. Potential countermeasures against hollow-organ abdominal injury should include measures to improve initial lap belt fit, and to retain engagement of the lap belt on the pelvis throughout the collision event.

1. Introduction

Abdominal injuries represent a serious threat to life in automobile collisions. Given that abdominal organs are highly vascularized, a laceration or disruption can cause exsanguination into the abdominal cavity, often correctable only through open abdominal surgery. Approximately 9000 cases of moderate or

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more severe abdominal injuries occur in front-row automobile occupants every year in the U.S. (Klinich et al., 2010).

Injuries to the hollow organs of the lower digestive system (the large intestine, small intestine, and mesentery) represent approximately 50–60% of abdominal organ injuries in belt-restrained occupants in frontal collisions (Lamielle et al., 2006; Elhagediab and Rouhana, 1998; Arbogast et al., 2007). In addition to potential for blood loss, perforations of the digestive system carry an increased risk of infection due to contamination by fecal bacteria, and can be complicated by difficulties in diagnosis leading to delayed morbidity and mortality (Mackersie et al., 1989; Kaban et al., 2004).

In belted occupants in frontal collisions, hollow-organ abdominal injuries are almost always attributed to loading of the abdomen by the seatbelt, as opposed to the door, steering wheel, or other interior structures (Elhagediab and Rouhana, 1998; Klinich et al., 2010). Thus, these types of injuries may benefit from refining the manner in which the restraint system interacts with the body. Despite this, hollow-organ abdominal injuries have been relatively understudied in the literature.

There are several hypothesized factors that may contribute to the occurrence of belt-related hollow-organ abdominal injury. Several experimental and case studies have demonstrated that hollow-organ abdominal injury can be caused by direct loading of the lower abdomen by the lap belt, just superior to the anterior superior iliac spines (ASIS) of the pelvis (Kent et al., 2008; Kaban et al., 2004; Steffan et al., 2002; Trosseille et al., 2002; Hardy et al., 2001; Lamielle et al., 2008; Rouhana et al., 2010). Thus, it stands to reason that anything that increases the risk of direct belt loading into the abdomen would also increase the risk of hollow-organ abdominal injury in belted occupants. This potentially includes poor initial belt position (with the belt placed superior to the pelvis and in the plane of the abdomen), or slip of the lap belt over the pelvis and into abdomen. The latter phenomenon is commonly termed "submarining", reflecting the forward motion of the pelvis underneath the lap belt (Leung et al., 1982).

The goal of this study is to elucidate the risk factors for hollow-organ abdominal injuries among belted occupants in frontal collisions, in order to help identify injury mechanisms and potential areas for intervention. The potential risk factors studied were based on factors that may affect initial belt fit and the propensity for submarining. Injury mechanisms were further investigated through examination of select cases from the Crash Injury Research and Engineering Network (CIREN).

2. Methods

A field survey data analysis was performed to examine the effects of various occupant and collision factors on the risk of moderate or greater severity injury to select hollow organs of the abdomen (i.e., small intestine, large intestine, or mesentery) among belted occupants involved in frontal collisions in the United States (U.S.).

Data originated from the National Automotive Sampling System Crashworthiness Data System (NASS) over the years 2000–2011. NASS data are selected based on a national level sampling scheme meant to best represent the annual frequency of crash occurrences within the U.S. The Crashworthiness Data System (CDS) subset of NASS includes police reported crashes in which at least one involved vehicle is towed-away due to damage, thus oversampling more severe crashes. However, for approximately 5000 randomly sampled crashes per year, the CDS collects detailed information, not readily available in from other sources, including vehicle and scene inspections, interviews with police and crash occupants, as well as medical outcomes and chart reviews.

Case inclusion consisted of occupants of age 16+ years that were restrained by a 3-point lap and shoulder belt and involved in a crash with a principal direction of force between the 11 and 1 o'clock frontal direction. Excluding individuals less than 16 years of age was done primarily on the basis of potential differences in body size. Pregnant occupants past their first trimester, and crashes involving any rollover, fire, or motorcycle occupants were excluded from the database. Beginning in 2009, NHTSA restricted the collection of injury information to occupants of crashed vehicles less than 10 years of age. As a result, crashes occurring in the years 2009–2011 only included vehicles less than 10 years old.

The primary outcome for the current study is described as injury to the small intestine, large intestine, or mesentery with a moderate or greater classification of severity according to the 2005 (2008 update) version of the Abbreviated Injury Scale (AIS 2+) (Gennarelli and Wodzin 2008). AIS codes were assessed by a trained user and accounted for older AIS codes that may be present in the NASS-CDS database. For the purposes of this study, these will be termed "hollow-organ" injury. The general bounds establishing the region of interest within the abdomen included the gastrointestinal track below the transpyloric plane (e.g., transverse colon) to the pelvic floor. Specifically, injuries to the colon, cecum, jejunum, ileum, and mesentery were assessed, as defined by AIS.

Independent factors studied included occupant height and weight (as well as the resulting Body Mass Index, BMI), age, seat position, and the total vehicle change-in-velocity (ΔV, or DV) during the collision. Given the inclusion criteria specified for frontal collisions, a large proportion of the total DV was experienced on the longitudinal axis of the vehicle. DV was assessed as a continuous variable and categorized into four levels: 0–24 kilometers per hour (kmph) (low), 25–40 kmph (moderate), 41–55 kmph (high), and 56+ kmph (very high). Levels were based on distributional characteristics and a general understanding for crash speed severity. BMI was used as a proxy measure (or indicator) for adipose tissue around the waistline, and assessed both as a continuous term and according to the standard four categories defined by the World Health Organization (WHO) (James et al., 2001). The occupant's seated position was categorized as either driver, front right passenger, or any rear occupant. Factors analyzed were selected based on a combination of previous literature and suggestive kinematics observed in both dummy (ATD) and cadaveric testing, as well as observational studies.

Survey weighted descriptive and comparative risk factor analyses were performed using SAS (version 9.3) and R statistical software packages that take into account the sampling structure of NASS-CDS (e.g., primary sampling unit and strata). Univariate and multivariable logistic regression models were developed to describe the effects of the independent risk factors on hollow-organ injuries of the abdomen and were adjusted for the potential confounding effects of the occupant's age. Concomitant injuries are also presented to provide further insight into the types of impact experienced by occupants with hollow organ injuries.

In order to reduce potential bias due to missing data, multiple imputation, using a chained-equations approach (van Buuren and Groothuis-Oudshoorn, 2011), was implemented for missing data to the DV, height, and weight variables. Crashes with missing DV tend to be less severe and are not considered to be "missing completely at random." Twenty multivariable imputations were conducted and based on observations with complete information pertaining to occupant age, height, weight, gender, seated position, entrapment status, vehicle model year, curb weight, DV, extent of maximum resultant crush, magnitude of primary intrusion, roadway alignment, number of travel lanes, traffic way flow and relation to junction, lighting conditions, speed limit, time of day, on-scene treatment and medical transportation. The proportion of missingness for these variables ranged between 0.0 and 0.295 (DV),