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Aortic injuries in newer vehicles☆

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ABSTRACT

The occurrence of AI was studied in relation to vehicle model year (MY) among front seat vehicular occupants, age ≥ 16 in vehicles MY ≥ 1994, entered in the National Automotive Sampling System Crashworthiness Data System between 1997 and 2010 to determine whether newer vehicles, due to their crashworthiness improvements, are linked to a lower risk of aortic injuries (AI). MY was categorized as 1994–1997, 1998–2004, or 2005–2010 reflecting the introduction of newer occupant protection technology. Logistic regression was used to calculate odds ratios (OR) and 95% confidence intervals for the association between AI and MY independent of possible confounders. Analysis was repeated, stratified by frontal and near lateral impacts. AI occurred in 19,187 (0.06%) of the 31,221,007 (weighted) cases, and contributed to 11% of all deaths. AIs were associated with advanced age, male gender, high BMI, near-side impact, rollover, ejection, collision against a fixed object, high ΔV, vehicle mismatch, unrestrained status, and forward track position. Among frontal crashes, MY 98–04 and MY 05–10 showed increased adjusted odds of AI when compared to MY 94–97 [OR 1.84 (1.02–3.32) and 1.99 (0.93–4.26), respectively]. In contrast, among near-side impact crashes, MY 98–04 and MY 05–10 showed decreased adjusted odds of AI [OR 0.50 (0.25–0.99) and 0.27 (0.06–1.31), respectively]. While occupants of newer vehicles experience lower odds of AI in near side impact crashes, a higher AI risk is present in frontal crashes.

1. Introduction

1.1. Background

Injuries to the aorta are highly lethal and significantly contribute to vehicular crash mortality. Reports estimate that aortic injuries (AI) are present in approximately 16–35% of individuals who die after motor vehicle collisions (MVCs) in the US (Neschis et al., 2008; Viano, 1983; Texeira et al., 2011), with 70–90% of those deaths occurring immediately. The vast majority of traumatic aortic injuries involve circumferential ruptures in the peri-isthmic region (Viano, 1983). While improvements in trauma systems, critical care and surgical techniques have improved the outcomes among those experiencing this injury (Neschis et al., 2008; Demetriades et al., 2008; Michetti et al., 2007; Fabian, 2009), primary prevention is necessary to make an impact upon the larger number of immediate deaths.

1.2. Underlying mechanism of injury

The underlying mechanism of aortic injuries during vehicular crashes is not completely understood (Baqué et al., 2006). While some researchers have not been able to consistently reproduce aortic injuries in the laboratory setting (Viano, 2011), others have been more succesful (Baqué et al., 2006; Hardy et al., 2008). Proposed mechanisms generally rely on the differences in mobility between the relatively free aortic arch and the relatively fixed descending aorta. This difference in mobility leads to stress concentrations in the peri-isthmic region of the aorta as the torso is deformed and the heart and aortic arch move relative to the spine (Hardy et al., 2008; Sevitt, 1977; Schrum et al., 1998). Deceleration and pressurization (Siegel et al., 2006), atherosclerosis (Hardy et al., 2008; Viano, 1978), "osseous pinch" between anterior thoracic bony structures and the vertebral column (Crass et al., 1990), and longitudinal stretching (i.e., axial elongation) (Hardy et al., 2008)

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have been proposed to play a role by different researchers. While rapid acceleration is comonly cited as playing a central causative role, acceleration alone (without compression) has not produced aortic injuries in the lab setting (Forman et al., 2008).

Epidemiological studies have associated aortic injuries with high delta-v and near-side impact MVCs, advanced occupant age and lack of seatbelt use (Michetti et al., 2007; Fitzharris et al., 2004; McGwin et al., 2002, 2003). While studies utilizing data based on autopsy reports have reproted a beneficial effect of vehicular safety improvements (e.g., airbag technology and structural design) (Siegel et al., 2004), others have shown no changes in the incidence of aortic injury deaths from 1993 through 2004 (Schulman et al., 2007). Thus, it remains unknown whether safety improvements implemented in newer vehicles have resulted in a decreased risk of aortic injuries. To address the paucity of research on this topic, the objective of the current study is to determine whether newer vehicles are associated with a lower risk of aortic injuries using a nationally representative sample of MVCs in the United States.

2. Methods

2.1. Data source and study population

The current study uses data from the National Automotive Sampling System Crashworthiness Data System (NASS-CDS) for years 1997 through 2010. NASS-CDS is a probability sample of all police reported crashes in the US containing detailed data on thousands of minor, serious, and fatal crashes. After statistical weights are applied, NASS-CDS is a representative, random sample of crashes in the US. Each year, NASS-CDS samples approximately 5000 cases over 24 regions (sampling units), and captures data that is collected by trained crash investigators, including data from crash sites, vehicle inspections, interviews with crash victims, and review of medical records to determine the nature and severity of injuries (NHTSA, 2008).

Front seat occupants of vehicles of model year (MY) 1994 or newer, aged 16 years or older were included in the study. For each individual, information was collected on demographics (e.g., age sex, and body mass index (BMI)), vehicle (e.g., model year and body type), and collision characteristics (e.g., collision orientation, whether a rollover was involved, vehicle mismatch, and ΔV).

The current study used NASS-CDS entries for years 1997 through 2010. Since sufficient numbers of early MY cases (i.e., MY 94–96) are present within NASS-CDS after 1997, in order to limit the potential effects of changes in EMS and Trauma Care on outcomes, we choose to avoid cases entered prior to 1997.

2.2. Study variables

Occupant age was categorized as less than 60 or 60+ years, based on prior research indicating a marked increased risk of AI at this age (McGwin et al., 2002). BMI was categorized according to the standards given by the Centers for Disease Control and Prevention, with a BMI below 18.5 kg/m^2 categorized as underweight, between 18.5 and 24.9 categorized as normal weight, between 25.0–29.9 categorized as overweight, and 30.0+ categorized as obese (NIH, 1998). Belt use was defined as the use of a manual or automatic belt system and seat track position was categorized as forward or back in relation to the middle track position of the seat (i.e., forward is closer to and back further from the dashboard of the vehicle).

Since it is not possible to determine the presence of each feature for each vehicle within NASS, we used MY categories that would broadly overlap with the introduction of newer features in the vehicular fleet. Vehicle model year was categorized as 1994–1997, 1998–2004, or 2005–2010, reflecting the introduction of newer occupant protection technology: first generation (1994–1997), second generation (depowered) airbag (1998–2004) and advanced airbag systems (2005 and later) (Braver et al., 2005, 2008a,b).

Table 1
Occupant characteristics and aortic injury risk (univariate analysis) (N = 31,221,007).

	%	Aortic injury (%)	Odds ratio (95% CI)	p value[a]
Age group (years)				
16–29	45.1	0.04	1	
30–39	18.9	0.04	0.88 (0.84–0.92)	
40–49	14.9	0.06	1.37 (1.31–1.43)	
50–59	10.2	0.07	1.65 (1.57–1.73)	
60–69	5.6	0.11	2.54 (2.42–2.68)	
70–79	3.7	0.24	5.52 (5.28–5.77)	
80+	1.7	0.20	4.52 (4.23–4.83)	<0.0001
Gender				
Female	48.8	0.05	1	
Male	51.2	0.07	1.55 (1.50–1.59)	<0.0001
Position				
Driver	82.4	0.06	1	
Passenger	17.6	0.08	1.30 (1.26–1.35)	<0.0001
BMI				
Underweight	4.3	0.02	0.46 (0.40–0.52)	
Normal	45.7	0.04	1	
Overweight	31.7	0.07	1.59 (1.53–1.64)	
Obese	18.3	0.11	2.59 (2.50–2.68)	<0.0001
Restraint				
No belt	18.0	0.20	1	
Seatbelt use	82.0	0.03	0.15 (0.15–0.16)	<0.0001

[a] Mantel–Haenszel chi-square.

In general, in the US fleet for model years 1998 and 1999 the majority of the vehicles were sled certified (70% and 99% respectively), and close to 90% of airbags were depowered or redesigned (i.e., second generation airbags) (Kahane, 2006). NHTSA's "advanced airbag final rule" did not take effect until September 2003 and requires all vehicles to comply by MY 2007 (beginning September 1, 2003, 20 percent of each manufacturer's vehicles intended for sale in the United States must meet NHTSA's advanced frontal air bag requirements, with at least 65 percent by September 1, 2004 and 100 percent by September 1, 2005). Furthermore, other occupant protection features (i.e., pretensioners, stability control and load limiters) were introduced simultaneously and their effect in modifying the risk of aortic injury can not be distinguished in our study. In regard to side impacts, occupant protection was first increased by side beam strengthening and padding, and later on with the introduction of side airbags. The prevalence of side airbags (head and/or torso) in the US vehicular fleet (as a standard feature) was 3.4% in 1997, 15%-34% between 1998 and 2004 and 39%-88% between 2005and 2010 (IIHS, 2012).

The principal direction of force (PDOF) of the crash is defined as the direction of the principal force acting on the vehicle. For purposes of the current study, PDOF was categorized as frontal, near-side lateral (i.e., left-side impact for drivers and right-side impact for passengers), far-side lateral and rear. The maximum change in velocity (ΔV) was categorized into deciles form 0 through 59 mph and $\Delta V \geq 60$ mph combined into one category. Mismatch was categorized as the posible combinations between the following vehicle categories: (1) passenger vehicles (P), (2) pick-up trucks (PU), (3) sport utuility vehicles and vans (SV), and (4) other type of vehicles or structures (Other). When both vehicles were of the same category, mismatch was clasified as "None".

Aortic injury was defined as any reported injury to the aorta and identified in the NASS-CDS data using AIS codes 420202.4 through 420299.4 (AAAM, 1998). Since in the studied population 96% of aortic injuries occurred among those in the front seat, analysis was limited to those in that position. Those younger than 16 were