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Vehicle occupant restraint systems impact on eye injuries: A review

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ABSTRACT

Vehicle occupant trauma to the eyes and associated facial structures has evolved rapidly in conjunction with safety-oriented vehicle design, including restraint systems. Trends vary worldwide with culture, personal factors, vehicle safety equipment, and the traffic environment—including physical, legislative, and enforcement. Wearing safety belts is essential to occupant protection. Airbags were designed as a supplement to protect the head from hard surfaces in frontal crashes, not as a primary countermeasure. Even where vehicle fleets are new with high airbag prevalence, but safety culture and knowledge of restraints is less than robust, injury attributable to not wearing seatbelts is frequent, especially in countries where high-powered vehicles are prevalent. Upper bodies of rapidly forward-moving unrestrained occupants collide with rearward-accelerating airbags. Airbag deployment produces injuries such as corneal abrasions, alkali burns, and the effects of globe compression.

1. Introduction

For over half a century safety belts have served as primary restraints for adults. Automobile safety belts were first introduced in Sweden by Volvo. They came into wider use in the 1960s following development of the first successful three-point systems introduced for front seat passengers in 1959 and rear seat passengers in 1972.[A,B] The first law mandating wearing of safety belts was implemented in 1970 in Victoria, Australia.[4,C] Since then, wearing rates in many industrialized countries has risen to 90% or above. The United States (U.S.) was slower to adopt and has gradually been catching up.[28,D,E] Safety belt wear produces remarkable reductions in mortality and morbidity, in conjunction with design to soften and round vehicle interiors and minimize shattering of glass.[62,F]

Nonetheless, even belted drivers sometimes strike steering wheels and other rigid parts of cars. Hence, airbags create

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a decelerating cushion between the head and thorax of front occupants and the dashboard, windshield, and steering wheel, and later, buffer side intrusions. Developed in the 1970s, they became common in the U.S. in the 1980s and Europe in the 1990s.

It was hoped that airbags, rather than functioning simply as secondary restraints, might also protect high-risk occupants who failed to wear primary restraints. The prevalence of unprotected occupants was high in the U.S. and has remained high in many global regions, including the Middle East,[12,90] as the result of inadequate legislation, lack of primary enforcement, insufficient knowledge, and traditional cultural views such as destiny.[G]

Patterns of injuries of the eye and neighboring structures evolved with development of safety restraints, including safety belts and, later, airbags, as well as structural and interior improvements in vehicles. This information allows clinicians to predict anatomical structures at risk of damage in the context of prevailing local mixes of host, vehicle, and environmental determinants.

We synthesize clinical and public health perspectives on trends in eye injuries. This synthesis posed major challenges because of rapid evolution in design of vehicles including safety restraints, marked differences in wearing of safety belts and other risk factors among countries, and scarcity of prospective clinical studies. We focus on human-restraint/object impact interfaces.[103]

2. Airbag dynamics

Airbags are stored within the steering column on the driver's side and in the dashboard on the passenger's side. In the U.S. fully inflated bags contain 60 liters of gas on the driver's side and 140 on the passenger's. Drivers' bags contain half this in Australia and Europe.[45] In frontal collisions, crash sensors within the vehicle structure detect rapid velocity change/severe crash force and send a signal to the airbag cartridge, which stores a propellant such as sodium azide to inflate the airbag.[113]

Airbags continue to evolve;[22–24,44,79] first-generation bags continued to 1994–97, second-generation bags from 1998–2004, and newer bags are manufactured to increasingly advanced designs. In countries where the appropriate use of airbags as a supplement to belts was low, bags were designed to inflate more forcefully to improve protection for the unrestrained occupants.[75] Unfortunately, in frontal crashes, rather than being cushioned by an already inflated airbag, unrestrained occupants move forward rapidly and may be struck forcefully by a rearward-expanding bag at velocities up to 200 miles per hour (mph).[87,99,110,113,115]

As wearing of restraints increased, airbags were modified to expand less forcefully and reconfigured by tethering to provide greater lateral and less rearward expansion. This resulted in a major reduction of airbag-associated injuries.[37]

3. Trends in automobile accident injuries as countermeasures evolved

3.1. *Mortality*

Safety belts prevent 40–50% of deaths and severe injuries[90] (Table 1),[31,33,H] (Table 2).[26,27,52,92,97] Airbags alone have little impact on overall mortality from all crashes, but partially protect in frontal two-vehicle collisions. The belt–bag combination prevents as many as 80% of deaths (Table 1).[31,33,H] Nevertheless, bags remain controversial, especially when used without belts.[56]

Mortality declines associated with effective safety belt legislation and enforcement occur largely by preventing ejection,[39,40,121] which is associated with greatly increased severe to fatal injury.

Early safety belts, attaching only across the lap, mainly protected against ejection, whereas lap-shoulder belts helped prevent heads from striking vehicle interiors. For frontal collisions, airbags further reduced morbidity and mortality, increasing deceleration distances between driver/passengers and vehicle surfaces by interposition of a soft barrier.

Although restraint systems prevent most deaths, fatal injuries still occur, many involving the head. In France during 1996–2004, proportionate fatal injuries included head (23%), thorax (30%), and a combination of the two (18%).[93]

Although airbags significantly reduce morbidity and mortality from frontal crashes, effectiveness varies, largely by whether used as adjuncts to belts or alone.[6,21,31,57,64,78,130] In the U.S. in 1990, bag-alone drivers were at 41% increased fatality risk compared with lap-shoulder-belt-alone.

Table 1 – Estimated effectiveness of occupant restraint systems in reducing risk of death, injury, and head injury for drivers in severe crashes, United States, 1987–1996

Severity of injury and location	Estimated percent reduction			Study population
	Lap-shoulder belt + airbag	Lap-shoulder belt alone	Airbag alone	
Fatal	50	45	13	All crashes
Severe all	59	60	7	All crashes
Severe all	69	60	–8[a]	Frontal crashes
Severe head	75	38	16[a]	All crashes
Moderate all	60	49	18[a]	All crashes
Moderate all	61	56	6[a]	Frontal crashes
Moderate head	83	59	46	All crashes

a Note: No significant difference with the unrestrained.
Adapted from NHTSA 1996 (National Highway Traffic Safety Administration)[H].