Biomechanical Analysis
(Note: This is a sample composite analysis and does not represent any specific incident)

Crash Overview

On the afternoon of June 28, 2008 Ms. Jane Doe was driving a 2010 Manufacturer SUV, VIN # XXXXXXXXXXXXX. Witnesses described that the vehicle was traveling at highway speeds when it suddenly veered to the right onto the paved shoulder. The vehicle veered back to the left, reentering the roadway. The driver corrected back to the right and the vehicle began to rotate clockwise as indicated by yaw marks in the road. The vehicle overturned, driver side leading, rolling several times before coming to rest on its wheels. The preliminary accident reconstruction indicates that the vehicle rolled driver side down through three complete rolls. Hair and blood were found in two distinct locations on the roadway through the path that the vehicle rolled.

Occupants
Driver: Ms. Jane Doe
Right front passenger: Mr. John Doe
First Responder Statements

The crash report and the witness document that all occupants were restrained with the available lap/shoulder belts. The vehicle is equipped with rollover-activated side-curtain airbags. They did not deploy. The first officer on the scene witnessed the front seat occupants belted inside the vehicle.

EMT first responder documented that the belts were cut before extricating the driver and front passenger. The EMT report noted that the female driver was unconscious with copious amounts of blood flowing from her nose and ears, as well as a significant injury to the left side of her face. She was having difficulty breathing and was removed from the vehicle and flown to the nearest trauma center. The male right-front passenger was seated upright in his seat, but pinned against the roof that had deformed inward and against his head restraint. He was conscious and breathing but could not move his arms or legs. He appeared to have no other injuries. The right rear male occupant was already out of the vehicle and ambulatory when the EMTs arrived.

Vehicle Damage

The scene photos show significant deformation to the roof over the front passenger seat with the roof in contact with the front passenger head restraint. The roof buckled up on the driver’s side and blood stains are evident on the interior of the driver’s door and the outboard edge of the driver’s seat. The glazing in all four door windows was broken out. The front seat belts were cut.

The vehicle was inspected on XX/XX/XX.¹ There were two distinct sets of directional striations on the roof, providing evidence of at least two rolls. The driver side occupant compartment was not significantly deformed and there was minimal loss of driver occupant survival space. In fact, the roof bowed upward over the driver’s seat due to passenger side roof deformation. The roof over the front passenger seat was deformed inboard and downward, resulting in roof contact with the front passenger head restraint. The static distance from the center of the seat bite to the roof over the front passenger seat was 26 inches. The rollover-activated side-curtain airbags did not deploy.

¹ Vehicle Inspection XX/XX/XX: Photographs and Vehicle Inspection Notes
Subject 1 Driver: Ms. Jane Doe

Ms. Doe, a 43 year-old female, was barely conscious upon arrival to the hospital emergency room and exhibited a decreased level of consciousness over time. Ms. Doe sustained severe injuries with tissue loss over the left side of her face, a basilar skull fracture, and a subdural hematoma resulting in her death.

Autopsy Report: Cause of Death- Basilar skull fractures with concomitant contusions of the brain.

Review of Medical Records

Head Injuries

Soft Tissue Injuries
- Multiple lacerations
- Left side of Face: Swollen with Ecchymosis
- Swelling and Ecchymosis left eye
- Raccoon eyes
- Bloody drainage from ears and nose
- Severe facial swelling and bruising
- Temporoparietal Contusion Left Side

Skull Fractures
- Basilar skull fracture: Hinge Fracture extending through the petrous portions of the temporal bones, sphenoid bones and sella turcica

Closed head injury
- Subdural Hematoma

Cervical Spine
- No evidence for cervical spine fracture or subluxation
Anatomy of the Basilar Skull Fracture

Hinge Fracture extending through the petrous portions of the temporal bones, sphenoid bone and sella turcica
Basilar skull fractures comprise a broad category of injuries that are essentially any fracture involving the floor of the anterior, middle, or posterior cranial fossa. The classic *ring type* basilar skull fracture originates in the region of the sella turcica or in the connection between the dorsum sellae and the body of the occipital bone and propagates through the sphenoid and the temporal bone, continuing through to the occipital bone. An incomplete *ring* fracture runs through the middle fossa of the base of the skull and continues a varying distance along both sides of the skull. *Hinge Fractures* are transverse fractures of the base of the skull that completely bisect the base of the skull, creating a hinge. Type I Hinge fractures run in the coronal plane, extending from the lateral end of one petrous ridge, through the sella turcica, to the lateral end of the contralateral petrous ridge. Type II Hinge fractures run from the front of the anterior fossa to the contralateral middle fossa, passing through the sella turcica. Type III Hinge fractures run from side to side in the coronal plane but do not pass through the sella turcica.

From the varied descriptions and photographs of Ms. Doe’s skull fractures, her fracture pattern follows that of an incomplete ring fracture or a Type I Hinge fracture.

Basilar skull fractures have been attributed to both direct and remote loading mechanisms. Researchers have associated basilar skull fractures with a variety of impact types including impacts to the lateral aspects of the head; impacts to the mandible; impacts to the face, chin or forehead resulting in hyperextension; and cranial vault impacts that drive the skull downward onto the cervical spine. *Hinge fractures have been mostly ascribed to impacts to the side of the head.* Basilar skull ring fractures associated with compressive loads to the top of the head and are more frequently associated with a cervical spine injury which Ms. Doe did not have.

Based on the injuries, it is likely that Ms. Doe’s skull fractures were induced by a significant impact to the side of her head.

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Anatomy of the Head and Brain Injuries

- Left Temporoparietal Contusion
- Left Subdural Hematoma

The severe swelling to the left side of Ms. Doe’s head, i.e. the Temporoparietal contusion and the left subdural hematoma are a result of a severe impact to the side of her head. The temporparietal contusion is a result of swelling between the scalp and the skull and the concomitant subdural hematoma involves intracranial bleeding in the space between the dura matter and the arachnoid membrane.

Mechanisms of Injuries

The injuries to Ms. Doe’s face and skull were from direct impact with the driver side window glass and the ground as the vehicle rolled over. There are blood stains and shattered glass on the road that correspond to the position of the driver side door window during the rollover. She had extensive soft tissue injuries to the left side of her head with a resultant subdural hematoma and a severe basilar skull fracture indicative of a severe side impact to the skull. She sustained no cervical spine injuries indicating that there was no axial loading to her head nor any lateral relative motion between her head and neck. There is no physical evidence in the vehicle of a head strike. Based on the physical evidence on the roadway and in the vehicle as well as the physical evidence on her body, it is most likely that she sustained a severe impact to the side of her head through the driver’s window.

Rollover-Activated Side-Curtain Airbags

Rollover-activated side-curtain airbags were developed to protect the occupant’s head during side and rollover impacts and to mitigate ejection during rollovers. Recent epidemiological data and experimental studies document the effectiveness of side curtain airbags in preventing full and partial ejection of the occupants seated adjacent to them.  

5 CIREN/NHTSA Presentation “Pedestrian Injuries: Analysis of the Burden with Case Illustrations”
7 ESV Paper-11-0173-O A Study of Curtain Airbag Design Factors for Enhancement of Ejection Mitigation Performance
8 ESV Paper-11-0368-O A Study of Occupant Ejection Mitigation
9 ESV-11-0319-O Effect of Side Impact Protection in Reducing Injuries
Conclusions

The fatal head impact, resulting in multiple head and brain injuries and a basilar skull fracture was a result of lateral loading to the side of Ms. Doe’s head by the driver’s door window glass and the road during the rollover. Had the rollover-activated side-curtain airbag deployed, Ms. Doe’s head would have remained in the vehicle. The energy imparted to her head would have been significantly diminished resulting in a reduction of force to the side of her head, likely resulting in survivable injuries.

Right Front Passenger: Mr. John Doe

Mr. Doe was a lap/shoulder belt-restrained right front passenger in a driver-side leading rollover. As a result of the rollover, the roof structure over his seating compartment was severely deformed downward and inboard, contacting the top of the head restraint. The roof deformation resulted in a severe reduction in Mr. Doe’s occupant survival space during the rollover, which caused a neck fracture that rendered him a quadriplegic.

Injuries

Skeletal Injuries:

Cervical Spine Fracture and Dislocation

- Fracture of Right C5 Lamina
- Fracture Right pedicle
- Small avulsion with bone fragment projecting into right C5/6 neural foramen and right lateral recess of C5

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10CIREN/NHTSA Presentation “Rollovers: Configuration, Kinematics, and Injury”
• C5/6 Bilateral Locked Facets
• Anterior Subluxation of C5 on C6
• Disruption of the Anterior and Posterior Longitudinal Ligaments at the C5/6 level related to the hyperflexion injury with tears of the Intraspinous Ligament

C5/6 Bilateral Locked Facets
Lower C5 Facets move up & over the Upper C6 Facets during flexion

Cervical Spine MRI:
Anterior Subluxation C5
(Note Anterior Position of C5 on C6)
C5
C6

**Occupant Kinematics and Mechanism of Injury:**

Mr. Doe was a lap/shoulder-belt restrained right-front passenger in a driver side leading rollover. Mr. Doe remained in his seat in a nominal upright position during the first part of the driver side leading roll. Centripetal forces acted on his body resulting in him moving up and outboard as far as his seat belt would allow, likely positioning his head inside against the roof/roof rail. [There is no physical evidence on his body, the vehicle or the roadway that he was partially ejected.] As the passenger side roof hit the ground, the roof structure over his seating compartment was severely deformed downward and inboard contacting the top of the head restraint and Mr. Doe’s head. This deformation significantly reduced Mr. Doe’s occupant survival space directly resulting in his cervical spine fracture and dislocation at C5/C6.
Mechanism of Injury

The mechanism of the bilateral locked facets is Flexion with a Compressive load vector resulting in fractures of the right lateral components of the spine.\textsuperscript{11, 12} The compression loading vector is likely oriented slightly off center down through the right side of his head resulting in the right sided nature of the fractures. The roof contact with his head pushed it down and forward relative to his torso, resulting in flexion and compression of the cervical spine. This flexion loading caused the C5 facets to move up and over the C6 facets below them. The right sided compression loading resulted in the comminuted fractures of the right lateral components.

Conclusions

The severe injuries sustained by Mr. Doe were a direct result of roof structure intrusion into the occupant survival space or “safety cage.” More specifically, the A- and B-pillars, roof header, and headliner collapsed, into intruding into the occupant compartment. This caused the head to move downward and forward relative to the shoulders resulting in hyperflexion and compression of the cervical spine causing the bilateral locked facets at C5/C6 and the right sided fractures at C5.

*Note: Safety Research & Strategies provides consulting only research, investigation and analysis. We do not offer expert witness testimony.

\textsuperscript{11} Chapter 4: \textit{Practical Biomechanics of Spine Trauma} in \textit{Clinical Biomechanics of the Spine}, White and Panjabi, eds. 2\textsuperscript{nd} Ed. 1990.
\textsuperscript{12} Chapter 15: \textit{Biomechanical Aspects of Cervical Trauma} in \textit{Accidental Injury: Biomechanics and Prevention}, 2\textsuperscript{nd} Ed. Nahum and Melvin, eds. 2002.
\textsuperscript{13} CIREN/NHTSA Presentation “An Evaluation of Spinal Cord Injury (SCI) Associated with Motor Vehicle Crashes including Rollovers”