Break a leg: Analyzing vehicle-pedestrian collisions

Accurately reconstructing the accident requires collecting and preserving key evidence

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This is an overview of how pedestrians and vehicles interact during a collision; the typical issues related to pedestrian collision litigation cases; the types of physical evidence to look for following a collision; common pedestrian injuries; and how to relate the injuries to the physical evidence.

Anatomy of a vehicle-pedestrian interaction

There are generally three distinct phases during a vehicle-pedestrian collision (Figure 1). The first phase is the initial impact, during which the pedestrian wraps around the front end of the vehicle and/or is carried by the vehicle. The second phase is the trajectory, during which the pedestrian separates from the vehicle and is projected forward of the vehicle. The third phase is the ground contact, which involves a combination of rolling, tumbling and/or sliding on the ground until the pedestrian comes to rest. The distance from the point of initial impact to the final rest position of the pedestrian is defined as the total pedestrian throw distance. Not surprisingly, throw distances generally increase with increasing impact speed.

When the front bumper of a vehicle first contacts with the lower extremities of a pedestrian, the legs are rapidly accelerated up to the speed of the vehicle while the head and torso of the pedestrian remain relatively still (Figure 2A). As the vehicle continues to move forward, the lower extremities begin to wrap around the contour of the front end of the vehicle (Figure 2B). The pelvis and torso of the pedestrian then begin to rotate and wrap around the front end and hood of the vehicle (Figure 2C) until the head strikes the vehicle (Figure 2D). Typically, head strike occurs on the hood or windshield, but the exact impact location depends on variables such as pedestrian height, vehicle geometry, and impact speed.

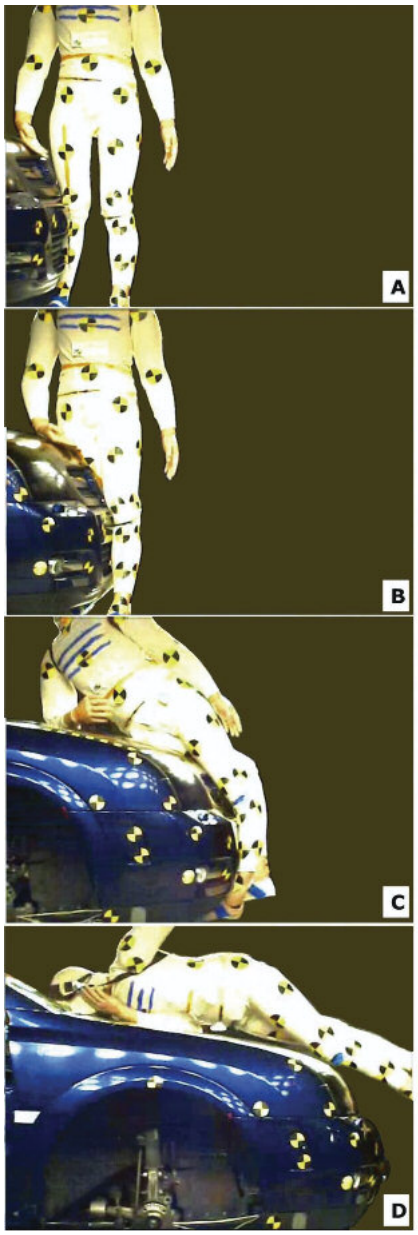

Figure 2: Image sequence showing the initial impact phase of vehicle-pedestrian collision at 25 mph. This collision resulted in a forward projection.

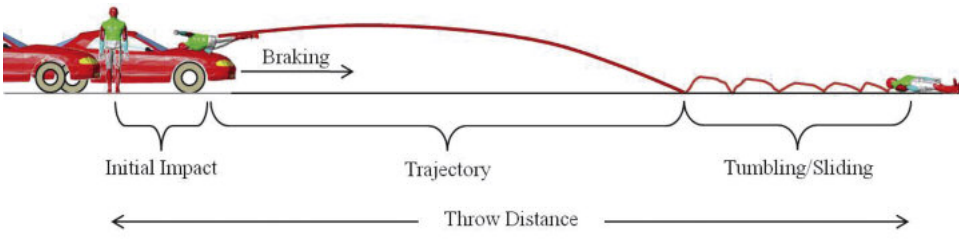

Figure 1: Phases during a typical forward projection vehicle-pedestrian collision with braking of the striking vehicle.

Pedestrian accident studies indicate that more than half of vehicle-pedestrian collisions involved the application of brakes at some point during the initial impact phase. The extent of braking, type of driver avoidance maneuver, area of impact on the vehicle, and relative vehicle-pedestrian geometry all influence the pedestrian's trajectory. Four general types of vehicle interactions occur as a result of the impact: forward projection, roof vault, fender vault, or dragging/run-over.

***Forward projection*:** Forward projections are the most common type of interaction and typically involve a decelerating vehicle (driver braking), either prior to or during the initial impact phase. The pedestrian is accelerated up to some percentage of the speed of the vehicle during the initial impact phase. The percentage depends on the relative vehicle-pedestrian geometry. As braking is applied, the vehicle slows down while the pedestrian is projected forward and comes to rest ahead of the vehicle (as illustrated in Figure 1).

***Roof vaults*:** Roof vaults (the pedestrian being thrown up and over the roof of the vehicle) occur when a vehicle maintains its speed during and following impact, or when the vehicle accelerates into impact. They can also occur when the bumper height of the vehicle's front end is much lower than the pedestrian's center of gravity (about navel height). Roof vaults are more common when the impact is close to the centerline of the vehicle, and if no sudden steering is applied by the driver during the impact. In these cases, the vehicle essentially drives under the pedestrian, and the pedestrian typically lands and comes to rest behind the vehicle.

***Fender vaults*:** Fender vaults involve the pedestrian going over one of the fenders of the vehicle. Impacts close to the side of the vehicle often lead to fender vaults, even without braking or steering. Cases where a sudden steering input is applied by the driver, or where the pedestrian runs across the front of the vehicle, can also lead to fender vaults. Fender vaults typically result in the pedestrian landing and coming to rest behind the vehicle and to one side of the vehicle's path.

***Dragging/run-over*:** Dragging or run-overs occur when the striking surface of the vehicle is higher than the center of gravity of the pedestrian, e.g., a bus striking an adolescent or small child. The pedestrian is knocked down by impact and then driven over by the vehicle. Dragging/run-over accidents usually occur at lower speeds. The pedestrian may be carried by the vehicle for a short distance before falling and being dragged underneath the vehicle. The pedestrian's rest position is typically under or behind the vehicle.

Gathering evidence

Pedestrian collision litigation cases often consist of four main issues: the location of the initial impact (e.g., crosswalk, sidewalk, bike lane, traffic lane); the speed of the vehicle at impact; the speed and orientation of the pedestrian relative to the vehicle at impact; and whether the accident could have been avoided (addressed from a human factors' perspective). Physical evidence gathered at the scene of the accident can help resolve these issues.

Establishing an accurate impact location is the first step. Blood stains, biological matter, shoe scuff marks on the roadway, and debris such as shattered headlamps or reflector lenses can be used to estimate the impact location. However, vehicle and scene evidence are volatile. Vehicles get repaired, washed, or salvaged. Roadway surfaces undergo continuous wear from other traffic and can be either repaved or altered by construction. Roadway evidence can also be altered by weather. Therefore, the vehicle and scene should be inspected as soon as possible after an accident in order to document and preserve this evidence for future analysis. If law enforcement personnel or witnesses took photographs of the accident scene, these photographs should also be requested and gathered as soon as possible to help corroborate the locations of the physical evidence at the scene.

Some pertinent information to gather when analyzing a pedestrian impact includes:

- Traffic Collision Report or accident report detailing the measurements and locations of key physical evidence at the scene, such as tire friction marks, debris, and rest positions.
- Detailed information regarding the scene of the accident (photographs taken at the scene, police measurements of the scene, and an independent inspection of the scene).
- Detailed information regarding the damage to the vehicle (photographs, property damage estimates, and an independent inspection of the vehicle).
- Detailed medical records of the pedestrian (height and weight, EMS and ambulance report, photographs of the injuries, hospital records, and radiographic reports and/or films).
- Statements from all involved parties and witnesses.

Physical evidence

The type of vehicle-pedestrian interaction can often be established from the vehicle damage. For forward projection impacts, the vehicle typically has damage to the front bumper cover consistent with initial leg contact, a dent close to the leading edge of the hood consistent with hip or pelvis contact, and a dent at the top of the hood or fracture at the base of the windshield consistent with head strike (Figure 3).

Roof vaults have damage patterns similar to that of the forward projection impacts, but the windshield fractures occur anywhere from the base to the top of the windshield. In many cases, there is evidence of physical contact to the roof and sometimes as far back as the trunk. If the pedestrian sustains an open wound as a result of the initial impact, blood or biological matter is often found along the roof, trunk, and rear end of the vehicle. Fender vaults normally occur closer to one of the sides of the vehicle; therefore,

Figure 3: Forward projection impacts generate a typical damage pattern that includes front bumper damage, a dented hood, and a fractured windshield.

the damage is usually more localized. In dragging/run-overs, blood and biological matter are often found on the vehicle's undercarriage and tires, as well as along the roadway surface.

In addition to vehicle damage, marks on the roadway and final rest positions can be valuable pieces of physical evidence. Tire friction marks on the roadway surface can be used to establish the behavior of the vehicle before, during, and after the collision (braking, swerving, etc.), and can also be used to calculate an impact speed. Final rest positions of the vehicle and the pedestrian (relative to the impact location) are important in determining the pedestrian throw distance. For simpler cases such as forward projection impacts, the total pedestrian throw distance can be used to estimate a range of impact speeds by relying on experimental data studies and empirical formulas.

Most common injuries

Pedestrian impact studies show that the majority of pedestrians involved in vehicle collisions within the United States were struck on the side while walking or running across a roadway. Approximately three quarters of these impacts occur at vehicle speeds of 25 mph or less. Head injuries are among the leading cause of death for pedestrians, while leg injuries are the most frequent disabling injuries.

Head injuries can involve scalp lacerations, skull fractures, concussions, intracranial swelling, hemorrhages, and hematomas. Traumatic brain injuries occur when the pedestrian's head strikes a hard surface such as the vehicle hood (with underlying stiff structures), windshield, or A-pillar. Head injuries can also occur during secondary contact with the ground or other objects in the surrounding environment.

The lower extremity injuries include soft tissue injuries (contusions, abrasions, lacerations, degloving), torn knee ligaments, long bone fractures (tibia, fibula and femur), and hip or pelvis fractures. These injuries are commonly caused by direct contact with the vehicle's front bumper and hood.

Torso injuries are generally more severe for impacts involving SUVs, trucks, and vans. The most common mild-to-moderate injuries involving the torso are to the ribcage, liver, and lungs.

Relating injury to physical evidence

Relating the physical evidence to the type and pattern of injury can establish how the injury occurred. Detailed medical records, as well as photographs showing the pedestrian's injuries, are vital in establishing this relationship.

Most of the severe pedestrian injuries occur during the initial impact with the vehicle, but injuries can also occur during the secondary impact with the ground or a subsequent run-over by the vehicle or other vehicle(s). Distinguishing injuries due to the initial impact from injuries due to a secondary impact is not always easy. When pedestrians have life threatening injuries, the minor external wounds (contusions, lacerations, abrasions, burns, etc.) can often be overlooked by the attending medical personnel. However, it is the details related to some of the minor injuries that can often delineate one injury source from another.

For example, when assessing lower extremity injuries, the fracture pattern described in the radiographic reports or visible in the actual radiographic films can help determine from what direction the leg was impacted. The direction of the impact typically corresponds to the orientation of the pedestrian relative to the vehicle at the time of impact. This can help establish the pedestrian's direction of travel relative to the vehicle at the time of the collision.

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