Seat Belt Injuries: Radiologic Findings and Clinical Correlation

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The seat belt syndrome consists of skeletal, soft-tissue, and visceral injuries associated with use of two- and three-point restraints in patients involved in motor vehicle accidents. Skin abrasions of the neck, chest, and abdomen—the classic seat belt sign—indicate internal injury in 30% of cases. Neck abrasions are associated with injuries to the carotid artery, larynx, and cervical spine; chest abrasions, with fractures of the sternum, ribs, and clavicles and injuries to the heart and thoracic aorta; and abdominal abrasions, with mesenteric tears, bowel perforation and hematoma, Chance fractures, and injuries to the abdominal aorta. The seat belt sign should prompt a diligent search for related injuries.

INTRODUCTION

Lap-type seat belts became standard equipment in automobiles in the United States in 1964. The three-point variety of seat belt (combined lap and shoulder belt) became standard in the auto industry in 1973. Theoretically, seat belts protect the wearer during a collision in three ways: They (a) prevent ejection from the auto, (b) allow a more controlled deceleration during the initial phase of the collision, and (c) reduce the severity of impact between the wearer and the car interior. There is no doubt that the use of seat belts, especially the three-point variety, lowers morbidity and mortality associated with motor vehicle accidents. A study performed by Volvo, a Swedish car manufacturer, in 1967 demonstrated that,
when only lap belts were used, fatal injuries occurred throughout the entire range of speeds, as low as 12 mph (1). With three-point restraints, no deaths occurred at speeds less than 60 mph.

The first seat belt–related injury—a small bowel injury in a trooper wearing a lap belt—was described by Kulowski and Rost (2) in 1956. A pattern of injuries distinctly different from those seen in unrestrained occupants has since been recognized in seat belt wearers. Garrett and Braunstein (3) were the first to use the term seat belt syndrome in describing the pattern of abdominal and skeletal injuries related to seat belt use. In this article, we review the common and unusual features of seat belt injuries, their radiologic appearance, and clinical and operative correlations.

Table 1
Patterns of Injuries Seen in Motor Vehicle Accidents

<table>
<thead>
<tr>
<th>Location</th>
<th>Unrestrained</th>
<th>Two-Point Restraint</th>
<th>Three-Point Restraint</th>
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<tbody>
<tr>
<td>Face, head, and neck</td>
<td>Fractures</td>
<td>. . .</td>
<td>Injuries to the carotid artery, larynx</td>
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<tr>
<td>Abdomen</td>
<td>Liver and spleen lacerations and rupture</td>
<td>Hollow viscus injuries</td>
<td>Hollow viscus injuries</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(mesenteric tears, perforations), abdominal wall disruptions</td>
<td>(mesenteric tears, perforations), abdominal wall disruptions</td>
</tr>
<tr>
<td>Chest, spine</td>
<td>Fractures of the thoracolumbar spine, pelvis, and extremities</td>
<td>Lumbar spine fractures (Chance)</td>
<td>Fractures of the clavicles, ribs, lumbar spine (Chance), and sternum</td>
</tr>
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</table>

very severe cases. Injuries caused by lap belts include mesenteric tears and perforations of the small bowel and colon. Proposed mechanisms for these injuries are shearing forces due to rapid deceleration against the small area of the lap belt and increased intraluminal pressure secondary to compression of a bowel loop between the seat belt and spine, which produces “blowouts” (5). In the spine, distractive forces cause characteristic horizontal fractures involving the anterior and posterior elements of the lumbar spine. Soft-tissue injuries attributed to lap belts include various abrasions (seat belt sign) and rupture of the abdominal wall muscles and peritoneum. These three injuries—hollow viscus injury, flexion-distraction fractures of the lumbar spine, and abdominal wall disruptions—are the classic seat belt injuries.

With three-point restraints, injuries most frequently involve the thoracic cage: the ribs, sternum, and clavicles. Catastrophic thoracic injuries such as aortic transection, ventricular blowouts, and massive lung lacerations and contusions usually occur only with very severe, high-speed collisions. Hollow-viscous abdominal injuries also occur. Fractures of the lumbar spine are less commonly found with three-point restraints than with lap belts. Cervical spine injuries, carotid and subclavian vascular injuries, and laryngeal trauma have been attributed to the crossing shoulder strap.

Table 1 summarizes the patterns of injuries found in restrained and unrestrained victims of motor vehicle accidents. The following sections elaborate on specific seat belt injuries and their radiologic findings.
Figures 1-3. (1) Abdominal seat belt sign. A large anterior abdominal wall abrasion extends from flank to flank in a victim of a high-speed motor vehicle accident. (2) Thoracic seat belt sign. Diagonal abrasions (arrows) extend from the right shoulder to the left side of the chest in the patient, who was seated on the passenger side of the auto. (3) Neck seat belt sign. Diagonal abrasions are present along the course of the shoulder strap.

■ TYPES OF INJURIES

■ Skin Abrasions
A linear abrasion across the lower abdomen extending from flank to flank is the classic seat belt sign (Fig 1). Although this finding is not an incontrovertible sign of significant internal injuries, we have found that they are present in approximately 30% of the patients with a seat belt sign.

A diagonal abrasion extending across the chest from a three-point restraint (Fig 2) is often associated with underlying rib fractures, clavicular fracture, or sternal fracture. In severe collisions, aortic transection or ventricular rupture should be considered, although these injuries are, in our experience, less common in patients who wore seat belts than in unrestrained occupants in comparable accidents.

A diagonal neck abrasion on the side of the shoulder strap (Fig 3) may be associated with vascular injury, tracheal or laryngeal injury, or, occasionally, cervical spine injury, including transverse process fractures.

■ Skeletal Injuries
Fractures of the thoracolumbar spine are common seat belt injuries in patients who wore two-point and, to a lesser extent, three-point restraints. The pattern of injury is frequently different from that of fractures sustained by unrestrained victims, and can be explained by the three-column concept of the structure of the spine by Denis (6). According to this theory, the anterior column is formed by the anterior longitudinal ligament, anterior annulus fibrosus, and anterior part of the vertebral body. The middle column is formed by the posterior longitudinal ligament, posterior annulus fibrosus, and posterior wall of the vertebral body. The pos-
Figure 4. Thoracolumbar junction flexion-distraction injury. (a) Anteroposterior radiograph shows anterolateral compression of the superior end plate of L-1 (large arrow). Injury to posterior elements may be suspected due to splaying of spinous processes (small arrows). (b) Lateral radiographic findings confirm distraction of posterior elements (arrow).

The anterior column is formed by the posterior bony elements and the posterior ligamentous complex. A flexion force on an unrestrained occupant has a fulcrum centered at the middle column, or posterior half of the vertebral body. This produces compression of the anterior vertebral body and, with more severe forces, distraction of the posterior elements. Moderate forces produce simple, neurologically stable, compression fractures in these cases. Severe forces produce flexion-distraction injuries and fracture dislocations due to failure of all three columns; such injuries are unstable and commonly associated with neurologic deficits. They occur most often at the thoracolumbar junction (Fig 4). The anterior compression may be mild or moderate. More important is the disruption of the posterior elements, which must be searched for carefully.

Restrained occupants, especially those wearing lap belts, show characteristic horizontal fractures, frequently at L-2 or L-3. These fractures were first reported by Chance (7) in 1948. Several variations of these injuries were reported by Smith and Kaufer (8) in 1969. These may involve a single vertebral level (body and posterior elements), two levels, purely soft-tissue disruption, or a combination. The mechanism of injury is the shifting of the fulcrum of the force to the anterior abdominal wall, caused by the seat belt, thus producing distraction on all three columns (anterior, middle, and posterior) of the spine. These fractures show little or no anterior compression of the involved vertebral body (Fig 5). Neurologic deficits are infrequent.

In some cases, distractive forces produce purely ligamentous disruption at the involved level, leading to a lumbar subluxation/dislocation or "Chance equivalent" injury. This injury usually involves disruption of the soft-tissue components of the posterior and middle columns of the spine (posterior ligamentous complex, posterior longitudinal ligament, and posterior annulus fibrosus). Radiographic findings of this unstable injury may be subtle: mild widening of the posterior aspect of the affected disk space, widened facet joints, and splaying of spinous processes. On the anteroposterior view, the latter abnormality produces the "empty hole sign" (Fig 6). Chance fractures and their lig-
Figures 5, 6. (5) Chance fracture of L-2. (a) Anteroposterior radiograph shows characteristic splaying of the spinous processes (double arrow), with fractures extending through both transverse processes and pedicles (curved arrows). (b) Lateral radiograph shows the fracture extending through the posteroinferior corner of L-2 (arrow), into the L2–3 disk space. (6) Ligamentous Chance injury at L3–4. (a) Anteroposterior radiograph shows mild widening of the involved disk space (large arrows) and an "empty hole sign" (small arrows), denoting splaying of the spinous processes. (b) Lateral radiograph more clearly shows splaying of the spinous processes (double arrow) and widening of the facet joints (curved arrow).
Figure 7. Rib fractures, three-point restraint pattern. (a) Posteroanterior radiograph shows the diagonal course of the shoulder strap. (b) Diagonal seat belt sign (arrowheads) is seen in the same patient. (c) Oblique radiograph shows fracture of the right first rib (arrow). (d) Anteroposterior radiograph shows fractures of the left fourth through ninth ribs (arrows). The sternum was also fractured, but there was no aortic or cardiac injury.
amentous equivalents are frequently seen in children and other back-seat passengers, since two-point restraints are still used in the back seats of most autos. New legislation making back-seat three-point restraints mandatory may decrease the number of such injuries.

Anterolateral compression fractures have been reported in occupants wearing shoulder restraints. These injuries occur at the thoracolumbar junction and may be due to a roll-out mechanism of combined flexion and rotation about the axis of the shoulder strap (9).

Rib fractures are common in all victims of motor vehicle accidents of moderate or severe force, regardless of whether restraints are used. With three-point restraints, fractures tend to align along the course of the diagonal strap (Fig 7). The frequency of severe flail chest with multiple fractures is said to be decreased with seat belt usage, however (10). Arndt (11) has also described fractures of the transverse processes of C-7 or T-1, associated with usage of shoulder harnesses.

Sternal fractures are common in patients with seat belt injuries. It is theorized that the deceleration force is absorbed by the sternum through the small area of the shoulder strap, accounting for the relatively low frequency of aortic transections or ventricular blowouts, except in victims of accidents of extremely severe force. We have observed fractures involving only the anterior cortex of the sternum immediately beneath the shoulder strap (Fig 8), which appears to be characteristic of this mechanism. Sternal fractures in unrestrained occupants or those with lap belts only (due to impact against the steering wheel or dashboard) are often associated with myocardial contusion. To date, we have been unable to document any cases of myocardial contusion associated with sternal fractures caused by shoulder straps.

Clavicle fractures are commonly associated with use of three-point restraints during motor vehicle accidents.

- **Soft-Tissue and Visceral Injuries**

Transverse tears of the rectus abdominis muscle and anterior peritoneal tears are becoming more frequently recognized as part of the seat belt syndrome. These injuries occur immediately beneath the site of the lap portion of the seat belt and may be quite subtle radiologically (Fig 9). Computed tomography (CT) may show only abrupt thinning of the involved muscle at the level of injury, and this finding may easily be overlooked. This injury is frequently associated with hollow viscus injury (12) and may provide a clue to the gravity of the injury.
Figure 9. Abdominal wall disruption. (a–d) CT images demonstrate rectus muscle disruption in a 14-year-old victim of a high-speed motor vehicle accident. Images show normal rectus abdominis muscles superiorly (straight arrows in a), virtually absent rectus muscles in the midportion of the abdomen (arrows in b, c), and normal-appearing muscles inferiorly (arrows in d). Subcutaneous flank hemorrhage was also seen (curved arrow in a). An abdominal seat belt sign was present. (e) Diagram illustrates transverse tears of the rectus abdominis muscles at the site of abdominal abrasions (arrows). (f) Intraoperative view shows an extensive tear of the anterior abdominal wall (arrows).
The most common significant injuries encountered in restrained patients are mesenteric tears and frank ruptures of the small bowel and colon. Vascular tears occur on the mesenteric side of the bowel, more frequently in the small bowel than in the colon. Perforations nearly always occur on the antimesenteric border. Jejunal and ileal perforations are most common, with large intestine and duodenal ruptures less frequent. In an examination of case reports, Williams and Kirkpatrick (13) found a higher rate of hollow viscus injury in patients who wore two- versus three-point restraints. Sixty-three of 82 injuries involved the small bowel; 19 involved the colon. Mesenteric tears and bowel perforations were equally common. The true frequency of these injuries cannot be determined from this study, however, since it represented an analysis of case reports.

The efficacy of CT in the evaluation of blunt abdominal trauma and potential hollow viscus injuries has been studied by several authors (14–17). In their 1989 study of 51 patients (37 of whom were in motor vehicle accidents), Rizzo et al (18) examined the frequency of the following CT findings: extraluminal air, free intraperitoneal fluid, thickened or infiltrated mesentery, and thickened bowel wall (Figs 10, 11). Extraluminal air was observed in only nine of 16 cases of perforation (56%). Two cases showed extravasation of orally administered contrast material. In all cases of bowel perforations, there were moderate to large amounts of free intraperitoneal fluid. Thickened bowel wall (75%) and mesenteric infiltration (88%) were also found in most cases of perforation. From this study and others, one may conclude that (a) free gas or extravasated contrast material are relatively specific but insensitive (56%) signs of bowel perforation; (b) the presence of moderate or large amounts of free intraperitoneal fluid, when not associated with solid organ laceration, should raise the suspicion of bowel perforation or mesenteric vascular tear; and (c)
localized mesenteric hematoma or the finding of a focal high-attenuation clot adjacent to bowel are helpful in localizing the site of injury. In the above situation, CT and diagnostic peritoneal lavage should be used as complementary diagnostic examinations.

The relative roles of CT and diagnostic peritoneal lavage in the evaluation of blunt trauma have been examined by a number of authors and remain controversial (19–25). In cases in which there is a high suspicion for bowel injury (seat belt sign or Chance sign},
fractures of the spine), judicious use of both tests is warranted. Because small bowel lacerations may initially be asymptomatic and since delay produces significant morbidity, rapid evaluation, with both tests if necessary, is recommended. When hollow viscus injury is suspected, CT should be performed prior to diagnostic peritoneal lavage, since the important CT signs of intraperitoneal fluid or free air may be related to the lavage itself (26).

The frequency of liver and splenic injuries is reduced with the use of two- and three-point restraints. Severe forces and crush injuries continue to produce the usual complement of liver lacerations (Fig 12), splenic lacerations and ruptures (Fig 13), and pancreatic (Fig 14) and renal injuries.

Significant injuries may be produced with less severe forces when there is improper positioning of the two- or three-point restraint (27,28). Proper usage dictates that the lap belt be positioned across the anterior iliac spine so that the forces are dissipated through the stable, bony pelvis. If the belt migrates up onto the abdominal wall (secondary to obesity, slouching, or "submarining"), the load of a sudden deceleration may be dissipated over the abdominal compartment, resulting in visceral injuries. Placement of the shoulder strap under the arm by a passenger-side occupant produces a force directly across the liver, with potentially devastating effects.

Intraperitoneal rupture of a distended bladder may occur due to lap belt pressure during an accident (Fig 15). Urethral injury has occasionally been reported as well. Several cases of uterine injury have also been reported (29), including a case in which rupture of a gravid uterus left a 6th-month fetus free in the abdominal cavity. Fortunately, such reports are rare.

Cases of diaphragmatic rupture have been reported in seat belt wearers (30) (Fig 16). The mechanism of the injury may be secondary to faulty placement of the belt or sliding of the occupant under the belt in the early stages of the impact, leading to upward abdominal pressure from the belt and subsequent herniation of abdominal contents into the thoracic cavity.
Common carotid angiogram demonstrates a transection (arrow) below the bifurcation. (b) CT scan of the same patient shows extensive gas in the soft tissues of the anterior and lateral aspects of the neck secondary to laryngeal fracture.

Vascular Injuries
We have seen one case of transection of the common carotid artery in a patient involved in a motor vehicle accident while using a three-point seat belt (Fig 17a). The same patient also had a fracture of the larynx that necessitated a tracheostomy (Fig 17b). Similar cases, as well as injuries to the internal carotid artery, subclavian artery, and superior vena cava, have also been reported in the literature (31–35).

The force of collision required to produce thoracic aortic tears appears to be greater in restrained occupants than in unrestrained persons. The shoulder strap may allow a more controlled deceleration of the chest during the collision, which may decrease the shearing force on the aorta somewhat. Still, aortic injuries are relatively common with severe forces (Fig 18) (36).

Seat belt–related injuries involving the abdominal aorta have been reported (37,38). We observed one case in which distal abdominal aortic occlusion occurred due to a near-complete transection (Fig 19). This patient also sustained a Chance fracture at the same level. The mechanism of injury was presumably distraction and compression of the aorta between the seat belt and spine.

CONCLUSIONS
Given the same force of impact during the accident, a seat belt wearer (especially three-point type belt) will usually sustain less severe injuries than a nonwearer. Seat
belts prevent ejection of the wearer from the vehicle and decrease the severity of the occupant’s impact with the steering wheel, dashboard, and other interior structures. However, a distinctly different pattern of injuries occurs in seat belt wearers. In our experience, the seat belt sign—abdominal, chest, or neck bruises and abrasions at the site of belt contact—is associated with significant internal injuries in approximately 30% of cases. Chance fractures and their ligamentous equivalents, large and small bowel perforations or mesenteric tears, and abdominal wall disruptions are more common than solid organ injury. Occasional significant vascular injuries also occur. Table 2 summarizes the various injuries associated with different seat belt abrasions. The history of a restrained occupant in a significant motor vehicle accident or the presence of the telltale seat belt sign should prompt a diligent search for these related injuries.

Table 2
Seat Belt Syndrome: Physical Signs and Related Injuries

<table>
<thead>
<tr>
<th>Location of Abrasion</th>
<th>Affected Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck</td>
<td>Injuries to the carotid artery, larynx, cervical spine, transverse process</td>
</tr>
<tr>
<td>Chest</td>
<td>Injuries to the sternum, ribs, clavicle, heart (myocardial contusion), thoracic aorta</td>
</tr>
<tr>
<td>Abdomen</td>
<td>Injuries to the small and large bowel (mesenteric tears, perforations, hematoma), vertebrae (Chance fractures, especially L-2, L-3), abdominal aorta and branches</td>
</tr>
</tbody>
</table>

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