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Clinical Review

CLINICAL SIGNIFICANCE OF THE SEAT BELT SIGN AS EVIDENCE OF A COMPROMISED OCCUPANT–SEAT BELT RELATIONSHIP

Mathew Greenston, MS, MD,*† Rawson L. Wood, MD, MPH,* and Lars Reinhart, MD*

*Biodynamic Research Corporation, San Antonio, Texas and †US Acute Care Solutions, Baptist Emergency Hospitals and First Choice ER, San Antonio, Texas

Corresponding Address: Mathew Greenston, MS, MD, Biodynamic Research Corporation, 12810 W Golden Ln., Ste. 107, San Antonio, TX 78249

☐ Abstract—Background: Seat belt marks are seen frequently on occupants after motor vehicle accidents. Over the years, the clinical significance of these marks has changed as restraint systems have evolved. With modern restraint systems, signs of a compromised occupant–restraint relationship are an important and easily identified bedside finding. Objectives: We sought to learn to recognize seat belt marks that demonstrate an abnormal occupant–restraint system relationship and to cultivate an understanding of significant soft tissue biomechanical loading associated with marks caused by a compromised occupant–restraint relationship. Discussion: A review of case studies from the literature combined with forensic work demonstrate a strong correlation between significant injury and improper seatbelt use. When evidence of a compromised occupant–restraint relationship exists, incorporating computed tomography angiography and observation may be clinically indicated. Conclusion: The recognition of seat belt marks made by a compromised occupant–restraint relationship is an important finding that allows risk stratification of the patient at the bedside. Further investigation with a prospective trial at a trauma center is warranted. © 2019 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

☐ Keywords—abdominal; abdominal injury; bowel injury; motor vehicle crash; seat belt sign; seat belt syndrome; spinal injury

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INTRODUCTION

Motor vehicle restraints save lives. Fatal injuries to drivers and front seat occupants can be reduced by 40–50% and rear seat occupants by 25–75% when seat belts, which have been standard equipment on vehicles sold in America since 1968, are worn by occupants in motor vehicle collisions (MVCs) (1). Airbags were the next passive restraint system improvement added by manufacturers starting in 1973, and in 1998 federal law made it mandatory for both sides of the front seat to have an airbag (2). Early after their introduction, engineers recognized that airbags provided even more protection when used in conjunction with the seat belts than when used alone.

Motor vehicle restraints have long been associated with certain injuries in particular populations. An early example was the lumbar fracture-dislocation noted by G. Q. Chance, the so called "Chance fracture," as described in 1948 (3). The classic abdominal seat belt mark associated with a Chance fracture is produced when the lap belt acts as fulcrum and the occupant's lumbar spine is subjected to a combination of a hyperflexion moment and axial tension. These crashes were particularly hazardous to younger vehicle occupants because of their larger relative head size and higher center of gravity than adults. Once the mechanism of injury was fully understood, several changes were made to

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restraint design to enhance safety. These included the addition of shoulder restraint belts, inclining the seat pan, lowering of seat belt anchor points, and the use of seat belt pretensioners. Via these changes, forward flexion of the trunk and slippage of the pelvis under the lap belt became more limited after frontal impact crashes.

The most common injury sustained from a seat belt is the “seat belt mark” or “seat belt sign” (SBS). This is simply an area of ecchymosis or abrasion within the dermis where the seat belt made direct contact with the occupant, thereby resulting in a seat belt mark. If the loading is high enough, dermal capillaries rupture causing microscopic bleeding within the dermis, resulting in visible cutaneous findings known clinically as the SBS. Depending on the type of vehicle collision, SBS can help predict injuries, guide clinical practice, and provide corroborative evidence with respect to occupant kinematics from vehicle movements.

Need for This Study

Extensive literature exists in the form of case reports with SBS-related intestinal or vascular injuries (4–69). A retrospective study from 2009 evaluated pediatric patients with an SBS and reported that the presence of an SBS was not necessarily indicative of a significant intra-abdominal injury (70). There appears to be an inconsistency between individual case reports, which suggest a high degree of association of an SBS with significant internal injury, and this retrospective case series, which suggests that most patients with an SBS did not have significant internal injury.

When one undertakes a review of case report photographs or clinical descriptions of cutaneous marks that have followed MVCs associated with significant internal injuries, evidence often exists that a compromised relationship between the vehicle occupant and the vehicle’s restraint system was present at the time of the crash. For example, Bala et al. provided evidence that supported this premise in their 2014 case series reporting patients with SBS who required laparotomy (71).

The biomechanics associated with SBS is not well explained in the clinical literature. The purpose of this article is to help physicians treating patients who have been involved in MVCs understand and appreciate the occupant kinematics and biomechanics that cause SBS. The ability to recognize SBS left by an improperly positioned seat belt allows knowledgeable clinicians to recognize a patient who is much more likely to have a significant underlying internal injury because of their compromised occupant–restraint relationship.

Aim

We present selected cases of SBS occurring in association with improper vehicle restraint system usage, in context of vehicular dynamics, occupant kinematics, and associated potential injuries. The purpose is to use these examples to describe the anatomic relationships between the vehicle occupant and the seat belt system when the restraint system has been properly positioned versus instances when a compromised occupant–restraint relationship existed at the time of an MVC. In this manner, the potential need for selected usage of advanced imaging or extended clinical observation will be described.

DISCUSSION

Underlying Biomechanical Principles

The purpose of a restraint system is to decelerate the occupant gradually over a longer period of time as well as distribute collision forces over a larger portion of the bony skeleton (clavicle, sternum, ribs, and pelvis). Soft tissues do not tolerate heavy loading as well as bones do, and therefore all other tissues are more likely to be damaged when collision forces are concentrated over small areas.

Figure 1 shows the path of a properly positioned belt webbing when in a normal driving position using a type II or 3-point seat belt restraint. The shoulder belt crosses the middle of the driver’s left clavicle, crosses the central chest/sternum, and extends to the latch plate/buckle complex that rests lateral to the pelvis and greater trochanter. The lap belt passes back across the anterior pelvis at or below the level of the anterior superior iliac spine. When the belt is properly positioned, inertial loads from the body interacting with the belt are distributed to a greater degree over the skeleton and to a lesser degree onto the soft tissues.

In MVCs, the vehicle’s impact-related change in velocity is known as the delta-V (Δv), a quantity that is widely accepted as a general estimate of impact severity (72,73). Another key concept is the principal direction of force (PDOF) and typically is referenced to a horizontal clock face oriented at the impact location (Figure 2). Frontal collisions are defined as having a PDOF of 11, 12, or 1 o’clock, while rear impacts are defined by a 5, 6, or 7 o’clock PDOF. The use of photographs, damage repair estimates, data from the vehicle’s event data recorder, or vehicle crush profiles can all be used to establish the Δv and PDOF (74–77). Vehicles that sustain little or no damage are typical of minor, low-speed collisions in which the Δvs are generally <10 miles per hour (mph).

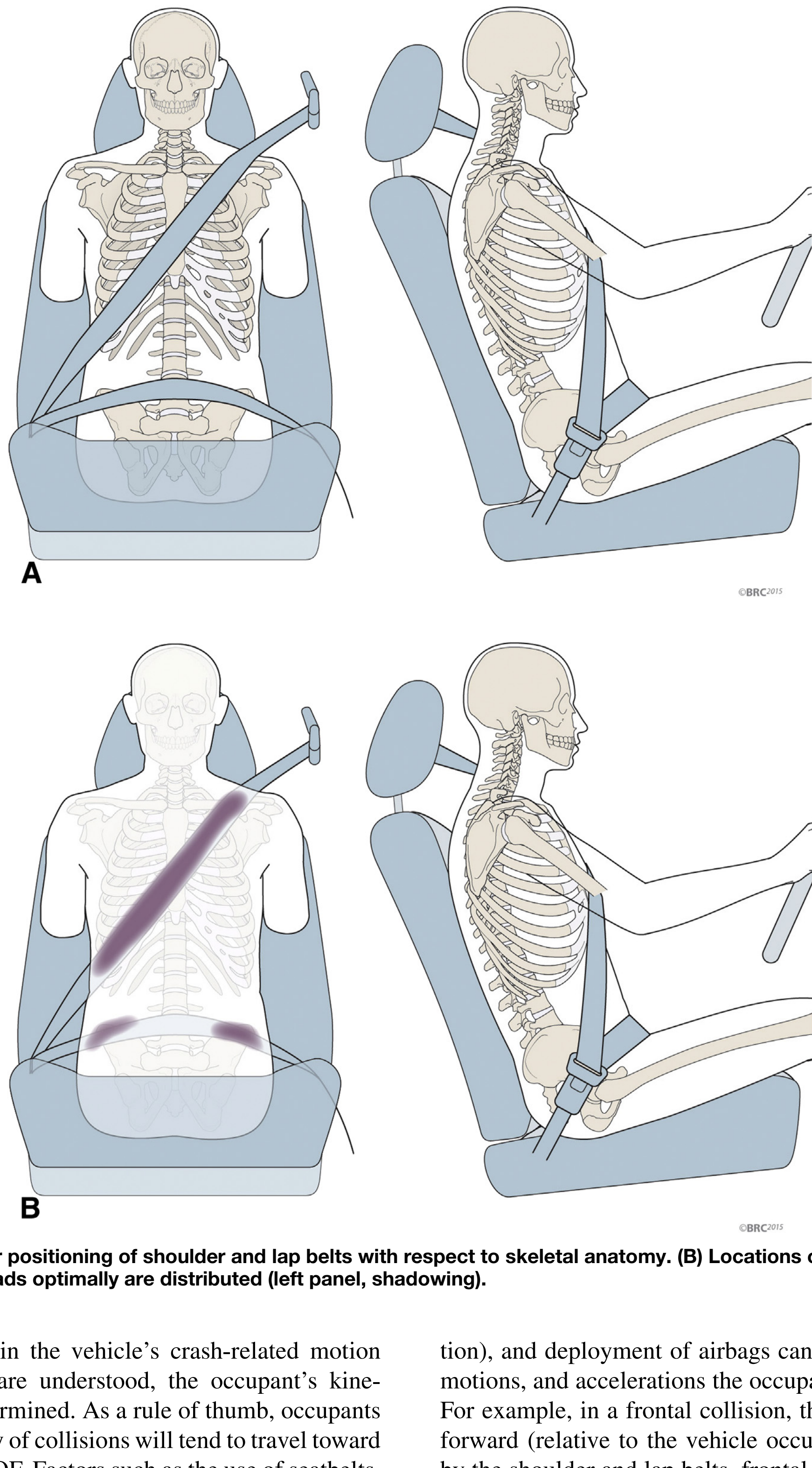

Figure 1. (A) Proper positioning of shoulder and lap belts with respect to skeletal anatomy. (B) Locations of seat belt signs are projected where loads optimally are distributed (left panel, shadowing).

Once changes in the vehicle's crash-related motion (PDOF and Δv) are understood, the occupant's kinematics can be determined. As a rule of thumb, occupants in the vast majority of collisions will tend to travel toward the collision's PDOF. Factors such as the use of seatbelts, occupant position (chiefly regarding whether at the time of the crash, the patient had neutral spinal posture vs. cervical or thoracic rotation, and whether the occupant had their seat back positioned upright or in a reclined position), and deployment of airbags can modify the forces, motions, and accelerations the occupant will experience. For example, in a frontal collision, the driver will move forward (relative to the vehicle occupied) until stopped by the shoulder and lap belts, frontal airbag, windshield, steering wheel, knee bolster, or some combination thereof, with different injury outcomes depending on which portions of the interior were contacted. Once the accelerations of the vehicle (Δv divided by the duration

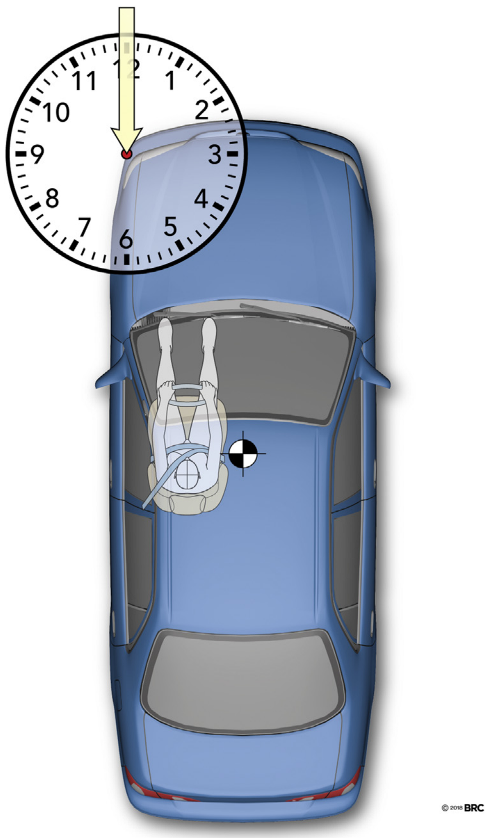

Figure 2. Principal direction of force diagram for a frontal impact at 12 o'clock.

of the vehicle contact [typically 100–120 msec]) are known, using Newton's second law (force = mass × acceleration), whole-body or individual tissue tolerances can be evaluated for injury potential. For example, in a 5 mph Δv collision, the peak vehicle acceleration is 4.5 g (1 g = 32.2 ft/sec^2) and generates <10 g of head acceleration (78).

The Abbreviated Injury Scale (AIS) is a standardized system for classifying the type and severity of injuries that result from vehicular crashes. This system was developed by the Association for the Advancement of Automotive Medicine and has been adopted as the standard for crash investigation teams that have been funded by the Department of Transportation, as well as by teams from many universities and industry-based research teams. The scale ranges from 0–6, with the following definitions of severity: 0 (none), 1 (minor), 2 (moderate), 3 (serious), 4 (severe), 5 (critical), and 6 (maximal). The scoring system allows injuries to be quantified and standardized, providing the basis for statistical analyses of injuries.

Richards et al. studied the incidence of thoracic and lumbar spinal injuries to restrained occupants in frontal impact MVCs, using a query into a national database of vehicle crashes (National Automotive Sampling System) (79). At Δvs <30 mph, AIS 2 + thoracolumbar spinal injuries occurred in <0.6% of occupants restrained with a 3-point restraint with or without an airbag. In this small cohort of occupants who sustained AIS 2 + thoracolumbar injuries, 51% also had AIS 2 + abdominal injuries. The coupling of these 2 injury patterns is consistent with compromise of the occupant–restraint relationship, where the lap belt interacted with the abdomen instead of the bony pelvis in these cases.

Exemplar Cases

A review of the case studies with SBS in the literature demonstrates hundreds of cases with catastrophic abdominal injuries and some of the cases contain actual photographs of vehicle occupant injuries that demonstrate an SBS. Figure 3 shows that the occupant's pelvis slipped under the lap belt (5). The marks extend above the iliac crests. He was diagnosed with a mesenteric injury causing devascularized small bowel. In the accident, his body moved forward into the belt. Instead of bearing the inertial load across the bony pelvis, the load was distributed across the soft tissues of his abdomen causing his injuries. In other words, an abnormal superior positioning of the lap belt was associated with increased transmission of crash forces to the vicera, and a resulting mesenteric injury.

Muñiz and Haynes described a case of an 8-year-old boy with delayed abdominal aortic rupture (80). He was a rear occupant in a high-speed MVC and had only a type I restraint (lap belt only). The initial bedside ultrasound (US) revealed free fluid in the pelvis. He was taken for exploratory laparotomy and underwent resection of 2

Figure 3. Mesenteric injury with devascularized small bowel. Permission to reproduce the images from the editor of the Irish Medical Journal. Obtained from Ekpete and Pritchard (5).

jejunal segments with end-to-end anastomosis and repair of a mesenteric vein injury. On postoperative day 1, he became hypotensive, and emergency bedside US revealed a 5.76-cm pseudoaneurysm of the distal aorta. His aorta had been normal on the initial CT scan. The SBS in Figure 4 is clearly above both iliac crests. As in the previous case, the inertial load was not carried by the pelvis but by the soft tissues of the abdomen. The use of a belt-positioning booster seat would have lowered the lap belt down onto the upper thighs and pelvis for proper inertial loading of the bony pelvis. The American Academy of Pediatrics recommends booster seat use for children until they have reached at least 4′9″ in height and are between 8 and 12 years of age (81).

A case report by Munshi and Patton shows a "unique" SBS (Figure 5A) found on a passenger restrained in the back seat with a 3-point, type II belt (82). In this case, the shoulder belt loading marks were located over her right lower rib cage and flank, consistent with a scenario in which the belt webbing was improperly routed, and in which the occupant was turned toward her left at the time of the frontal impact. The occupant–restraint relationship was compromised because the belt was routed under her shoulder instead of across her right clavicle (Figure 5B). The combination of compromised occupant–restraint relationship and being turned in the seat created a unique SBS. Abdominal and pelvic CT scans with intravenous contrast dye revealed a right eleventh rib fracture and dislocation that projected toward the right colon associated with free fluid adjacent to the medial part of the cecum. Right lateral abdominal wall disruption was also noted on the CT scan. She was transferred to a level I trauma center and at laparotomy was found to have hemoperitoneum, right paracolic hematoma, and 2 large mesenteric tears of the mid–small bowel causing ischemia.

Figure 4. Mesenteric injury with devascularized small bowel. Permission to reproduce the images from the publisher, Wolters Kluwer Health and authors Muñiz and Haynes. Obtained from Muñiz and Haynes (80).

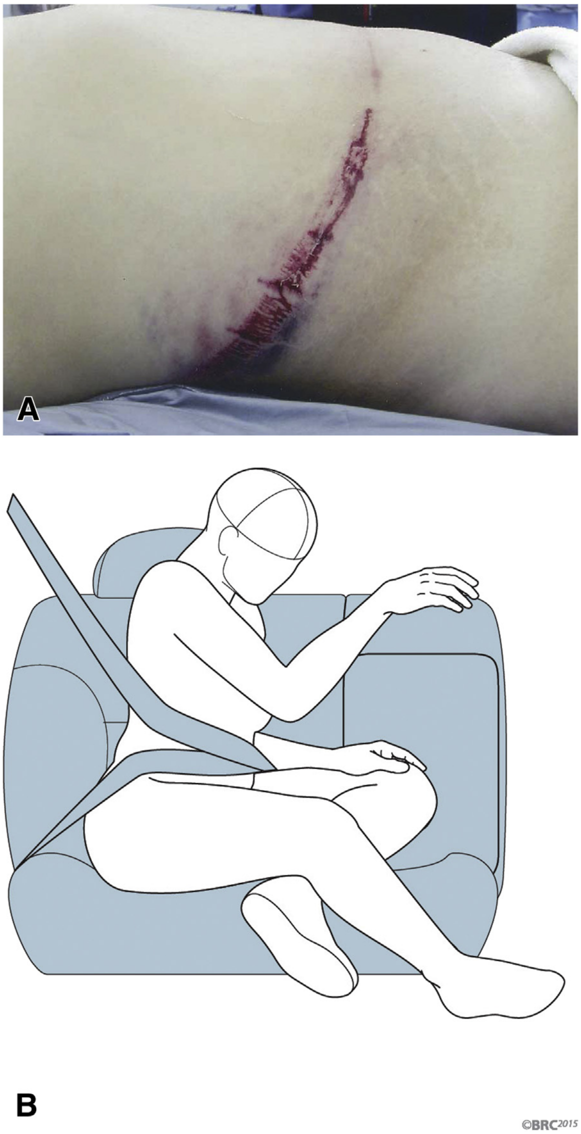

Figure 5. (A) Unusual seat belt mark on a rear passenger wearing a 3-point restraint. (B) Compromised occupant–restraint relationship illustrated. Permission to reproduce from the publisher, Elsevier. (A) Obtained from Munshi and Patton (82).

Another example of abdominal wall rupture from improper restraint use is presented from a previously closed case file. This case involved an improperly restrained driver (Figure 6A) in a 3-point, type II belt. She was involved in an MVC with a Δv of 38 mph and a PDOF between 12 and 1 o'clock. Inspection of the chest (Figure 6B) revealed a shoulder belt mark that traveled superior to the breasts instead of traversing between them. Large ecchymosis at the right lower quadrant (Figure 6C) reflected load concentration from unusual shoulder belt routing. The load was not uniformly spread across her anterior chest. A CT scan demonstrated a

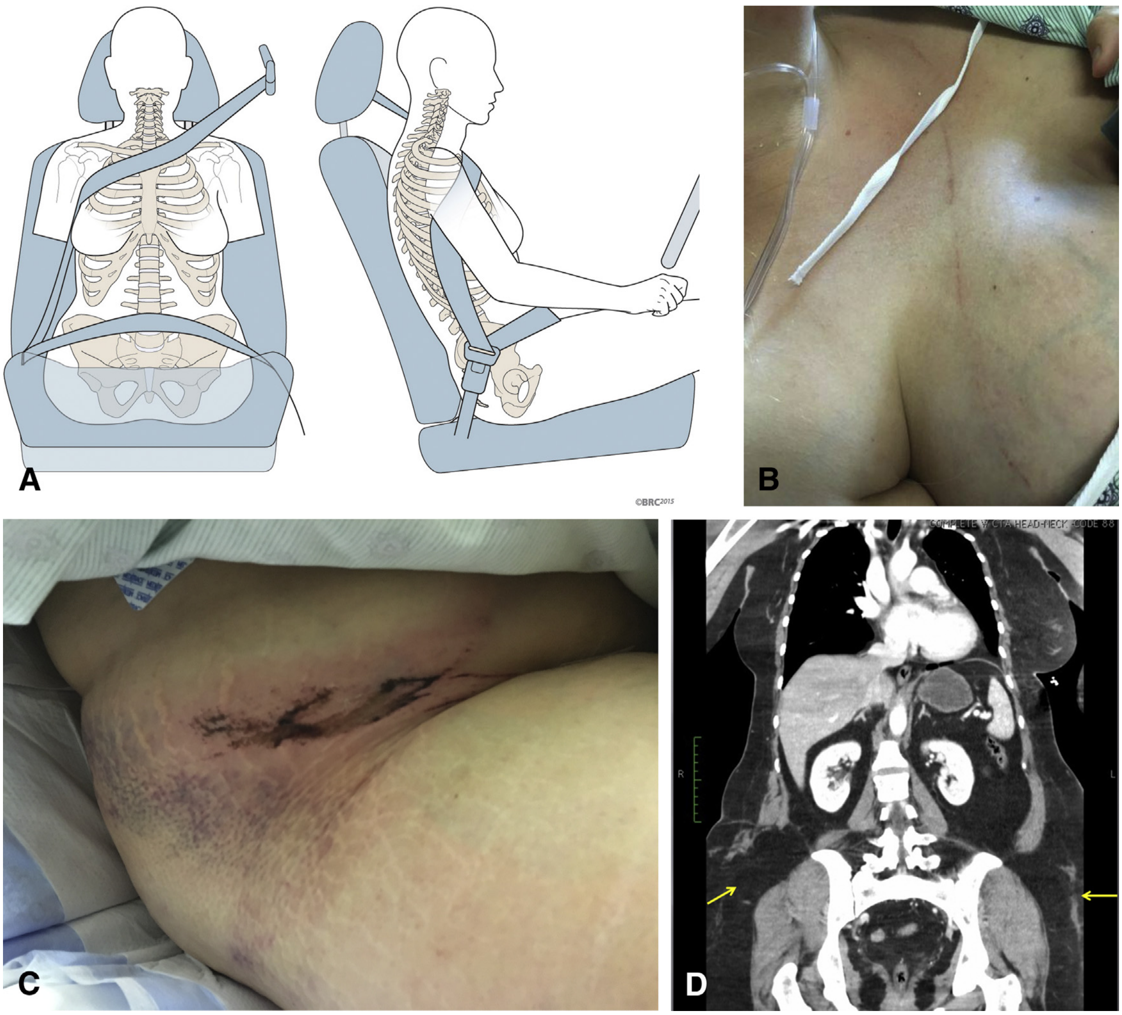

Figure 6. (A) Novel belt placement superior to the breasts and down the right side of the chest results in an unusual injury pattern. (B) Ecchymosis from the shoulder belt as it traverses superior to both breasts. The patient's neck is shown in the upper left corner of the photograph. (C) Marked bruising in the right lower quadrant that is a combination of unusual belt placement and the principal direction of force coming from the patient's right. (D) A computed tomography scan showing right lower quadrant abdominal wall rupture.

traumatic right lower quadrant abdominal wall defect (Figure 6D). The unusual seat belt routing altered the position of the buckle–latch complex and loaded her abdominal wall abnormally, causing a traumatic abdominal wall hernia in the right lower quadrant.

The cases discussed here include frontal impacts with occupants that had a malpositioned seat belt/shoulder harness at the time of impact. Not discussed here are scenarios where the occupant is properly positioned with respect to the restraint system, but marks are left, suggesting an abnormal path for the seat belt webbing. Such out of position marks are seen when there is significant rotation in a planar crash or roll over event. Regardless of the mechanism, out of position marks demonstrate abnormal soft tissue loading and can be indicative of increased risk of significant internal injury.

CONCLUSIONS

Emergency physicians have been taught to recognize seatbelt marks and SBS that are frequently observed on patients after MVCs. Many patients demonstrating a SBS are evaluated radiographically with CT scans. Over the years, the clinical significance of the SBS has become refined as vehicular restraint systems have improved. In the current era of enhanced automotive safety, signs of a compromised occupant–restraint relationship is an important and identifiable finding at the bedside. When the SBS presents evidence of a compromised occupant–restraint relationship, incorporation of CT angiography or an extended period of clinical observation may be clinically indicated. Patients with negative CT scans and no signs of compromised occupant–

restraint may be candidates for discharge. Further investigation with a prospective trial at a trauma center is warranted.

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ARTICLE SUMMARY

1. Why is this topic important?

The biomechanical distribution of the inertial loads that accrue to a vehicle occupant after a motor vehicle collision is accomplished by the vehicle's passenger restraint system. A seat belt mark that demonstrates a compromised occupant–restraint relationship can be easily identified at the bedside. Patients with these marks are at significantly increased risk for abdominal and vascular injuries.

2. What does this review attempt to show?

This review attempts to show how to distinguish between marks made by a properly worn restraint and those in which the occupant–restraint relationship is compromised.

3. What are the key findings?

Ecchymosis outside of the expected path of a seat belt or shoulder harness can be indicative of an increased risk of significant internal injury.

4. How is patient care impacted?

Patients with seat belt marks made by a compromised occupant–restraint relationship are more likely to have significant abdominal, vascular, and spinal injuries than properly restrained occupants. They are more likely to benefit from computed tomography angiography than patients without these marks. Patients with a normal abdominal computed tomography scan and no evidence of a compromised occupant–restraint relationship may not benefit from prolonged observation.