CME Article

Biomechanics of road traffic collision injuries: a clinician's perspective

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ABSTRACT

Understanding the biomechanics of road traffic collision injuries is important for diagnosing and managing road traffic injured patients. As road traffic collisions may entail high-energy trauma, the degree of injury will depend on the mass and speed of the collided vehicles. Collisions can be front impact, back impact, side impact; the vehicle may turn over or the patient may be ejected from the vehicle. Each of these mechanisms has a specific pattern of injury. The injury will vary depending on whether the passenger was restrained with a seat belt or not. Seat belts tend to reduce head injuries and increase the abdominal injuries. Compression injuries of the intestines and urinary bladder tend to be more severe, causing rupture of these hollow organs if pressure within these organs was high. Pedestrian injuries consist of three phases: the bumper impact, hood and windscreen impact, and ground impact. The injury pattern and impact of motor vehicle collisions with large animals will depend on the size, height and weight of the animal. Clinical examples of road traffic collision patients will highlight the value of understanding biomechanics in patient management.

Keywords: injury, motor vehicle collisions, pedestrian injuries, road traffic collision, trauma, trauma biomechanics

Singapore Med J 2007; 48(7):693–700

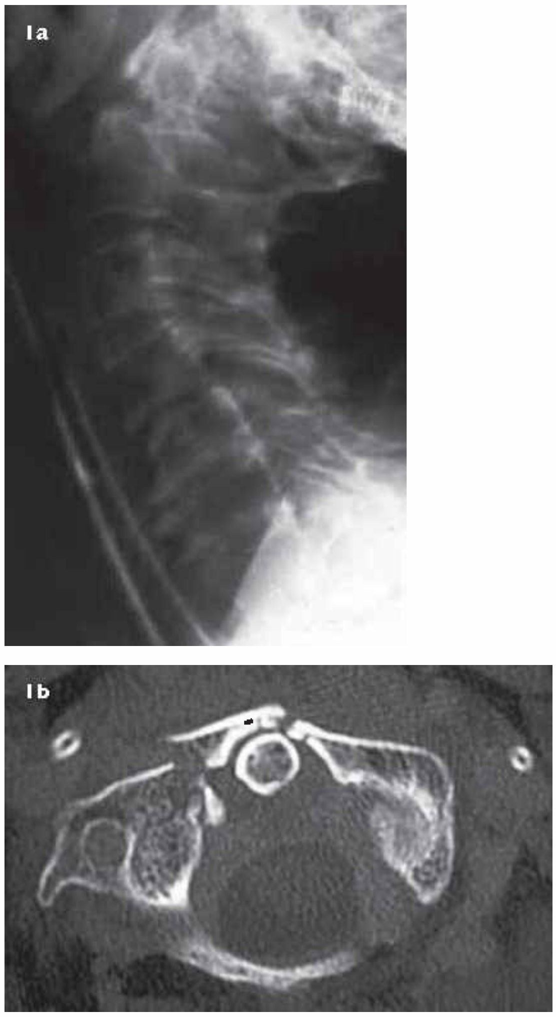

Fig. 1 (a) Lateral cervical spine radiograph shows osteoporotic bone with suspicion of widened C1-C2 space and fracture of the odontoid peg; and (b) axial CT image of the cervical spine shows the fractured anterior arch of C1 in a 90-year-old female pedestrian who was hit by a car. On presentation, her GCS was 9 and she could not move her upper or lower limbs. The patient did not survive her multiple injuries.

INTRODUCTION

Understanding the biomechanics of road traffic collision injuries is important for diagnosing and managing injured patients. Clues to identify patient's injuries can be provided by analysis of biomechanics of trauma.[1-3]

BASIC PHYSICS

When two objects collide, each of them has an amount of energy. The energy can be calculated from the formula, Energy = ½ mass × V^2, where V is velocity.[1] This means that the relationship between energy and mass is linear, while the relationship between energy and velocity is exponential. That is why the relationship between velocity and mortality from road traffic collisions is exponential. As objects collide, energy will be transferred from one object to another depending on the direction, speed, position and nature of the objects. Another important factor is the characteristics of the injured tissue. For example, aged pedestrians who are hit by vehicles easily incur cervical spine injuries because of osteoporosis (Fig. 1). In contrast

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Fig. 2 Sagittal T2-W MR image shows contusion of the spinal cord and at T1–3 levels in a four-year-old male pedestrian who was hit by a car. The patient was paraplegic with loss of sensation below the T2 level. CT of the thoracic spine was normal. This case illustrates the unique presentation of SCIWORA (spinal cord injury without radiological abnormality) in children.

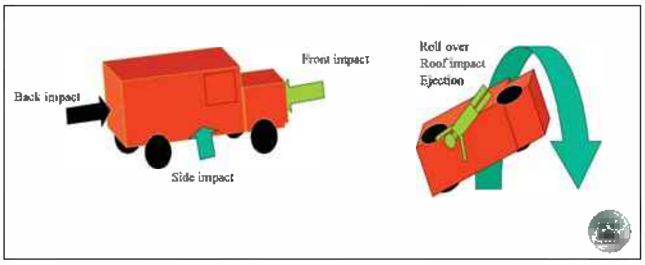

Fig. 3 Diagram illustrates the different types of motor vehicle collisions.

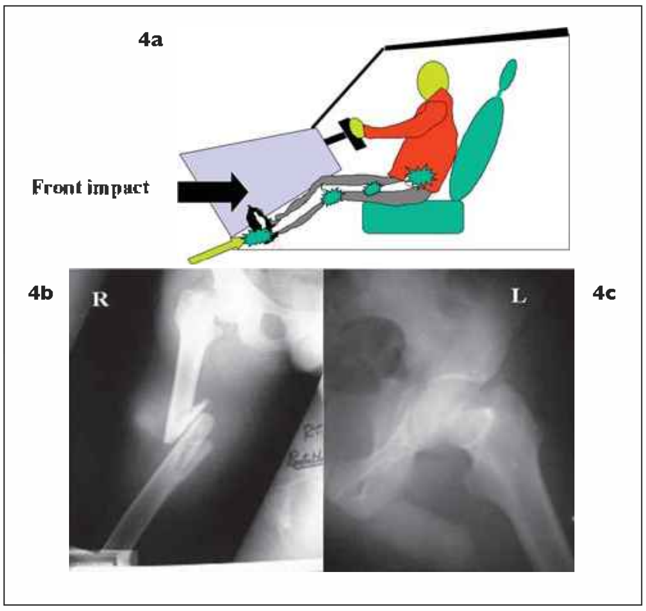

Fig. 4 (a) Diagram shows a driver who was not wearing a seat belt and who had a front impact collision. Radiographs show fractures of the (b) right femur; and (c) left acetabulum, caused by the energy transmitted to both lower limbs from the collision.

to that, the elastic soft tissue of children can lead to major soft tissue injury without skeletal fracture. Fig. 2 shows an example of a spinal cord injury that occurs in children.

MOTOR VEHICLE COLLISIONS

The impact caused by motor vehicle collisions can be front impact, back impact, side impact or combined impact. Furthermore, the vehicle may be turned over, or the patient may be ejected from the vehicle (Fig. 3).[1,4] The amount of energy and the direction of impact are major factors that determine the outcome of a collision.[1]

Front Impact. When a front impact occurs, there is a deceleration of the vehicle as it hits another vehicle or a fixed object such as a tree.[2,4,5] Initially, the impact of injury is transmitted through the lower limbs of the patient from foot to hip.[2,5] Transmission of energy will strain the lower limb at its weakest point, which can be the ankle, knee, femur or hip. The hip is the weakest part of the lower limb.[5] The flexed knee may also hit the dashboard and the energy can be transmitted through the femur upwards or through the tibia downwards. Fractures/dislocations of the lower limbs will occur depending on the position of the limbs upon impact (Figs. 4 & 5).[2,5] The severity of the injury will also vary, depending on whether the passenger was restrained with a seat belt.[2] If the driver was not restrained, a hinge effect occurs at the hip.[2,5] The driver will lean forward and the chest will be compressed against the steering wheel.[2,4] Finally, the head will hit the windscreen (Figs. 6 & 7).[2,4]

Unrestrained backseat passengers try to avoid injury during the crash by pushing their extended upper limbs against the front seat. Transmitted energy through their upper limbs classically causes upper limb fractures/dislocations. Unrestrained back seat passengers are considered as "flying bullets" within the vehicle as they hit others.[6] Seat belts are effective in preventing injuries and death in all types of motor vehicle crashes.[6] They reduce head injuries but increase abdominal injuries. Abdominal compression occurs when the restrained occupant is subjected to high speed deceleration.

Fig. 5 Radiograph of a patellar fracture of a 29-year-old driver who sustained a dashboard injury.

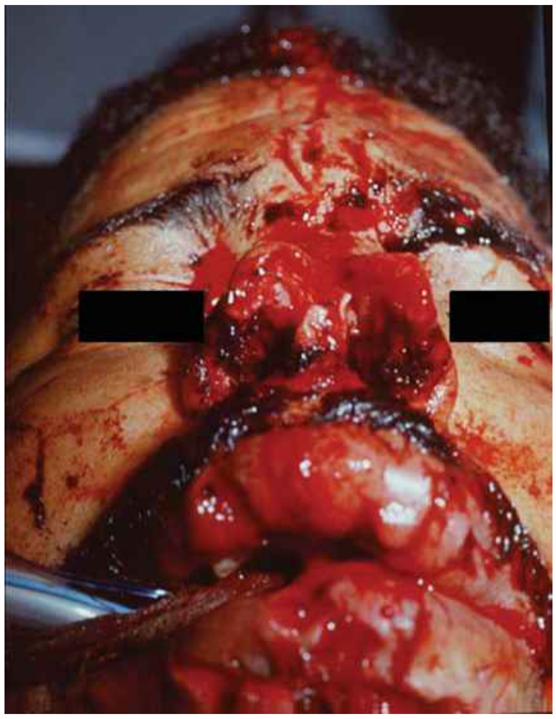

Fig. 7 Photograph shows a front seat passenger, who sustained the classical windscreen injury of the face, in a frontal impact collision while not wearing a seat beat.

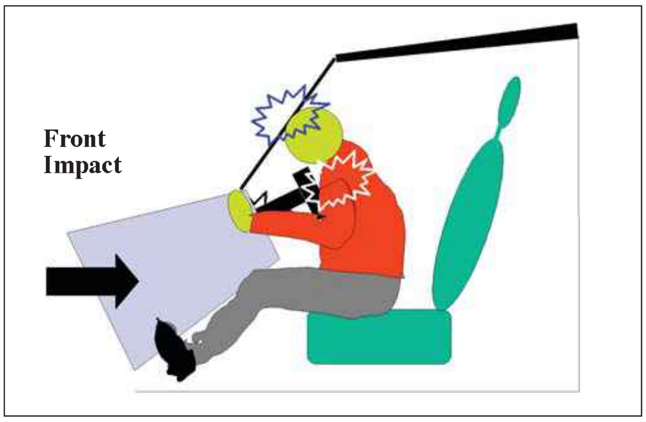

Fig. 6 Diagram shows how an unrestrained driver will sustain injuries to the chest and head in a collision with frontal impact. (Modified and reproduced with permission from the American College of Surgeons, Advanced Trauma Life Support for Doctors, 7th ed, 2004:320, Fig. 2).[1]

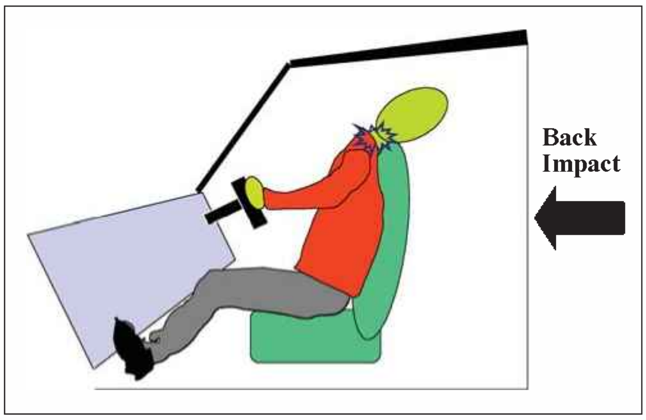

Fig. 8 Diagram shows how a whiplash neck injury can occur in a back-impact collision in the absence of a head restraint. (Modified and reproduced with permission from the American College of Surgeons, Advanced Trauma Life Support for Doctors, 7th Ed, 2004:321, Fig. 3).[1]

Back Impact. Back impact is associated with acceleration of the vehicle which leads to hyperextension of the head.[2,4,7] If the occupant is restrained, this will be followed by a rebound flexion of the head. Both movements are called whiplash injury.[2,4,7] The front seat occupants are at high risk of getting whiplash injury especially in the absence of head restraints (Fig. 8).[7] If the head contacts with a head restraint, the hyperextension movement of the neck will be prevented and the severity of injury is reduced.[2,7] Furthermore, presence of head restraint prevents collision between front and back seat occupants.

Side Impact. Side impact could occur due to collision between two vehicles, between a vehicle and an object, or due to rollover of the vehicle. Occupants' injuries vary depending on their position during the crash.[8] The region of the body which is close to the side of impact will be injured directly, while those away from the impact may hit the other side of the vehicle[2] (Fig. 9). Severe brain and thoracic injuries and mortality occur more frequently in side impact crashes compared with other types.[4,9] The nearer the occupant is to side of the impact, the more serious his/her thoracic or abdominal injury will be.[8]

Fig. 9 Photograph shows the remains of a car after a side-impact collision with a palm tree. The 30-year-old female driver answered her cell phone while she was driving and lost control of her car. She sustained frontal brain contusion, needed ventilation and was admitted to the ICU. At discharge one month later, she had no neurological deficit but was found to lack concentration.

Fig. 10 Photograph shows a rollover and roof impact accident of a four-wheel vehicle. The driver was travelling at 160 km/hour and lost control of the vehicle. The car rolled over and the roof of the car impacted with a palm tree, which was pulled out from its roots from the collision.

Rollover and Roof Impact. As the vehicle rolls over, the roof can be compressed, and if the roof is not strong enough, the occupant can sustain head and spinal cord injuries (Fig. 10).[2] Unrestrained occupants inside the vehicle are susceptible to more serious injury as they are vulnerable to injuries caused by movements inside the car. They can also be ejected from the vehicle. Ejection from the vehicle triples the injury severity and increases admissions to intensive care units and mortality.[4] Ejected victims are unprotected and are hence susceptible to be run over by another running vehicle.

SEAT BELTS AND AIRBAGS INJURIES

Safety devices of vehicles have been introduced so as to prevent severe collision injuries.[5,6,10] Although they can reduce both morbidity and mortality, they may also cause other specific injuries.[2,11] Seat belts may cause injuries either by compression or hyperflexion.[2] Abdominal wall ecchymosis, internal abdominal injuries and spine fractures were firstly described in 1962 as a seat belt syndrome.[11,12] Clavicle fracture of vehicle occupants is the commonest injury produced by seat belts in front and side impacts.[13] Airbags play a supplementary role to seat belts in preventing severe injuries.[2,10,14,15] Their deployment may cause certain injuries, especially in children and short adults.[10] Direct contact with airbags will injure unrestrained vehicle users.[2] While the majority of airbag injuries are mild, severe head and neck injury may occur.[10] Deployment of the airbag may push the upper extremities against the inner structures of the vehicle, causing upper limb fractures.[10,13,16] Furthermore, corneal abrasion, eyelid laceration, retinal contusion and detachment, and eye lens dislocation have been reported.[14] The rapid deployment of the airbag releases large amounts of heat energy, which can lead to thermal burns on the face and forearm either directly, or from melting clothes. Chemical materials released during airbag deployment may also cause alkali burns to the skin and eyes.[15]

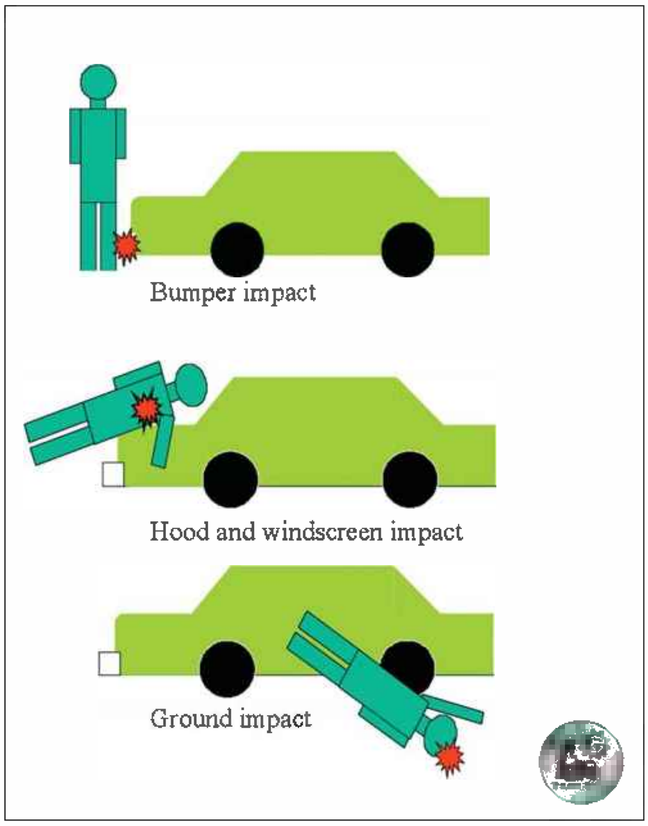

Fig. 11 Diagram shows the classical three phases of pedestrian injury.

Fig. 12 Radiographs show (a) comminuted fractures of the tibia and fibula in both lower limbs; and (b) a haemothorax in the left side of the chest, sustained by a 50-year-old male pedestrian who was hit by a vehicle.

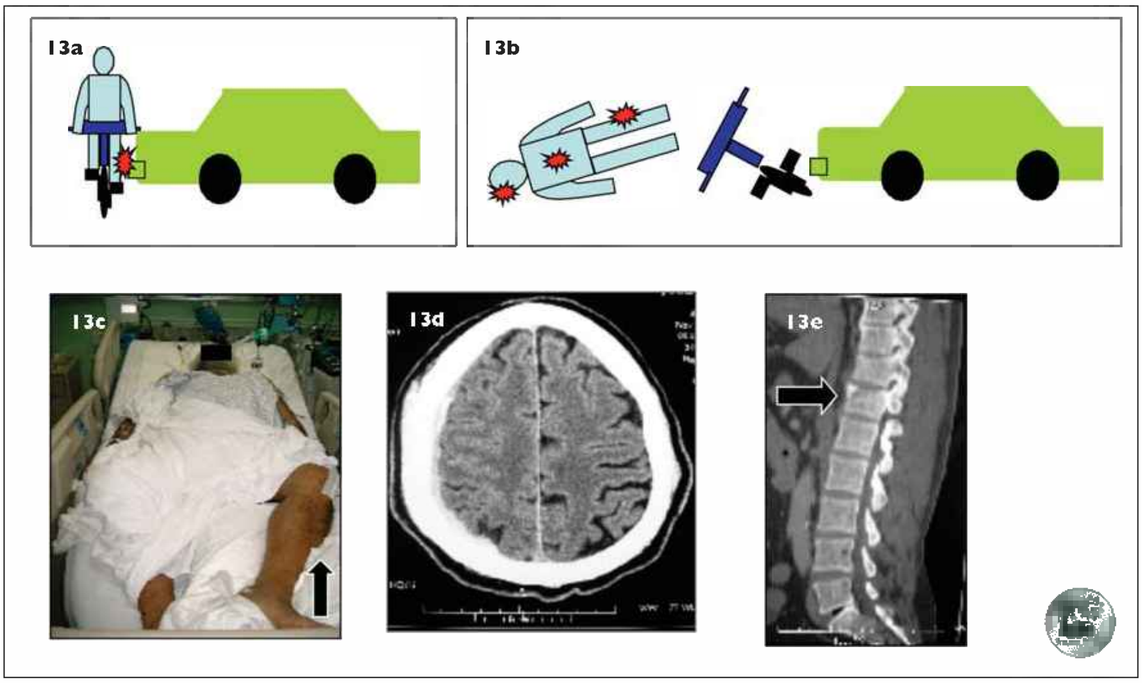

Fig. 13 Diagrams show how a 60-year-old male cyclist (a) sustained a lateral motor vehicle impact on his left side; (b) followed by hitting the ground. (c) Photograph shows that his left leg was swollen without fracture (arrow), while CT images show that he had sustained (d) right subdural haematoma; and (e) flexion compression injury of T12 (arrow).

PEDESTRIAN INJURIES

Pedestrian injuries are a major cause of morbidity and mortality. These injuries are more common in developing countries, where the majority of the population do not have transportation facilities.[2] The body of the pedestrian is not protected when it is hit by a vehicle. The size of both the vehicle and the victim will affect the pattern of injuries.[4] Classically, pedestrian injuries consist of three phases: the bumper impact, hood and windscreen impact and the ground impact (Fig.11).[17,18] This will lead to classical lower limb injury due to the bumper impact, chest and abdominal injuries due to the hood and

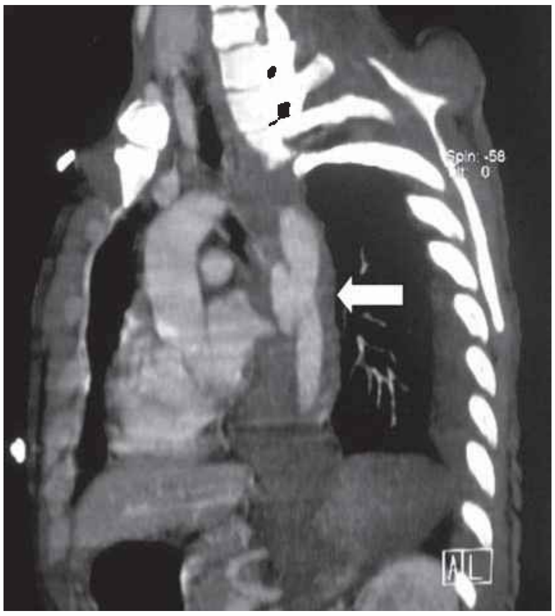

Fig. 14 Reformatted coronal CT image of the chest with intravenous contrast shows a thoracic aortic tear 5 cm distal to the left subclavian artery (arrow). The 37-year-old male driver, who was unrestrained, had a deceleration front-impact collision upon which his chest hit the steering wheel. He complained of severe agonising epigastric pain. His vital signs were stable, and his abdomen was soft and lax.

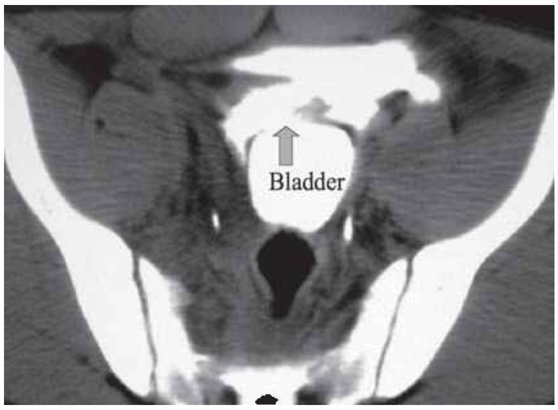

Fig. 15 CT scan shows a rupture to the urinary bladder (arrow), caused by an abdominal compression injury.

windscreen impact, and head and cervical spine injuries due to the ground impact[2,4,17,18] (Fig. 12). This mechanism of pedestrian injury is called Waddle's Triad.[17,18] The higher the vehicle bumper, the higher the region of the body that will sustain injury.[2,4] Serious injuries to the pelvis, abdomen and chest of the pedestrian may occur by a direct impact of the bumper of a four-wheel drive vehicle.[4] In child pedestrains, serious head injuries can occur if the bumper hits their head.[4]

CYCLISTS

In cycling, the commonest causes of injury are falling down, and striking against a vehicle or a fixed object.[2,19,20] Although the body extremities sustain most of the injuries among bicyclists, head injury is the main cause of hospitalisation and mortality.[20] Components of the bicycle itself could also injure the riders. Falling on the handlebars of the bicycle produces hepatic or pancreaticoduodenal injuries. Leg and foot injuries can be caused when the foot gets caught in the moving wheel of the bicycle. The spokes can also inflict injuries upon the rider. Genital and rectal injuries might be sustained in crashes involving the saddle and seat-post. If a motor vehicle hits the bicyclist, the cyclist's head may sustain multiple impact injuries from hitting both the motor vehicle and the ground (Fig. 13).[2] Motor vehicle collision is the cause for 30%–50% of bicycle-related injuries requiring hospitalisation. Moreover, it is a major cause of head injury and death of bicyclists.[20] Focal brain injuries as extradural haematomas are caused by direct blows to the head, while diffuse axonal injuries are produced by rotational movement, especially in the coronal plane. Cycle helmets protect against head and brain injuries in all ages and in all types of accidents.[20,21] To be effective, it should be worn at all the times during cycling, should properly fit the head, and should be made of high quality material to absorb the impact shock.

COLLISIONS WITH LARGE ANIMALS

These collisions occur in certain areas of the world where large animals live in the wild.[22] The impact of injury will depend on the size, height and weight of the animal.[22] Moose and camels, for example, inflict distinctive patterns of damage to the vehicle An impact with the moose often results in significant damage to the roof of the car, while the front and bonnet remain fairly undamaged. Severe head injury usually occurs to the occupants as a result of a collision with the moose.[22] An accident involving the camel will result in the destruction of the windscreen and cause the collapse of the vehicle roof. Occupants in the front seats will therefore sustain the most injuries.[22,23] Occupants' head and neck are the areas which sustain the injury. As the passenger flexes his body to avoid the injury, the occiput and cervical spine sustain the impact dorsally. The resulting vertical force causes compression fractures of the spine and possible paraplegia may occur.[21] The injuries caused by collisions with smaller animals have less severity.[22,24]

INTERNAL ORGAN INJURIES

We have previously discussed the extent of injury, caused by collision impact, on the patient. The internal organs of the patient can also be injured by sudden acceleration, deceleration or strong compressive forces.

Acceleration-deceleration injuries. Blunt traumatic rupture of the thoracic aorta, which is a life threatening injury, typically represents a deceleration injury.[2,25] This may occur in motor vehicle collisions and pedestrian crashes.[25] It is more common in vehicular front and lateral side impacts.[8,25] The ascending aorta and its arch are mobile while the descending aorta is fixed.[25] Because of their difference in mobility, when subjected to sudden deceleration, the descending aorta will decelerate sooner, while momentum continues to carry the arch of the aorta forward. This difference in deceleration causes a classical injury that occurs 5–10 cm distal to the left subclavian artery, where the fixed and mobile parts meet (Fig. 14). In addition, a fracture of the thoracic vertebrae can also directly injure the aorta, due to their close proximity to each other.

Compression injury. Compression of the hollow viscus, such as closed intestinal loops or urinary bladder, will cause injury when pressure within these organs increases suddenly. They are especially susceptible to injury when their walls are stretched (Fig. 15). In contrast, if these organs were empty, a larger force is required to cause injury.[2] This occurs due to the effect of tri-axial stress when the organ is stretched. As a demonstration of tri-axial stress, if one touches an inflated balloon with the tip of a pencil, the balloon ruptures as soon as contact is made. This is because the structural strength of the balloon fibres is compromised in the inflated state. In contrast, if the same balloon were to be subjected to the same pressure from the pencil tip in a deflated state, there will be difficulty in trying to pierce the balloon. By applying the same principle, a sudden increase in intra-abdominal pressure can cause diaphragmatic rupture.[2]

Understanding these mechanisms is essential to diagnosing life-threatening occult lesions in blunt trauma.[2] For example, a patient who is haemodynamically stable and complains of epigastric pain while his/her abdomen is soft and lax, may have a ruptured diaphragm, aortic injury or pancreaticoduodenal injury. These conditions may not be associated with intraperitoneal bleeding. From our experiences, we have found that only by appreciating the biomechanisms of high energy trauma, associated with high clinical suspicion can these conditions be diagnosed at an early stage.

CONCLUSION

It is essential for clinicians to take a proper history of the event of injury. Each case is unique. With knowledge and understanding in this area, a bit of imagination, and critical thinking, biomechanics of trauma becomes a very interesting and useful tool for clinicians.

REFERENCES

1. American College of Surgeons. Advanced Trauma Life Support for Doctors. 7th ed. Chicago, IL: American College of Surgeons, 2004: 315-35.
2. Mackay M. Engineering in accidents: vehicle design and injuries. Injury 1994; 25:615-21.
3. Stefanopoulos N, Vagianos C, Stavropoulos M, Panagiotopoulos E, Androulakis J. Deformations and intrusions of the passenger compartment as indicators of injury severity and triage in head-on collisions of non-airbag-carrying vehicles. Injury 2003; 34:487-92.
4. Hunt JP, Weintraub SL, Wang YZ, Buechter KJ. Kinematics of trauma. In: Moore EE, Feliciano DV, Mattox KL. Trauma. 5th ed. New York: McGraw-Hill, 2004: 141-58.
5. Rupp JD, Schneider LW. Injuries to the hip joint in frontal motor-vehicle crashes: biomechanical and real-world perspectives. Orthop Clin North Am. 2004; 35:493-504, vii.
6. Mayrose J, Jehle D, Hayes M, et al. Influence of the unbelted rear-seat passenger on driver mortality: "the backseat bullet". Acad Emerg Med 2005; 12:130-4.
7. Maher J. Report investigating the importance of head restraint positioning in reducing neck injury in rear impact. Accid Anal Prev 2000; 32:299-305.
8. Newgard CD, Lewis RJ, Kraus JF, McConnell KJ. Seat position and the risk of serious thoracoabdominal injury in lateral motor vehicle crashes. Accid Anal Prev 2005; 37:668-74.
9. Bazarian JJ, Fisher SG, Flesher W, et al. Lateral automobile impacts and the risk of traumatic brain injury. Ann Emerg Med 2004; 44:142-52.
10. Mayberry JC. Blunt injury mechanisms. In: Trunkey DD, Lewis FR. Current Therapy of Trauma. 4th ed. St. Louis: Mosby, 1999: 50-3.
11. Campbell DJ, Sprouse LR 2nd, Smith LA, Kelley JE, Carr MG. Injuries in pediatric patients with seatbelt contusions. Am Surg 2003; 69:1095-9.
12. Munshi IA, Patton W. A unique pattern of injury secondary to seatbelt-related blunt abdominal trauma. J Emerg Med 2004; 27:183-5.
13. Conroy C, Schwartz A, Hoyt DB, et al. Upper extremity fracture patterns following motor vehicle crashes differ for drivers and passengers. Injury 2007; 38:350-7.
14. Cooper H, Thomas T. Ocular injuries related to airbag use. Am J Emerg Med 2004; 22:135-7.
15. Tsuneyuki Y, Gozo N, Masaki F, Osamu M. Facial contact burn caused by air bag deployment. Burns 2003; 29:189-90.
16. Duma SM, Boggess BM, Crandall JR, et al. Upper extremity interaction with a deploying side airbag: a characterization of elbow joint loading. Accid Anal Prev 2003; 35:417-25.
17. Grossman MD. Patterns of blunt injury. In: Peitzman AB, Rhodes M, Schwab CW, Yealy DM, Fabian TC, eds. The Trauma Manual, 2nd ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002: 6-7.
18. Waddle's Triad in Pedestrian Stuck by Automobiles. Available at: www.medal.org. Accessed March 18, 2007.
19. Abu-Zidan FM, Nagelkerke N, Rao S. Factors affecting severity of bicycle-related injuries: The role of helmets in preventing head injuries. Emerg Med Australas [online] 2007, June 6. doi:10.1111/j.1742-6723.2007.00967.x
20. Eid HO, Bashir MM, Muhammed OQ, Abu Zidan FM. Bicycle-related injuries: a prospective study of 200 patients. Singapore Med J. In press.
21. Lee AJ, Mann NP. Cycle helmets. Arch Dis Child 2003; 88:465-6.
22. Bashir MM, Abu Zidan FM. Motor vehicle collisions with large animals. Saudi Med J 2006; 27:1116-20.
23. all-Sebai MW, al-Zahrani S. Cervical spinal injuries caused by collision of cars with camels. Injury 1997; 28:191-4.
24. Abu-Zidan FM, Parmar KA, Rao S. Kangaroo-related motor vehicle collisions. J Trauma 2002; 53:360-3.
25. Richens D, Field M, Neale M, Oakley C. The mechanism of injury in blunt traumatic rupture of the aorta. Eur J Cardiothorac Surg 2002; 21: 88-93.

SINGAPORE MEDICAL COUNCIL CATEGORY 3B CME PROGRAMME
Multiple Choice Questions (Code SMJ 200707B)

	True	False
Question 1. The basic physics of transmission of energy in motor vehicle collisions indicates:		
(a) The relationship between the energy and velocity is linear.	☐	☐
(b) The relationship between velocity and mortality is exponential.	☐	☐
(c) Spinal cord injury without radiological findings is more common in old age compared with children.	☐	☐
(d) Low energy trauma may cause severe injuries in old age.	☐	☐
Question 2. In motor vehicle collisions with side impact:		
(a) The occupant near the side of impact will move towards the impact.	☐	☐
(b) The severity of injury is related to the depth of intrusion.	☐	☐
(c) Severe injuries and mortality are less compared with other types.	☐	☐
(d) Seat belts protect against side impact injuries.	☐	☐
Question 3. In pedestrians' injuries:		
(a) The pattern of injury is affected by the height of the vehicle's bumper and the position of the victim.	☐	☐
(b) The Waddle's Triad consists of bumper impact, hood impact and windscreen impact.	☐	☐
(c) Injuries are more severe and mortality is higher compared with vehicle occupants.	☐	☐
(d) Compound comminuted tibial fractures are common.	☐	☐
Question 4. In bicycle-related injuries:		
(a) Extremities are the most affected region.	☐	☐
(b) Handlebar trauma may cause localised energy transfer to the liver and pancreas.	☐	☐
(c) If a motor vehicle hits a bicycle, the bicyclist's head may sustain a two-hit impact.	☐	☐
(d) Helmets can prevent low facial injuries.	☐	☐
Question 5. Concerning internal organ injuries:		
(a) The descending aorta is usually injured by acceleration mechanism.	☐	☐
(b) Majority of blunt traumatic aortic rupture involves the ascending aorta.	☐	☐
(c) The full urinary bladder is injured by biaxial stress effect.	☐	☐
(d) More energy is needed to cause damage in empty hollow organs.	☐	☐

Doctor's particulars:

Name in full: ____________________

MCR number: ____________________ Specialty: ____________________

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SUBMISSION INSTRUCTIONS:

(1) Log on at the SMJ website: **www.sma.org.sg/cme/smj** and select the appropriate set of questions. (2) Select your answers and provide your name, email address and MCR number. Click on "Submit answers" to submit.

RESULTS:

(1) Answers will be published in the SMJ September 2007 issue. (2) The MCR numbers of successful candidates will be posted online at **www.sma.org.sg/cme/smj** by 15 September 2007. (3) All online submissions will receive an automatic email acknowledgment. (4) Passing mark is 60%. No mark will be deducted for incorrect answers. (5) The SMJ editorial office will submit the list of successful candidates to the Singapore Medical Council.

Deadline for submission: (July 2007 SMJ 3B CME programme): 12 noon, 25 August 2007