

Survival following a vertical free fall from 300 feet: The crucial role of body position to impact surface

Weckbach *et al.*

CASE REPORT

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Survival following a vertical free fall from 300 feet: The crucial role of body position to impact surface

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Abstract

We report the case of a 28-year old rock climber who survived an "unsurvivable" injury consisting of a vertical free fall from 300 feet onto a solid rock surface. The trauma mechanism and injury kinetics are analyzed, with a particular focus on the relevance of body positioning to ground surface at the time of impact. The role of early patient transfer to a level 1 trauma center, and "damage control" management protocols for avoiding delayed morbidity and mortality in this critically injured patient are discussed.

Introduction

Vertical deceleration injuries represent a significant cause of preventable deaths and long-term morbidity in survivors [1]. The amount of energy absorbed by the falling body is dependent on the fall height and the characteristics of the contact surface. For example, a fall onto concrete results in an instantaneous loss of speed, whereas falling onto a soft surface will allow for a more gradual deceleration over time [2]. In addition, the position of the body relative to the impact surface represents an important determinant of injury severity. The *American College of Surgeons' Committee on Trauma* (ACS-COT) defines a critical threshold for a fall height in adults as > 20 feet (6 meters), as part of the field triage decision scheme for transport to a designated trauma center [3]. A retrospective analysis of 101 patients who survived vertical deceleration injuries revealed an average fall height of 23 feet and 7 inches (7.2 meters), confirming the notion that survivable injuries occur below the critical threshold of a falling height around 20-25 feet [1]. A more recent study on 287 vertical fall victims revealed that falls from height of 8 stories (i.e. around 90-100 feet) and higher, are associated with a 100% mortality [4]. Thus, a vertical falling height of more than 100 feet is generally considered to constitute a "non-survivable" injury.

The present case report describes the rare survival of a 28-year old rock climber who survived a free fall from 300 feet onto a solid rock surface. This report emphasizes the crucial relevance of body positioning at the time of impact, and the importance of standardized institutional "damage control" management protocols for survival.

Case report

A 28-year old woman was free climbing with her boyfriend near Gunnison, Colorado. Both were wearing a helmet and a harness for safety. The girl had 20 years of experience of rock climbing, being taught early tricks by her father at the age of 8 years. The ascent consisted of three pitches of 90-100 feet (ca. 30 m) each. The climbing distance was defined by the climbing rope which had been fixed at a defined length. The girl took the lead on the third pitch, to a total height of 300 feet (ca. 90 m). After securing the anchor at that height, the rope - which was lacking a security knot - slid through her harness. She then fell a total of 300 feet, with a first impact at 200 feet onto a flat rock surface, and a further fall for about 100 feet. Based on this falling height, the velocity at the time of impact is estimated around 75-80 mph. Her boyfriend witnessed the entire fall, climbed back down and provided first aid at the scene. The patient was awake and moaning, but not responsive to verbal or painful stimuli. She was intubated at the scene and transported to a local level IV trauma center, where she was resuscitated and transfused with 4 units of packed red blood cells (PRBC). Due to ongoing hypotension and transfusion requirements, a

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decision was made for transfer to our regional level 1 trauma center. On arrival, the patient was intubated and sedated. She was hypotensive, with systolic pressures in the 80s. She was successfully resuscitated with crystalloids and blood products, using a standardized institutional massive transfusion protocol with point-of-care thrombelastography-guided resuscitation [5,6]. The patient was managed according to the ATLS guidelines for initial assessment and management, and by our institutional “damage control” protocols, including the initial spanning external fixation of femur shaft fractures [7,8] and a proactive “spine damage control” approach [9].

The patient sustained the following combination of injuries:

- Blunt chest trauma with sternal fracture, bilateral hemo-/pneumothoraces, bilateral pulmonary contusions, right 1 and 2 rib fractures, left 9-11 rib fractures.
- Blunt abdominal trauma with grade 3 liver laceration, grade 2 splenic laceration, and a devascularized right kidney.
- Mild traumatic brain injury.
- Rotationally unstable flexion/distraction injury at T6 (AO/OTA type 52-C2.1) with traumatic spinal cord transection and complete paraplegia ASIA grade A below T6.
- Unstable L1 burst/split fracture (AO/OTA type 53-A3.2).
- Unstable pelvic ring injury with bilateral SI-joint disruption, bilateral L5 transverse process fractures, bilateral pubic rami fractures, and left-side transalar/transforaminal Denis type 2 sacral fracture (Young-Burgess type LC-3, AO/OTA type 61-B3.3).
- Right femur shaft fracture (AO/OTA type 42-A3.2).
- Right type IIIA open talar body fracture (AO/OTA type 81-C3) and associated posterior facet calcaneus fracture (AO/OTA type 82-C2)
- Left comminuted joint-depression type calcaneus fracture (AO/OTA type 82-C3).

The injury pattern of bilateral lower extremity fractures and of the pelvic ring injury are shown in Figure 1.

The chest trauma was managed by placement of bilateral chest tubes. The patient responded well to initial resuscitation and remained normotensive and well oxygenated, with a blood pressure of 115/80 mmHg, heart rate of 82/min, and 100% SO₂ on 0.6 FiO₂. She was taken to the operating room for “damage control orthopaedics” (DCO) procedure with unilateral spanning external fixation of the right femur fracture, surgical debridement of the open talar fracture with primary wound closure, and spanning external fixation of the right ankle in a delta-frame. The contralateral



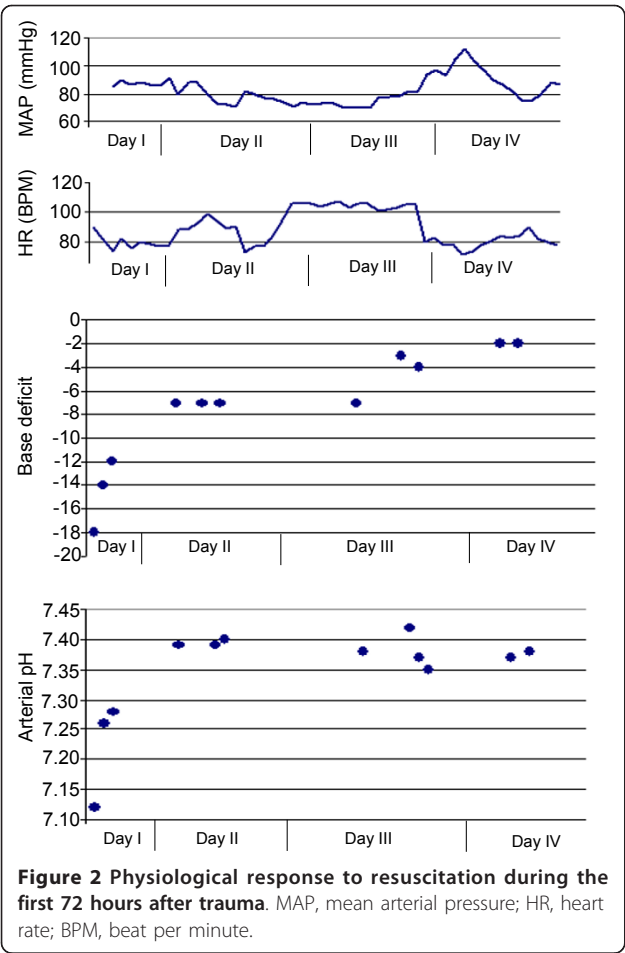
Figure 1 Injury pattern of bilateral lower extremities and pelvic fracture on initial multislice CT scan. The patient sustained a right-side open, comminuted talar body fracture, and a contralateral comminuted “joint-depression”-type calcaneus fracture, and a highly unstable pelvic ring injury with bilateral sacro-iliac joint disruptions (arrows).

comminuted calcaneus fracture was placed in a well padded bulky Jones splint. The patient was then transferred to the surgical intensive care unit (SICU) for further resuscitation. The physiological response to resuscitation during the first 72 hours is depicted in Figure 2.

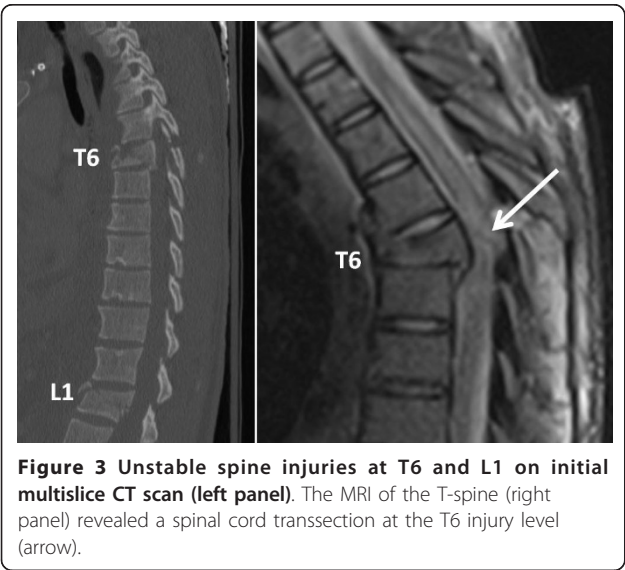
An MRI of her C-/T-/ and L-spine was obtained the next morning which documented a traumatic spinal cord transection at the level of the rotationally unstable T6 flexion/distraction injury (Figure 3). She was taken the same day for preliminary spinal fixation as a “spine damage control” procedure [9]. This included a posterior spinal fusion from T4-T8 with laminectomy and spinal canal decompression at T6, as well as posterior spinal fusion T12-L2. The patient tolerated the procedure well and was brought back to the SICU in stable conditions. She was mobilized with physical and occupational therapy on day 1, and placed on low molecular weight heparin for DVT prophylaxis. The intraabdominal injuries were managed non-operatively.

On day 2, she was taken back to the operating room for stabilization of the pelvic ring injury using bilateral “triangular osteosynthesis” with lumbo-pelvic fixation from L4 to the ilium, and placement of bilateral 7.3 mm cannulated sacro-iliac screws through a safe surgical corridor [10]. On day 3, an IVC filter was placed due to the high risk constellation for a thromboembolic complication.

The patient recovered well from her injuries and from the “damage control” procedures. She was extubated on hospital day 4, and was successfully weaned to room air (Figure 4). She remained fully awake and alert, with a GCS of 15. She had a normal neurological function to bilateral upper extremities, but lack of sensory function below T6, and complete paraplegia to bilateral lower

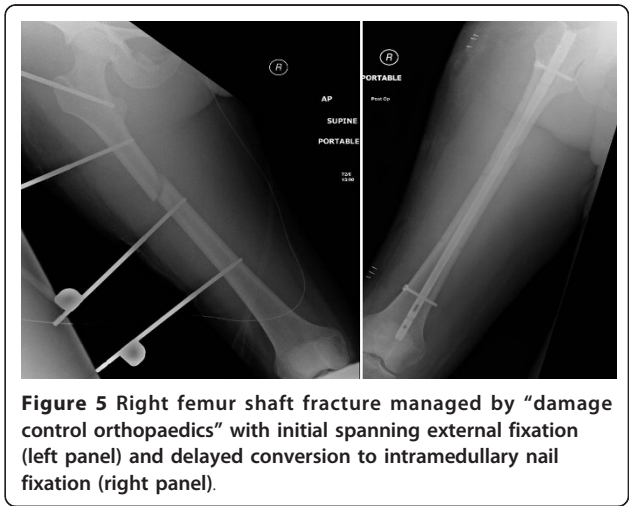


extremities. On day 5, she was taken back to the operating room for locked intramedullary nail fixation of the right femur shaft fracture (Figure 5), removal of the



spanning external fixator, and cannulated lag screw fixation of her right talar body fracture.

The patient had an excellent recovery and was mobilized into a wheelchair with physical and occupational therapy. On day 13, she was taken back to the operating room for completion 360° fusion T5-T7 and T12-L2, with anterior corpectomy of T6 and L1 vertebral bodies, anterior spinal canal completion decompression, and placement of two titanium expandable cages and bone grafting (Figure 6). This procedure was performed through less-invasive left-side posterolateral approaches, including a transthoracic approach to T6 and a retroperitoneal approach to L1 (Figure 7). This less invasive technique was shown to be well tolerated by patients and allow early functional rehabilitation without restrictions [11-13].



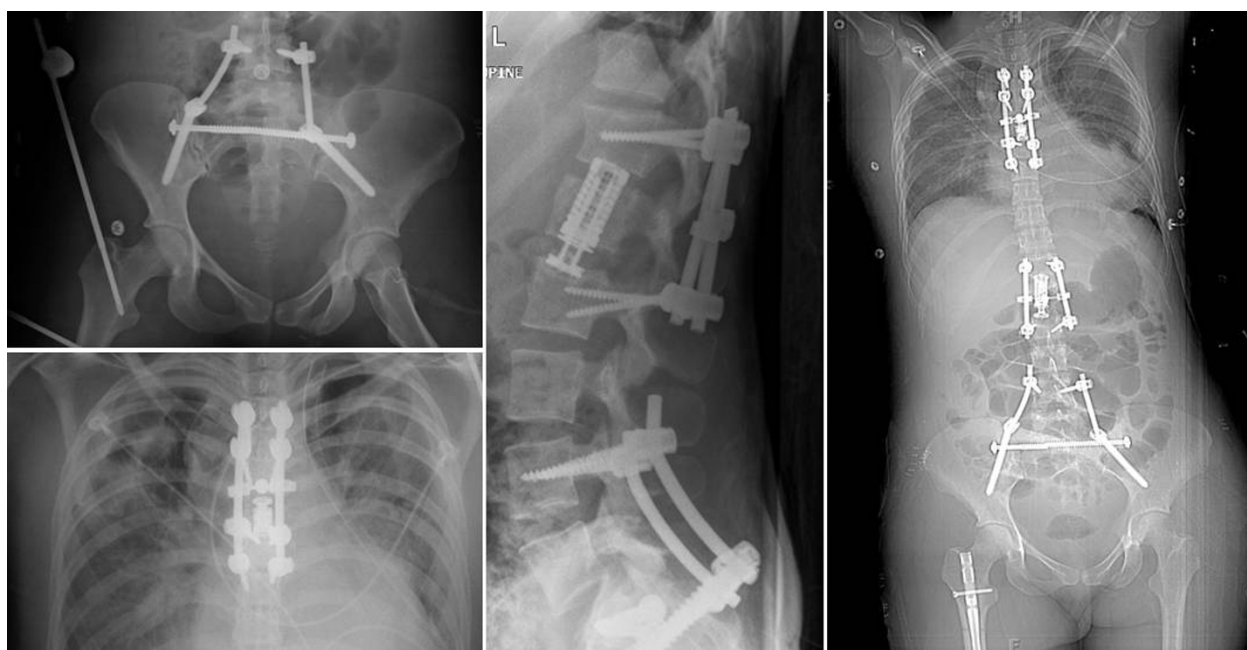


Figure 6 Postoperative X-rays after stabilization of the pelvic ring injury with bilateral lumbo-pelvic/triangular osteosynthesis, and 360° fusion of the unstable T6 and L1 injuries.

The patient had an uneventful further recovery. All surgical wounds healed well, and there were no postoperative complications. At that time, X-rays of her multiple orthopaedic injuries were obtained, which showed early signs of uneventful fracture healing (Figure 8). She was transferred to our neurorehabilitation unit on hospital day 18. The patient remained flaccid below the level of lesion related to the T6 ASIA grade A complete spinal cord injury. She remained in spinal shock until approximately 6 weeks after trauma. She also showed some general processing and impaired short term memory deficits related to her mild traumatic brain injury. Nerve conduction studies confirmed the notion from MRI imaging, in that there was no secondary neurologic conus injury due to the L1 burst fracture which may have further complicated her bowel and bladder management. The applied spinal and pelvic fixation techniques facilitated her mobilization without adjunctive truncal bracing. The initial efforts for self-care and mobilization, however, were complicated by orthostatic hypotension, nausea and anxiety felt to be multi-factorial in etiology. The weight bearing precautions to the lower extremities were discontinued around 9 weeks post injury, based on progressive callus formation seen on follow-up X-rays (Figure 8). The patient quickly progressed to independent transfers. Her cognitive processing improved to essentially normal. The IVC filter was removed prior to discharge. She was transferred to her local community regional spinal cord rehabilitation center out-of-state at 2½ months after injury in

excellent conditions, for completion of her neurorehabilitation program.

Discussion

This is the first case report, to our knowledge, which documents survival from a free vertical fall of 300 feet onto a hard surface. The anecdotal threshold for sustaining critical injuries from a vertical fall has been defined by the *American College of Surgeons' Committee on Trauma* (ACS-COT) at >20 feet (6 meters) [3]. This threshold is corroborated by the published literature on survivors from accidental and suicidal free falls [1]. In general, a falling height of >100 feet is considered a "non-survivable" injury [4]. The height of 300 feet is ascertained by the fact that in "lead climbing", the climbing rope is fixed at a defined length, corresponding to 150 feet in the present case. The patient's boyfriend took the lead on the first pitch of 150 feet, where after she took over the lead on the next 150 feet. After securing the anchor at 300 feet height, the rope slid through her harness and she sustained an undamped vertical free fall onto a flat rock surface.

Most falls from rock climbing result in simple sprains which affect ankle, elbow, and shoulder joints [14]. A retrospective analysis revealed that fractures of the spine and lower limbs represent the most frequent injury pattern in survivors from vertical falls from a height [1]. These findings concur with the notion presented in this case report, that a fall on both feet represents the "ideal"

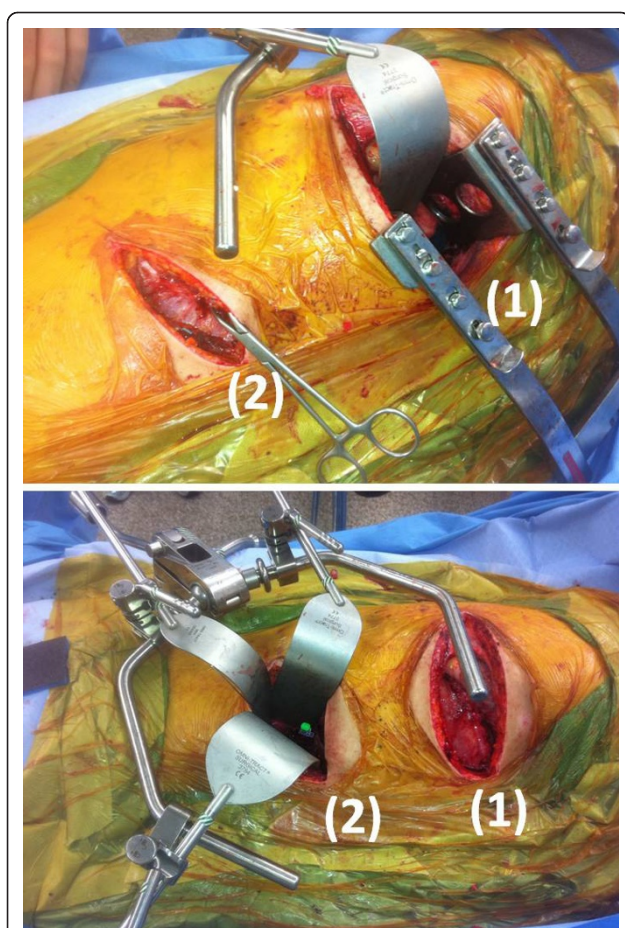


Figure 7 Less-invasive two-cavity approach for anterior corpectomy, spinal canal decompression, and anterior spinal fusion of the unstable thoracic and lumbar spine fractures. The T6 injury was managed through a small posterolateral thoracotomy (1), while the L1 fracture was addressed through a retroperitoneal approach along the 11th rib (2). The less-invasive procedure was tolerated well by the patient, and allowed for early mobilization without restrictions.



Figure 8 Early fracture healing documented by X-rays obtained at 6 weeks post injury.

body to impact surface position with regard to survival from vertical falls. In contrast, brain injuries and cervical spine injuries resulting from a fall on the head represent the main cause for lethal outcomes after falls [15]. The patient's specific injury pattern is suggestive of a trauma mechanism by which the patient landed on both feet first, followed by a deceleration/twisting mechanism to her right femur and the thoracic and lumbar spine, ending in a fall on the back which induced the final deceleration forces leading to the intra-abdominal and thoracic injuries. As outlined by the presumed trauma mechanism depicted in the diagram in Figure 9, the patient landed feet first, leading to an energy transfer over a longer deceleration area from feet (**panel A**) to femur and pelvis (**panel B**) to a rotational flexion/distraction mechanism of the thoracic spine (**panel C**), followed by a fall on the back (**panel D**), which is associated with a distribution of the deceleration force over a larger surface area. Since the soft tissues and viscera decelerate slower than the skeleton, the final impact likely led to the chest trauma and intra-abdominal injuries to the parenchymal organs (**panel D**). This patient would likely not have survived the same injury mechanism, if she had landed head and neck first.

Furthermore, the rapid intubation, early resuscitation, and timely transfer to a qualified level 1 trauma center likely contributed to this patient's survival. It is striking to note that, despite the critical overall injury pattern, the patient did not sustain significant complications which may have been expected as the sequelae of the traumatic impact, including posttraumatic/postoperative infections, and the development of remote organ insults, including acute respiratory distress syndrome (ARDS) and multiple organ failure, which represent the main cause of late deaths in patients who survive the initial injury [16-18].

Likely, the application of standardized resuscitation strategies, in conjunction with thrombelastography-guided administration of blood products, and the limited exposure to the interventional burden by "damage control" strategies applied in the first few days after trauma, contributed to the survival of this patient [5-7,9,11,19,20].

The impact of falling height, quality of impact surface, and the position of the body to the impact surface on injury severity and outcome require further investigation in ex-vivo experimental and biomechanical studies.

Written informed consent

Written informed consent for publication of this case report and of all radiological images and pictures was obtained from the patient by the senior author. She agreed to publish the case report including all figures shown in this paper. Written consent by the patient is available to the journal's Editor-in-Chief upon request.

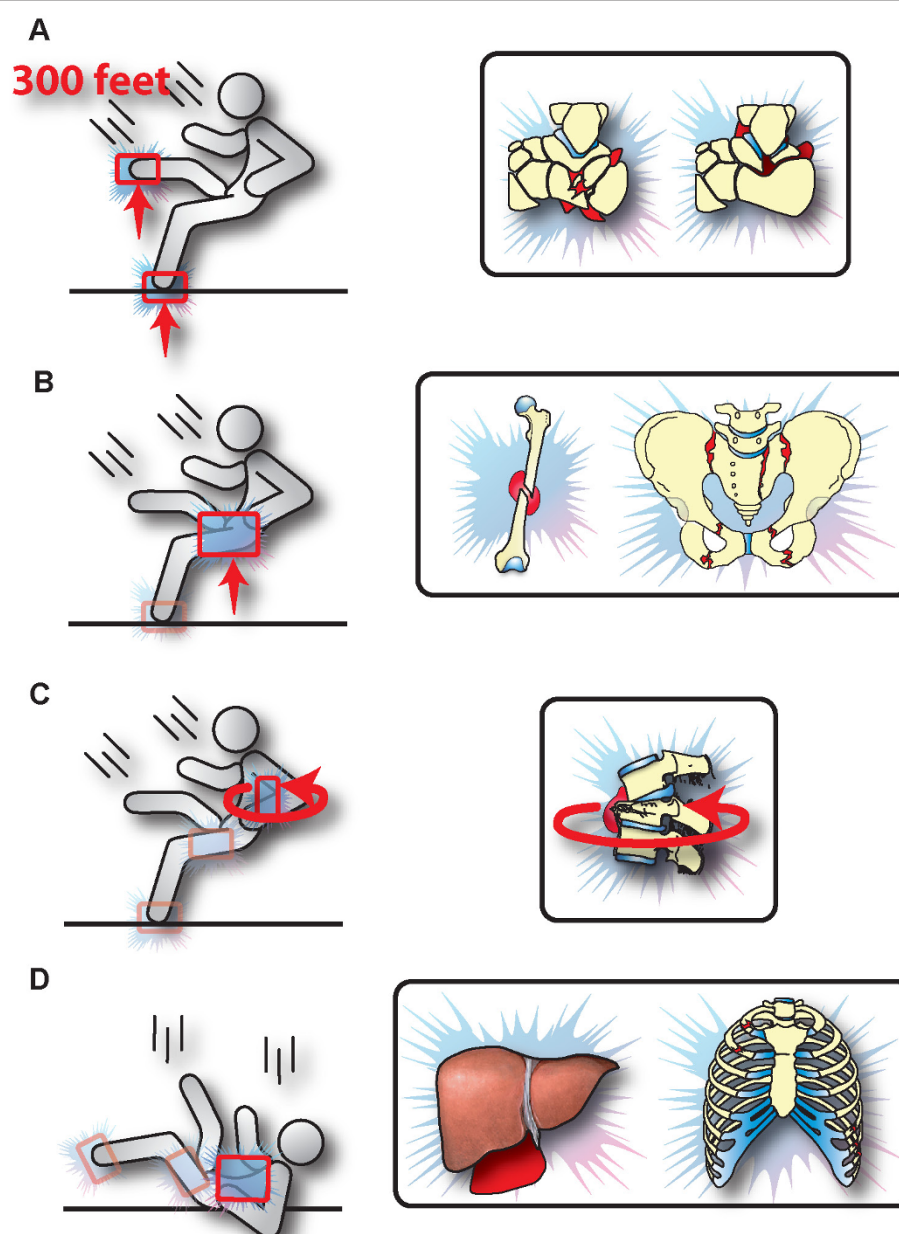


Figure 9 Presumed trauma mechanism resulting from a 300 feet vertical fall in the present case. Landing feet first is the likely root cause for survival in this 28-year old patient who sustained an injury mechanism generally classified as “non-survivable”. Please refer to text for details.

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Authors' contributions

PFS, EEM, and CCB designed this case report. PFS and SW drafted the first version of the manuscript. MAF contributed the graphic artwork in Figure 8. EEM and CCB managed the initial resuscitation and performed all general surgery procedures. PFS performed all orthopaedic surgical procedures. MB was in charge of the neurorehabilitation of this patient. All authors

contributed to the revised drafts of this manuscript and approved the final version of this paper.

Competing interests

The author declares no competing interests with regard to this manuscript.

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