Orthopaedic Injuries Associated With Fall From Floor Forty-Seven

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Summary: This case report provides background reviewing mortality rates associated with falls from height before detailing the clinical history of a patient who survived a fall from a height of 43 stories. A multidisciplinary team treated both orthopaedic and nonorthopaedic injuries with the ultimate goal of preserving potential for independent function. A discussion of relevant pathoanatomy seen after falls from a height is included, and the discussion concludes with a review of damage control orthopaedics.

Key Words: fall from height, free fall, deceleration injury

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BACKGROUND

Falls from a height remain a relatively frequent cause of injury and death in the urban environment, estimated to account for more than 15,000 deaths annually in the United States alone.[1] Large urban environments such as New York City have an abundance of tall buildings providing ample opportunity for falls from significant heights. Reports of accidental and intentional falls from heights do not commonly report high survivorship from falls greater than 5 stories. In a case series from New York City's Harlem Hospital, Lewis et al[2] recorded only 3 survivors of 20 people presenting to the hospital after falls from greater than 5 stories and no survivors falling from greater than 8 stories. Similarly, Lapostolle et al[3] reported no survivors from a population of 28 patients who had fallen from greater than 7 stories. Other studies from urban centers have reported similar data,[6–9] although a few papers have documented higher survival rates, typically in the setting of excluding patients who died at the scene, died during resuscitation in the emergency department (ED), or were dead on arrival in the hospital such as Scalea et al[4] who recorded 60% survivorship from a height of 7 stories in a study including patients who were alive on initial presentation. Even without explicit exclusion criteria, many published series of fall victims are hospital based and inherently biased toward survival as nonsurvivors may not be transported to a hospital at all. Lapostolle et al[3] estimated that 70% of fall mortalities occur without the patient ever reaching the hospital, suggesting true survival rates are likely lower than reflected in published data.

Overall, survivorship from heights of greater than 6 stories is low and a mortality of 50% (known as the T50) has typically been associated with a fall from either 4 or 5 stories. A classic article by DeHaven[10] in the now defunct journal *War Medicine* reported 1 case of survival after a fall from approximately 10 stories, but reports of survival from such heights are rare. Few reports of falls from extreme heights exist in the orthopaedic literature, principally because of low survivorship. We present the remarkable story of a patient presenting to the ED after a fall from an incredible height.

CASE REPORT

U.N. was a 37-year-old male window washer who presented to a Level I trauma center in a large urban city after a fall from the roof of a nearby apartment building. A work platform gave way as the patient and his coworker stepped from the roof of the 47-floor building onto the platform, sending them falling roughly 43 stories to an elevated surface below. The patient's coworker was pronounced dead at the scene whereas UN was taken 14 blocks by ambulance to the nearest ED. On arrival in the ED, the patient had a Glasgow Coma Scale score of 8 but was initially hemodynamically stable. Although emergency medical service reported that he was interactive in the field, he was unresponsive in the ED except for withdrawal to pain. The patient was moving all extremities intermittently and was noted to be stridorous. Physical examination was significant for an open left proximal tibia fracture and deformity with crepitus on range of motion of the right elbow. Other than moderate bleeding from his open left tibia fracture site, there was no evidence of brisk active bleeding apparent on his arrival in the ED, he had strong peripheral pulses in all extremities, and his pelvis was clinically stable. U.N. was intubated in the ED and a radiographic trauma series was obtained that demonstrated no pelvic or cervical spine injuries. Computed tomography (CT) scans of the head, chest, abdomen, and pelvis demonstrated changes consistent with diffuse axonal injury and subdural hematoma, a right-sided hemothorax, pericardial effusion, L3 burst fracture with retropulsion of fragments into the spinal canal, but no abdominal or pelvic injuries. The right and left legs and the right arm were splinted before the patient was quickly transferred to the surgical intensive care unit (SICU). On arrival in the SICU, a massive transfusion protocol was initiated as the patient became hypotensive and coagulopathic. During this initial resuscitation period, UN received 24 units of packed red blood cells, 19 units of fresh frozen plasma, 4 units of platelets, and over 15 liters of crystalloid to address blood loss, hypotension, and coagulopathy. A bedside irrigation and debridement of the open tibial plateau fracture was performed by the orthopaedic team within several hours of first presentation in the ED, and the neurosurgeons placed a ventriculostomy to evacuate the subdural hematoma once the patient's platelet count

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was maintained above 100,000/mm^2. Shortly thereafter, a bedside open laparotomy was needed for abdominal compartment syndrome heralded by worsening oxygenation from elevated abdominal pressures and the abdomen was subsequently left open. See Table 1 for a complete listing of surgical interventions during the patient's hospital course. Portable radiographs obtained in the SICU on hospital day 1 demonstrated a Schatzker V fracture of the open left tibial plateau, a right transverse Weber B lateral malleolar fracture with a comminuted talar body fracture, and a comminuted intraarticular fracture of the distal right humerus (Fig. 1). The patient was splinted and monitored in the SICU overnight where his hemodynamic status stabilized. On hospital day 2, UN was able to be transferred to the CT scanner for further evaluation of his musculoskeletal injuries. Imaging with CT delineated the severe comminution associated with the left tibial plateau, the right talus fracture, and the distal right humerus fracture. After the CT scan, the patient was deemed stable enough to be taken to the operating room (OR) for exploration of his laparotomy, hematoma evacuation, and placement of a vacuum-assisted dressing. During the same trip to the OR, external fixation and formal irrigation and debridement of UN's open left tibial plateau fracture and a prophylactic 4 compartment fasciotomy were performed. Because of residual swelling in the right ankle that precluded definitive fixation, an external fixator spanning the right ankle joint was applied on hospital day 7 under the same anesthesia as the general surgery team used to close the laparotomy. On hospital day 12, the tibial plateau fracture was fixed definitively with both medial and lateral proximal tibial locked compression plate but required attention from the plastic surgeons because of inadequate soft tissue coverage after a thorough debridement of nonviable soft tissue associated with the open wound (Fig. 2). Subsequently, the right lateral malleolus and talus and the right distal humerus were definitively fixed when soft tissue swelling had resolved (Fig. 2). A physical therapy regimen was initiated, tailored to the patient's neurologic status and limitations imposed by the burst fracture. Stenosis associated with the L3 burst fracture was decompressed and an instrumented fusion performed by the neurosurgical team. Persistent sagittal plane instability prompted application of a hinged Ilizarov external fixator on hospital day 33.

Although the patient showed slight signs of improving mental status, by hospital day 14, he was still noncommunicative and only occasionally opening his eyes to stimulus—prospects for recovery of higher cognitive function were guarded but uncertain. The following week was characterized, however, by improving mental status, and he began following simple commands and eventually speaking when his tracheostomy collar was capped. The patient's mental status continued to improve, and he started to have meaningful visits with family members. Although U.N. remained non-weight bearing on both lower extremities, he began to be able to actively participate in physical therapy and to tolerate a regular diet. By the end of his impatient hospitalization, U.N. had right elbow range of motion from −15 to 120 degrees, his right ankle was immobilized in a short leg cast with the ankle in neutral position, and the left knee flexed to 30 degrees from full extension. On hospital day 45, UN was cleared for transfer to a rehab facility. On recent outpatient follow-up 9 months after his fall, UN's right elbow range of motion was from 10 to 110 degrees, his right ankle had 20 degrees of plantar flexion and 15 degrees of dorsiflexion, and his left knee ranged from full extension to 50 degrees of flexion. Prominent hardware was removed from the lateral aspect of his left tibial plateau once bony healing had occurred, and although he is at risk for developing posttraumatic arthritis, he has painless range of motion of all affected joints. Although UN still has not yet begun to work again, he is able to walk with a normal gait without assistive devices and is living with his family independently.

DISCUSSION

This is a case of survival after a fall from an extreme height. The failure of the scaffolding and the beginning of the fall was witnessed by passing pedestrians but the impact was

TABLE 1. Surgical Interventions During Hospitalization

Hospital Day	Surgery	Service
1	Presentation in ED	
1	Left open tibia irrigation and debridement (I&D), vaccum dressing (VAC) placement	Orthopaedics
1	Ventriculostomy	Neurosurgery
1	Exploratory laparotomy for abdominal compartment syndrome	General surgery
2	Left tibia I&D, external fixation, fasciotomy	Orthopaedics
2	Dressing change for abdomen, clot evacuation	General surgery
4	Inferior vena cava (IVC) filter placement	Vascular surgery
4	Gastric tube placement, partial abdominal closure, tracheostomy	General surgery
4	Left open tibia I&D	Orthopaedics
7	Right ankle spanning external fixation	Orthopaedics
7	Abdominal I&D, vicryl mesh placement for abdominal defect	General surgery
11	Abdominal I&D	General surgery
11	Left open tibia I&D, partial wound closure	Orthopaedics
14	Left tibial plateau ORIF, removal of external fixator	Orthopaedics
20	Right talus ORIF, removal of external fixator	Orthopaedics
22	Abdominal wound closure	General surgery
27	R distal humerus ORIF	Orthopaedics
29	L1–L5 decompression, fusion for L3 burst fracture	Neurosurgery
29	Left open tibia wound debridement	Plastic surgery
33	Left knee hinged Ilizarov external fixator application	Orthopaedics
36	Left leg split thickness skin grating to open wound associated with tibial plateau fracture	Plastic surgery

*$P < 0.05$.

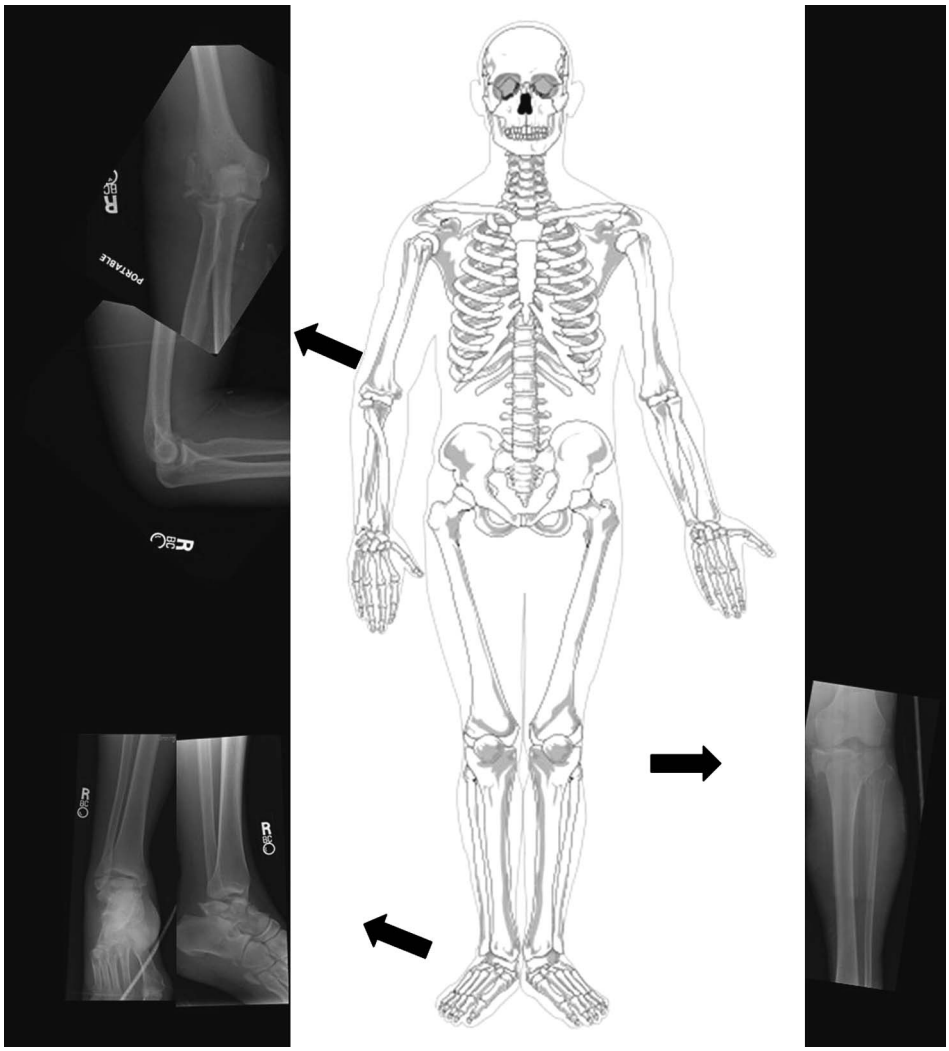

FIGURE 1. Radiographs demonstrating left tibia bicondylar Schatzker V tibial plateau fracture and associated proximal fibular fracture, right ankle transverse Weber B lateral malleolar fracture, and comminuted talar body fractures and right humerus intraarticular, comminuted fracture of lateral condyle.

unwitnessed. The impact dismembered the other person involved in the accident but left UN with relatively mild injuries in relation to the height of the fall.

The 2 types of injuries seen in patients falling from a height are deceleration injuries and direct impact injuries. Deceleration mechanisms bear responsibility for damage to internal organs while most orthopaedic injuries result from direct impact.[11] Orthopaedic injuries in survivors of falls are heavily influenced by the site of impact and the patient's position at impact, lending some predictability to the resultant fracture patterns if details of impact are available. Feet-first impact is classically associated with calcaneal injuries, and the force of impact can be transmitted to other bones in the lower extremity and the pelvis. Vertical transmission of energy is responsible for the incidence, reported to range up to 75%,[11] of lumbar and thoracic spinal fractures in fall victims with calcaneal fractures. Buttocks landings are associated with pelvic fracture in as many as 80% of cases and with vertebral fractures in roughly 50%.[12] Many falls are unwitnessed or unreliably witnessed, however, and the trauma team must let the primary and secondary surveys guide their acute efforts in the ED.

In their text on free fall pathophysiology, Warner and Demling[5] discuss the relationship between fall height and velocity at impact. By their calculation, velocity ($v=\sqrt{(2gh)}$) where g = gravitational constant of 32 feet/s and h = the height of the fall. Velocity becomes terminal when the drag resistance prevents further acceleration—calculated by Warner and Demling to be 120 mph from a height of 32 stories. Surviving an impact onto any hard surface at this speed is unimaginable, most probably hinting that UN did not free fall all 43 stories. Eyewitness accounts report several strikes against the building while the patient fell, and it seems probable based on accounts of the impact scene that he fell along with the platform, the surface area of which likely slowed his descent via a parachute-like effect. A final mitigating factor was a feet-first landing, a position that provides a longer distance for deceleration and kinetic energy dissipation before the trunk and head strike the ground in comparison to a torso- or buttocks-first landing. In the present case report, the patient likely landed on both feet causing severe intraarticular comminution of the right talus and left tibial plateau at direct impact with vertical transmission of impact force to the lumbar spine causing the L3 burst fracture.

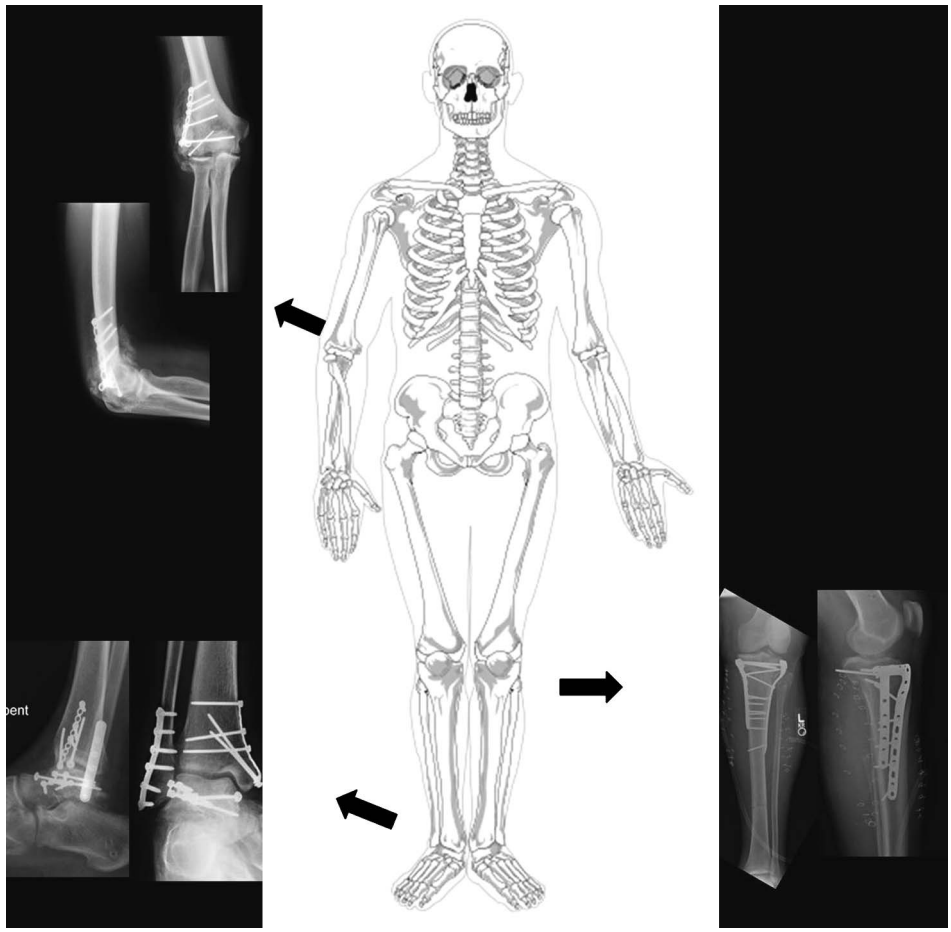

FIGURE 2. Radiographs demonstrating open reduction, internal fixation of the left tibial plateau fracture, right ankle, and right distal humerus.

Damage control orthopaedics (DCO) is a principle directing acute care of multiply injured patients and advocates early temporary fracture stabilization as part of comprehensive multidisciplinary care.[13,14] This approach developed over the past 40 years as it became clear that early intervention was essential for optimal long-term results in a large subgroup of multiply injured patients. DCO evolved from a similar concept in the general surgical literature suggesting early control of hemorrhage after penetrating abdominal trauma followed by a period of resuscitation before definitive surgery could optimize outcomes.[15] Similarly, DCO has been described to include 3 stages: early surgical intervention for temporary stabilization of fractures followed by a period of resuscitation in the SICU before definitive fixation of long-bone injuries in a delayed manner. Nowotarski et al[16] described inclusion criteria for temporary expedient external fixation of fractures to include progressive hypoxia, coagulopathy, hemodynamic instability, elevated intracranial pressures, and risk of disturbing solid organ injuries through positioning and movement during orthopaedic surgery. In this context, only unstable patients or those in extremis are managed by the DCO pathway. Resuscitation endpoints have been described to include stable hemodynamics and oxygen saturation, lactate levels <2 mmol, normal coagulation, normalized temperature, urinary output >1 mL/kg/h, and no requirement for inotropic support.[13] Conversion to definitive osteosynthesis should be performed after these parameters have been satisfied, typically after a delay of several days or more to allow for overall stabilization and normalization of the inflammatory cascade that accompanies severe injury.[17]

One challenge that a multitrauma patient in critical condition presents to the treating orthopaedic team is coordination of procedures with the other surgical services. Flexibility of the schedule of the attending orthopaedic surgeon and a good working relationship with the general surgeons facilitates performing multiple procedures under the same anesthetic, an important consideration in the unstable patient to reduce OR time and transport time.

During the course of UN's hospital course, it was often difficult to prioritize his orthopaedic injuries given the gravity of his other injuries, particularly the traumatic brain injury. Even once the patient had stabilized hemodynamically, he was still ventilator dependent and was given a poor prognosis for a meaningful neurologic recovery by the neurology and neurosurgical teams. When a patient is facing such long odds of recovery, questions of orthopaedic futility are bound to arise, especially when the musculoskeletal injuries are severe and will require a complicated reconstruction across multiple surgical procedures. In addition to the technical demands of complex periarticular ORIF, questions also arose about how to

maintain postoperative range of motion when the patient was unable to actively participate in physical therapy. While there was uncertainty regarding the patient's neurologic recovery, a limited window to address the numerous fractures motivated timely ORIF during periods of relative medical stability. Soon after the tibial plateau and talus fractures were fixed, the patient began to show signs of neurologic improvement, which was timely considering the pressing need for him to participate in postoperative physical therapy. Although he could not bear weight because of the bilateral nature of his injuries, aggressive joint mobilization with a dedicated group of physical therapists helped UN achieve an optimal result.

CONCLUSIONS

Falls from heights greater than 5 stories have a survivorship, which is difficult to accurately quantify due to inclusion biases but is less than 50% and likely decreases sharply above 7 stories. Because initial information regarding the height of the fall and position at impact is often unreliable, strict adherence to advanced trauma life support and DCO protocols with a multidisciplinary approach is critical for comprehensive evaluation and treatment of patients who survive such falls. The case presented in this report required a coordinated effort from orthopaedic surgeons, general surgeons, oral surgeons, neurosurgeons, plastic surgeons, and the SICU in addition to the ED staff. Despite the initially guarded prospects for recovery of mental status, concerted efforts were made in this case to optimally treat all injuries expediently and in a manner so as to preserve potential for ambulation. This strategy was rewarded when UN's neurologic recovery exceeded initial expectations and provides a final learning point regarding optimizing fracture management when the degree of neurologic injury and potential for recovery are uncertain.

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