Polytrauma in a Jet Pilot After Low-Altitude Ejection Without Parachute Deployment

Molly M. Zivkovic; Brannon L. Inman; Matthew R. Figlewicz; Jason A. Burchett; Craig D. Nowadly

BACKGROUND: Ejection seats are designed to be a lifesaving device for aircrew in emergencies. Modern ejection seats are widely prevalent in fighter and bomber aircraft and are occasionally associated with acceleration injury from axial loading (G_z) during the catapult phase of ejection, limb flail injury due to windblast, or parachute landing fall, especially if the ejection is outside of the seat's performance envelope.

CASE REPORT: We present the first known case in the medical literature of a military pilot who survived a low-altitude, high-angulation (>90° of bank angle) ejection where the pilot's ejection seat parachute did not deploy due to contact with the ground before completion of the ejection sequence. The patient's initial exam upon arrival at a trauma center was significant for a Glasgow Coma Scale of 3T, with evidence of cranial and extremity trauma. The patient presented with respiratory acidosis and required upsizing of his endotracheal tube placed in the field. The patient's injury list included bilateral subdural and subarachnoid hemorrhages, a Hangman's fracture, spinal burst fractures, and extensive extremity fractures. After a prolonged hospital stay, the patient was discharged to rehabilitation. The patient made a functional and neurological recovery, including return to independent completion of his activities of daily living.

DISCUSSION: This case provides evidence of favorable outcome after a low-altitude, high-angulation ejection without parachute deployment. This case details the medical and traumatic pathology medical personnel should expect from an ejection that occurs outside of the seat's performance envelope.

KEYWORDS: aircraft, ejection seat, acceleration, military, axial, spinal fracture, aerospace medicine.

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Over the nearly 80 yr since their implementation, ejection seats have proven to be a life-saving tool for military aircrew in a range of otherwise catastrophic circumstances.[1] Advanced sensor suites within the ejection seat automate separation and parachute deployment, limiting pilot injury during all phases of ejection.[1] Aircraft ejections often expose the pilot to more than 10 times the amount of gravity (Gs) of axial (G_z) acceleration in an effort to rapidly remove the pilot from the unsafe situation.[2] Decades of improvement of ejection seat mechanics have afforded an increase in survivability and favorable aircrew outcomes after aircraft mishap or combat damage leads to unrecoverable flight conditions.[3] However, injuries of variable severity are common even in survived ejections, given forces associated with the ejection, the opening shock of parachute deployment, and eventual landing.

We present the first known case in the medical literature of a military pilot who survived a low-altitude, high-angulation ejection where the pilot's ejection seat parachute failed to deploy due to interruption of the ejection sequence when the ejection seat impacted the ground. This report describes the injury patterns sustained by the pilot and the initial medical management of the pilot's injuries, provides clinical images from the patient's initial resuscitation, and documents the patient's recovery.

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CASE REPORT

A previously healthy man in his 30s was brought to the Emergency Department (ED) of a tertiary, academic Level 1 Trauma Center by helicopter emergency medical services (HEMS) after ejecting from an aircraft at low altitude and high angulation (>90° of bank angle) just prior to an aircraft collision that occurred during landing. The patient's ejection seat parachute did not deploy due to interruption of the ejection sequence when the ejection seat impacted the ground. The patient was found several hundred feet away from the aircraft still attached to his ejection seat. The patient was unconscious with agonal breathing and was subsequently intubated by on-scene personnel with a cuffed 5.5 endotracheal tube prior to transport to the ED. The patient was hypotensive en route and received 2 g of tranexamic acid and 2 units of cold-stored whole blood. The patient arrived at a tertiary, academic Level 1 trauma center intubated, on a backboard with a cervical collar, and left leg traction splinted in place.

Upon arrival at the ED, the patient was tachycardic with a heart rate of 110, a blood pressure of 102/65, and oxygen saturation of 94%. On primary survey, he had bilateral equal breath sounds, 2+ pulses in the bilateral upper extremities, and minimally Dopplerable pulses in his bilateral lower extremities. His pupils were 1–2 mm and fixed bilaterally, and his Glasgow Coma Scale was 3T. He had delayed capillary refill in his left lower extremity. There was no evidence of ongoing major hemorrhage.

Secondary survey was significant for a hemostatic laceration on his posterior scalp, a firm abdomen, bilateral upper extremity and posterior left thigh ecchymosis, and bony deformities of the right shoulder, right ankle, and left thigh. Notable negatives from the secondary survey included normal facial stability, a stable pelvis, and no palpable spinal step-offs.

Trauma bay plain film X-ray imaging of the chest and pelvis identified no immediate life-threatening cardiopulmonary or pelvic abnormalities. However, there was evidence of a right anterior shoulder dislocation, left scapular fracture, and nondisplaced fractures of fifth and sixth ribs on the patient's chest X-ray. The Extended Focused Assessment with Sonography in Trauma exam was negative. Plain film X-rays of the extremities were notable for a right anterior shoulder dislocation, left scapular fracture, nondisplaced fractures of fifth and sixth ribs, comminuted and displaced fracture of the left femoral midshaft, right thumb Bennet fracture, left ulnar styloid fracture, right calcaneus fracture, right talus fracture, left fibular fracture, and fractures of several metacarpophalangeal joints.

The patient's initial laboratory results are presented in **Table I**. His results were notable for a respiratory acidosis with a pH of 7.146, a P_{CO_2} of 71.2, a lactate level of 2.8, a leukocytosis of 13.68, and mild elevations in creatinine and transaminases. Notable normal laboratory values included a bicarbonate of 24, hemoglobin of 14.6, and platelets of 222.

Computed tomography (CT) scan of the head identified a 5-mm right frontotemporal subdural hematoma (SDH); a 3-mm parafalcine SDH, bilateral, multifocal subarachnoid hemorrhage involving the frontal and temporal lobes; and evidence of intraventricular blood products without hydrocephalous. There was no evidence of midline shift. The patient's CT of the cervical spine, chest, abdomen, and pelvis showed a nondisplaced occipital bone fracture, C2 Hangman's fracture (**Fig. 1**), incomplete burst fractures of T5 and T6 (**Fig. 2**), and a mildly displaced sternal fracture. A CT of the left lower extremity showed a displaced distal femoral fracture without evidence of vascular compromise (**Fig. 3**).

Cervical spine precautions were maintained throughout his ED course. Given his intracranial injuries, the patient was placed into 30° reverse Trendelenburg position, and administered a bolus of 3% hypertonic saline and a loading dose of levetiracetam for seizure prophylaxis. He also received a tetanus immunization, cefazolin, calcium chloride, and a combination of propofol and fentanyl infusions for sedation.

As noted above, the patient's initial venous blood gas testing revealed a respiratory acidosis (P_{CO_2} of 71.2) despite increased

Table I. Venous Blood Gas and Electrolytes Obtained Upon Arrival and Approximately 30 Min After Arrival Compared to an Arterial Blood Gas Obtained Approximately 15 Min After Tube Exchange.

PARAMETER	ARRIVAL VENOUS BLOOD GAS	PRE-TUBE EXCHANGE VENOUS BLOOD GAS	VBG REFERENCE RANGE	POST-TUBE EXCHANGE ARTERIAL BLOOD GAS	ABG REFERENCE RANGE
pH	7.150	7.146	7.32–7.43	7.31	7.35–7.45
p_{CO_2} (mmHg)	63.8	71.2	41–51	39.1	35 – 45
P_{O_2} (mmHg)	20.8	23.1	38–42	192.4	75–100
HCO_3 ($mEq \cdot L^{-1}$)	21.7	24.0	22–29	19.5	22–26
Base Excess ($mEq \cdot L^{-1}$)	-7.7	-6.3	−2 to +3	−6.2	−4 to +2
Lactate ($mmol \cdot L^{-1}$)	1.85	2.80	0.9–1.7	1.97	0.0–2.0
Hemoglobin ($g \cdot dL^{-1}$)	11.9	14.1	12.0–17.0	12.9	12.0–17.0
Sodium ($mmol \cdot L^{-1}$)	113.8	136.8	132–146	139.1	132–146
Potassium ($mmol \cdot L^{-1}$)	3.94	4.27	3.5–4.5	4.33	3.5–4.5
Chloride ($mmol \cdot L^{-1}$)	100	103	98–107	109	98–107
Calcium ion ($mmol \cdot L^{-1}$)	1.24	1.27	1.12–1.32	1.18	1.12–1.32

The patient's initial pH and P_{CO_2} are consistent with a respiratory acidosis. Repeat point-of-care venous blood gas after optimization of the patient's ventilator settings showed worsening of the patient's respiratory acidosis, driving the decision to perform a tube exchange. The post-tube exchange arterial blood gas showed improvement in the respiratory acidosis.

VBG: venous blood gas; ABG: arterial blood gas.

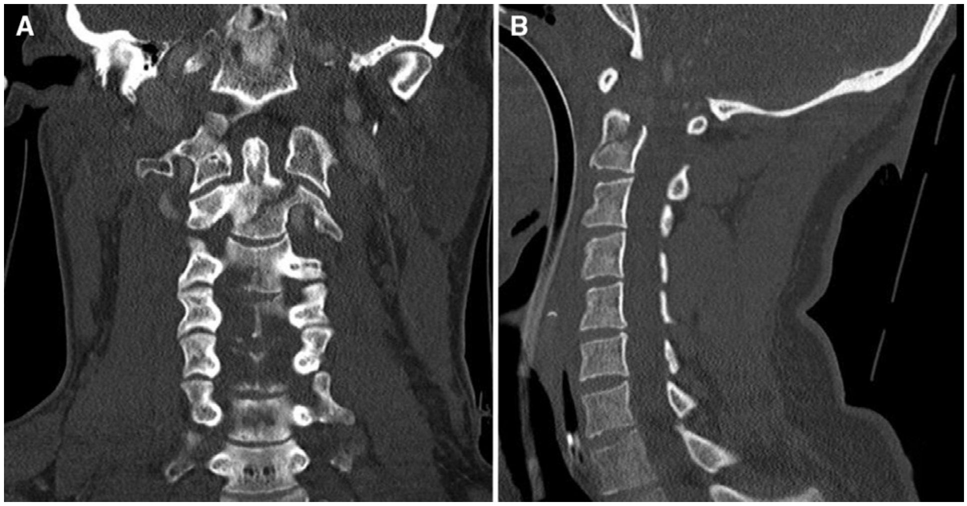

Fig. 1. CT imaging of the cervical spine performed upon arrival at the trauma center. A) Axial CT of the cervical spine demonstrating a displaced oblique fracture through the body of C2, consistent with a C2 Hangman fracture. There is an additional fracture through the right lamina of C2 with extension into the inferior articular facet extending into the left lateral mass. B) Lateral CT of the cervical spine demonstrating the C2 Hangman fracture.

mechanical minute ventilation. Given a normal hemoglobin and a reassuring lactate despite his injuries, it was assumed that the patient's hypercapnia was due to placement of a 5.5-sized endotracheal tube in the field. The decision was made to perform an endotracheal tube exchange to correct this patient's acid/base disturbance. An 8.0-mm endotracheal tube was subsequently placed and the patient had interval improvement in his respiratory acidosis. The airway exchange was complicated by upper airway muscle tone, which required the original endotracheal tube to be removed, the administration of ketamine and rocuronium, and reintubation. Given hypotension and transient hypoxia during reintubation, the patient required an intravenous infusion of norepinephrine to ensure mean arterial pressures >65.

A spinal fusion of the T4–T8 vertebrae and halo placement for cervical stabilization were performed on hospital day 1. A closed reduction-external fixation of the left femur was performed on hospital day 1 with intermedullary nailing of the left femur subsequently performed on hospital day 4. Closed reduction percutaneous pinning of the right thumb Bennet fracture

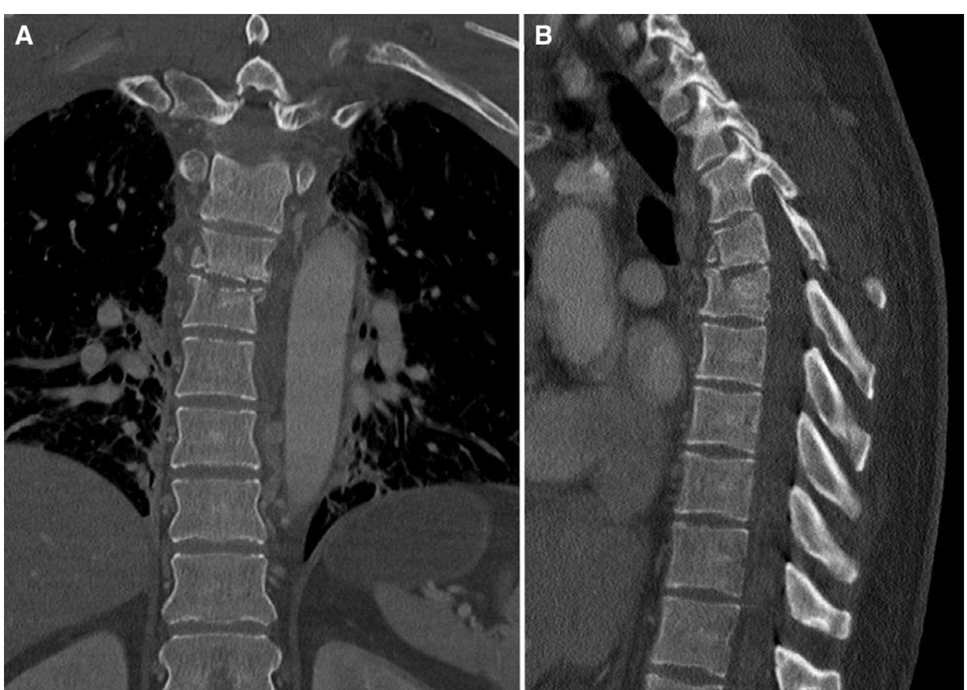

Fig. 2. CT imaging of the thoracic spine performed upon arrival at the trauma center. A) Axial CT of the thoracic spine demonstrating an incomplete burst fracture of T5–T6. B) Lateral CT of the thoracic spine demonstrating the incomplete burst fracture of T5–T6, subtle widening of the T5–T6 spinous processes, and retropulsion of a fracture fragment posteriorly into the spinal canal.

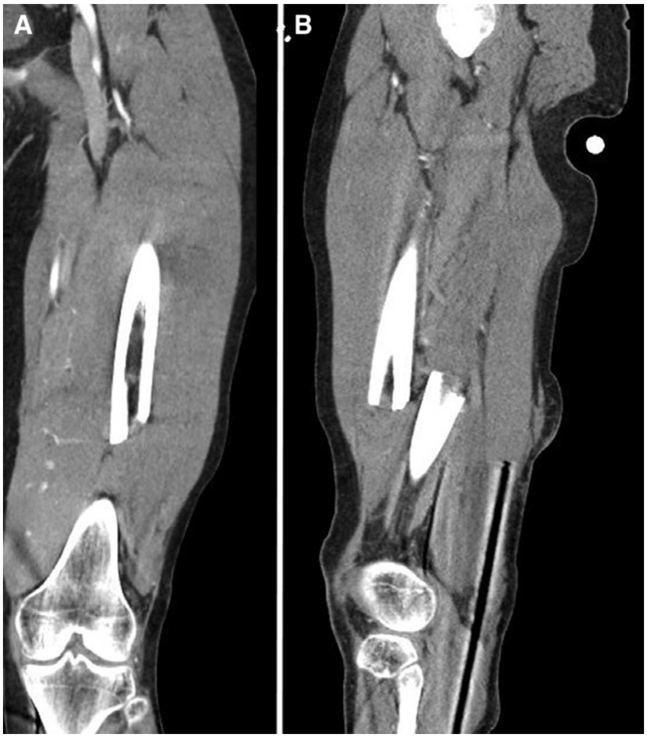

Fig. 3. CT imaging of the left femur performed upon arrival at the trauma center. A) Axial CT of the femur demonstrating a displaced femoral fracture fragment. B) Lateral CT demonstrating a comminuted and displaced fracture of the left femur.

was performed on hospital day 4. There were no surgical complications and all remaining fractures were managed nonoperatively. The halo remained in place for 9 wk, at which point it was removed and the patient was transitioned to a cervical collar. The patient was extubated on hospital day 8 and remained in the surgical intensive care unit for 4 wk as his course was complicated by delirium and agitation. Following his prolonged ICU course, the patient was transferred to a polytrauma rehabilitation center and residential care program, where he remained for 6 wk and 1.5 wk, respectively. After completion of the residential care program, he was discharged home. He was followed regularly by occupational therapy, physical therapy, and speech language pathology. Initial post-discharge neuropsychological testing met criteria for neurocognitive disorder with deficits in memory, novel problem solving, and mental flexibility. However, he continued to improve over the next several months and was ultimately able to return to activities of daily living, work independently in a nonflight capacity, and pass the Air Force Fitness Test without restrictions.

DISCUSSION

Ejections from fighter aircraft are typically survivable, but when an ejection occurs outside of a seat's performance envelope, such as the very low-altitude and high-angulation ejection in this case, the rate of injury increases and chance of survival diminishes considerably.[4] Success of an ejection is contingent on the complicated interactions between the seat's performance envelope, flight dynamics preceding the ejection, and the environmental conditions.[4] In this manuscript we present the first known case of a pilot with favorable outcomes after sustaining severe traumatic injuries from a low-altitude ejection without parachute deployment due to seat impact with the ground.

Medical literature has sought to identify common injury patterns associated with ejection from aircraft, most common reasons for ejection, and how factors such as velocity and altitude of the aircraft at time of ejection impact survival rates. The most common major injuries include spinal fractures, which have historically occurred in 20–30% of ejections, followed by extremity and head trauma.[3,5] Due to patient positioning and axial (G_z) accelerative forces, the cervical and thoracic spines are particularly susceptible to compressive fracture, although injury of the thoracolumbar junction, fracture-dislocations, and burst fractures have also been reported.[6,7] As shown in the above case and corresponding imaging, the patient in this case had classic findings associated with ejection seat complications, including a severe head injury, cervical and thoracic spinal fractures, and significant extremities fractures. We believe that our case report is the only case report to include high-definition radiology images from a recent aircraft ejection associated with severe injuries. Furthermore, the CT spinal imaging shows the fracture patterns associated with axial G-loading and the extent of the C2 vertebral fracture. Although the specific magnitude and direction of maximal acceleration is unavailable in this case, it highlights that mishap response personnel should assume pilots have multiple, severe spinal injuries after ejection until a complete primary and secondary survey can be completed by properly trained medical personnel.

Modern jet aircraft are equipped with "zero-zero ejection seats," meaning that the ejection seat is designed to provide safe deployment at zero velocity and zero altitude. However, while designed to function across a wide range of flight conditions, ejection seats cannot fully compensate for all flight conditions. In an analysis of survivability and injury in 232 rocket-assisted ejection cases, there was a 95.7% rate of survival when a seat ejected within its performance envelope, but only a 23.8% rate of survival for out-of-envelope ejections.[8] In a similar analysis of 461 U.S. Air Force ejections from 1978–2013 using the ACES II ejection system, 8.9% (41) of ejections were ultimately fatal, 23 of which were due to being outside of the seat's performance envelope.[1] Other common factors contributing to fatal ejection include delayed ejection decisions, ejection system failure including damage to the seat prior to ejection, midair collisions, and drowning.[1,4] Furthermore, low-altitude ejections, as in the case of our patient, often considered to be those below 500 ft (152 m), result in a significantly decreased rate of survival of approximately 50%.[4,9,10] Low-altitude ejections do not allow ample time for proper parachute deployment and seat separation and often entail more obstacles in the ejection path that can cause damage to the seat or additional injury to the aviator.

On initial presentation, the patient's blood gas was consistent with respiratory acidosis. The patient was intubated by on-scene personnel prior to HEMS transport. Although not sized for an adult male and contributing to subsequent physiological abnormalities, the 5.5 endotracheal tube provided a secured airway for immediate transport and was a lifesaving intervention in this case. However, despite an increase in the patient's ventilator respiratory rate after arrival at the ED, he remained persistently hypercapnic, so a decision was made to upsize his endotracheal tube in order to improve his ventilation. The endotracheal tube exchange required sedation given persistent upper airway tone (jaw clenching, etc.) and was associated with postintubation hypoxia and hypotension, a common side-effect after airway management during trauma. This case highlights a challenge for on-scene emergency responders. For high-risk, low-volume events, such as airway management after an aviation mishap, endotracheal intubation requires significant clinical experience and training. However, this represents a definitively secured airway, if successful. Supraglottic airways, by contrast, are easy to place, but may not provide a secured airway during long-duration HEMS transport. Military flight medicine and emergency response teams should determine the correct airway management strategies for their location, provider skillsets, aircraft type, and transport times to definitive care.

Despite the patient's spinal and extremity trauma, it is important to highlight that the patient had relatively limited trauma to the chest or abdomen. Although the patient had a minimally displaced sternal fracture, a pulmonary contusion, and rib fractures, these injuries did not require intervention and did not pose an immediate threat to life. It is likely due to the restraint design and support from the main body of the ejection seat, limiting movement of the chest and abdomen, which prevented an additional fatal injury to the chest or abdomen. The patient's injury list, including SDH, subarachnoid hemorrhage, multiple skull fractures, a C2 Hangman's fracture, T5–6 burst fractures, and extensive extremity trauma, demonstrates the severity of the patient's polytrauma. We hope this case provides education to future flightline emergency personnel and aerospace medicine providers, stressing the need for proper ejection seat safety and flight line airway management.

Ejecting from jet aircraft, while often survivable, can be associated with spinal fractures and extremity trauma. The factors that impact survival include both ejection seat and aircraft flight conditions, as well as those specific to the pilot, such as weight and restraint positioning. Low-altitude or high-angulation ejections are associated with worse clinical outcomes. In this case, we present the survival of a pilot who ejected from a jet aircraft at high angulation and low altitude, despite no parachute deployment. The patient presented with respiratory acidosis, which required upsizing of his endotracheal tube. This case provides clinical imaging of injuries classically associated with aircraft ejection. The patient had extremely favorable neurological and functional outcomes despite severe initial injuries.

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