Neurosurgical injuries resulting from the 2011 tornados in Alabama: the experience at the University of Alabama at Birmingham Medical Center

Clinical article

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Object. The April 27, 2011, tornados that affected the southeastern US resulted in 248 deaths in the state of Alabama. The University of Alabama at Birmingham (UAB) Medical Center, the largest Level I trauma center in the state, triaged and treated a large number of individuals who suffered traumatic injuries during these events, including those requiring neurosurgical assessment and treatment.

Methods. A retrospective review of all adult patients triaged at UAB Medical Center during the April 27, 2011, tornados was conducted. Those patients who were diagnosed with and treated for neurosurgical injuries were included in this cohort.

Results. The Division of Neurosurgery at UAB Medical Center received 37 consultations in the 36 hours following the tornado disaster. An additional patient presented 6 days later, having suffered a lumbar spine fracture that ultimately required operative intervention. Twenty-seven patients (73%) suffered injuries as a direct result of the tornados. Twenty-three (85%) of these 27 patients experienced spine and spinal cord injuries. Four patients (15%) suffered intracranial injuries and 2 patients (7%) suffered combined intracranial and spinal injuries. The spinal fractures that were evaluated and treated were predominantly thoracic (43.5%) and lumbar (43.5%). The neurosurgery service performed 14 spinal fusions, 1 ventriculostomy, 2 halo placements, 1 diagnostic angiogram, 1 endovascular embolectomy, and 1 wound debridement and lavage. Twenty-two patients (81.5%) were neurologically intact at discharge and all but 4 had 1 year of follow-up. Three patients had persistent deficits from spinal cord injuries and there was 1 death in a patient with multisystem injuries in whom no procedures were performed. Two patients experienced postoperative complications in the form of 1 wound infection and 1 stroke.

Conclusions. The April 27, 2011, tornados in Alabama produced significant neurosurgical injuries that primarily involved the spine. There were a disproportionate number of patients with thoracolumbar fractures, a finding possibly due to the county medical examiner's postmortem findings that demonstrated a high prevalence of fatal cervical spine and traumatic brain injuries. The UAB experience can be used to aid other institutions in preparing for the appropriate allotment of resources in the event of a similar natural disaster.

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KEY WORDS • tornado • trauma • spine injury • spinal cord • traumatic brain injury

TORNADOS in America are relatively common occurrences and can be incredibly destructive. Tornados form within a type of cumulonimbus cloud named supercells that rotate in a counter-clockwise direc-

tion in the Northern Hemisphere. These supercells can generate tornados that average 250 feet across and generally travel several miles. Wind speeds encountered in supercells are typically between 100 and 150 miles per hour (www.wikipedia.org). The 206 confirmed tornados across the southeastern US on April 27, 2011, were much more powerful than the average tornado. The Northern Alabama tornado, measuring EF5 on the Enhanced Fujita Scale, had wind speeds in excess of 205 miles per hour, was 1.25 miles wide, and traveled 132 miles.¹⁹ This tornado left a path of destruction over 105,000 acres. The Tuscaloosa-Birmingham tornado, affecting the primary catchment area of the UAB, was rated an EF4.¹ This tor-

Abbreviations used in this paper: AIS = American Spinal Injury Association Impairment Scale; CDC = Centers for Disease Control and Prevention; ICA = internal carotid artery; MCA = middle cerebral artery; PLIF = posterior lumbar interbody fusion; SAH = subarachnoid hemorrhage; SDH = subdural hematoma; TLICS = Thoracolumbar Injury Classification and Severity Score; TLIF = transforaminal lumbar interbody fusion; TLSO = thoracic lumbosacral orthosis; UAB = University of Alabama at Birmingham.

Neurosurgical injuries from tornadoes in Alabama

nado caused a total of \$2.2 billion in damages, and resulted in 64 casualties (www.wikipedia.org).⁸ In total, on April 27, 2011, there were 62 tornadoes in the state of Alabama (Fig. 1), which killed 248 people, affected 44,000, and resulted in more than \$4 billion of negative economic impact.

The UAB Medical Center, the largest Level I trauma center in the state, triaged and treated a large number of individuals who suffered traumatic injuries during the tornadoes on April 27, 2011. Community hospitals were also affected and recognition of their contributions to the care of these patients is warranted.

Methods

A retrospective review was conducted of all adult patients triaged at UAB Medical Center during the tornadoes occurring in Alabama on April 27, 2011. Patients diagnosed with and treated for neurosurgical injuries were included in this cohort. The inclusion criteria required that the patients were injured during the tornadoes or as a direct result of the immediate postimpact activities, such as cleanup and evacuation. This project was submitted to The UAB Institutional Review Board for Human Use and was determined to be exempt from requiring informed consent based on the use of deidentified data.

Results

The Division of Neurosurgery at the UAB Medical

Center received 37 consultations in the 36 hours following the tornado disaster. An additional patient presented 6 days later, having suffered a lumbar spine fracture ultimately requiring operative intervention. Twenty-seven patients (73%) suffered injuries as a direct result of the tornadoes (Tables 1–3). The patients were predominantly Caucasian (92.6%) and 13 were women (48%). The age distribution was relatively uniform across age groups ($p = 0.0086$), with a mean age of 43.3 ± 14.9 years (range 16–72 years).

Twenty-three (85%) of 27 patients experienced spine and spinal cord injuries. Four patients (15%) suffered intracranial injuries and 2 patients (7%) had combined intracranial and spinal injuries (Tables 1 and 2). Sixteen patients (59%) required operative intervention, with 9 of these procedures performed in the first 8 hours after the tornadoes occurred. All operations with the exception of a wound revision were performed within 24 hours after the tornadoes struck the area. The neurosurgery service performed 14 spinal fusions, 1 ventriculostomy, 2 halo placements, 1 diagnostic angiogram, 1 endovascular arterial thrombectomy, and 1 wound debridement and lavage (Fig. 2).

Patients presented with a wide variety of fractures as a result of being thrown or crushed during the tornado. Spinal fractures evaluated and treated were predominantly thoracic ($n = 10$, 43.5%) and lumbar ($n = 10$, 43.5%; Table 3). Fourteen patients required surgical fusion for burst ($n = 6$), Chance ($n = 3$), combined C1–2 ($n = 1$), Type II odontoid ($n = 1$), and bilateral lumbar facet fractures (n

Fig. 1. National Weather Service Map illustrating the location and severity of the April 27, 2011, tornadoes in relation to the UAB Medical Center. Modified from: http://www.srh.noaa.gov/bmx/?n=event_04272011.

TABLE 1: Patients with cranial injuries as a result of the April 27, 2011, tornadoes in Alabama*

Case No.	Age (yrs), Sex	Neurological Injury/Findings	Neurosurgical Treatment	Other Injuries	Neurological Outcome	Complications
1	35, M	rt cerebral contusions w/ diffuse traumatic SAH	external ventricular drain	chest trauma, sigmoid colon injury & hemoperitoneum, lt fibular fx & compartment syndrome, pelvic trauma	complete neurological recovery	none
2	46, F	open depressed skull fx	irrigation & debridement	none	complete neurological recovery	none
3	68, F	rt parietal SAH, falcine SDH, Type III rt occipital condyle fx	none	chest trauma, pelvic trauma, perinephric/retroperitoneal strangling, multiple extremity injuries	death	NA
4	55, M	rt tentorial & parafalcine SDH	none	rt fibula fx	complete neurological recovery	none

* fx = fracture; NA = not applicable.

= 1); 1 patient suffered a fracture dislocation of L1–2 resulting in spondyloptosis (Fig. 3). The nonoperative fractures (n = 12, 44%) consisted of 1 patient requiring halo immobilization without subsequent internal fixation and fusion for multilevel cervical spine fractures. Three patients were discharged with external orthosis in the form of cervical collars (n = 2) and a TLSO (n = 1). Eight patients (33%) were believed to have clinically insignificant fractures and required no bracing.

Surgical treatment of the cervical, thoracic, and lumbar fractures (n = 13) was varied and in 3 patients (23%) involved a multidisciplinary approach. These 3 patients required corpectomies at T-12 (n = 1) and L-1 (n = 2). One patient with an L-1 burst fracture required a corpectomy, anterior and posterior internal fixation, and fusion. The remaining 2 patients had no adjacent-level fractures and were fused ventrally over the adjacent levels. The fusion constructs in 2 patients were augmented with a TLIF (n = 1) and a PLIF (n = 1) for traumatic spondylolisthesis. The Type II odontoid fracture was treated with an odontoid screw. One patient underwent halo placement and subsequent C1–2 fusion for combined C-1 and C-2 fractures. In total, 14 patients received fusions over 49 levels as a result of this tremendous natural disaster.

The number of skull fractures and intracranial injuries observed was surprisingly low. One patient required a ventriculostomy for a severe head injury. This patient returned to work and was without residual deficit by the 4-month follow-up clinic visit. One open skull fracture was closed by the neurosurgery service at the bedside and required no operative intervention.

Patient outcomes varied; there was 1 death in a patient with diffuse axonal injury and multisystem organ injury in whom no procedures were performed. One patient experienced a postoperative wound infection following a multilevel spinal fusion. *Pseudomonas aeruginosa* was cultured from the wound and the patient underwent 3 washout procedures. One patient had a left MCA stroke on postoperative Day 2 following a thoracic fusion for TLICS Grade 7 T-9 and T-10 Chance fractures.¹³ The patient was urgently taken to the angiography suite where a mechanical thrombectomy of the MCA was performed

and partial recanalization was achieved. The patient had significant blunt chest trauma, and the stroke was attributed to a likely cardioembolic mechanism. The patient's expressive aphasia and hemiparesis improved following a prolonged inpatient rehabilitation. Upon discharge he was ambulating as far as 225 feet and was appropriately answering questions. Three patients presented with significant spinal cord injuries and only 1 did not improve postoperatively. Four patients (14.8%) were lost to follow-up, but all were neurologically intact at hospital discharge.

Discussion

The April 27, 2011, tornadoes resulted in 248 deaths in the state of Alabama.⁸ The Division of Neurosurgery at UAB Medical Center received 27 consultations for tornado-related neurosurgical injuries. Tornado-related injuries are injuries that occur during a tornado as a result of the tornado's direct impact or immediate postimpact activities. The majority of injuries were the result of being thrown or crushed while taking cover. The mechanisms of injury were oftentimes incredible. Many patients suffered significant injuries while using their bodies to protect their children or loved ones. Many were found outside of their homes and some were found more than 100 yards from where they had taken cover. The CDC found that 40% of the dead were found outside their homes.⁸

The injuries suffered were a testament to the power of these storms. The National Oceanic and Atmospheric Association released an assessment of the atmospheric conditions that set the stage for the largest tornado outbreak in history. They found that a low-pressure cold front moving across the Great Plains collided with a very unstable, moist atmosphere in the Southeast, setting the perfect stage for tornado development.¹⁷ The result was the most prolific month of tornadoes in recorded history. In the southeastern US there were 206 tornadoes on April 27, 2011, and 62 occurred in the state of Alabama (www.wikipedia.org). The number of tornadoes coupled with their severity produced the most tornado-related deaths since the great Tri-State Tornado of 1925 that produced 695 confirmed fatalities (www.wikipedia.org).

TABLE 2: Patients with both cranial and spinal injuries as a result of the April 27, 2011, tornadoes in Alabama

Case No.	Age (yrs), Sex	Spinal Level	Neurological Injury/Findings	TLICS	Neurosurgical Treatment	Other Injuries	Neurological Outcome	Complications
5	42, F	thoracic	cranial: rt MCA infarction, rt ICA Biffl Grade II injury w/ intraluminal thrombus; spinal: T-6 Chance fx, T-2, T-3, T-5, T-7, & T-12 compression fxs	7 (T-6), 1 (T-2), 1 (T-3), 1 (T-5), 1 (T-7), 1 (T-12)	T3–8 dorsal fixation, aspirin	chest trauma, hepatic laceration, rt scapula & glenoid fxs, pelvic trauma	complete neurological recovery	none
6	35, M	thoracic	cranial: lt SDH; spinal: T-9 & T-10 Chance fxs	7 (T-9), 7 (T-10)	T8–12 dorsal fixation, arterial thrombectomy, aspirin	chest trauma, mesenteric strangling	aphasia, rt hemiparesis	MCA infarction (aphasia, rt hemiparesis), likely cardioembolic from significant chest trauma

Head, spine, and orthopedic injuries are the most common tornado-related injuries requiring hospital admission.^{2,3,5–7,9–12,14–16,19,20} The literature regarding tornado-related traumatic brain and cervical spinal cord injuries cites a mortality rate as high as 82%.^{6,14,16} The mortality rate for patients surviving to reach our neurosurgical service during these tornadoes was 3.7%. The final CDC mortality report listed traumatic brain injury as the cause of death for 21.9% of fatalities, the vast majority of whom never arrived at a hospital.⁸ These patients had significant injuries and either died immediately or were unable to survive the length of time required to identify and transport hundreds of patients during this natural disaster.

Reported risk factors for injuries include poor building anchorage such as that found with mobile homes, a location other than in a basement, advanced age, and wind speed. Wind speed was especially correlated with morbidity and mortality, with 90% of deaths occurring with the EF4 and EF5 tornadoes.⁸ Advance warning and a lead time of more than 1 hour in many places had little impact on mortality, as these tornadoes were powerful enough to destroy even the most well-built homes and businesses. The injuries observed at UAB were largely believed to be unavoidable, because every patient had advance notice of the impending disaster.

Our findings with respect to the most frequent types of injuries differed from what has been previously reported. There were a disproportionate number of patients with spinal injuries (85%) that predominantly involved the thoracolumbar region (76%). Only a small number of patients sustained head and cervical spine injuries. This difference can be explained by both the Jefferson County medical examiner's postmortem examinations demonstrating a high prevalence of fatal cervical spine injuries (Birmingham is located in Jefferson County) and the CDC report documenting a high rate of fatal combined traumatic brain and spinal cord injuries.^{8,18}

The experience at Children's Hospital in Birmingham demonstrated a much higher prevalence of traumatic brain injuries.⁹ The children injured in the tornadoes were in the exact location as many adults, yet they suffered different injuries. Chern et al.⁹ noted that 11 children required cranial operations compared with only 1 spinal fusion. Adult neurosurgeons in the community performed several emergency lifesaving operations in children. On the frontlines of such a disaster one must be prepared to save the lives of the injured, regardless of age.

The successful management of patients following these tornadoes was dependent on several factors. The first factor was strong institutional support and leadership. Advanced weather forecasting allowed the institution to make arrangements for multiple shifts of vital personnel to be available during the main wave of the patient influx. The postoperative recovery areas were converted to intensive care units and all elective cases were cancelled the following day. One hundred thirty-four patients were seen in the UAB emergency room; 44 suffered major trauma and 23 were admitted to the intensive care units.

Management of patients in a natural disaster is truly a multidisciplinary undertaking. The Department of Surgery at UAB Medical Center had a predefined leadership

TABLE 3: Patients with spinal injuries as a result of the April 27, 2011, tornados in Alabama*

Case No.	Age (yrs), Sex	Spinal Level	Neurological Injury/Findings	TLICS	Neurosurgical Treatment	Other Injuries	Neurological Outcome	Complications
7	46, F	cervical	lt C-1 lateral mass fx, rt C-7 facet fx	NA	halo orthosis	chest trauma	intact	none
8	52, M	cervical	Type II odontoid fx, rt C-7 lamina fx	NA	cervical collar	none	intact	none
9	53, M	cervical	Type II odontoid fx, rt C-6 lamina/facet fx, C-7 vertebral body fx, rt pedicle/lamina fx	NA	odontoid screw	chest trauma, lt ulnar fx	intact	none
10	61, F	cervical	lt C-7 pars fx, C-7 superior endplate fx	NA	cervical collar	extensive rt flank soft-tissue contusion, rt femoral fx, lt styloid fx	intact	none
11	18, F	cervicothoracic	bilat Type I lt occipital condyle fx, rt C-1 anterior & posterior arch fx, C-2 fx, lt C-6 facet fx, T-7 Chance fx	7 (T-7)	halo orthosis, C1-2 dorsal fixation, T5-9 dorsal fixation	chest trauma, pelvic trauma, facial fxs, lt foot fxs, rt olecranon fx	complete neurological recovery	none
12	53, M	thoracic	T-3 compression fx	1 (T-3)	none	none	intact	none
13	28, M	thoracic	T-8 compression fx	1 (T-8)	TLSO brace	chest trauma, hepatic laceration, splenic contusion	intact	none
14	16, M	thoracic	T-8, T-10, T-11, & T-12 compression fxs	1 (T-8), 1 (T-10), 1 (T-11), 1 (T-12)	none	lt radius, ulnar fxs	intact	none
15	24, F	thoracic	T-9 Chance fx, T-6 & T-8 burst fxs, T-5 compression/lt lamina fx, T-7 compression/rt lamina fx	7 (T-9), 2 (T-6), 2 (T-8), 1 (T-5), 1 (T-7)	T4-11 dorsal fixation	chest trauma	intact	none
16	72, M	thoracic	T-10 Chance fx	4 (T-10)	T9-L1 dorsal fixation, 3 wound washouts	chest trauma, rt radius & ulnar fxs, facial fx	intact	postop <i>Pseudomonas</i> infection
17	42, F	thoracic	T-12 burst fx	4 (T-12)	T-12 corpectomy, ant fixation T11-L1	rt radius fx	intact	none
18	55, M	thoracolumbar	L-1 burst & T-8 compression fxs	4 (L-1), 1 (T-8)	T11-L3 dorsal fixation	chest trauma, lt clavicle fx, rt adrenal hemorrhage	intact	none
19	29, M	lumbar	L1-2 spondylolysis	9 (L1-2)	L1-2 TLIF, T10-L4 dorsal fixation	facial fxs	AIS Grade A	none
20	58, M	lumbar	L-1 burst & L-4 compression fxs	4 (L-1), 1 (L-4)	T11-L3 dorsal fixation	rt radius fx	intact	none
21	43, F	lumbar	L-1 & L-2 compression fxs	1 (L-1, L-2)	none	chest trauma, lt scapula fx, lt femoral fx	intact	none
22	55, F	lumbar	L-1 burst fx	7 (L-1)	L-1 corpectomy, ant fixation T12-L2	lt hand fx, lt tibia fx, lt ear partial amputation	AIS Grade C	none

(continued)

TABLE 3: Patients with spinal injuries as a result of the April 27, 2011, tornados in Alabama* (continued)

Case No.	Age (yrs), Sex	Spinal Level	Neurological Injury/Findings	TLICS	Neurosurgical Treatment	Other Injuries	Neurological Outcome	Complications
23	20, F	lumbar	L-1 Chance fx	10 (L-1)	L-1 corpectomy, ant fixation T12-L2, T10-L3 dorsal fixation	chest trauma, splenic injury	AIS Grade D	none
24	33, F	lumbar	suspected lt L-3 fx & L-5 transverse process fx	NA	none	none	intact	none
25	53, M	lumbar	suspected L-2 compression fx	NA	none	chest trauma, lt foot fx	intact	none
26	40, M	lumbosacral	lt L5-S1 disc herniation	NA	none	pelvic trauma, hip dislocation	intact	none
27	36, F	lumbosacral	L5-S1 traumatic spondylolisthesis	6 (L-5)	L5-S1 PLIF, L4-S1 dorsal fixation	none	intact	none

* ant = anterior.

FIG. 2. Case 5. Images obtained in a 42-year-old woman who was injured in the tornado and presented with multiple thoracic fractures. This patient was found to have a left facial droop with ipsilateral facial anesthesia. Diffusion-weighted MRI (A) was consistent with showering of thrombus and the patient was urgently taken to the angiography suite, where she was found to have a right blunt traumatic Biffl Grade II ICA injury with an intraluminal thrombus⁴ (B). She was given 325 mg of aspirin per day and experienced a complete neurological recovery. She additionally required a T3–8 dorsal internal fixation and fusion for a TLICS Grade 7 fracture at T-6 (C–E). Diffusion-weighted MR image (A), lateral digital subtraction angiogram (B), sagittal thoracic CT scan (C), anteroposterior (D) and lateral (E) plain radiographs.

hierarchy in place that allowed for the appropriate allocation of resources between the trauma, orthopedic, and neurosurgical services. Additionally, the trauma surgeons provided surgical access (via laparotomy or thoracotomy) for 3 patients requiring corpectomies. Without a team approach and fluent communication between services it would have been impossible to provide the modern neurosurgical standard of care during a natural disaster.

Conclusions

Tornados can devastate communities and place unique strains on health care providers. Neurosurgeons are a vital part of the front line of care for patients injured in tornados and need to have well-thought-out plans for dealing with these types of natural disasters, especially if practicing within an endemic area. The UAB experience can be used to aid other institutions in preparing for the appropriate allotment of resources in the event of a similar natural disaster.

Fig. 3. Case 19. Images obtained in a 29-year-old man who sustained an impressive L1–2 fracture dislocation (**A and B**) resulting in spondyloptosis and an AIS Grade A on the motor examination. He required T10–L4 dorsal internal fixation (**C and D**). He made no neurological recovery postoperatively. Sagittal lumbar CT scan (**A**), axial CT scan (**B**), lateral (**C**) and anteroposterior (**D**) plain radiographs.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Acquisition of data: Zywicke, Fleming, Griessenauer, Whisenhunt, Okor, Harrigan. Analysis and interpretation of data: Hadley, Okor, Harrigan. Drafting the article: Hadley, Miller. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Hadley. Administrative/technical/material support: Fleming, Griessenauer, Whisenhunt, Pritchard. Study supervision: Hadley, Zywicke, Okor, Harrigan, Pritchard.

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