Overlooked Diagnoses in Chronic Pain: Analysis of Survivors of Electric Shock and Lightning Strike

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Objective: *Patients who survive lightning strikes are rarely seen in clinical practice and patients with electrical injury are seen infrequently. This article reports the most commonly overlooked diagnoses so that physicians can improve their evaluations.* ***Methods:*** *A total of 19 patients who survived a lightning strike and 53 patients who survived electrical shock had a partial or complete multidisciplinary evaluation at Mensana Clinic. A variety of diagnostic studies were ordered.* ***Results:*** *In 19 lightning strike survivors, referring physicians did not mention 133 diagnoses, later established by Mensana Clinic. The overlooked diagnosis rate was 93%. In 53 patients who survived electrical shock, referring physicians did not mention 436 diagnoses, later established by Mensana Clinic. The overlooked diagnosis rate was 98.2%.* ***Conclusions:*** *Patients who survive electric shock and lightning strikes are often misdiagnosed because they are infrequently seen in a medical practice.* (J Occup Environ Med. *2005;47:796–805*)

Hendler has published articles indicating that 40% to 67% of patients with chronic pain who are involved in litigation have overlooked diagnoses.[1,2] For certain disorders, such as complex regional pain syndrome - type I, (CRPS I) or as it was previously called, reflex sympathetic dystrophy (RSD), the misdiagnosis rate may reach 71%.[3]

The diagnosis and treatment of patients who have survived a direct or indirect lightning strike is even more complicated because it involves not only chronic pain and/or nerve damage but a host of other conditions.[4] However, the reported incidence of people hit by lightning ranges from 2000 a year, with 600 deaths,[5] to 9818 injuries, and 3239 deaths from 1959 to 1994, for an incidence of 280 injuries, and 93 deaths a year.[6] Therefore, it is highly unlikely that a physician would ever encounter a lightning strike survivor in his or her practice. Additionally, old myths about lightning strikes still exist in the literature, which further impede diagnosis.[7]

Likewise, the diagnosis and treatment of patients who have survived electric shock injury is equally as complicated. Misconceptions about electrical injury still exist in the literature. As an example, one article tells physicians to immediately treat the entrance and exit wounds after electric shock[8] because these wounds are thought to be consistent findings in victims of electric shock. In truth, entrance and exit burn wounds are not a consistent finding after

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electrical shock injury.[9–11] Even after fatal electric shock, 9% of the victims did not have burn wounds.[12]

Although there are a number of articles addressing the immediate sequelae from electric injury[8,12,13] there are few articles in the medical literature describing the long-term aftermath of electrical injuries and lightning strike.[14] The scarcity of information about the long-term effects of these injuries further impairs an appropriate diagnosis and treatment of these patients. In an effort to more fully describe the long-term complications found in survivors of these injuries, a review was conducted of the medical conditions of patients referred to Mensana Clinic for chronic pain problems many months after these injuries.

Subjects

A patient population of 37 subjects who survived lightning strike and 77 patients who experienced an injury after an electrical shock were selected from a pool of 1579 new evaluations referred to Mensana Clinic (a multidisciplinary diagnostic and treatment center for chronic pain) during a period from January 1999 to June 2003. There were differences in the age, education and duration of complaints between men and women. Seventy-five percent of patients who came to the Mensana Clinic were from 44 states and 8 foreign countries, so there is a national database for the patients in this study. Of the 37 patients who survived lightning strike, 19 received a partial or complete evaluation at Mensana Clinic. Of the 77 patients who survived electrical injury, 53 had a partial or complete evaluation at Mensana Clinic. The demographics of lightning strike patients are shown in Table 1, and electric shock survivors are shown in Table 2.

TABLE 1
Demographics of 37 Patients Who Survived Lightning Strike (N = 37)

	Males = 23		Females = 14	
Demographic Variable	**Mean**	**Range**	**Mean**	**Range**
Age	43	14–69	42	27–61
Education (Yrs) (9th grader to lawyer, CPA and Ph.D.)	13.3	9 to Ph.D.	13.7	11 to MSW
Duration of complaint (months from accident to Mensana Clinic evaluation)	42.3	2–168	77.3	5–276
Days in hospital	2.5	0–28	0.63	0–4
After lightning strike (0 = never went, not permitted to go)	1.26*	0–5	0.36*	0–1
*Discarding one outlying datum point		61*		4*
	Inside	Outside	Inside	Outside
Location when hit (outside = golf course, hiking, working, canoeing, walking, sports) (inside = open window, on telephone, on computer, in an airplane, working at a drive through bank window)	6	17	7	7
	Yes	No	Yes	No
Burns or blisters present	11	12	4	10
Cardiac symptoms at time of lightning strike	6	17	3	11
Loss of consciousness at time of lightning strike	8	15	2	12

TABLE 2
Demographics of 77 Patients Who Survived Electric Shock (N = 77)

	Males = 63		Females = 14	
Demographic Variable	**Mean**	**Range**	**Mean**	**Range**
Age	42.5	15 to 68	39.8	27 to 51
Education (yrs) (9th grader to lawyer, and Ph.D.)	12.5	9 to 22	14.4	12 to 19
Duration of complaint (months from accident to evaluation)	48.4*	21 to 144	29.3	19 to 42
*Discarding one outlying datum point		362*		
	Yes	No	Yes	No
Went to hospital	37	26	3	11
	Average	Range 0 to 4 not included 30,75,57,14,13*	Average	Range
Days in hospital after electrical shock (0 = kept less than a day) *Discarding five outlying data points	0.9*		1	1 to 1
	Yes	No	Yes	No
Burns or blisters present after electrical shock	23	40	1	13
Cardiac symptoms at time of electrical shock	8	55	0	14
Loss of consciousness at time of electrical shock	16	47	1	13

Materials and Methods

The criteria for patient selection included patients who survived either a direct or indirect lightning strike or electrical injury that produced symptoms for which they sought medical care. A review was conducted of the complete medical chart before referral to Mensana Clinic, including psychological testing, laboratory results, and clinical

reports from consulting physicians. As part of the Mensana Clinic program, all patients were evaluated by the clinical director for at least 1 hour.

For lightning strike survivors, 19 of the 37 received additional diagnostic studies and laboratory tests conducted at area hospitals or radiology groups. Eighteen of the 37 patients did not have adequate insurance coverage to pursue a multidisciplinary evaluation. Of the remaining 19 patients, of the original 37 patients, 6/19 had only a partial evaluation, and 13/19 had a complete multidisciplinary evaluation.

For electrical shock survivors, 53 of the 77 received additional diagnostic studies and laboratory tests conducted at area hospitals or radiology groups. Twenty-four of the 77 patients received only an initial evaluation because they did not have adequate insurance coverage to pursue a multidisciplinary evaluation. Of the remaining 53 patients, 12 of 53 had only a partial evaluation and 41 of 53 had a complete multidisciplinary evaluation.

Only patients with partial or completed evaluations are included in this study. Depending on the patient's symptoms, objective testing included flexion extension x-rays of the spine, Doppler flow studies, MRI of the spine, 3D-CT of the spine, bone scan, electromyography (EMG, nerve conduction velocity [NCV] studies, neurometer studies (current perception threshold),[15] root blocks, facet blocks, nerve blocks, sympathetic blocks, provocative discograms, blood studies, PET of the brain, SPECT of the brain, EEG, MRI of the brain, and neuropsychological testing. After testing was completed, the patients also received evaluations for their complaints by various medical specialists who are on the faculty of Johns Hopkins University School of Medical or University of Maryland School of Medicine. With the exception of neurometer testing, Mensana Clinic receives no financial gain from testing or referrals.

To evaluate the findings from the laboratory testing in a clinically consistent manner, we tabulated abnormalities and categorized them as (1) none present, (2) mild, or (3) moderate to severe, based on quantitative and qualitative interpretations. Table 3 shows this information for patients who survived lightning strikes, and Table 4 shows this information for patients who survived electrical shocks. Specific criteria for inclusion in a particular category for each test were codified. An MRI of the cervical or lumbar spine was considered mildly abnormal if there was a small central disc herniation, moderately abnormal if the report indicated frank disc herniation, and severely abnormal if the report mentioned

TABLE 3
Distribution of Test Results Based on Severity of Abnormality in Lightning Strike Patient $N = 19$ patients

Study	Number of Patients Tested	Abnormality			Percent Abnormal
		None	Mild	Moderate/ Severe	
EMG/NCV	12	6		6	50%
Neurometers	16	1		15	94%
3D-CT	19	5	3	8	69%
Root block	11			11	100%
Facet block	9	2	1	6	78%
Doppler Flow	7	4		3	43%
Provocative Discogram	10		2	8	100%
MRI	16	3	3	10	81%
Nerve Block	8			8	100%
Neuropsych Testing	9	4	2	3	56%
PET of Brain	10	9		1	10%
SPECT of Brain	3	1	1	1	67%
Bone Scan	6	1	1	4	83%
EEG	4	1		3	75%
ENG/BAER	10	5		5	50%
Total number of tests	150	42	13	92	71%

TABLE 4
Distribution of Test Results Based on Severity of Abnormality of Electric Shock Survivors 53 of 77 had partial or complete evaluations ($N = 53$)

Study	Number of Patients Tested	Abnormality			Percent Abnormal
		None	Mild	Moderate/ Severe	
EMG/NCV	24	3	4	17	88%
Neurometers	43	2	3	38	95%
3D-CT	28	2	16	10	93%
Root block	24	4	2	18	83%
Facet block	20	6	1	13	70%
Doppler Flow	17	7	0	10	59%
Provocative Discogram	28	8	1	19	71%
MRI	37	3	4	30	93%
Nerve Block	16	0	1	15	100%
Neuropsych Testing	12	2	2	8	83%
PET of Brain	36	17	0	19	53%
SPECT of Brain	14	5	0	9	64%
Bone Scan	14	2	9	3	86%
EEG	11	11	0	0	0
ENG/BAER	9	4	2	3	56%
Total number of tests	333	76	45	212	77%

root compression, cord compression, and/or spinal stenosis. Bulging discs, spondylosis, degenerative discs, and reduced disc space height were not considered abnormal. Provocative discograms were considered moderately abnormal only if the patient experienced pain concordant with the anatomical distribution of pain they normally experienced, at the time of the provocation, with a rating of 5 of 10 or 6 of 10 for their pain. Ratings of 7 of 10 or greater were considered severely abnormal. Doppler studies of the arms were considered moderately abnormal only if there was reduction of pulse wave amplitude of 30% to 50% with Roos maneuver or 180 degrees of abduction and severely abnormal if the reduction was 51% or greater. Neural foraminal stenosis was graded based on the radiologist's report of mild, moderate or severe findings on 3D-CT and/or MRI. Neurometer results were considered abnormal based on previously published criteria for abnormality.[15] EMG and NCV abnormalities were graded according to the reports from the physiatrist or neurologist performing the test. Root blocks, nerve blocks and facet blocks were graded on a comparison of pain reduction, between pre-block and post block pain, using a subjective 0 to 10 pain rating scale. The severity of abnormality of the PET scan and/or SPECT of the brain was based severity noted on report from the radiologist.

Diagnoses were given to each patient at 4 stages in their treatment: (1) referral diagnoses, that they had prior to being seen at Mensana Clinic; (2) preliminary diagnoses, which were after the initial evaluation with the clinical director of Mensana Clinic; (3) intermediate diagnoses, which were made after the initiation of the diagnostic evaluation, but before all diagnostic studies and consultations were completed; and (4) final diagnoses after a complete multidisciplinary evaluation at Mensana Clinic. A table of the distribution of the diagnoses most commonly used by referring physicians and the change made in diagnoses from referral diagnoses to intermediate and/or final diagnoses is shown in Table 5 for lightning strike patients, and Table 6 for electric shock patients. The most common diagnoses not mentioned by the referring physician were compared with diagnoses only if they were documented by abnormal objective testing (not a clinical diagnosis), after a diagnostic evaluation was initiated and/or at discharge from Mensana Clinic, (stage 3 and 4 of the evaluation), and is shown in. Thus, tables 5 and 6 represents diagnoses typically used by referring physicians (error of omission), and Tables 7 and 8 represents diagnoses that are typically overlooked by referring physicians.

For the purposes of this article, a patient was considered to have an overlooked diagnosis if:

1. The referring physical had made a diagnosis that was descriptive

TABLE 5
Diagnoses Used by Referring Doctors for Lightning Strike Survivor Compared to Diagnoses After Evaluation at Mensana Clinic (N = 19)

Diagnosis	Cases at Referral	Cases at Discharge
Chronic pain, unknown etiology	14	0
Cervical sprain	4	0
Lumbar sprain	2	0
Psychogenic pain	1	0
Reflex sympathetic dystrophy	2	0
Degenerative disc disease	6	0
Chest pain, unknown etiology	1	0
Nerve entrapment in arm	4	24
Nerve entrapment in leg	5	25
Temporal lobe epilepsy	2	4
Total	41	53

TABLE 6
Diagnoses Used by Referring Doctors For Electric Shock Survivor Compared to Diagnoses Confirmed at Mensana Clinic (N = 53)

Diagnosis	Cases at Referral	Cases at Discharge
Chronic pain, unknown etiology	4	0
Cervical sprain	3	0
Lumbar sprain	5	0
Psychogenic pain	1	0
Reflex sympathetic dystrophy	3	0
Degenerative disc disease	2	0
Chest pain, unknown etiology	1	0
Arm pain	3	0
Leg pain	6	0
No residual from shock	19	0
Partial complex seizure	1	1
Cortical damage	1	1
Headache (unspecified)	3	0
Fibromyalgia	2	0
Ulnar nerve entrapment	1	1
Radial nerve entrapment	1	1
Thoracic outlet syndrome	1	1
Migraine headache	2	0
Arthritis	2	0
Myofascial syndrome	3	0
Total*	64	5

(* some patients had multiple diagnoses)
Percentage of diagnoses made by referring physicians that were accurate (7%). So 93% of the time the referring physician did not have a proper diagnosis.

TABLE 7
The Most Common Diagnoses in Lightning Strike Patients Overlooked by The Referring Physicians but Confirmed by Objective Testing at Mensana Clinic (N = 19) Partially Completed or Completed Evaluations (of 37 Patients Seen After Lightning Strike)

	Number of Patients Diagnosed by Referring Physicians	Number of Patients Diagnosed by Mensana Clinic	Percent of All Patients with a Given Diagnosis
Temporal Lobe or Cortical Damage (a)	0	10	52%
Partial Complex Seizures (b)	2	4	21%
Thoracic Outlet Syndrome (c)	0	8	42%
Cervical Radiculopathy (d)	0	9	47%
Cervical Facet Syndrome C2-4 (e)	0	8	42%
Cervical Facet Syndrome C4-7 (e)	0	4	21%
Disrupted Cervical Disc (f)	0	10	52%
Temporal Mandibular Joint Syndrome (g)	0	1	52%
Vestibular or Labyrinthine Lesions (h)	0	5	26%
Cervical Neural Foraminal Stenosis (i)	0	6	31%
Ulnar nerve damage (j)	1	11	57%
Median nerve damage (j)	2	9	47%
Radial nerve damage (j)	0	4	21%
Acromo-clavicular joint impingement (k)	0	4	21%
Supraspinatus or bicipital tendonitis (k)	0	4	21%
Tibial nerve damage (j)	3	8	42%
Peroneal nerve damage (j)	0	7	37%
Sural nerve damage (j)	2	9	47%
Saphenous nerve damage (j)	0	0	0
Femoral nerve damage (j)	0	1	5%
Disrupted Lumbar Disc (f)	0	6	31%
Lumbar Neural Foraminal Stenosis (i)	0	1	5%
Lumbar Facet Syndrome L3-S1 (e)	0	2	10%
Lumbar Radiculopathy (d)	0	7	37%
Lumbar or Cervical Spinal Stenosis (l)	0	3	15%
Low testosterone (m)	0	2	10%
Reflex Sympathetic Dystrophy (n)	2	0	0
Causalgia (o)	0	0	0
Total Diagnoses	12	143	

Tests used to confirm diagnoses

(a) PET, SPECT and/or neuropsychological tests, (b) EEG and/or positive clinical response to anti-convulsants, (c) Dopplers and/or EMG/NCV, (d) EMG/NCV and/or root block, (e) 3D-CT, MRI and/or facet block, (f) MRI, 3D-CT and/or provocative discogram, (g) cine MRI, (h) ENG and/or BAER, (i) 3D-CT and/or MRI, (j) neurometer, EMG/NCV and/or nerve block, (k) MRI, (l) MRI and/or 3D-CT, (m) blood levels, (n) bone scan and/or sympathetic blocks, (o) bone scan, sympathetic blocks, and/or nerve blocks. Overlooked diagnosis was 131/143 or 92%. All 19 patients had multiple diagnoses.

(low back pain) and not a diagnosis at all,

2. The referring physician made a diagnosis that was not supported by objective anatomical or physiological testing later done at Mensana Clinic (having a referral diagnosis of RSD, but having negative bone scan, and no pain relief for even one hour, after a properly performed sympathetic block), or
3. Mensana Clinic established a diagnosis, not previously mentioned by the referring physician, and confirmed the diagnosis by objective testing at Mensana Clinic (such as no mention of tibial nerve entrapment by the referring physician, and having the diagnosis made during the Mensana Clinic evaluation, and confirmed by EMG/nerve conduction velocity testing and at least one hour of pain relief after a tibial nerve block).

Results

The average lightning strike survivor was a high school graduate and middle aged. Of the 37 patients, 23 were men and 14 were women. None experienced the loss of a limb. Despite the commonly held belief that lightning strikes produce entrance and exit wounds, no patients had burns that required plastic surgery, and only 15 of 37 had entrance or exit wounds. Ten of 37 lost consciousness at the time of the strike, and 9 of 37 had cardiovascular events. These data are shown in Table 1.

Of the 37 lightning strike survivors initially evaluated, 19 patients had a partial or complete multidisciplinary evaluation at Mensana Clinic. Eighteen of the 23 men and 7 of 14 women were hit by lightning while on the job. As the result of the diagnoses obtained at the time of the initial evaluation, a variety of diagnostic studies were ordered. The results of these diagnostic studies are shown in Table 2. Of the 150 tests ordered for these 19 patients, 71.4% were mildly, moderately, or severely abnormal and confirmed the original clinical diagnosis 95% of the time. Table 4 lists 143 confirmed diagnoses established by Mensana Clinic in the 19 survivors of lightning strikes. Only 10 diagnoses, made by referring physicians, were later substantiated by Mensana Clinic, and 2 were not confirmed. Referring physicians did not mention 133 diagnoses, which were later confirmed by Mensana Clinic. On the basis of these findings, the overlooked diagnosis rate for patients after lightning strike was 93%.

Table 5 shows the diagnoses used by referring physicians for their patients after lightning strike. Of the 41 diagnoses made by referring physicians in 19 patients, only 11 were later confirmed by Mensana Clinic. In this instance, the referring physician made unsubstantiated diagnoses 73% of the time.

TABLE 8
The Most Common Diagnoses In Electrical Shock Patients Overlooked by the Reffering Physicians but Confirmed by Objective Testing at Mensana Clinic (N = 53 partially completed or completed evaluations (of 77 patients seen after electrical shock)

	Number of Patients Diagnosed by Referring Physicians	Number of Patients Diagnosed by Mensana Clinic*	Percent of All Patients with a Given Diagnosis
Temporal Lobe or Cortical Damage (a)	1	31	61%
Partial Complex Seizures (b)	1	4	8%
Thoracic Outlet Syndrome (c)	1	15	29%
Cervical Radiculopathy (d)	0	22	43%
Cervical Facet Syndrome C2-4 (e)	0	8	16%
Cervical Facet Syndrome C4-7 (e)	0	11	22%
Disrupted Cervical Disc (f)	0	22	43%
Temporal Mandibular Joint Syndrome (g)	0	10	20%
Vestibular or Labyrinthine Lesions (h)	0	5	10%
Cervical Neural Foraminal Stenosis (i)	0	24	47%
Ulnar nerve damage (j)	1	35	68%
Median nerve damage (j)	0	35	68%
Radial nerve damage (j)	1	31	61%
Acromo-clavicular joint impingement (k)	0	17	33%
Supraspinatus or bicipital tendonitis (k)	0	17	33%
Tibial nerve damage (j)	0	29	57%
Peroneal nerve damage (j)	0	22	43%
Sural nerve damage (j)	0	24	47%
Saphenous nerve damage (j)	0	1	2%
Femoral nerve damage (j)	0	1	2%
Disrupted Lumbar Disc (f)	0	21	41%
Lumbar Facet Syndrome L3-S1 (e)	0	11	22%
Lumbar Neural Foraminal Stenosis (i)	0	12	24%
Lumbar Radiculopathy (d)	0	10	20%
Lumbar or Cervical Spinal Stenosis (l)	0	14	27%
Low testosterone (m)	0	7	14%
Reflex Sympathetic Dystrophy (n)	3	0	0
Causalgia (o)	0	1	2%
Syringomyelia (p)	0	1	2%
Thoracic disc or radiculopathy (q)	0	3	6%
TOTAL DIAGNOSES	8	444	

Tests used to confirm diagnoses
(a) PET, SPECT and/or neuropsychological tests, (b) EEG and/or positive clinical response to anti-convulsants, (c) Dopplers and/or EMG/NCV, (d) EMG/NCV and/or root block, (e) 3D-CT, MRI and/or facet block, (f) MRI, 3D-CT and/or provocative discogram, (g) cine MRI, (h) ENG and/or BAER, (i) 3D-CT and/or MRI, (j) neurometer, EMG/NCV and/or nerve block, (k) MRI, (l) MRI and/or 3D-CT, (m) blood levels, (n) bone scan and/or sympathetic blocks, (o) bone scan, sympathetic blocks, and/or nerve blocks, (p) MRI, (q) MRI, 3D-CT, and/or root block
Overlooked diagnosis rate was 436/444 or 98%
*all 53 patients had multiple diagnoses

As shown in Table 2, the average patient was a high school graduate and middle aged. Of the 77 electric shock survivors, there were 63 men and 14 women. None of the 77 patients in this study had a loss of limb. Despite the commonly held belief that electrical injuries produce entrance and exit wounds, only 3 patients had burns that required plastic surgery, and only 24 of 77 had entrance or exit wounds, only 17 of 77 lost consciousness at the time of the shock, and 8 of 77 had cardiovascular events. These data are shown in Table 2.

Of the 77 electric shock survivors initially evaluated, 53 patients had a partial or complete multidisciplinary evaluation at Mensana Clinic. As the result of the diagnoses obtained at the time of the initial evaluation, a variety of diagnostic studies were ordered. The results of these diagnostic studies are shown in Table 4. Of the 333 tests ordered for these 53 patients, 77.1% were mildly, moderately, or severely abnormal and confirmed the original clinical diagnosis 94% of the time. Table 8 lists 444 confirmed diagnoses established by Mensana Clinic in the 53 electrical shock patients. Only 8 diagnoses, made by referring physicians, were later substantiated by Mensana Clinic. Referring physicians did not mention 436 diagnoses, which were later confirmed by Mensana Clinic. On the basis of these findings, the overlooked diagnosis rate for patients after electrical shock was 98.2%.

All 63 males and 9 of the 14 females who survived electrical shock received their injury on the job. These data are shown in Table 9. Table 6 shows the diagnoses used by referring physicians for their patients after electric shock injury. Of the 64 diagnoses made by referring physicians in 53 patients, only 5 were later confirmed by Mensana Clinic. In this instance, the referring physician made unsubstantiated diagnoses 96.8% of the time.

Discussion

Several consistent clinical features have been observed in this research and are supported by articles in the literature. One factor in the diagnosis of survivors of lightning strikes and electrical injuries is the depression they have as the result of pain they often experience from their injuries. Chronic pain patients get depressed as the result of their chronic pain.[16,17] Depression occurs in 77% of patients with chronic pain, and 89% of these patients had never been depressed before the onset of their pain.[18] The depression may last from 3 to 12 years after the onset of pain.[18] This depression has dire consequences. Fishbain et al[19] report that the completed suicide rate

TABLE 9
Employment and Source of Injury Demographics of 77 (N = 77)

VOoltage Received BY Type of Injury	Males = 63			Females = 14		
		Mean Voltage	Range Voltage		Mean Voltage	Range Voltage
Touched overhead wire	N = 4	4,040	7,200 to 13,800	N = 1	7,200	7,200
Welding	N = 3	370	230 to 440	N = 0	0	0
Doing electrical job work	N = 28	2,343	110 to 15,000	N = 0	0	0
Household activities	N = 0	0	0	N = 5	150	110 to 220
Boat, submersible pump	N = 4	220	220 to 220	N = 0	0	0
Faulty equipment, short	N = 21	2,133	110 to 10,000	N = 8	140	110 to 220
Static electricity discharge on job	N = 3	?	static discharge	N = 0	0	0

among white male chronic pain patients is 2 times higher that the general population, and for white females, it is 3 times higher than the general population. However, more startling is the suicide rate for white males involved in workers compensation litigation: the completed suicide rate jumps to 3 times higher than the general population.

Not only do survivors of lightning strike and electric shock have issues with depression, but a spectrum of problems have been found in neuropsychological and psychological testing, with symptoms ranging from cognitive dysfunction, memory impairment, attention disturbances, affective problems, depression, anxiety, irritability, and poor frustration tolerances, to physically aggressive outbursts.[20–22] The variety of these disorders has been attributed to the multiple variables associated with lightning injuries, ranging from heat generated by the injury to damage to various nerve tissues, which can appear acutely or appear months from the date of the original injury.[21] After electrical injuries, Pliskin et al[23] reported neuropsychological disturbances ranging from memory loss, to conceptual difficulties. Others have reported post-traumatic stress disorder in a previously well adjusted individual.[24]

Emergency room physicians report that care of lightning injuries is very different than injuries after high-voltage injuries.[25] Wide variation in the physical properties of lightning discharges and the discharges from power supplies at home and in industry means that all kinds of injuries can be encountered.[11,20,21] Lightning injuries differ because they have high current flow, but extremely short duration, compared with the longer (by comparison) duration and lesser current flow of electrical injuries.[26] An understanding of the pathophysiological mechanism of tissue damage after lightning strike compared with electrical shock may help explain the variety of clinical presentations of lightning strike survivors. The first variable to consider is the form of the electricity itself. Lee and his coworkers report that electrical shock has complex pattern of injury because of multiple modes of frequency-dependent field interactions.[27] Originally, Joule heating was thought to the only source of electrical injuries to tissue by commercial frequency electrical shocks. However, in addition thermal burns caused by Joule heating, permeabilization of cell membranes and direct electroconformational denaturation of macromolecules such as proteins have been identified as tissue damage mechanisms.[27] However, lightning seems to be less fatal when the voltage drop caused by "flashovers" occurred immediately after a peak point, and the wave form of the current was a sharp peak. This is opposed to when the current wave form was a blunt shaped cone, and the voltage drop caused by the "flashover" was delayed by more than a few milliseconds.[28] Therefore, fast "flashovers" result in less energy being delivered to the body, with a higher survival rate.[28]

There seem to be 5 mechanisms by which lightning injury occur: (1) direct strike, (2) contact, (3) side flash, (4) ground current, and (5) weak upward streamers from the ground ranging from 10 to 400 A.[29] A sixth proposed mechanism suggests the rapid evaporation of water on the body surface produces a concussive effect, like a blast injury.[30] For lightning strikes, the victim receives approximately 300 kilovolts for less than 2 milliseconds, and most of the current passes over the body surface, which is a process called "external flashover."[28] This is different from electrical shock, which is typically 20 to 63 kilovolts for about 500 milliseconds.[28] This difference may account for the fact that industrial shock victims may exhibit deep-tissue destruction along the entire current pathway, whereas lightning burns seem to be at the entry and exit sites.[28] Moreover, 5 of 9 patients who experienced presumptive "flashovers" survived, whereas only 6 of 41 patients who had no signs of this "flashover" effect survived.[28]

The pathophysiological mechanism of tissue damage after electrical shock differ from lightning strike. The first variable to consider is the electricity itself. A clinician must take into account the type of current (AC or DC), voltage (110 to 15,000), frequency of the current (50 Hz to 196 MHz), amperage (milliamps to 100 amps), Joules, length of time of shock, resistance of the skin (wet or

dry) or any other dielectric interface (leather soles versus rubber soles), location of the electric shock, and whether or not there was direct contact, or an arc effect. At a minimum, there are 9 independent variables, just for the elements of the electrical shock alone, which means there are 9 factorial, or 362,880 possible combinations to consider when analyzing the type of an electrical shock a patient might have received. From this simple calculation, it is clear that there is no such thing as a "typical electrical shock."

Other factors in the production of an injury after electric shock involve the complex pattern of injury because of "multiple modes of frequency-dependant field interactions."[27] Originally, thermal injury was thought to the only source of electrical injuries to tissue by electrical shocks. However, "in addition thermal burns due to Joule heating, permeabilization of cell membranes, and direct electroconformational denaturation of macromolecules such as proteins have been identified as tissue damage mechanisms."[27] An intense electrical pulse can produce 2 effects on a cell, one caused by field, or the electric potential, and the other caused by current, or the electrical energy.[31] The explanation of tissue damage caused by electrical injury by doctors Tsong and Su is so elegant that it bears unaltered repetition: "The field induced transmembrane potential can produce electro-conformational changes of ion channels, and ion pumps, and when the potential exceeds the dielectric strength of the cell membrane (approximately 500 mV for a pulse width of a few milliseconds), electro-conformational damages and electroporations of the membrane proteins and lipid bilayers. These events lead to the passage of electric current through the membrane-porated cells, and to heating cell membranes and cytoplasmic content. The subsequent denaturation of cell membranes and cytoplasmic macromolecules brings about many complex biochemical reactions, including oxidation of proteins and lipids. The combined effects may cripple the cells beyond repair. Thermal effects of electric shock are thermal denaturation of cellular components and functions, such as nucleosomes, and the electron transport chain, and ATP synthetic enzymes of the mitochondrial inner membrane. Lipid peroxidation and the subsequent loss of the engery-transducing ability of cell may occur even at moderate temperatures between 40 C and 45 C."[31]

This explanation helps elucidate the variable clinical responses seen to electrical shock, and the delay in the onset of some symptoms, because the temperature range that can cause loss of "energy transducing ability of the cell" reported by Tsong and Su,[31] is at a level that may not even cause second-degree burns and the accompanying blisters.[32] In studies of sensory nerve fibers in animals, with 3 shocks at 37 V/cm, 75 V/cm, and 150 V/cm for 12 ms, thermal effects were negligible.[33] Sensory nerve measurements showed electric shock damage was mainly to large, fast myelinated fibers, and higher field strengths do more damage, and histology demonstrated that the more heavily shocked myelinated fibers had more damage.[33]

Almost every organ system can be injured by lightning.[4] Acutely, lightning injuries produce a variety of tissue injuries from first-degree skin burns, muscle tenderness, ST-segment elevation, creatinine kinase (muscle) elevation, transient hypertension, and tinnitus.[5,34] Nervous system symptoms develop, ie, seizures, cerebral edema, muscle, and nerve lesions.[14,22] There are reports of peripheral nerve disorders,[14] acute polyneuropathy, with transient quadriplegia, acute renal failure, rhabdomyolysis, respiratory distress syndrome, autonomic dysfunction, perforated ear drum, uveitis, and cataracts.[35] Massive muscle contractions caused by nerve stimulation or direct triggering of striated muscles can cause ruptures, ligamentous tears, fractures, and joint dislocations.[14,20,21] Other findings reported were EEG changes,[35] optic nerve neuropathy,[36] spinal cord lesions, and damage to the entire neuraxis from the cerebral hemispheres to the peripheral nerves,[37] demyelination,[38] fracture of the bone, and brachial plexus neuropathy,[39] tympanic membrane rupture, middle ear injury, and sensorineural hearing loss.[34] With this thought in mind, it would be difficult to say there are typical sequelae to lightning strike.[38–40]

Likewise, variability of the symptoms after electric shock injury has been found in neuropsychological and psychological,[21,23,24] orthopedic fractures,[41–43] neurological,[44–48] ophthalmological,[49] gastrointestinal,[50] endocrine systems,[10,51] and muscle contractions caused by electrical shock so severe that the spasms broke bones, even at low voltages.[41–43] Massive muscle contractions caused by nerve stimulation or direct triggering of striated muscles can cause ruptures, ligamentous tears, fractures, and joint dislocations,.[11,41–43]

The findings of this article show that disc disruptions occur in a significant number of lightning strike and electric shock survivors. The proposed mechanisms for the cause of these disrupted disc are the severe muscle contractions, which can cause broken or dislocated bones and can also cause hyperflexion or hyperextension type injuries.[11,41] Additional proposed mechanisms are the secondary injuries that occur when a patient is propelled from the injury site by a lightning strike, or electric shock or trauma from falls from a ladder or other elevation as the result of losing consciousness, or being dislodged by the lightning strike or electrical shock.[21,42,43]

Another important concept reported in the literature is the delay that occurs in the appearance of symptoms after electric shock.[44] Depending on the type of nerve tissue injured, and whether it is peripheral or central, symptoms may not ap-

pear for 1 to 44 months after the injury.[44–46] This may explain the failure to find symptoms soon after the original shock injury, and also explains the progressive nature of many of the symptoms of electric shock.

All 63 males and 9 of the 14 females who survived electrical shock received their injury on the job. Additionally, 18 of the 23 males and 7 of the 14 females were hit by lightning while on the job. Determining whether a patient has a valid complaint of pain is the first step toward accurate diagnosis. One insurance company found they could save an average of $1654 per claim by using the Mensana Clinic Pain Validity Test in place of surveillance and independent medical evaluations.[52] Proper diagnosis can enhance the return to work rate in injured workers. Most insurance companies report that if a person is out of work for 2 years or more on a workers compensation injury, the return to rate work is less than 1%.[53] Using the Mensana Clinic Pain Validity Test and a multidisciplinary evaluation technique in patients out of work for an average of 4.9 years, the Mensana Clinic reported a return-to-work rate of 19.5% for workers compensation cases and 62.5% for auto accident cases.[53] Interestingly, the type of litigation was the most important factor in determining the return to work rate.[54]

In summary, injuries in response to lightning strike and electrical shock can be varied and affect a number of different systems in the body, from neurological to endocrine, sometimes as the sole source of injury and sometimes in combination with others injuries. The onset of the injuries may be immediate or may take months to develop. The lightning or electric shock may impact the peripheral nervous system, the central nervous system, or both. The effects may be as obvious as cardiac death or as subtle as cognitive deficits. The results of lightning or electrical shock may range from injuries caused by direct current contact or a secondary effect of an injury sustained when falling after the lightning or electric shock or be as bizarre as having a rider survive a lightning strike while his or her horse is killed.[55,56] The data presented in this paper support the concept that the long-term effects of lightning or electrical shock injury have a variety of clinical presentations, and most of the clinical symptoms are not well recognized by the medical community as sequelae of lightning strike or electrical shock. Thus, a physician is cautioned to explore all complaints to avoid overlooking a correctable lesion.

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