Long-term sequelae of electrical injury

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EDITOR'S KEY POINTS

- For those who survive electrical injury, the immediate consequences are usually obvious and often require extensive medical intervention. However, the long-term sequelae might be more subtle, pervasive, and less well defined, and are particularly difficult to diagnose, as the link between the injury and the symptoms can often go unrecognized by patients and their physicians. This review summarizes the current evidence-based knowledge about the long-term sequelae of injuries from electrical current.

- Pain is a common and difficult complaint after electrical injury. Permanent peripheral neurologic injury at the site where the current entered is extremely common after such injuries. Neuropsychological sequelae of electrical injury are also common, including behavioural changes and difficulty with verbal memory and attention. As many as 6% of those suffering electrical injury will develop cataracts in the first year following the exposure, with a smaller number of additional patients developing cataracts within 3 years.

- Most of the literature associates these long-term sequelae with a highly diffuse injury that has likely altered cellular response or with an unknown biochemical sequence of events that was triggered by the electrical contact.

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Abstract

Objective To summarize the current evidence-based knowledge about the long-term sequelae of injuries from electrical current.

Quality of evidence MEDLINE was searched for English-language articles published in the past 20 years using the following search terms: *electrical, injuries, wound, trauma, accident, sequelae, long-term, follow-up,* and *after-effects.* For obvious reasons, it is unethical to randomly study electrical injury in controlled clinical trials. By necessity, this topic is addressed in less-rigorous observational and retrospective work and case studies. Therefore, the strength of the literature pertaining to the long-term sequelae of electrical injury is impaired by the necessity of retrospective methods and case studies that typically describe small cohorts.

Main message There are 2 possible consequences of electrical injury: the person either survives or dies. For those who survive electrical injury, the immediate consequences are usually obvious and often require extensive medical intervention. The long-term sequelae of the electrical injury might be more subtle, pervasive, and less well defined, but can include neurologic, psychological, and physical symptoms. In the field of compensation medicine, determining causation and attributing outcome to an injury that might not result in objective clinical findings becomes a considerable challenge.

Conclusion The appearance of these consequences of electrical injury might be substantially delayed, with onset 1 to 5 or more years after the electrical injury. This poses a problem for patients and health care workers, making it hard to ascribe symptoms to a remote injury when they might not arise until well after the incident event.

Séquelles à long terme des blessures d'origine électrique

Résumé

Objectif Résumer les connaissances actuelles fondées sur des données probantes concernant les séquelles à long terme des blessures dues au courant électrique.

Qualité des données Une recension dans MEDLINE a servi à trouver des articles en anglais publiés au cours des 20 dernières années à l'aide des expressions de recherche suivantes: *electrical, injuries, wound, trauma, accident, sequelae, long-term, follow-up* et *after-effects*. Pour des raisons évidentes, il est contraire à l'éthique de faire une étude randomisée des blessures d'origine électrique dans le contexte d'essais cliniques contrôlés. Par nécessité, ce sujet est traité dans des travaux observationnels et rétrospectifs moins rigoureux et des études de cas. Par conséquent, la rigueur des travaux scientifiques portant sur les séquelles à long terme des blessures d'origine électrique est affaiblie par la nécessité d'avoir recours à des méthodes rétrospectives et à des études de cas qui décrivent typiquement de petites cohortes.

Message principal Il y a 2 conséquences possibles à une blessure d'origine électrique: la personne survit ou meurt. Chez celles qui survivent, les conséquences immédiates sont habituellement évidentes et exigent souvent une intervention médicale exhaustive. Les séquelles à long terme de la blessure par électricité peuvent être plus subtiles, et insidieuses, et moins bien définies; elles peuvent inclure des symptômes neurologiques, psychologiques et physiques. Dans le domaine des évaluations médicales à des fins d'indemnisation, la détermination des causes et l'attribution de conséquences à une blessure, qui sont susceptibles ne pas résulter de constatations cliniques objectives, peuvent s'avérer un défi considérable

Conclusion L'apparition de telles conséquences à une blessure d'origine électrique peut être substantiellement retardée, surgissant de 1 à 5 ans après l'événement. Cette situation est problématique pour les patients et les professionnels de la santé, et rend difficile l'attribution de symptômes à une blessure lointaine puisqu'ils peuvent apparaître bien longtemps après la survenance de l'incident.

There are 2 possible consequences of electrical injury: the person either survives or dies. For those who survive electrical injury, the immediate consequences are usually obvious and often require extensive medical intervention. However, the long-term sequelae of the electrical injury might be more subtle, pervasive, and less well defined, and are particularly difficult to diagnose, as the link between the injury and the symptoms can often go unrecognized by patients and their physicians.[1] For family physicians who include compensation or legal medicine in their scope of practice, to present an informed, accurate medicolegal opinion, determining causation and attributing outcome to an ill-defined problem that might not result in objective clinical findings becomes a difficult challenge. Many who suffer electrical injury have considerable difficulty returning to work.[2] The appearance of nonresolving, non–path-related symptoms following electrical injury is a scientific puzzle.[3]

Quality of evidence

The purpose of this review of a subset of the literature is to summarize the current evidence-based knowledge regarding long-term sequelae of injuries from electrical current. This is not a meta-analysis or systematic review. Using the search terms *electrical, injuries, wound, trauma, accident, sequelae, long-term, follow-up,* and *after-effects,* we searched MEDLINE for English-language articles about electrical injuries in adults published in the past 20 years. A total of 69 articles were obtained, but most of these focused on lightning or burn-specific injury. Of these retrieved articles, only 24 addressed the spectrum of long-term outcomes of man-made electrical injury and were considered relevant to the scope of the defined topic.

The quality of medical literature affects the application of results to clinical practice. The strongest medical evidence that is free of medical bias is derived from prospective, blinded, placebo-controlled randomized trials. Retrospective studies are less rigorous, and case reports and expert opinion offer little in the way of proof, and have less effect on evidence-based medicine. For obvious

POINTS DE REPÈRE DU RÉDACTEUR

- Chez ceux qui survivent à une blessure d'origine électrique, les conséquences immédiates sont habituellement évidentes et exigent souvent une intervention médicale exhaustive. Par ailleurs, les séquelles à long terme peuvent être plus subtiles et insidieuses, et moins bien définies; et elles sont particulièrement difficiles à diagnostiquer parce que les patients et leurs médecins omettent souvent de faire le lien entre la blessure et les symptômes. La présente révision résume les connaissances actuelles fondées sur des données probantes à propos des séquelles à long terme des blessures causées par le courant électrique.

- La douleur est une plainte fréquente et difficile après une blessure d'origine électrique. Des lésions neurologiques périphériques permanentes au site d'entrée du courant sont extrêmement fréquentes après de telles blessures. Les séquelles neuropsychologiques des blessures dues à l'électricité sont souvent courantes, y compris les changements de comportement et les difficultés avec la mémoire verbale et l'attention. Un pourcentage aussi élevé que 6 % de ceux qui ont subi une blessure d'origine électrique développeront des cataractes durant la première année suivant l'exposition et un nombre moins grand de patients additionnels souffriront de cataractes au cours des 3 années suivantes.

- La plupart des travaux scientifiques associent ces séquelles à long terme à une blessure hautement diffuse qui a probablement altéré la réponse cellulaire ou à une séquence biochimique inconnue qui a été déclenchée par le contact électrique.

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reasons, it is unethical to randomly study electrical injury in controlled clinical trials. By necessity, this topic is addressed in less-rigorous observational and retrospective work and case studies. Therefore, the strength of the literature pertaining to the long-term sequelae of electrical injury is impaired by the necessity of retrospective methods and case studies that typically describe small cohorts.

Main message

Summary of electricity. Electrical injury from lightning has been a feature of human life since time immemorial. Injury due to man-made electrical power sources has been a hazard from the beginning of the 20th century. Most industrial sources of electricity range from 0 Hz (batteries) to 10 kHz (high-tension power lines). There are 2 types of electrical injury: low-voltage injury from sources less than 1000 V, and high-voltage injury from sources greater than 1000 V.

The basic physics of electrical current are represented by the formula $V = I \times R$. This identifies that voltage (V) is a product of current (I) and resistance (R). The terms *AC* and *DC* describe the flow of electrical current, with direct current (DC) traveling in one direction and alternating current (AC) resulting from the changing direction of the electrical flow. The number of field directional changes is referred to as a *cycle,* and 1 cycle per second represents 1 Hz. Standard North American household power is 60 cycles per second, or 60 Hz.

It seems counterintuitive, but low-voltage electrical injuries are more often fatal than high-voltage injuries are. With sources greater than 300 V, current might be transmitted by arcing caused by formation of conductive plasma between the source and the ground. The blast effect of high-voltage arcing can throw the victim away from the source, limiting the contact time. In such situations the degree of injury can be surprisingly small. However, a 60-Hz AC current can stimulate muscle contraction, causing an involuntary grip that prolongs the contact with the electrical current and that substantially increases the degree of injury. In general, high-voltage injury results in a greater degree of acute injury, but the potential for a spectrum of late sequelae of electrical injury is not affected by the magnitude of electrical force.[1,4-7]

Electricity follows the path of least resistance through the body and creates heat, resulting in thermal damage to various tissues along the path of the current. Tissues with high resistance experience more damage from heat. Bone, tendon, and fat have greater resistance than skin; nerve and vascular tissue have less resistance. Muscle tissue has intermediate resistance, but the greater volume of muscle tissue results in muscle carrying most of the current with an electrical injury. Compared with general burn or thermal injuries, electrical injury results in substantially greater injury to nerve, muscle, bone, and skin, with more complications and short- and long-term morbidity.[8]

Immediate effects of electrical injury. Immediate effects of electrical injury are obvious: burns, cardiac arrhythmias, paresthesias, seizures, and sensory and motor deficits.[1,4,9] Acute neurologic symptoms after electrical injury have a better prognosis for recovery than delayed-onset neurologic symptoms do.[10] The initial electrical injury might result in a transient neurapraxialike situation, but progressive cellular damage and death account for the evolution of delayed-onset symptoms. The severity of the electrical injury is, however, not proportional to the source voltage, visible burns, loss of consciousness, cardiac arrest, or neuroimaging findings. Electrical injury is unique in that it typically results in low mortality rates, but very high rates of short- and long-term morbidity.[1-25]

Electrical injury causes direct damage to nerves. Proprioceptive nerves are the most prone to damage, followed by nerves involved in touch, pressure, motor function, pain, and temperature; preganglionic autonomic, nonmyelinated pain fibres; and finally postganglionic autonomic nerves.[15] Thus, there might be a valid basis for claims of unsteadiness and frequent falls in the absence of hard neurologic findings after electrical injury.

Long-term sequelae of electrical injury. The long-term sequelae of electrical injury are difficult to study. The strength of the literature is impaired by the necessity of retrospective methods and case studies that typically describe small cohorts. Despite these limitations, there are consistent reports of similar findings of late effects of electrical injury.[1-25]

Neurologic: Permanent peripheral neurologic injury at the entry site of the current is extremely common after electrical injury.[1,4,6,9,23] Peripheral mononeuropathies or polyneuropathies are common sequelae of electrical injury.[1,4,5,10,22] Neurologic symptoms are believed to arise from structural lesions such as hemorrhage, cerebral edema, or chromatolysis of pyramidal cells.[18] However, possible organic damage does not readily explain the delayed onset of symptoms sometimes occurring days to years after electrical injury.

Psychological: Neuropsychological sequelae of electrical injury are common, including behavioural changes and difficulty with verbal memory and attention.[5,13,16,19,21] Irritability, frustration, anger, and physically aggressive behaviour have been described after electrical injury in persons without preinjury mood or personality disorders.[18,21] These effects are often very difficult to assess, and preinjury psychopathology augments the neuropsychological effects of electrical injury.[13] Neurologic ($P = .02$) and psychological ($P = .006$)

symptoms are significantly more prevalent in those who have suffered electrical injury than in control groups.[2,24] As many as 78% of those who have experienced electrical injury develop a *Diagnostic and Statistical Manual of Mental Disorders,* 4th edition, psychiatric diagnosis.[22] Several possible explanations for the neuropsychological sequelae have been proposed,[1] including progressive neurologic compromise or increasing stress as patients attempt to resume preinjury activity and employment activities and realize the extent of their biopsychosocial deficits.[13] Several authors have noted similarity between the nonfocal neuropsychological sequelae of electrical injury and head trauma.[1,16] This supports the notion that mechanisms other than thermal injury from the electric current are involved in symptom genesis.[5,13]

Although electrical injury victims often endorse a variety of symptoms similar to those resulting from traumatic brain injury, the literature on brain injury symptomatology in relation to electrical injury is not reliable. Most of the studies performed relied on retrospective questionnaires, or cursory cognitive assessments in which bias and effort were not examined at all. Patients with various kinds of trauma within the previous month, but no diagnosed head injury, endorsed cognitive symptoms if they had concurrent emotional distress. On formal cognitive assessment, only those patients with objective brain injury had objective cognitive difficulties. This suggests the need to perform comprehensive neuropsychological assessment to validate brain injury associated with electrical injury.[2,16,19]

Depression and posttraumatic stress disorder have been described with greater frequency in electrical injury patients who experience the phenomenon of "no-let-go" or involuntary muscle contraction prohibiting their release from the electric current.[13] Loss of consciousness, altered states of consciousness (amnesia), and being knocked away from the electrical source are also correlated with clinical diagnoses of depression and posttraumatic stress disorder.[18] Objective measures have identified that electrical injury results in considerable emotional distress and anxiety, with poor quality-of-life, sexuality, and physical scores.[21] However, 5 years after injury, physical scores improve on quantitative assessment, but measures of work satisfaction, sexuality, and affect remain substandard.[19] Studies have shown that 2 years after the date of electrical accident, victims are 14 times more likely to be affected by a formal *Diagnostic and Statistical Manual of Mental Disorders,* 4th edition, psychiatric diagnosis than those who suffered traumatic brain injury or those in burn populations.[13,21] Further, patients with previous psychiatric diagnoses have worse outcomes following electrical injury, as psychiatric diagnoses can confound the expression of subjective cognitive and emotional concerns. The progression of psychiatric difficulty in patients after electrical injury is important considering that the literature demonstrates that other traumatically injured populations improve with time from the injury.[21] As a result, those who have suffered electrical injury demonstrate deficits on all cognitive outcome measures, including verbal memory, executive functioning, and attention.[17] This raises questions about whether electrical injury has unique properties that induce chronic and progressive psychiatric distress.[21]

Ocular: As many as 6% of those suffering electrical injury will develop cataracts in the first year following the injury, with a smaller number of additional patients developing cataracts within 3 years.[6,11,18] Often the head is involved as the point of electrical contact, and cataract formation is greater on the side that is nearer to the site of entry of the electrical current. However, ocular changes do not occur in electrical injury at voltages less than 200 V.[11]

Pain: Pain is a common and difficult complaint after electrical injury.[1,7,18,23,24] It is often multifactorial and appears disproportionate to any measurable neuropathy. The literature identifies that many patients will not be satisfactorily relieved of pain after electrical injury, regardless of treatment methods used, but combining somatic and psychosocial techniques results in the most favourable outcomes.[5]

Table 1 summarizes the long-term sequelae described in the literature.

Conclusion: diffuse electrical injury

The difficulty with recognizing and diagnosing these long-term sequelae of electrical injury is that the complaints are often not proportional to the degree of acute injury, the electrical current or voltage, or the current's pathway through the body. Complicating this is the lack of a pathophysiologic explanation for complaints that are persistent and occasionally progressive, but which are vague, nonspecific, and prevalent in the general population. The challenge presented to the family physician is to determine if there are enough data to conclude that this common symptomatology has an organic basis.[3] Most of the literature associates these long-term sequelae with a highly diffuse injury that has likely altered cellular response or with an unknown biochemical sequence of events that was triggered by the electrical contact.[3] The appearance of these late consequences of electrical injury might be substantially delayed, with onset 1 to 5 or more years after the electrical injury. This poses a problem for patients and health care workers, making it hard to ascribe symptoms to a remote injury when they do not arise until well after the incident event.

Morse[7] coined the term *diffuse electrical injury.* This refers to electrical injury that results in diffuse symptoms that exist in locations remote to the theoretical current pathway and that produces

Table 1. Long-term sequelae of electrical injury

PSYCHOLOGICAL SYMPTOMS	NEUROLOGIC SYMPTOMS	PHYSICAL SYMPTOMS
Depression	Memory loss	Generalized pain
Posttraumatic stress disorder	Numbness	Fatigue, exhaustion
Insomnia	Headache	Reduced range of motion
Nightmares	Chronic pain	Contracture
Anxiety	Weakness	Pruritus
Flashbacks	Poor concentration	Muscle spasm, twitches, aches
Fear of electricity	Paresthesia	Headache, migraine
Frustration	Syncope	Night sweats, fever, chills
Hyperarousal	Loss of balance	Joint stiffness
Panic attacks	Gait ataxia	
Low self-esteem	Sciatica	
Guilt	Carpal tunnel	
Moodiness	Seizure disorders	
Memory loss or impairment	Dizziness	
Increased temper	Poor coordination	
Reduced attention span	Tinnitus	
Poor verbal learning	Tremor	

remote physical, neurologic, or neuropsychological symptoms. *Diffuse electrical injury* seems appropriate to encompass the vague and nonspecific nature of much of the prolonged and progressive somatic, cognitive, and emotional sequelae of electrical injury that are described in the literature and that hamper patients' work, family, and community functioning.

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Contributors
Both authors contributed to the literature review and to preparing the manuscript for submission.

Competing interests
None declared

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