Electrical Trauma: The Pathophysiology, Manifestations, and Clinical Management. R. C. Lee, F. G. Cravalho & J. F. Burke, Eds.: 33–77. Cambridge University Press, London/New York.
3. HOPEWELL, C. A. 1983. Serial neuro-psychological assessment in a case of reversible electrocution encephalopathy. Clin. Neuropsychiatry **5**(2): 61–65.
4. DANIEL, M., G. F. HABAN, W. L. HUTCHERSON, J. BOLTER & C. LONG. 1985. Neuropsychological and emotional consequences of accidental high-voltage electrical shock. Int. J. Clin. Neuropsychiatry **7**(2): 102–106.
5. HOOSHMAND, H., F. RADFAR & E. BECKNER. 1989. The neurophysiological aspects of electrical injury. Clin. Electroencephalogr. **20**(2): 111–120.
6. MANCUSI-UNGARO, H. R., A. R. TARBOX & D. J. WAINWRIGHT. 1986. Post-traumatic stress disorder in electric burn patients. J. Burn Care Rehabil. **7**(6): 521–525.
7. ZANARINI, M. C. 1991. Structured clinical interview for DSM-III-R axis I disorders: McLean version (SCID-1-MAC).
8. DIAGNOSTIC AND STATISTICAL MANUAL OF MENTAL DISORDER (Third edition). 1987. American Psychiatric Association. Washington, District of Columbia.
9. TRZEPACZ, P. T., M. HERTWECK, C. STARRATT, L. ZIMMERMAN & M. ADATEPE. 1992. The relationship of SPECT scans to behavioral dysfunction in neuropsychiatric patients. Psychosomatics **33**(1): 62–71.
10. SACKEIM, H. A., J. PRUDIC, D. P. DEVANAND, J. E. KIERSKY, L. FITZSIMONS, B. J. MOODY, M. C. MCELHINEY, E. A. COLEMAN & J. M. SETTEMBRINO. 1993. Effects of stimulus intensity and electrode placement on the efficacy and cognitive effects of electrotherapy. N. Engl. J. Med. **328**(12): 839–846.
11. BARSKY, A. J. 1992. Amplification, somatization, and the somatoform disorders. Psychosomatics **33**(1): 28–34.

Neuropsychiatric Aspects of Electrical Injury

A Review of Neuropsychological Research

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It is well known that electrical injury can cause damage to the central nervous system, affecting both the brain and spinal cord. Both acute and delayed neurological syndromes have been reported[1,2] in victims of electrical injury involving a variety of symptoms, including loss of consciousness, seizures, aphasia, visual disturbances, headaches, tinnitus, paresis, and memory disturbance.[3] Neurologic sequelae can occur whether or not the head is a point of direct contact with the electrical current. Central nervous system damage results from direct thermal and mechanical effects of electrical shock, and histopathological changes in the central nervous system such as coagulation necrosis (death of tissue due to clotting of blood vessels), reactive gliosis (increase in nonneural support cells within the central nervous system as a response to injury), demyelinization (destruction of the protein covering to many nerves), vacuolization (small holes within the brain tissue), and perivascular hemorrhage (small areas of bleeding) have been documented.[4–6,9] Central nervous system damage may also occur from anoxia due to cardiorespiratory arrest or ischemic damage resulting from thrombosis.[4,6] Cause of death in fatal cases is generally ascribed to ventricular fibrillation with subsequent cardiorespiratory arrest.[7]

Diverse neuropsychological changes have also been reported in electrical injury (EI) patients including confusion, altered consciousness, visual disturbance, memory loss, compromised intellectual function, psychomotor problems, and aphasia.[8–13] In comparison to the medical literature, however, relatively little has been written about the neuropsychological effects of EI. The purpose of this paper is to critically review the existing neuropsychological literature on electrical trauma and to present a model for future studies.

Hopewell[8] described a patient who sustained a high-voltage injury and suffered cardiorespiratory arrest and coma for 4 days. Neurological examination during the subacute phase was interpreted as essentially normal, although the examining neurologist was struck by the patient's disorientation and continued memory problems during hospitalization. An EEG indicated left temporal slowing as well as bursts of theta slowing with frontal accentuation, although the record was read as being minimally abnormal. Neuropsychological evaluation conducted 7 days after

injury found the patient to be disoriented, with Galveston Orientation and Amnesia Test (GOAT) scores ranging from 7 to 60 until the tenth day posttrauma (75 or better is "normal" range). At 50 days postinjury, orientation was within the normal range (GOAT = 79), although the patient showed difficulty in storing and retrieving auditory information on the Selective Reminding Test (a list learning test). In addition, the patient had deficits in memory for digits and in rhythm identification, decreased right-hand grip strength, and expressive and receptive language impairment. These results were felt by the investigator to be largely consistent with relatively greater dysfunction of the left cerebral hemisphere, consistent with the EEG results. Hopewell's study demonstrated for the first time the importance of utilizing serial neuropsychological evaluation in the documentation of persistent neuropsychological symptoms that might have otherwise been missed or dismissed.

Daniel *et al.*[9] conducted neuropsychological evaluations on 11 individuals who sustained high-voltage electrical injuries (220 to 8000 volts). Patients received standardized measures of intellectual and memory function (Wechsler Scales), as well as selected tests from the Halstead-Reitan Neuropsychological Test Battery. Eight of 11 patients were found to have neuropsychological impairment, although no single characteristic pattern could be discerned among the 8 patients (4 generalized, 2 left hemisphere, 1 right posterior, and 1 bilateral posterior). One patient received serial neuropsychological assessments at 1, 4, 9, 12, and 20 months postinjury, but did not receive cognitive retraining or psychotherapy during this period. This patient's neuropsychological performance was characterized by initial improvement followed by progressive deterioration of cognitive performance. Additionally, an assessment of emotional function using the Minnesota Multiphasic Personality Inventory-2 (MMPI-2) was given to 9 patients. The results indicated significant emotional disturbance in the form of anxiety, depression, and concern for their physical symptoms in 8 of the 9 patients. The researchers concluded that electrical injury victims could suffer progressive deterioration of cognitive and emotional functioning. However, the "interactive influence" of multiple factors on cognitive function was too complex to assess and the extent of impairment could not be estimated simply on the basis of demographics (e.g., age, physical health) or injury parameters (e.g., current) alone.

Troster and Ruff[10] reported three cases of electrical injury, one of which was serially assessed. The pattern of neuropsychological test performance revealed a common set of deficits in verbal learning and memory, arithmetic, logical and abstract thinking, and selective attention. No patient displayed deficits in perceptual or visuospatial abilities. The researchers suggested that many of the observed sequelae of electrical injuries may reflect a delayed neurological syndrome that could be a risk factor for a subsequent dementia.

In the lone longitudinal investigation of more than one patient, Hooshmand *et al.*[11] reported on a series of 16 patients who sustained electrical injuries and were followed over a period of 5 to 9 years postinjury. Severe anxiety and depression were present in 14 of the 16 patients. The researchers reported that 12 of the 16 patients demonstrated neuropsychological impairment at the outset of the study on tests of recent memory, concentration, judgment, and nonverbal achievement when compared to normative values. However, no specific demographic or cognitive data were provided and no follow-up neuropsychological assessment was reported.

Considering the disproportionate number of electrical workers and construction workers who are injured, it is also not surprising that cerebral injuries secondary to falls often occur in conjunction with an electrical trauma. Some investigators have observed, however, that electrical injury produces a diffuse pattern of dysfunction similar to what is observed in patients with traumatic brain injury,[10,11,13] even when no head injury occurred. In a retrospective study, Heilbronner *et al.*[13] compared the neuropsychological test performance of 8 electrical injury victims to a group of head-injured controls matched on age, education, and length of time since injury. Results revealed significant differences between the groups on only a few of the neuropsychological measures, with both groups performing below normative standards on almost all of the tests. Poor performance was observed in the electrical injury subjects relative to head-injured patients on the Information subtest of the Wechsler Memory Scale and the Memory Quotient, which is a measure of immediate memory capacity. However, there was no distinguishing syndrome of cognitive deficits in electrical injury victims, prompting the investigators to conclude that electrical injury produces a diffuse pattern of dysfunction similar to that observed in patients with traumatic brain injury.

Our review of the neuropsychological studies of electrical injury suggests that many patients suffer neuropsychological impairment (e.g., memory, attention, language functioning, problem-solving ability) and emotional disturbance (primarily anxiety and depression). However, despite reports of left hemisphere or diffuse impairment in electrical injury, no consistent constellation of neuropsychiatric symptoms has emerged either within or across studies, possibly because of methodological problems in the majority of studies. Specifically, all of the neuropsychological studies to date have examined extremely small sample sizes or have been multiple case reports. Additionally, large differences exist within samples of electrical injury patients despite the fact that patients within studies tend to be viewed as homogeneous groups. For example, the type of injury suffered (e.g., ac versus dc, electric shock versus lightning, current), loss of consciousness, and cardiorespiratory arrest, as well as secondary head trauma, were never adequately addressed or controlled for in these investigations. Moreover, despite the overwhelming emotional disturbance reported in some populations,[8,9,11] studies have failed to control for the effects of depression or other psychological trauma on neuropsychological performance. Furthermore, the nature and the progression of neuropsychological dysfunction and psychiatric disturbance in electrical trauma patients have not been adequately addressed due to the lack of longitudinal investigations. In addition, the impact of litigation on neuropsychological test performance and the paucity of preinjury information are important influences on neuropsychological test performance that have yet to be addressed. Finally, the potential impact of selection bias has not been adequately controlled. Examination of the individuals who present to outpatient clinics with complaints following electrical injury may not be representative of the longitudinal adjustment achieved in the broader pool of EI patients, many of whom may make successful adjustment. In fact, there have been several studies that have not found evidence for neuropsychological impairment or have found it to be only transient,[6,7] although it should be noted that in these studies patients were not followed longitudinally.

In sum, important questions remain unanswered regarding the neuropsychologi-

cal impact of electrical injuries. For example, is there a characteristic pattern of neuropsychological dysfunction in patients with electrical trauma? If so, is it essentially akin to the minor head trauma syndrome as has been suggested by some researchers? Do all shocked patients suffer from neuropsychological deficits? If not, what factors predict the type and magnitude of injury? What roles do other parameters such as pending litigation, preinjury intelligence, or preinjury personality characteristics play in the presence or absence of neuropsychological deficits? Are some of the emotional sequelae reported in these patients the consequence of subtle neuropsychological deficits? Finally, are some of the neuropsychological symptoms reported in electrical injury patients (e.g., memory failure) the consequence of psychiatric/emotional problems?

To address the methodological shortcomings that characterize the current knowledge base related to the neuropsychological effects of electrical injury, several suggestions for future research can be offered. First, studies must be longitudinal. This is necessary in order to assess the nature and progression of neuropsychological and emotional sequelae, the stability of symptoms, whether there is resolution following initial impairment, and whether patients develop delayed neuropsychological effects. Second, studies must not be limited to patients that present with neuropsychological complaints. These patients are important to study, but may be a highly selected subset of the electrical injury population. Ideally, every patient suffering an electrical injury should be evaluated as soon as medically stable. Examining a broader range of patients, particularly if the neuropsychological assessment is embedded within a study that also formally assesses current and historical personality characteristics, would allow for an evaluation of many parameters that may also impact on neuropsychological functioning. These include type and magnitude of injury, secondary injuries (head trauma, anoxia), premorbid intelligence and personality, and litigation. Optimally, a study of this kind could also evaluate patients who return many months or years postinjury. Perhaps even the identification and prescreening of high-risk employees (e.g., linesmen working around high-voltage equipment) could be considered in order to have a better understanding of preinjury neuropsychological and personality characteristics. Third, studies must include large numbers of subjects. This is necessary in order to ensure that the many factors that may contribute to neuropsychological dysfunction can be adequately controlled statistically and to observe trends that might not be apparent in examining smaller groups of patients. Careful neuropsychological and personality evaluation of this kind can significantly further our understanding of the impact of electrical injury on the central nervous system.

In our ongoing longitudinal investigation of electrical injury victims at the University of Chicago, each inpatient admission to the Electrical Trauma Unit receives an extensive neuropsychological battery of tests as part of a multidisciplinary comprehensive evaluation. Demographic and injury information are carefully collected. Each patient also receives a standardized personality evaluation using both objective and self-report psychological measures. In addition, a family member/spouse is asked to complete a personality measure (Millon Clinical Multiaxial Inventory) "as if they were the patient before the injury". Each inpatient is being followed and reevaluated at six-month intervals. Victims of electrical accidents suffering only flash burns are controls for the study, with a matched sample of

head-injured patients also serving as a comparison group. In this manner, we hope to determine the critical factors contributing to neuropsychiatric changes following electrical injury.

REFERENCES

1. CHRISTENSEN, J., R. SHERMAN, G. BALIS & J. WAUMETT. 1980. Delayed neurologic injury secondary to high-voltage current with recovery. J. Trauma **20**(12): 166–168.
2. FARRELL, D. & A. STARR. 1968. Delayed neurological sequelae of electrical injuries. Neurology **18:** 601–606.
3. GRUBE, B. J. & D. M. HEIMBACH. 1992. Acute and delayed neurological sequelae of electrical injury. *In* Electrical Trauma: The Pathophysiology, Manifestations, and Clinical Management. R. C. Lee, E. G. Cravalho & J. F. Burke, Eds. Cambridge University Press. London/New York.
4. DIVINCENTI, F., J. MONCRIEF & B. PRUITT. 1969. Electrical injuries: a review of 65 cases. J. Trauma **9**(6): 497–507.
5. PRUITT, B. A. 1979. High tension electrical injury. Lancet **271**.
6. WILKINSON, C. & M. WOOD. 1978. High-voltage electrical injury. Am. J. Surg. **136:** 693–696.
7. PETTY, P. G. & G. PARKIN. 1986. Electrical injury to the central nervous system. Neurosurgery **19:** 282.
8. HOPEWELL, C. 1983. Serial neuropsychological assessment in a case of reversible electrocution encephalopathy. Clin. Neuropsychol. **2:** 61–65.
9. DANIEL, M., G. F. HABAN, W. L. HUTCHERSON, J. BOLTER & C. LONG. 1985. Neuropsychological and emotional consequences of accidental high-voltage electrical shock. Int. J. Clin. Neuropsychol. **7**(2): 102–106.
10. TROSTER, A. J. & R. M. RUFF. 1988. Accidental high-voltage electrocution: neurobehavioral sequelae in three cases. Presented at the National Academy of Neuropsychology meeting.
11. HOOSHMAND, H., F. RADFAR & E. BECKNER. 1989. The neurophysiological aspects of electrical injuries. Clin. Electroencephalogr. **20:** 111–120.
12. FRAYNE, J. H. & B. S. GILLIGAN. 1989. Neurological sequelae of lightning strike. Clin. Exp. Neurol. **15:** 195–200.
13. HEILBRONNER, R. L., S. ROTHKE, W. GARMOE & J. R. ROUECHE. 1991. Neuropsychological test performance in accidental high-voltage electrical injury. Presented at the 1991 Annual Meeting of the American Psychological Association (San Francisco).