Neurological Outcomes After Near-Drowning

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In this article, the current literature on prognostic indicators of neurological outcome after near-drowning is reviewed and critically appraised. A conflict arises between the desire to avoid resuscitating patients who will live only to exist in a persistent vegetative state and the desire to avoid denying even a small number of patients a chance for meaningful survival and recovery. Prolonged and futile resuscitation efforts only magnify pain and suffering for patients and their families, in addition to contributing to the escalating costs of medical care.[1] Although various predictors of neurological outcome after near-drowning currently exist, assessment findings that can guide resuscitation efforts in these patients must be defined better and validated.

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SIGNIFICANCE AND DEFINITIONS

Drowning is defined as "death from asphyxia while submerged or within 24 hours of submersion."[2] Near-drowning is defined as a submersion "episode of sufficient severity to warrant medical attention for the victim that may eventually lead to morbidity and mortality."[2] Drowning is the fifth leading cause of accidental death in persons less than 65 years old[3,4] and the most common cause of death in children less than 5 years old in the United States.[5] Tragically, most drownings occur in children less than 4 years old.[4] In addition to these deaths, submersion accidents leave many more children and adults with various degrees of neurological impairment. With the increased availability of advanced care, the number of deaths is expected to decrease, with a resulting increase in the number of neurologically impaired survivors of near-drowning. If a method or finding were available that would enable neurological outcome after near-drowning to be predicted reliably, it could be used to guide further resuscitation efforts and provide appropriate counseling for families about the prognosis of their loved ones.[6]

ETIOLOGY OF PRECIPITATING FACTORS

Drowning typically does not occur as the classic image shown on television, in which the drowning person desperately thrashes about in the water gasping for air. On the contrary, people more often quietly disappear below the surface of the water or dive into the water and never resurface.[7] These findings indicate that drowning often occurs in association with another event, such as head or neck injuries sustained in a dive into the water. Cardiac arrhythmias and myocardial infarction, along with cerebral events such as a cerebral vascular accident, syncope, or seizures, may also precipitate drowning.[7]

Regardless of a person's age, drug and alcohol use can impair judgment and physical abilities[8] and can compound the incapacitating effects of cold water (eg, confusion, lack of coordination, and muscle rigidity).[9]

PATHOPHYSIOLOGY

Why is it that some persons do not drown despite prolonged submersions? Two theories have been proposed to explain this concept: the diving response and hypothermia. The diving response involves the body's reactions to asphyxia and its conservation of oxygen for those tissues most sensitive to hypoxia. Profound bradycardia and a subsequent reduction in cardiac output are part of the diving response; those responses minimize myocardial oxygen demands. Coupled with the intense vasoconstriction of the vasculature supplying the gut, kidneys, and skeletal muscles, these adjustments maximize blood flow to the heart and brain. Only about 15% of persons have this response, hence the alternative theory of hypothermia.[10]

For cerebral tissues to be protected from irreversible hypoxic damage solely by hypothermia, the brain temperature would have to decrease by at least 7°C from the normal core body temperature within the initial 10 minutes of submersion. However, the maximum cooling, even in 0°C water, is about 2.5°C during this brief period.[10] It has been speculated that additional cooling is caused by the ingestion or aspiration of large quantities of cold water,[11] although other studies have refuted this concept.[12-14] Modell et al[13] found no evidence of aspiration of large quantities of water in patients who experienced near-drowning who were alive on reaching the hospital, and no studies[10,14] support the idea that persons who nearly drown swallow substantial amounts of water. Thus, some combination of hypothermia and the diving reflex is currently thought to be responsible for protecting the cerebral status of someone who experiences near-drowning.

The ability of different persons to tolerate hypoxia depends on a variety of factors, including age, previous health status, water temperature, and the promptness and effectiveness of the resuscitation efforts.[2] Adverse complications of hypoxia can affect the cerebral tissues in as few as 5 minutes.[7] Although aspiration of fluid into the lungs affects the pulmonary system (pulmonary edema and altered surfactant) and serum electrolyte levels (rare),[2] the true lasting effects of drowning include anoxia, cerebral edema and herniation, clinical brain death, and alterations in the blood-brain barrier.[2] Depending on the duration of the hypoxic trauma, neurological sequelae can range in severity from no perceptible alterations to persistent vegetative state to clinical brain death or physiological death.

OVERVIEW OF RECENT PUBLICATIONS

I reviewed eight recent studies[1,6,15-20] on the neurological outcomes of patients who had near-drowning episodes to determine predictors related to these outcomes. Factors used to assess and predict neurological outcomes included the age of the patient (child or adult), cold or warm water, time of neurological assessment (before hospitalization, in the emergency department, in the ICU), and clinical indicators. Clinical indicators evaluated in these studies included modified versions of the Glasgow Coma Scale, pupillary reaction, initial fasting blood glucose levels, and cortical and brain stem functions.

The Glasgow Coma Scale is a commonly used standard neurological assessment device. Dean and Kaufman[15] (see Table) retrospectively reviewed the records of 94 children admitted after near-drowning episodes in warm water. Patients were examined to determine their neurological status, and three categories of outcomes were established. "Normal recovery" was defined as the child returning to the same condition as before hospitalization. "Transient neurological sequelae" was the outcome listed for patients who had severe neurological deficits at the time of discharge from the hospital but later returned to their preinjury state. "Permanent neurological sequelae" was the outcome assigned for patients who had no apparent cognitive function.[15] Residual neurological damage did not vary significantly with age in this sample. Morbidity, mortality, and neurological outcome in patients with a score of 5 or less on the Glasgow Coma Scale were significantly different from those in patients with a score greater than 5. In this study, all patients with a score of 6 or greater on the Glasgow Coma Scale when they arrived at the emergency department recovered with full gross neurological function. Notably, these patients were not followed up after discharge from the hospital to assess for the long-term effects of their near-drowning episode. Three patients in this study had neurologically normal outcomes despite particularly low scores on the Glasgow Coma Scale (3–4), a finding that emphasizes

Summary of research on predictors of neurological outcome in patients who experienced near-drowning

Study	n	Sample	Outcome predictor(s) studied	Clinical indicators used	Findings
Dean and Kaufman[15]	94	Children	Age Warm water ED assessment	GCS score	No differences in neurological sequelae based on age All patients with GCS score of 6 or more had full neurological recovery Three patients with GCS score of 3-4 had full neurological recovery
Lavelle and Shaw[1]	44	Children	Warm water ED and ICU assessment	GCS score Pupil reactivity	"Minimal" neurological deficits with reactive pupils in ED or GCS score greater than 5 in the ICU Two patients in full cardiac arrest in ED had full neurological recoveries
Conn et al[16]	30	Children	Warm water ICU admission assessment	Modified GCS score	"Good" outcomes with spontaneous respirations and purposeful response to pain 70% had full neurological recovery if displaying abnormal extension/flexion posturing and abnormal breathing patterns "Poor" outcomes if flaccid, unresponsive, or history of cardiac arrest
Oakes et al[17]	40	Children and adults	Warm water ED assessment	Modified GCS score Vital signs and findings on neurological examination	All patients arriving in the ED with a spontaneous pulse were discharged neurologically intact Results of neurological and hemodynamic assessment in ED more prognostic than results of assessments done in critical care unit Devastating sequelae if patient had cardiac arrest while hospitalized 19% of patients in full cardiac arrest in ED had complete neurological recoveries
Bratton et al[18]	40	Children	Warm water ICU assessments	Modified GCS score Brain stem reflexes	Initial findings in ED or ICU not sufficiently predictive of neurological outcome Assessment 24 hours after injury carried much better predictive value
Graf et al[6]	194	Children	Warm water ED assessment	GCS score Pupil reactivity Initial blood glucose level Sex	"Favorable" neurological outcome if not comatose "Unfavorable" outcome associated with unreactive pupils, elevated initial blood glucose level, and male sex
Quan and Kinder[19]	77	Children	Warm water Prehospital assessment and history	Submersion time Results of neurological examination Cardiac status	Only the extremes of submersion and resuscitation times were reliable predictors of neurological outcome Advanced life support before hospitalization associated with better outcomes
Fisher et al[20]	89	Children	Warm water ICU assessment	Results of BAER testing	All patients studied had history of cardiac arrest BAER results from examinations 6 and 24 hours after injury most prognostic of neurological outcomes

ED, emergency department; GCS, Glasgow Coma Scale; BAER, brain stem auditory-evoked response

the need for aggressive initial resuscitation of all patients who experience near-drowning.

To evaluate neurological outcome and the role of aggressive cardiopulmonary and cerebral resuscitation, Dean and Kaufman[15] and Lavelle and Shaw[1] (see Table) retrospectively reviewed records of 44 children who had near-drowning episodes in warm water. Patients with concurrent head trauma and patients who did not survive until admission to the ICU were excluded from the study. Unreactive pupils in the emergency department or a score of 5 or less on the Glasgow Coma Scale on admission to the ICU were associated with poor neurological outcome (death or persistent vegetative state). Even those patients who had experienced a full cardiac arrest or were unresponsive before hospitalization but had reactive pupils in the emergency department or a score greater than 5 on the Glasgow Coma Scale in the ICU had a good outcome (none to "minimal" neurological deficits). Minimal neurological deficit was not defined by the authors. As in the study by Dean and Kaufman,[15] some patients had outcomes that were much better than predicted by the responsiveness of their pupils or their scores on the Glasgow Coma Scale. The study by Lavelle and Shaw[1] was especially useful because it looked at predictors in both the emergency department and critical care units. Suggestions for further studies include the need for additional neurological follow-up (after discharge from the hospital) and further descriptions and delineations of true neurological status at the time of discharge.

Although research in this area continues, the study by Conn et al[16] (see Table) and the classification system they developed for neurological sequelae after near-drowning is a frequently used standard in attempts to predict neurological outcomes. That classification system uses a modification of the Glasgow Coma Scale and is applied when the patient is admitted to the ICU. It includes six categories: A, B, and C1 to C4. Patients in category A (awake) are alert and have minimal neurological injury but require observation for the neurological or pulmonary complications that may develop after admission. Patients in category B (blunted or obtunded) have some reversible cortical dysfunction that is manifested by a stuporous state, normal breathing patterns, and purposeful responses to pain. Patients in category C (comatose) have damage of the cortex and brain stem as shown by abnormal, inappropriate breathing patterns; posturing or flaccidity; and possible seizures. Category C is further divided into four subgroups: C1, comatose patients with abnormal flexion posturing and Cheyne-Stokes respiration; C2, comatose patients with abnormal extension posturing and central nervous system hyperventilation patterns; C3, comatose patients with flaccid, ataxic, or cluster breathing patterns; and C4, patients in full cardiopulmonary arrest.[5,16]

Conn et al[16] examined 30 consecutive children who had near-drowning episodes in warm water, and used the children's outcomes to create the categories of neurological findings. Not all patients fit the criteria. When aggressive treatment (supplemental oxygen, intubation, ventilatory support, and management of cerebral edema) was started before hospitalization and continued in the hospital, most of the patients in categories A, B, C1, and C2 had good outcomes. Specifically, patients in categories A and B usually survived neurologically intact if oxygen was provided and pulmonary complications such as pneumonia and adult respiratory distress syndrome were treated. Even among those patients in class C1 and C2, with aggressive care before hospitalization and in the hospital, a large proportion (70%) survived neurologically intact. However, patients who were flaccid or unresponsive, whether before hospitalization or in the ICU, and patients with a history of full cardiac arrest had dismal neurological outcomes, including persistent vegetative states and clinical brain death or physiological death.[5,16] The reliability of these findings is questionable because of the relatively small number of patients in the study and the lack of long-term neurological follow up. Repeated studies with larger numbers of patients, additional follow-up, and standardized cerebral management would make these categories more valuable in predicting outcomes.

In a study similar to the one by Conn et al,[16] Oakes et al[17] (see Table) retrospectively reviewed the charts of 40 children and adults who were categorized according to the A, B, or C system of Conn et al on admission to the emergency department. In addition, other groups were delineated on the basis of results of physical examination at admission. Patients in group I (normal examination findings), group II (stable vital signs with abnormal neurological findings such as blunted sensorium, coma, or posturing), and group III (cardiac arrest) were examined at the time of discharge from the hospital and 1 year later for the severity of neurological sequelae, as contrasted with their baseline neurological status before injury. The data were similar to those of Conn et al,[16] with the startling finding that all patients who arrived at the emergency department with a spontaneous pulse (groups I and II) were eventually discharged neurologically intact. However, of patients who had a cardiac arrest while hospitalized, half died and one third required total care for neurological deficits at discharge. The worse the classification was at admission (A, B, or C scale or group I to III), the worse the prognosis was. Nineteen percent of patients assigned to class III (full cardiac arrest) eventually regained consciousness and were discharged "neurologically normal,"[17] reiterating the need for aggressive cardiopulmonary resuscitation. The findings of Oakes et al[17] were slightly contrary to those of Lavelle and Shaw[1]: Oakes et al found that the neurological and hemodynamic status when the patient arrived in the emergency department, rather than presentation in the critical care unit, was most diagnostic for the degree of neurological damage when neurological status was assessed at discharge and 1 year later. Standardized cerebral resuscitation and invasive monitoring protocols would further enhance the applicability of these findings.

Bratton et al[18] (see Table) retrospectively looked at cortical and brain stem function at the time of admission to the pediatric ICU and daily thereafter in 40 children who had a near-drowning episode in warm water. Additional follow-up was done for a minimum of 6 months after discharge from the hospital. The data showed that the results of cortical examination 24 hours after injury distinguished the children who had a "satisfactory" outcome (no deficits or mild ataxia or dysarthria) from those who died or had a "severe" outcome (spastic quadriplegia, no self-help skills, persistent vegetative state, clinical brain death, or physiological death).

Bratton et al[18] used the Children's Hospital and Medical Center (CHMC) Brain Stem Coma Score to evaluate patients' neurological status. This scale includes a modified Glasgow Coma Scale (cortical function) and assessment of brain stem reflexes (pupillary light, oculovestibular, corneal, and respiratory patterns). The results showed that the initial findings in the emergency department or ICU were not always accurate predictors of final neurological outcome. Despite severe brain injuries, neurological findings 24 hours after the injury were highly predictive of later outcomes. Although the modified Glasgow Coma Scale was a part of the CHMC scale, the inclusion of measures of brain stem function added to the prognostic value of the scale. Bratton et al reiterate the need for prospective studies with greater numbers of patients to evaluate the diagnostic power of the neurological examination 24 hours after the injury. Also, the CHMC score is used in only one institution, and a standardized detailed assessment scale should be used in future studies.

Graf et al[6] (see Table) did a retrospective study of 194 children in an attempt to predict neurological outcome in children who experienced a near-drowning in warm water. On admission to the emergency department, a favorable outcome (no impairment to severe impairment, but not vegetative state) was predicted for patients who were not comatose. Unfavorable outcomes (persistent vegetative state, clinical brain death, or physiological death) were most strongly associated with, in order, absence of the pupillary light reflex, elevated initial blood glucose level, and male sex. One report[21] indicated that males have an increased mortality in the postneonatal period; however, other studies[22-24] found no difference in survival or better survival in males than in females. Graf et al[6] suggest that the best predictive model would include initial blood glucose levels and "some measure" of neurological function (Glasgow Coma Scale, reactiveness of pupils) and that further study of the relevance of sex of the patient is required. Graf et al acknowledged the limitations of their study, including the relatively small number of patients in their sample (largest number of comatose patients who experienced near-drowning, however), the unknown length of time that patients survived in a persistent vegetative state, and the aggressive advanced life support given to the children in the study before the patients reached the hospital. Another major limitation is the lack of stratification of sample size based on the length of time the victim was submerged. The issue of advanced life support may not be applicable to areas outside the United States, where care before hospitalization may be minimal or nonexistent.

Quan and Kinder[19] (see Table) studied care received before hospitalization as a predictor of neurological outcome in patients who had near-drowning episodes in warm water. The results showed predictors for good outcomes (functioning at the same level as before injury or mild ataxia or dysarthria) and poor outcomes (spastic quadriplegia, no self-help skills, persistent vegetative state, or clinical brain death or physiological death) at the time of discharge from the hospital, Charts of 77 consecutive children who experienced near-drowning were retrospectively reviewed. Submersion for more than 10 minutes and resuscitation times greater than 25 minutes had a high predictive value for death or a poor outcome. Patients who were submerged for fewer than 5 minutes; who had a pulse, sinus rhythm, or reactive pupils before hospitalization; and who were alert while in the emergency department had good outcomes.[19] All patients who were not found in cardiac arrest were subsequently discharged without neurological impairments. Quan and Kinder followed up all these patients until the patients were discharged from the hospital, and followed up the patients with poor outcomes for up to 2 years. Only the extremes of duration of submersion and resuscitation were reliable predictors of neurological outcome, and advanced life support before hospitalization was associated with better outcomes.

All eight studies involved assessment findings and laboratory tests that can easily be done on adults and children. As additional technology becomes more available, procedures such as brain stem auditory-evoked response testing (BAER)[20] may be increasingly used. BAER evaluates the status of the auditory brain stem neuronal pathway and offers a quantifiable assessment of global cerebral injury. It is a useful test in the context of near-drowning because the results, unlike with the case with the Glasgow Coma Scale or the classification system of Conn et al,[16] are not affected by muscle relaxants, narcotics, or barbiturates. Fisher et al[20] (see Table) did BAER tests on 89 children who had near-drowning episodes in warm water. All 89 subjects had a cardiac arrest of various duration after submersion. Initial BAER testing was done within 6 hours of submersion and then once daily until the child's condition was stable or the patient was discharged from the hospital or died. On the basis of specific interpretation criteria, Fisher et al found that the results of BAER tests done 6 and 24 hours after submersion were most prognostic of the extent of neurological injury and resulting state. However, BAER testing is relatively new, and national standards for testing children do not yet exist. In conjunction with other assessment models, BAER may be useful in the prediction of neurological outcomes.

RESEARCH IMPLICATIONS

Research in the areas of assessment findings, diagnostic tests, and resulting prognoses after near-drowning episodes is ongoing. According to studies done to date, aggressive initial resuscitation measures should be undertaken on all patients after a near-drowning episode, because of the possibility of complete neurological recovery, even after full cardiac arrest.[1,17,18] If the initial resuscitation is successful, survivors' neurological status should be assessed in the emergency department and in the ICU to help predict their neurological outcomes. The decision truly then becomes not when to start resuscitation efforts but when to stop aggressive measures.

Early cessation of resuscitation efforts may become more customary as assessment findings that are better for predicting outcomes are found.[19] In addition to the easily performed assessments and laboratory tests, BAER testing[20] can be used in conjunction with serial assessments. No single prognostic tool is currently available that allows acceptably precise and accurate prediction of the neurological outcome of patients who experience near-drowning. Therefore, aggressive resuscitation is currently advocated before hospitalization and in emergency departments. In the future, assessment tools used both in the emergency department and in critical care units may help guide healthcare personnel in their efforts to provide holistic care properly for these patients and the patients' families. ✚

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