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Acute Spinal-Cord Lesions from Diving—Epidemiological and Clinical Features

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The aquatic activity that produces the greatest number of spinal-cord lesions is diving. Persons in the general population at greatest risk are males aged 15 to 19 years. Of the cases identified, 45 percent resulted from diving into a river or stream, 27 percent into swimming pools and 28 percent into lakes, reservoirs or the ocean. Distribution by age differed for the major groups of bodies of water. The incidence of spinal-cord injuries was related to season (spring-summer) and day of the week (weekends). The incidence of injuries was highest in those county areas with the least opportunity for exposure to swimming pools or rivers. Of the injured persons, 60 percent were tetraplegic at hospital admission. The most frequent radiologic finding was wedge fracture. This finding, in the absence of objective evidence that most divers struck the bottom of the water reservoir or a hard object, suggests that hyperventroflexion was the mechanism responsible for injury in most of the cases. Physicians and others should be aware of strategy options for preventing or reducing such injuries.

AMONG the most popular leisure-time activities of Americans are aquatic sports including swimming, diving, scuba diving, waterskiing and surfing. The injuries that may result range from trivial ones to spinal-cord lesions and to death from drowning. The aquatic recreation that produces the greatest number of spinal-cord lesions is diving. In fact, greater than 75 percent of all acute spinal-cord lesions that are recreation-related result from diving.[1] (Recreation-related spinal-cord injuries include those associated with athletics, sporting events, aquatic recreation, hiking [falls] and the like. Such injuries from recreational motoring or hunting are classified as injuries from motor vehicle collisions or firearms.) The neurological lesion is often severe enough to result in permanent tetraplegia.

The incidence and epidemiologic features of spinal-cord lesions from diving have not been reported aside from several clinical descriptions of series of cases. Presented here are the results of a

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study of the incidence of acute traumatic spinal-cord lesions due to aquatic diving among residents of 18 Northern California counties. This paper reports on the methods used in case ascertainment, overall incidence rates, human and environmental factors associated with the injuries, and the clinical features of all incidence and prevalence cases identified.

Methods and Materials

The methods used in case ascertainment for the study of traumatic spinal-cord lesions in 18 Northern California counties have already been presented elsewhere.[1] For completeness, this report recapitulates important methodologic considerations.

Definition of Spinal-Cord Injury and Incidence Criteria

For the purposes of this study, a spinal-cord lesion was defined as an acute traumatic lesion of the spinal cord, including trauma to nerve roots that results in sensory or motor deficit, or both. The diagnosis of spinal-cord injury and description of the resulting deficits were accepted as recorded by an attending physician in the hospital admission or discharge record, autopsy protocol or other medical record. All information used was obtained from existing records, not by interview.

For inclusion as an incidence case, the injury must have occurred in 1970 or 1971 to a usual resident of the 18 prespecified Northern California counties (regardless of place of occurrence or place of treatment of the injury). The years 1970 and 1971 were selected to utilize 1970 United States Census data as a denominator in deriving incidence rates according to sociodemographic factors.

Reference Population and Geographic Region

The population at risk was defined as the usual residents of the 18 Northern California counties, a population (1970 United States Census) of slightly more than 5.8 million persons (29.1 percent of the state's population). The counties involved included Shasta, Tehama, Nevada, Placer and El Dorado (mountain region); Butte, Yuba, Sutter, Yolo, Sacramento, San Joaquin and Solano (central valley region); Contra Costa, Alameda, Marin, San Francisco, San Mateo and Santa Clara (coastal region).

TABLE 1.—*Hospital Admission Indexing Code Numbers and Rubrics Used for Spinal-Cord Injury Case Ascertainment**

*Rubric No.**	*Rubric*
349	...... Other diseases of spinal cord (mono-, hemi-, para-, quadriplegia)
725	...... Displacement of intervertebral disk
772.1	...... Birth injury without mention of cause
805	...... Fracture and fracture dislocation of vertebral column without mention of spinal-cord lesion
806	...... Fracture and fracture dislocation of vertebral column with spinal-cord lesion
839	...... Other dislocation: spine
958	...... Spinal-cord lesion without evidence of spinal-bone injury
959	...... Other nerve injury
03	...... Surgical operations: operations on spinal-cord structures

*International Classification of Diseases, Adapted, 8th Revision.[2]

Method of Case Ascertainment

Case ascertainment involved a systematic, exhaustive review of records, files and reports from all hospitals and coroner's offices in each county and records of the State of California Departments of Health (Crippled Children's Service), Rehabilitation and Industrial Relations (Workmen's Compensation). There were three phases to case ascertainment: (1) review of all hospital admission records (the principal method of ascertainment); (2) examination of all autopsy protocols* for evidence of spinal-cord lesions, and (3) review of all records on file with the State of California Departments of Health (Crippled Children's Service), Rehabilitation and Industrial Relations (Workmen's Compensation) to identify spinal-cord injuries possibly missed in the previous two phases.

Before case ascertainment through examination of hospital admission records, indexing rubrics were examined to determine which could best identify those admitted to hospital with a potential spinal-cord injury. All hospitals used the *International Classification of Diseases, Adapted* (ICDA),[2] the hospital adaptation of ICDA[3] or, to a lesser extent, the *Standard Nomenclature of Diseases and Operations*.[4] Tests of potential rubrics at hospitals led to adoption of a final list of nine hospital admission and discharge rubrics (Table 1). The medical record of each potential case with one or more of these rubrics was examined to determine conformance with the defi-

*California law requires that all persons who sustain an unexpected, sudden, violent, or unattended death shall have a postmortem examination and a coroner's investigation (Section 27491, California Government Code).

nition of spinal-cord injury and whether the incidence criteria were met.

Case ascertainment was begun in October 1972 and completed in January 1974. Several months were devoted to case ascertainment outside the 18-county region to identify persons with a spinal-cord injury who were usual residents of the 18-county region but injured elsewhere. For this purpose, admission records of major hospitals in counties on the periphery of the 18-county study region were used (that is, the remainder of California, western Nevada and southern Oregon). A complete search was made of the files of the State of California Crippled Children's Service, Department of Rehabilitation and Workmen's Compensation, to identify all possible cases which met the criteria of incidence. Autopsy protocols were reviewed from 30 of the most populous counties in California, western Nevada and southern Oregon.

Data on the numbers of swimming pools in each of the 18 counties (limited to the type of pool built in the ground) were obtained from a private commercial firm (personal communication, Baker Advertising and Mailing, 3923 West 6th Street, Los Angeles 90020). Data on the numbers of lakes and reservoirs as well as miles of rivers and streams in the 18-county region were obtained from the State of California Department of Fish and Wildlife.

Results

Epidemiologic Features

Incidence. In all, 45 persons with confirmed acute spinal-cord lesions due to diving were identified from the records reviewed. Twelve did not meet residency and year of injury criteria. The remaining 33 persons among the 5.8 million residents of the 18-county area gave an average annual incidence rate of 2.8 per million population. Incidence was about the same for 1970 and 1971. Incidence by age, sex, racial-ethnic group or type of body of water involved was not related to year of occurrence. The single death (dead on arrival) among the 33 cases gives a fatality rate of 3 percent. (In all 45 cases there were two deaths.)

Age, Sex and Race-Ethnicity. Table 2 gives the numbers and rates of injury by age and sex. With both sexes, peak incidence was from 15 to 19 years of age. Incidence rates were about six times as high for males as for females. Persons in the general population at greatest risk were males aged 15 to 19 years. None of the persons were under thirteen or over 44 years old. At the time of the 1970 United States Census, slightly greater than 12 percent of the population of the study area was Mexican-American, and 7.3 percent was black. On the basis of the percentage distribution of the general population by race-ethnicity, the injuries would have been expected to involve four Mexican-Americans and two blacks. In fact, two Mexican-Americans were identified, but no blacks, a difference which was not statistically significant.

External Cause and Types of Bodies of Water. Incidence cases involved diving, except one somersault into a swimming pool. There were no spinal-cord injuries from waterskiing, surfing or boating. Table 3 gives a distribution according to type of body of water and age of injured person. Of the 33 cases, 15 (45 percent) resulted from diving into a river or stream. Swimming pools were second in frequency (27 percent). Distribution by age differed with each of the major groups of bodies of water. For example, six of the nine injuries in swimming pools involved persons 25

TABLE 2.—*Number and Average Annual Incidence of Spinal-Cord Lesions from Diving According to Age and Sex, 18 Northern California Counties, 1970-1971*

	Sex								
	Male			Female			Both Sexes		
Age*	Persons Injured	Population at Risk	Rate per Million	Persons Injured	Population at Risk	Rate per Million	Persons Injured	Population at Risk	Rate per Million
10-14	3	286,930	5.2	1	277,077	1.8	4	564,007	3.5
15-19	10	260,408	19.2	3	256,429	5.8	13	516,837	12.6
20-24	4	251,388	8.0	0	265,925	..	4	517,313	3.9
25-34	6	403,437	7.4	1	404,889	1.2	7	808,326	4.3
35-44	5	343,047	7.3	0	349,306	..	5	692,353	3.6
All ages†	28	2,853,297	4.9	5	2,947,653	0.8	33	5,800,950	2.8

*There were no reported cases for persons 0-9 or over 44 years of age for either sex.
†Rates calculated on the basis of the populations of 18 Northern California counties combined.

TABLE 3.—*Number of Persons with a Spinal-Cord Lesion from Diving by Age and Type of Body of Water, 18 Northern California Counties, 1970-1971*

Age	Swimming Pool	River, Stream, or Creek	Lake	Ocean	All Types
	Type of Body of Water				
10-14	1	3	0	0	4
15-19	2	5	4	2	13
20-24	0	4	0	0	4
25-34	3	2	1	1	7
35-44	3	1	1	0	5
All age groups	9	15	6	3	33

years old or above, whereas 16 of the 21 injuries in rivers, lakes and streams involved persons 24 years of age or younger.

Other Factors. Spinal-cord lesions occurred exclusively in May through September, peaking in the three middle months; 3 in May, 9 in June, 9 in July, 8 in August and 4 in September. There were too few cases for statistical test of any relation between month of injury and age; however, the ratio of observed to expected frequencies was highest for those 25 years old or above injured in May and September (Table 4).

The injuries were not distributed evenly throughout the week. Of the 33 injuries, 12 were on Sundays, 5 on Saturdays, 4 on Mondays, 5 on Tuesdays, 3 on Wednesdays and 2 each on Thursdays and Fridays. Day of occurrence was not related to age (<25, ≥25 years).

Injury rates were not calculated by county of residence because the numbers were so low for almost all of the counties. However, incidence was highest (5.9 per million) for the mountain counties, intermediate (4.4 per million) for the central valley counties and lowest (2.2 per million) for the north coastal counties. The ratio of spinal-cord lesions per 1,000 in-ground swimming pools was highest in the mountain counties (8.5 per 1,000 pools), and lowest in the valley and coastal counties (0.5 and 0.2 per 1,000 pools, respectively). It should be noted that the ratio for the mountain counties was based on a single injury per 118 in-ground pools. The ratio of injuries per 1,000 miles of rivers and streams for each of the three areas was highest for the coastal counties (9 per 100 miles) and lowest for the valley and mountain counties (0.3 and 0.2 per 100 miles, respectively). The information available to us gave no data on water depths, or heights and types of dives.

Although the injuries were too few for a statistical test of significance, excess numbers of persons with tetraplegia were associated with diving into a lake, a quarry or the ocean, and excess instances of persons with tetraparesis were associated with diving into swimming pools (Table 5). Similarly, no statistical test could be made of association between age and neurologic impairment levels since three of six cells (Table 6) had expected frequencies of less than five. However, the number of tetraplegics was higher than expected for those less than 25 years of age.

Clinical Features

The spectrum of neurologic injuries observed in all 45 cases identified (33 incidence, 12 prevalence) varied from no sensory and minimal motor deficit to complete sensory motor tetraplegia. Three patients with fractures of neural arches of C1-4, wedge fractures of C5 and subluxation of C2-3 and C3-4 were neurologically intact on admission, although all had severe paresthesias at the time of injury. Three patients with only minimal motor weakness of one upper extremity had fractures of neural arches of C5 and C6 and wedge fracture of C6. Ten patients had clinical features of acute central cervical cord syndrome with various degrees of sensory and motor loss. A total of 27 patients (21 <25 years of age and 6 ≥25 years of age) were completely tetraplegic at admission, and only 1 of these showed func-

TABLE 4.—*Number and Ratio of Observed to Expected* Frequencies of Spinal-Cord Lesions from Diving by Month of Occurrence and Age, 18 Northern California Counties, 1970-1971*

Age Group (years)	May	June	July	August	September	Number Observed, All Months
	Month of Occurrence					
<25	0.5	1.1	0.9	1.6	0.4	
OBS/EXP	(1/1.9)	(6/5.7)	(5/5.7)	(8/5.1)	(1/2.5)	21
≥25	1.8	0.9	1.3	0.0	2.0	
OBS/EXP	(2/1.1)	(3/3.2)	(4/3.2)	(0/2.9)	(3/1.5)	12
Number observed, all ages	3	9	9	8	4	33

*Based on row × colum ÷ total number observed.

tional neurologic return and achieved independent ambulation. Of the 27 patients with tetraplegia, there were two physiologic transections of the spinal cord at C4, fourteen at C5, ten at C6 and one at C7. The distribution of locations of transections of the spinal cord was not related to age of the patient or type of body of water. Two patients were admitted in a comatose state with flaccidity, areflexia and tetraplegia possibly secondary to intracranial injuries. These two patients died two and four days, respectively, after hospital admission, and results of autopsy showed bilateral cortical softening, severe maceration of the spinal cord, and fracture dislocation of C3 on C4 and C5 on C6.

Of 13 patients with bradycardia (pulse rate 60 per minute or below), hypothermia and hypotension, there was functional return in only one; the others remained tetraplegic. Those 13 patients with a systolic pressure of 100 mm of mercury or below, with or without bradycardia, also remained tetraplegic.

Most of these patients reported difficulty in breathing, and had been rescued by persons nearby at the time of injury. Only three of these patients had scalp lacerations, suggesting that they struck the bottom of the water reservoir or hard objects.

Two patients with no previous history of peptic ulcer disease developed stress ulcers four to six weeks after the injury, and one of these developed perforation of a duodenal ulcer.

The Queckenstedt test was carried out on six patients. Three in whom there was a positive result were found to have a contused or macerated spinal cord on laminectomy. In one in whom test results were equivocally positive, the spinal cord was reported to be edematous. Those four patients remained tetraplegic. As to the two patients with negative results on a Queckenstedt test, one had acute central-cord syndrome and the other had minimal motor weakness of one upper extremity.

Radiologic Findings. All 45 patients had injury to the cervical spine. None had an injury to the thoracic or lumbar spine. Radiographic evidence of osteoarticular injury was detected in 44 of the 45 patients. The patient in whom there was no radiographic evidence of osteoarticular injury was found on autopsy to have a crush fracture of C3 vertebral body with subluxation on C4. In all, there were 56 vertebral-body fractures in 40 pa-

TABLE 5.—*Number of Persons with a Spinal-Cord Lesion from Diving by Functional Impairment Level and Type of Body of Water, 18 Northern California Counties, 1970-1971*

Type of Bodies of Water	Impairment Level: Tetraplegia* Number		Tetraparesis Number		Other Neurologic Deficit Number		All Levels Total
	Observed	Expected†	Observed	Expected	Observed	Expected	
Swimming pool	1	(4.1)	5	(2.7)	3	(2.2)	9
River/stream	7	(6.8)	5	(4.5)	3	(3.6)	15
Lake/ocean	7	(4.1)	..	(2.7)	2	(2.2)	9
All types	15	(15.0)	10	(9.9)	8	(8.0)	33

*Includes one in-hospital death.
†Expected values based on column total×row total÷total number of cases (e.g., 15×9÷33=4.1).

TABLE 6.—*Number of Persons with a Spinal-Cord Lesion from Diving by Functional Impairment Level and Age, 18 Northern California Counties, 1970-1971*

Age Group	Impairment Level: Tetraplegia Number		Tetraparesis Number		Other Neurologic Deficit Number		All Levels Total
	Observed	Expected†	Observed	Expected	Observed	Expected	
<25	12*	(9.5)	5	(6.4)	4	(5.1)	21
≥ 25	3	(5.5)	5	(3.6)	4	(2.9)	12
All age groups	15	(15.0)	10	(10.0)	8	(8.0)	33

*Includes one in-hospital death.
†Expected numbers calculated on the basis of column total×row total÷total number of cases (e.g., 15×21÷33=9.5).

TABLE 7.—*Osteoarticular Injuries from Diving According to Vertebral Level, 18 Northern California Counties, 1970-1971*

Fractures			Luxations		
Level	Vertebral Body	Neural Arch	Level	Sublux-ation	Dislo-cation
C1	..	1	C1/2	1	..
C2	..	2	C2/3	1	..
C3	3	2	C3/4	4	..
C4	8	2	C4/5	7	2
C5	28	10	C5/6	11	..
C6	15	3	C6/7	3	2
C7	2	..			
TOTAL	56	20		27	4

TABLE 8.—*Number of Persons Sustaining Wedge Fractures from Diving According to Vertebral Level and Types, 18 Northern California Counties, 1970-1971*

	Number of Persons with at Least One Wedge Fracture			
Vertebral Level of Fracture	One Wedge Fracture	Two Wedge Fractures	One Wedge Plus Additional Fracture	Two Wedge Plus Additional Fracture
C3	2	..	..	..
C4	0	..	..	..
C5	8	..	..	..
C6	4	..	..	..
C3-4	..	1	..	..
C4-5	..	3	3*	..
C5-6	..	6	1	1*
All levels	14	10	4	1

*Includes additional burst fracture.

tients (Table 7). A total of 16 patients had fractures at two levels, and all the fractures were of adjacent vertebral bodies in continuity. In 24 patients there was fracture at one level only. More older persons ($\geq$25 years) than expected had a fracture at a single level of the cervical vertebrae ($x^2=6.45$, $p=0.01$). Excess numbers of patients with fractures at two levels of the spine were associated with dives into rivers and lakes ($x^2=3.95$, $p=0.05$). Of the 56 vertebral-body fractures, there were 40 wedge, 11 burst and 5 teardrop fractures. The type of vertebral body fracture was not associated with the age of the patient or the type of body of water. In 12 patients there were fractures of the posterior elements or neural arches. In 11 of the patients with fractures of the neural arch there also were associated vertebral-body fractures.

Wedge fracture was the most common type of osteoarticular injury. There were 40 wedge fractures in 29 patients. In 14 of these patients there were single wedge fractures and in 10 two wedge fractures. Four patients had a wedge fracture and a burst fracture in the adjacent vertebral body. One patient had two wedge fractures and a burst fracture in the adjacent vertebral body. The distribution of wedge fractures by vertebral level is given in Table 8. For those with a single wedge fracture, the most common level was the C5 vertebral body. For those with two wedge fractures the C5-6 vertebral bodies were most commonly involved.

There were 25 patients with subluxations at various levels. In addition, there were 4 patients with dislocations of the cervical vertebrae (Table 7). Of the 29 patients with subluxations and dislocations, 28 also had a fracture of a vertebral body or of posterior processes of a vertebra.

Myelograms were carried out on eight patients. Three patients with evidence of myelographic block had a swollen, contused, or macerated cervical spinal cord at the time of operation, and all three remained tetraplegic. Two other patients with myelographic block had a normal-appearing spinal cord on laminectomy, and only one had a functional neurologic return. Three patients with no myelographic defect had central cervical-cord syndrome, and two of the three had excellent neurologic recovery.

Management. Initially, all patients with radiologic evidence of injury to the cervical spine were immobilized and Vinke, Crutchfield, or Cone-Barton tongs were applied for skull traction. Five patients were placed in a Halo body cast without any complication. Decompression laminectomy was carried out on nine patients on the day of injury, and on one patient four days after the injury. Three of the laminectomies were done concomitantly with posterior fusion and wiring. In one patient anterior interbody fusion was done, in addition to laminectomy and posterior fusion, and in another patient who had a laminectomy on the first day, anterior fusion was done because of instability nine weeks later. One patient who had made good recovery following central-cord syndrome had posterior fusion done 12 weeks later because of the persistent instability. Anterior decompression and interbody fusion by Cloward or Smith-Robinson technique were carried out on 12 patients: on seven within one week of the trauma, and on five from 2 to 16 weeks following the injury.

Correlation of Radiographic Findings and Neurologic Return

Radiographic abnormalities of the cervical spine are of little significance in the absence of neurologic deficit. Hence, the different types of osteoarticular injuries were compared with neurologic recovery of residual deficit.

Eleven burst fractures were present in nine patients, associated with variable degrees of subluxations in eight of them. Teardrop fractures were present in five patients. Three of them had central-cord syndrome and made an excellent recovery, and the other two had second- and third-degree subluxation, with complete tetraplegia that remained unchanged on discharge from hospital.

Forty wedge fractures were seen in 29 patients. Eighteen of these patients remained tetraplegic. Three of four patients with wedge and burst fractures at different levels remained tetraplegic. One patient with a wedge and teardrop fracture at two levels also remained tetraplegic.

Of 16 patients with fractures of two vertebral bodies, 12 had complete tetraplegia. Of these 12 patients, there was functional recovery in only one.

Dislocation or third-degree subluxation was present in four patients; all were tetraplegic. Their neurologic status remained unchanged on hospital discharge. Of 24 patients with subluxation, 22 had associated fractures of vertebral body or neural arch, or both.

Functional Impairment

Of the total 45 patients, six had minimal sensory or motor deficit and within a week were free of any detectable neurologic abnormality. Ten patients with acute cervical central-cord syndrome showed good improvement, and all but one were independent in their activities of daily living 6 to 12 months after the injury. Five of these still had a mild residual sensory and motor loss. Hyperreflexia and positive Babinski sign persisted in all these patients as long as they were followed. In all, 27 patients were tetraplegic at admission, and their impairment remained unchanged except that one patient showed some functional return and was ambulatory with crutches. Two patients died as a result of complications from intracranial injury, and in both there was evidence of cervical spinal-cord maceration on autopsy.

Discussion

The National Institutes of Health have estimated that the cost to society of spinal-cord injury is second only to that of mental retardation, among the neurologic and sensory disorders.[5] Of particular significance in this respect are acute traumatic lesions of the spinal cord as a result of diving, since these injuries always involve the cervical spine and the resulting neurologic deficit, if permanent, is tetraplegia. The actual incidence of spinal-cord lesions in the United States from diving injuries is not known. Burke[6] reported that 8 percent of traumatic spinal-cord lesions in Australia resulted from diving. Kewalramani and Taylor[7] found that 18 percent of spinal column injuries over four years were from diving. This percentage included those with spinal-column injury with and without a spinal-cord lesion. Of the 619 spinal-cord lesions identified in the present study, 5.3 percent were from diving, producing an average annual incidence of 2.8 per million population. Projected nationally, this rate indicates an annual total of 600 to 650 spinal-cord injuries due to diving. This range may be an underestimate because many drownings may have resulted from paralysis from spinal-cord injury. A more thorough postmortem examination of persons who have drowned for evidence of spinal-cord damage could provide information on this question.

Spinal-cord injuries from diving occur mostly among the young. Greater than 51 percent of the cases occurred among teenagers. The number of persons exposed to the risk of injury in diving by age and sex is unknown. Nonetheless, the tragic consequences include a lifetime of permanent disability for a substantial number of young people.

Interestingly, only one of the 15 cases with tetraplegia resulted from diving into a swimming pool. In northern California in 1970 and 1971, there were about 35,500 in-ground public or private swimming pools. In the mountain counties, with only 118 pools, there was one case of spinal-cord injury. The frequencies of diving-related spinal-cord lesions in the valley counties (with about 6,500 pools) and the coastal counties (with almost 29,000 pools) were substantially lower than expected. Although the ratios of injuries per 1,000 pools were based on a total of only nine cases, they suggest highest risk associated with least opportunity of exposure.

Of 15 cases of tetraplegia, 14 resulted from diving into rivers, streams, lakes or the ocean. The numbers of lakes or reservoirs and the numbers of miles of rivers, streams and canals were selected as indication of potential exposure to injury. The ratio of injury was highest in counties with the least opportunity for exposure (coastal counties) and lowest in those counties with the greatest opportunity for exposure based on number of miles of rivers and the like.

The anatomical site of injury in all cases was the cervical spine. In almost 60 percent of the 45 cases identified, the patients were still completely tetraplegic at hospital discharge. The two patients who died because of associated head injury also had destruction of the cervical spinal-cord which would have resulted in tetraplegia.

Information in some of the medical records indicated that patients had underestimated the depth of water, but only three patients had objective evidence (scalp laceration or hematoma) of having struck the bottom of a water reservoir or a hard object. Lack of functional recovery had a 96 percent correlation (26 of 27 cases) with complete sensory or motor tetraplegia at admission; these patients remained permanently paralyzed. All ten patients with acute cervical central-cord syndrome had significant functional return. The other equally important predictor of neurologic outcome with a 92 percent correlation (12 of 13 cases) was impairment of autonomic function at admission, that is, bradycardia, hypothermia or hypotension. Radiographic abnormalities were less reliable predictors of functional return than were clinical findings at admission. All the same, in most of the cases, fractures at two levels of the cervical spine or burst fractures and dislocation were suggestive of severe and permanent neurologic deficit.

Wedge fractures are generally accepted to be flexion injuries to the vertebral body. Sarpyener[8] postulated that severity of wedging was directly related to the weight of the diver, height of the dive and depth of the water reservoir. This conclusion was not based on experimental data, and, unfortunately, we have no data to confirm or refute this conclusion. Flexion forces in combination with rotary motion would rupture the posterior ligament complex or, without rupture, cause fracture of tips of the spinous processes in addition to wedge fracture. The present series included 29 patients with one or more wedge fractures. In diving it is the combination of flexion and vertical compressive forces over the cervical spine that results in wedge, burst and teardrop fractures, and subluxation or dislocation of vertebrae depending upon the degree of initial flexion of the spine at the time the person contacts the water surface. The angle of projection, velocity of mass center and angular momentum are established in the takeoff of the dive.[9] These factors play a major role in determining the success of the dive, and the alertness and expertise of the diver can modify these factors considerably. Although alcohol or other drugs would probably affect alertness of the diver, no information was available on the use of alcohol or other drugs preceding the injuries incurred.

Burke[6] concluded from the high percentage (88 percent) of burst fractures in diving activities that these were incurred from hitting the bottom of the water reservoir. In the present series, however, only 20 percent of the fractures were burst fractures, with the other 80 percent being wedge and teardrop fractures. Of the three patients who had objective evidence (scalp lacerations) of having struck the bottom of a water reservoir, only two had radiologic evidence of injury: wedge and burst fractures at two levels. This finding would support our hypothesis that hyperventroflexion was the mechanism responsible for injury in most of the cases. Because of the customary slight flexion of the neck in diving, impact with the water surface tending to counteract the momentum of the falling body, would cause hyperventroflexion or hyperretroflexion, depending on the angle of entry into the water, perhaps being great enough to produce the variety of fractures reported *without* any collision with the bottom or hard objects.

About 80 percent of the patients noticed an inability to move the upper and lower limbs immediately after the injury and also reported difficulty in breathing. All were removed from the water by other persons. Most would probably have drowned if not rescued. Many persons who participate in saving lives following diving injury probably have no knowledge of the water-rescue procedures that would be proper when the spinal cord may have been injured. Conventional water-rescue procedures need to be revised in the light of possible cervical spinal-cord injury in diving. Improper moves could aggravate the severity of injury.

The problem of spinal-cord injuries should be examined from an etiologic perspective as well as anatomic and pathologic points. Spinal-cord injuries from diving result from the forces produced in the energy exchanges that result from impacts with the surface of the water or with hard objects or structures in or under it. Haddon[10] has identified a series of strategy options for reducing losses from energy exchange and related injuries such as drowning, an injury produced by interference with normal energy exchange. Drawing on Haddon's analysis, some options for reducing losses from diving include:

- Prevent the aggregation of water suitable for diving or attempted diving (for example, do not build swimming pools).
- Reduce the amount of energy marshaled (to reduce the heights of diving boards for swimming pools would be one preventive tactic illustrating this option).
- Prevent (or modify the rate of) the release of the energy of the diver on the board (preventing the untrained from using high boards and eliminating shallow water reservoirs are examples of tactics for this option).
- Separate populations at risk and opportunities (places) for diving (locating hazardous bodies of water far away and fencing them illustrate this option).
- Modify the contact surface or basic structure (two important tactics involve softening the bottoms of swimming pools or removing rocks, pilings or other hard obstacles from lakes, rivers and oceans where swimming and diving are practiced or are likely to occur).
- Strengthen divers to make them less susceptible to excess energy delivered to the body in a dive (muscle strengthening exercises are a tactic illustrating this option).
- Increase the availability, speed and competence of emergency medical care and transport (training in techniques to ensure nonaggravation of existing spinal-cord damage during procedures to prevent drownings, or during emergency transport is one tactic that illustrates this option).
- Increase the availability of reparative and rehabilitative measures to stabilize the injury and restore injured persons to maximum functional status.

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