

## Diving-related cervical spine injuries –a systematic review, treatment, and educational approach

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### Abstract:

Irresponsible diving in places not intended for it may result in serious injuries of the cervical spine and, consequently, in severe and permanent disability. The authors present their own experiences of five years of treating diving-related cervical spine injuries. The majority of these injuries were severe, required surgical treatment, and caused permanent disability. Such injuries concerned young males. The authors also present a systematic review of the literature published over nearly 100 years on the epidemiology, treatment and the problem of disability of people who sustained diving-related cervical spine injuries. The conclusion is that irresponsible diving in unsuitable places such as unguarded bathing areas on lakes, rivers or even garden pools may result in a severe spine injury and permanent disability requiring lifelong rehabilitation and care. Appropriate education seems to play a significant role in prevention.

**Key Words:** cervical spine, trauma, diving-related injuries

### Introduction

Diving into shallow water is the third cause of spine and spinal cord injury, following car accidents and falls from a height [Bailes et al., 1990; Bárbara-Bataller et al., 2017]. It is not clearly defined whether cervical spine injuries related to diving into water are classified as sports-related injuries or as falls [Good et al., 1980]. This is important in the statistical analysis of sports-related injuries. It should be emphasized that cervical spine injuries occur relatively rarely when practicing water sports in professional sports facilities or under professional supervision [Good et al., 1980; Bailes et al., 1990; Boden et al., 2009]. The sports activities associated with the highest risk of catastrophic spinal injuries are football, ice hockey, wrestling, skiing, snowboarding, rugby, and cheerleading [Bailes et al., 1990]. Diving into water, which in turn causes serious injuries to the cervical spine, takes place most often in places prohibited for this type of activity, mainly in wild bathing areas, on lakes and rivers, where such diving is generally prohibited [Boden et al., 2009]. Such injuries are also observed during recreation in garden pools. Activities of this kind do not constitute sport in the strict sense, but rather irresponsible and unsafe behavior [Bailes et al., 1990; Branche et al., 1991]. Ample literature data confirm that diving into water, associated with causing spine injuries, is common among people after drinking alcohol. Such injuries are most frequent during the holiday season and in the warm months of the year in Poland, when the temperature is favorable for water-related activities in the open space and they befall young people, mostly men [Albrand et al., 1976; Branche et al., 1991]. The Voivodeship of Kujawsko-Pomorskie, with a population of over two million, has a large number of lakes, rivers and places for active recreation near water, therefore this type of activity is popular in this region of Poland. The lakes of Kujawsko-Pomorskie constitute nine percent of all lakes in Poland and there are over 30 official bathing areas. It is believed that there may be many more places where illegal and unguarded water activity is practiced. There are also rivers and regatta tracks in the province, where canoeing, rowing, and sailing are practiced. People may irresponsibly dive into the water while practicing these sports and activities. Diving is especially dangerous in rivers where the rushing current can carry objects to the bottom that a diver can hit head causing a cervical injury [Boden et al., 2009].

Spine injuries as a result of irresponsible diving into water often lead to serious injuries, especially to the cervical spine [Boden et al., 2009]. These are most often subaxial compression flexion injuries which can cause severe neurological symptoms such as paralysis of the limbs or respiratory failure [Anderson et al., 2008]. From an anatomical point of view, the following injuries of the cervical spine with damage to the neural elements can occur [Anderson et al., 2008]:

- root injury (RI), associated with symptoms involving the upper limbs.
- incomplete spinal cord injury (ISCI), associated with additional paresis of the lower limbs, and with possible disorders of thoracic breathing.

- complete spinal cord injury (CSCI), associated with paralysis of the lower limbs and total loss of thoracic breathing; in the case of damage above the C4 level, total respiratory failure occurs, and such injuries are usually lethal.

The more severe the injury, the poorer the prognosis for improvement, regardless of immediate treatment. People affected by limb paralysis as a result of cervical spine fractures after diving into water require intensive, long-term rehabilitation and care. Furthermore, they are unable to work. Such injuries most often befall young people, which is why such disability is severe in psychological and social terms [Anderson et al., 2008]. The economic aspect is also important, because a person disabled after diving into water requires significant financial resources, which is often a problem for families. Due to the drama of paralyzed patients in diving accidents, it is believed that education plays a very important role from an early age. It is very important to educate the public and raise the awareness that even one careless diving stunt can result in irreversible trauma for the rest of life [Davis et al., 1974; Bailes et al., 1990; Branche et al., 1991; Anderson et al., 2008].

#### Material & methods

The study involved eighteen patients with spinal cord injuries caused by diving into water, all of whom were treated at our department of neurosurgery between 2015 and 2020. The patients were treated in spring and summer, when the ambient temperature was favorable for engaging in water-related activities outdoors. It should be noted that our neurosurgical department in University Hospital No. 1 in Bydgoszcz, Poland, as part of the Medical College of Nicolaus Copernicus University, is a government-established trauma center for the entire Voivodeship of Kujawsko-Pomorskie, so most diving-related spine injury patients from this region of Poland are brought to our center for treatment. The Kuyavian-Pomeranian Voivodeship has a population of over 2 million. The majority of the patients treated here had sustained severe injuries requiring surgery; conservative treatment was applied only in two cases (11.11%). All severe injuries of the cervical spine in the study group were subaxial compression flexion injuries.

Imaging studies performed at the emergency department showing cervical spine fractures were computed tomography (CT) as shown in Figure 1, and in some cases also immediate magnetic resonance imaging (MRI) was performed to visualize spinal cord injury and edema, as shown in Figure 2.



Figure 1. CT with C6 fracture



Figure 2. MRI after trauma with spinal cord lesion and acute edema

The patients were qualified for surgery by authors, using Subaxial Injury Classification (SLIC) guidelines, as described in Table 1. The neurological condition of the patients undergoing surgical treatment (SLIC  $\geq 4$ ) was relatively severe and consisted of paralysis of the lower limbs and deep paresis of the upper limbs with severe sensory loss, at the time of admission to the hospital emergency department, each patient was respiratorily efficient, although with only diaphragmatic breathing.

Table 1. SLIC used for qualification for treatment

Injury / most severe injury level	Points
<b>Morphology</b>	
No abnormality	0
Simple compression	1
Burst fracture	2
Distraction	3
Rotation / Translation	4
<b>Discoligamentous complex</b>	
Intact	0
Indeterminate	1
Disrupted	2
<b>Neurologic status</b>	
Intact	0
RI	1
CSCI	2
ISCI	3
Continuous cord compression with neural deficit	+1

All of the patients were treated surgically using the anterior approach. Five patients with subluxation without vertebral body fracture were treated by anterior cervical interbody fusion (ACIF) supported by titanium anterior plate and screws. ACIF conditioned the decompression of neural elements at the subluxation level and spine stabilization. Eleven patients with burst fractures with bone fragments compressing the spinal cord were treated by corpectomy using a high speed drill. Subsequently, vertebral prosthesis was inserted, and then an anterior plate and screws to achieve fusion. Summary information on the surgical techniques is also provided in Table 2. In 2020, thanks to the use of modern prostheses which were screwed to vertebral bodies during corpectomy procedures, no additional plate is visible in Figure 3. The authors of this manuscript preferred this type of implants because such a prosthesis allowed spondylodesis with only one implant, which significantly shortened the time of the procedure. However, both techniques represented a fused corpectomy and were biomechanically equal.

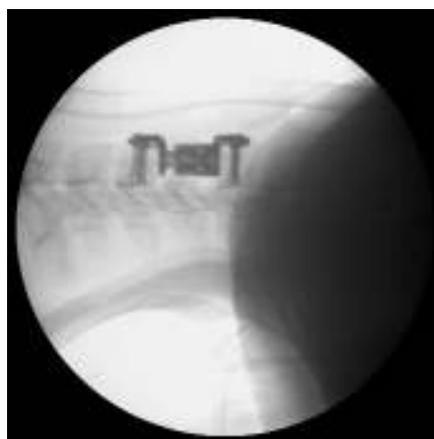


Figure 3. X-ray with vertebral prosthesis with no additional plate

In the postoperative period, early rehabilitation was implemented. Out of 16 surgically treated patients – six of them were admitted to the intensive care unit due to respiratory failure - of these, one died as a result of persistent respiratory failure and severe systemic complications, and five survived, regained respiratory efficiency by diaphragmatic breathing and were admitted to rehabilitation departments where, after intensive 3-month improvement, the ability to move in a wheelchair was achieved. Follow up results are also presented in Table 2. Control MRI was performed, which most often showed permanent lesions of the spinal cord as shown in Figure 4.



Figure 4. MRI after surgery with permanent lesion of the spinal cord

Table 2. Epidemiological and clinical data about treated patients with diving-related cervical spine injury

No	year	age	sex	ALC	PWA	IL	NEIT	fracture	Subluxation	treatment	recovery
1	2015	16	M	-	L	C5	ISCI	+	-	CORP	PD
2	2015	23	M	+	L	C4	CSCI	+	+	CORP	death
3	2015	32	M	+	R	C6	CSCI	+	-	CORP	PD
4	2015	40	M	+	G	C7	ISCI	-	+	ACIF	PD
5	2016	19	M	+	L	C6	ISCI	+	-	CORP	PD
6	2016	16	M	-	R	C6	CSCI	+	-	CORP	PD
7	2016	21	M	+	L	-	-	+	-	collar	good
8	2016	23	M	+	R	C6	CSCI	+	-	CORP	PD
9	2016	27	M	+	L	C5	CSCI	+	+	CORP	PD
10	2017	21	M	+	L	C6	CSCI	-	+	ACIF	PD
11	2017	37	M	+	L	C6	+	+	-	CORP	PD
12	2017	22	M	+	R	C6	ISCI	-	+	ACIF	PD
13	2018	20	M	-	L	-	-	+	-	collar	good
14	2018	26	M	+	L	C6	RI	-	+	ACIF	good
15	2019	18	M	+	R	C5	ISCI	+	-	CORP	PD
16	2019	41	M	+	G	C7	CSCI	+	-	CORP	PD
17	2020	25	M	+	L	C6	RI	-	+	ACIF	good
18	2020	23	M	+	L	C6	CSCI	+	-	CORP	PD

ALC – alcohol, CORP - corporectomy, G - garden pool, IL - injury level, L - lake, NEIT - neural elements injury type, PD - permanent disability, PWA - place of water-related activity (accident site), R - river

One of the authors of this manuscript, in addition to the neurosurgical experience in surgical treatment of cervical spine injuries after diving into water, also conducts educational activities addressed to children aged six, years aimed at drawing attention to irresponsible diving. By showing children appropriately persuasive presentations and images as shown in Figure 5, the author of this manuscript proves that such diving into water may result in a lifelong, permanent disability.



Figure 5. Educational meeting of the author (ZS) with children about the dangers of irresponsible diving

## Results

Although statistical analysis is impossible due to the insufficient number of patients treated, the authors observed the following facts as described in Table 2:

- the vast majority of the injuries were serious; they constituted fractures or subluxations of the cervical spine, and required surgery.
- the most frequently damaged level was C6 (50.00%), followed by damage to C5 (16.67%), C7 (11.11%), C4 (5.55%). In 11.11% of the cases, there was no significant damage to the neural structures.
- The most common surgical technique was corpectomy (68.75%), less often ACIF (31.25%).
- The most frequently injured patients were under the influence of alcohol (83.33%).
- The most common places where people were injured were lakes (61.11%), less often rivers (27.78%). The authors also noted the injuries sustained in garden pools (11.11%), which were also severe.
- The most common prognosis was permanent disability (72.22%), good recovery to full fitness was achieved only in 22.22% of the cases, and death was confirmed in 5.55%.

## Discussion

The authors reviewed available literature on diving-related cervical spine injuries over the past one hundred years. It is common in the history of medicine, sports and trauma that irresponsible diving into shallow water can result in spine injuries and serious neurological consequences. Numerous authors have also emphasized the economic side of such injuries – the cost of treatment, nursing, rehabilitation and insurance issues.

A.S. Taylor [Taylor et al., 1929] described diving-related cervical spine injuries and noted methods of dealing with such patients through cranial-cervical traction. The morphology of subaxial fractures and subluxations described by Taylor is consistent with the current knowledge. In the first half of the 20th century, patients with diving-related cervical spine injuries were treated conservatively or using traction [Taylor et al., 1929; Coleman et al., 1938], or surgically through posterior decompression or laminectomy in order to release the compressed spinal cord [Coleman et al., 1938].

The strategy of surgical treatment of cervical spine injuries changed significantly in the 1950s, when anterior cervical spine approach was improved. One of the precursors was Ralph Bingham Cloward [Cloward, 1958] who described anterior approach as ACIF, also known as Cloward procedure. Thus, the strategy of cervical spine surgical treatment basically acquired a modern character, because nowadays diving-related cervical spine injuries in our department have been treated using the anterior approach, as presented in Table 2. It is emphasized in numerous references that diving-related cervical spine injuries are associated with serious neurological consequences and are characterized by a poor prognosis of improving the patient's neurological state. The authors of publications from the 1960s [Klaus et al., 1960; Paillas et al., 1961; Arnaud et al., 1961; Landrot et al., 1964; Guttman, 1964] and from the 1970s [Davis et al., 1974; Kewalramani et al., 1975, 1977; Albrand et al., 1976; McElhaney et al., 1979] reported epidemiological data and treatment strategies similar to modern data on the morphology and management of diving spine injuries.

In Polish literature, the largest report with most extensive epidemiological data on diving-related cervical spine injuries was prepared by Kiwerski [Kiwski, 1980]. He examined in 1965-1978, 194 patients with cervical spine injuries, caused by diving into water. In 182 cases, spine fractures were accompanied by a spinal cord injury. The epidemiological data described by Kiwerski, although coming from 40 years ago, are consistent with our own observations and with data from contemporary literature. It is worth emphasizing that after diving into water, any cervical spine injuries are most often associated with adverse symptoms from the spinal cord.

Samples, in turn, [Samples, 1989] analyzed 2435 patients admitted to the Northwestern University-Midwest Regional Spinal Cord Injury Unit. Of these, nine percent had documented diving-related cervical spine fractures, representing the largest series of acute diving injuries analyzed in the 20th century. The average age of these patients was 21 years, and males predominated, which is consistent with the epidemiological data in our study. Almost all of the patients [Samples, 1989] were admitted within 48 hours of injury, and in our analysis, the admission time after diving was significantly shorter. Such a significant difference between those data [Samples, 1989] and our data seems to result from technological advances in medical transport and rescue organizations, including the spread of medical helicopters over the last 30 years. In the manuscript [Samples, 1989] associated injuries were rare and no patient had intracranial or systemic injuries. The most common levels of injury were C5 and C6, with 70 patients having fractures at more than one level. Neurological signs were sustained in 70% of patients, while 30% of patients were neurologically intact, which is also generally consistent with our observations, in which the majority of patients presented neurological abnormalities, although the most frequently damaged level in our study was C6. According to Samples [Samples, 1989] 66.8% of patients underwent posterior cervical fusion, and anterior fusion was performed in 16.4%, which is different from our observation, in which all patients were treated by anterior approach surgery.

Blanksby [Blanksby et al., 1997] examined multifaceted aspects of diving entries into water which were the cause of many critical injuries and therefore had important safety ramifications. According to Blanksby [Blanksby et al., 1997] compression fractures were most common, which is consistent with the data from the

literature and our observations. Blanksby noted that diving-related injuries ranged from 2.3% in a South African study to 21% of spinal cord injuries in Poland [Blanksby et al., 1997], which in relation to our manuscript, written on the basis of Polish patients, is a relevant epidemiological conclusion. Blanksby emphasized that the role played by water depth has not been conclusively ascertained, although 89% of injuries occur in water <1.52m and minimum depth values for diving vary from 1 to 1.52m [Blanksby et al., 1997]. Proper technique, and therefore education, appear to be more important considerations in injury prevention [Blanksby et al., 1997]. Also authors of this manuscript put emphasis on early childhood education as an important part of the prevention. Lack of education is an issue which needs to be addressed, and many references make recommendations for safety practices such as steering up to the surface, head protection with the arms and only diving when absolutely necessary [Blanksby et al., 1997]. Blanksby underscored the effect of alcohol consumption on frequency of diving related spine injuries [Blanksby et al., 1997], which also coincides with our observations, because most of the patients we treated were under the influence of alcohol.

Bárbara-Bataller [Bárbara-Bataller et al., 2017] noted that diving accidents were one of the leading causes of spinal cord injury after falls and car accidents. In the study of Bárbara-Bataller all patients were male, with a mean age of 29 years and approximately 65% were under 30 years [Bárbara-Bataller et al., 2017]. Almost all patients had a fracture of the C5, and burst fractures were the most common. A total of 86% of the cases underwent surgery. All the spinal cord injuries were cervical, with C6 being the most often affected neurological level [Bárbara-Bataller et al., 2017]. A total of 65% of spinal cord injuries were complete injuries [Bárbara-Bataller et al., 2017]. The clinical and epidemiological data presented in that study [Bárbara-Bataller et al., 2017] are also consistent with our own observations. In our study, all patients were male, the fractured vertebrae were C5 or C6, and the most common level of neurological damage was also C6. Many patients in our study were in a severe neurological condition, indicating a complete spinal cord injury.

### Conclusions

Cervical spine injuries related to diving into water are most often severe, require surgical treatment and most often cause permanent disability. They are caused by irresponsible behavior, very often after drinking alcohol, even in garden pools. Since damage to the spinal cord is irreversible, prevention and education from an early age seem to be the most appropriate procedure.

**Conflicts of interest** - The authors declare that they have no conflict of interest.

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