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Clinical Article

Overview of Cervical Spine Injuries Caused by Diving Into Shallow Water on Jeju Island: A 9-Year Retrospective Study in a Regional Trauma Center

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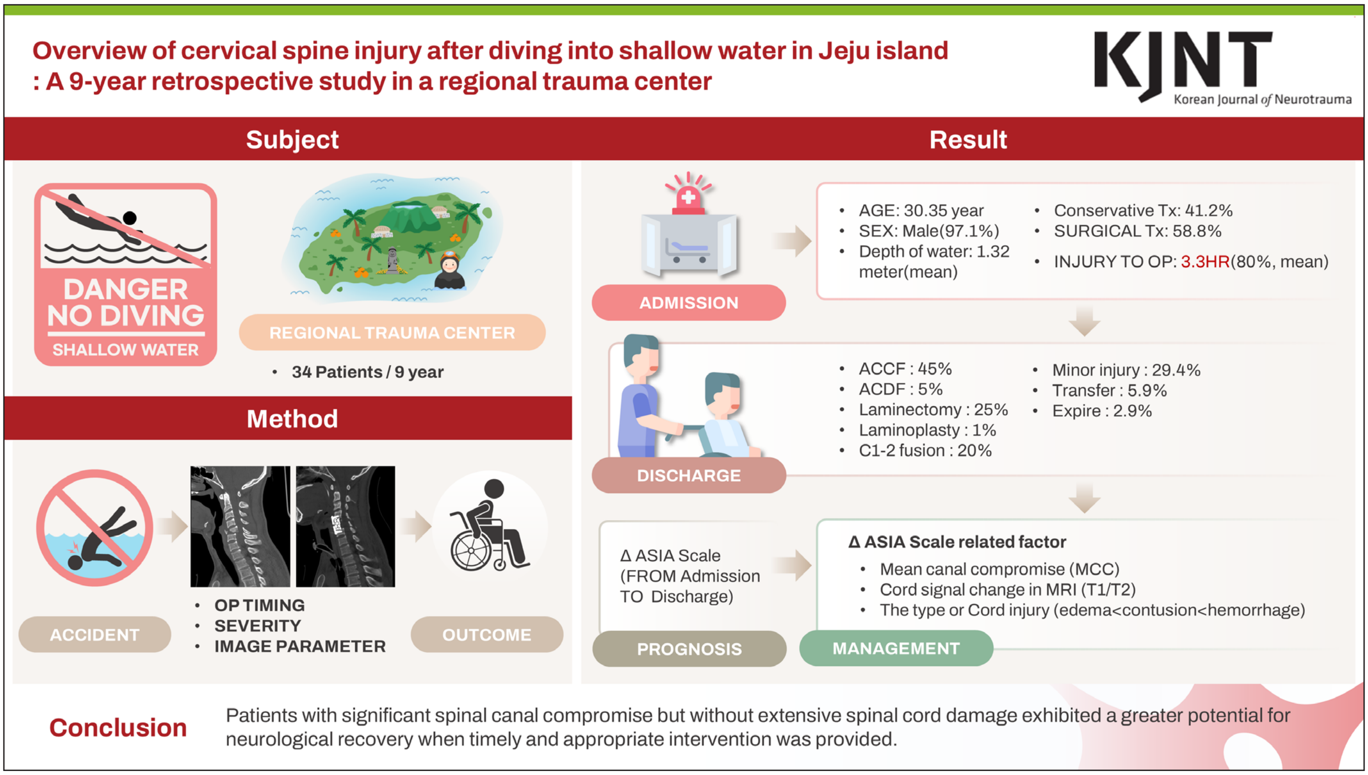
ABSTRACT

Objective: Shallow water diving-related spinal cord injuries (SCIs) are a significant cause of cervical spine trauma, particularly in younger individuals. This study retrospectively evaluated the outcomes of patients with SCI caused by shallow-water diving accidents at a regional trauma center on Jeju Island, South Korea. The primary aim of this study was to investigate the relationships between the timing of treatment, injury characteristics, and prognosis.
Methods: A retrospective analysis was conducted of patients with cervical SCI resulting from shallow-water diving injuries admitted to the trauma center over a 9-year period. The data were obtained from medical records and neurological outcomes were measured using the American Spinal Injury Association scale. Statistical analyses, including correlation and multiple regression analyses, were performed to identify factors influencing prognosis.
Results: Thirty-four patients with cervical SCI resulting from shallow-water diving were included in this study. No statistically significant correlation was found between surgical timing and prognosis; however, significant correlations with prognosis were identified for mean canal compromise (MCC), mean spinal cord compression, and lesion length. In the multiple regression analysis, higher MCC and severe SCI, particularly hemorrhagic injury, were associated with prognosis. The mean time from injury to surgery was 1.25 days.
Conclusion: This study indicates that, specifically for patients with a higher MCC but less severe SCI, appropriate and more rapid intervention may improve prognosis. However, further large-scale studies are required to clarify the favorable factors and their role in achieving a good prognosis.

Keywords: Diving; Spinal injuries; Spinal cord injuries; Operative time; Trauma centers

GRAPHICAL ABSTRACT



Ethics Approval
This clinical article was carried out following approval from the Institutional Review Board of the hospital (approval No. 2025-L06-01).

INTRODUCTION

Several sports and recreational activities are common causes for spinal cord injury (SCI). According to research, sports injuries worldwide account for between 7%–18% of all SCI,[37] with the majority induced by specifically diving accidents.[11]

Most injuries to the spine and spinal cord occur after diving in shallow water,[18] defined as water with a maximum depth of 1.5 m.[9] Diving induced SCI are usually caused by a badly performed, head-first jump,[35] with the impact often causing benign head injury but also associated with spinal trauma, especially in the cervical spine while causing severe lesions. The dive- or fall-related cervical injuries, often leading to quadriplegia or death, constitute a subgroup of cervical spine injuries, particularly due to axial loading and hyperflexion injury.[11,35]

Following the primary injury to the spinal cord at the time of the accident, secondary injury usually resulting in further loss of viable neurons in the surrounding area because of local ischemia, vasospasm, and hypoperfusion.[4,5,21] Ischemia exacerbates the disruption of the blood-spinal cord barrier, which triggers a rapid influx of inflammatory cells releasing proinflammatory cytokines and results in cell death via apoptosis and necrosis.[12,14] Theoretically, timely and optimal management has been shown to reduce or limit secondary damage[15,19] and minimize neurological damage by reversing spinal cord compression which contributes to the pathophysiology of SCI.[15,26]

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Although many recent studies show improved neurological outcomes when surgery is performed earlier (<24 hours)[13,25] and current guidelines suggest that surgical decompression performed within the first 24 hours improves six-month outcomes for patients, regardless of the level of SCI,[18,25,36,37] This theory remains controvercial as some studies with the same early surgery protocol (<24 hours) have failed to show improvement.[10] Thus, the timing of decompression for acute SCI has been a topic of considerable debate for many years and there is significant variability in surgical practices worldwide, with existing guidelines offering recommendations based on limited clinical evidence.[26]

Jeju Island is the largest island in Korea, located off the southwest, known as the tourist destination which between 13 to 14 million tourists visited annually. Because of its geography and abundant private swimming pools, Jeju Island provide ample opportunities for both tourists and residents to enjoy marine and water leisure activities and a significant number of tourists every year sustain SCI due to diving accidents. However, there is still insufficient statistical data regarding SCI related to diving incidents.

This paper aims to retrospectively describe and analyze cases of SCI resulting from diving at Jeju's regional trauma center, where almost all spinal injury patients from the region are systematically treated. Through this analysis, we aim to investigate the current state of diving related spinal injury in jeju Island and the relationship between the strategy of treatment and prognosis of SCIs caused by diving.

MATERIALS AND METHODS

A retrospective analysis of patients admitted to our institute after a shallow-water diving injury over a period of 9 years was undertaken. The patients' charts were reviewed with regard to the following factors: the patient's condition (gender, age, site of accident, mechanism of injury, and social history), neurological status (motor power grade, sensory grade, anal tone, and the American Spinal Injury Association [ASIA] Impairment Scale [AIS][27] upon admission), radiological information (grade of stenosis, grade, type and length of SCI, grade of soft tissue injury, and various parameters), and therapeutic and prognostic factors (therapeutic methods, time taken from injury to treatment, and neurological outcomes).

Upon patient admission, the mechanism of injury (flexion, extension, or axial loading) was determined based on the patient's history and the location of external wounds. Neurological symptoms were assessed through motor power and sensory levels. The patient's prognosis was estimated by comparing the AIS at admission and 6 months later, and patients who were hospitalized for less than six months were investigated based on their final recorded status instead.

For patients who underwent surgery, the time from injury to the initiation of surgery was recorded. Additionally, the location of the lesion, type of fracture, and surgical approach were documented.

Regarding imaging, for patients who underwent magnetic resonance imaging (MRI), we assessed the following various parameters to compare with prognosis: the grade of spinal stenosis (Grade 0 to 3),[16,28] SCI (Grade 0 to 2),[6] and soft tissue injury (Grade 1 to 5),[30,31] besides that, spinal cord lesion vertical length,[1,2,10,22] characteristics of cord injury (cord hemorrhage, cord contusion, or cord edema only),[22] mean canal compromise (MCC),[22,30] mean spinal cord compression (MSCC),[22] and T1/T2 signal patterns.[6] Additionally, cervical spine computed tomography (CT) was used to evaluate the type of fracture or dislocation.

To assess the patient's prognosis, the AIS was evaluated and compared at the time of initial admission and 6 months after treatment. The data was qualified, and statistical analysis was performed to identify correlations and related variables.

All *p*-values were calculated using 2-tailed tests. The *p*-value of <0.05 was considered statistically significant. Statistical analyses were performed using SPSS software, version 19.0 (IBM Corp., Armonk, NY, USA). All confidence intervals were calculated using a 95% confidence interval unless otherwise specified.

RESULTS

Demographic characteristics of patients

During a 9-year period (August 2018 to September 2024), 34 patients were admitted to our institute with cervical spinal injuries resulting from shallow diving injuries, comprising 9.63% of all admitted cervical spine injuries (353 cervical spine trauma patients received care in our unit over the same period). Looking at the monthly incidence rate of diving-related spinal injuries in shallow water, 1 case (2.9%) occurred in November, 2 cases (5.7%) in February, while the highest numbers were reported in July with 10 cases (28.6%) and in August with 11 cases (31.4%). No cases were reported in March, April, October, or December (**FIGURE 1**).

The gender distribution among the participants showed a higher number of males (97.1%), with only 1 female (2.9%) in the group (male:female=33:1). The age of the participants varied from a minimum of 15 years to a maximum of 54 years, with an average age of 30.61±10.02 years.

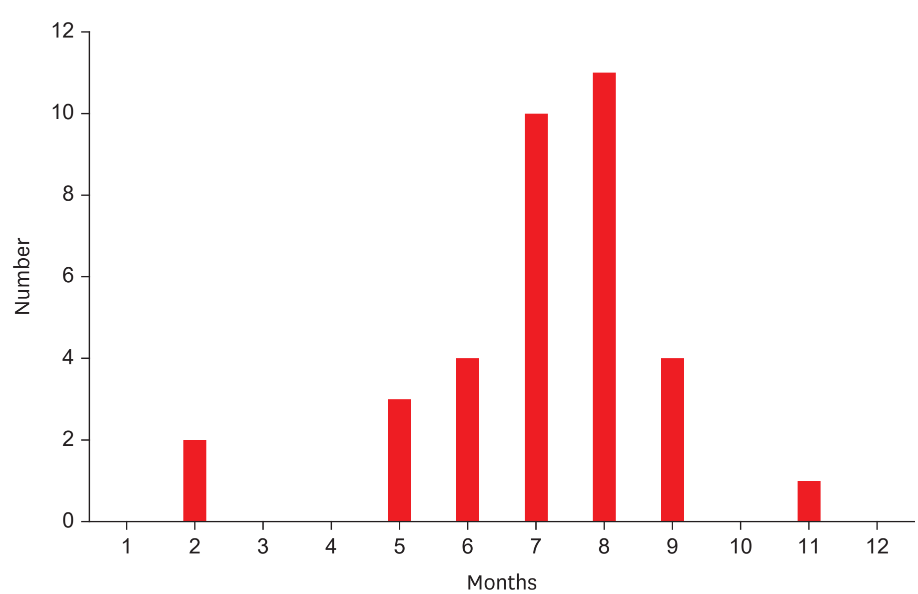

FIGURE 1. Monthly incidence of diving related injuries in Jeju Island.

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TABLE 1. Summary of patient information

Category	Values
Age (years)	
Mean ± SD	30.35±9.81
Median	29
Range	16–54
Sex	
Male	33 (97.1%)
Female	1 (2.9%)
Currnet smoker	16 (47.1%)
Consumes alcohol	18 (52.9%)
Osmolar gap >10	5 (14.7%)
Site	
Outdoor	22 (64.7%)
Indoor	12 (35.3%)
Depth of water (m)	
Mean ± SD	1.32±0.28
Median	1.32
Range	1–2
Surgical treatment (n=20, 58.8%)	
ACCF	9 (45.0%)
ACDF	1 (5.0%)
DL+PF	5 (25.0%)
Laminoplasty	1 (5.0%)
C1-2 fusion	4 (20.0%)
Conservative management (n=14, 41.2%)	
Transfer without operation	2 (5.9%)
Expire	1 (2.9%)
Minor injury	10 (29.4%)
Halovast traction	1 (2.9%)

Values are presented as number (%) not otherwise specified.
SD: standard deviation, ACCF: anterior cervical corpectomy and fusion, ACDF: anterior cervical discectomy and fusion, DL+PF: decompressive laminectomy with posterior fusion.

The osmolar gap was calculated to indirectly assess alcohol consumption. As a result, alcohol consumption was suspected in a total of 5 patients (14.7%) with an osmolar gap greater than 10 (**TABLE 1**).[20,23]

Regarding the location of the accidents, we categorized them into outdoor (beach) and indoor (pool, bathhouse) environments. Among the participants, 22 individuals (64.7%) were involved in accidents at outdoor locations, while 12 individuals (35.3%) were involved in indoor accidents (outdoor:indoor=1.83:1). The water depths ranged from a minimum of 1 meter to a maximum of 2 meters, excluding the height from which the individuals fell. The average height of falls was 1.32±0.28 m (**TABLE 1**).

Due to the nature of Jeju Island as a tourist destination, some patients were transferred to other hospitals due to patients' place of origin (n=3, 8.82%). These transfers included cases both after surgery (n=1, 2.9%) and without surgery (n=2, 5.9%).

Injury mechanism, type and management

All patients who visited the emergency room underwent spinal CT and MRI scans, including X-rays. However, for patients whose conditions were stable and showed no signs of fractures or neurological abnormalities or in cases where the patient's vital signs were highly unstable and the patient expired after all, MRI could not be performed (n=2, 5.9%).

Among the 32 patients who underwent MRI (94.1%), a total of 24 patients (75%) had SCIs. Of these, 10 patients (41.6%) had cord edema, 5 patients (20.8%) had cord contusion, and 9 patients (37.5%) had hemorrhagic cord injury. Nineteen patients (55.9%) had a lesion in the lower cervical spine (C5–C7), 9 patients (26.5%) had a lesion in the middle cervical spine (C3–C4), 4 patients (11.8%) had a lesion in the upper cervical spine (C1–C2), and 2 patients (5.9%) had combined lesions. Two patients (5.9%) had no lesion but had cervical sprain (**TABLE 2**).

TABLE 2. Demographic characteristics of the patients

No	Age	Sex	Site	Injury mechanism			Duration to operation (minutes)	Diagnosis	Name of operation	AIS		Smoking	Alcohol	Osmolar gap >10	Remarks
				Depth (m)	Mechanism	Axial loading				Initial	6-month				
1	46	M	Pool	1	Extension	Yes	170	C7 Bursting fracture	C7 Corpectomy	A	A	None	Yes	−11	Transfer
2	30	M	Pool	1	Flexion	Yes	178	C5 Bursting fracture	C5 Corpectomy	A	A	None	None	−6	
3	35	M	Beach	1.5	Flexion	Yes	2,755	C3 Bursting fracture	C1−2−4−5 Laminectomy+Post fusion	A	A	Yes	Yes	12	Unstable vital sign
4	29	M	Pool	1	Flexion	Yes	175	C6 Bursting fracture	C6 Corpectomy	A	C	Yes	None	−16	
5	26	M	Pool	1.5	Extension	Yes	-	Lt C6 Superior articular process fracture	None	D	E	Yes	Yes	−3	Transfer
6	21	M	Beach	1.5	Extension	Yes	-	C3−4 Cord contusion	None	D	E	Yes	None	−2	Transfer
7	42	M	Pool	1	Flexion	Yes	4,200	C6 Bursting fracture	C6 Corpectomy	D	E	Yes	Yes	−10	Mild symptom
8	39	M	Beach	1.5	Extension	No	-	C5 Transverse process fracture	None	E	E	None	None	3	Transfer
9	17	M	Pool	1	Flexion	Yes	140	C5,6 Bursting fracture	C4−5−6−7 Laminectomy+Posterior fusion	A	A	None	None	−3	
10	26	M	Pool	1.2	Flexion	Yes	-	C6 Bursting fracture	None	E	E	None	None	0	
11	39	M	Beach	2	Flexion	Yes	129	C5 Bursting fracture, C4−5 UID	C3−4−5−6 Laminectomy+Posterior fusion	B	B	None	None	9	
12	39	M	Beach	1.5	Flexion	Yes	166	C5−6 UID	C5−6 ACDF+C4−5−6 Post fusion	B	D	Yes	None	−11	
13	34	M	Beach	1.3	Extension	No	-	Cervical sprain	None	E	E	Yes	None	1	
14	29	M	Pool	1.2	Flexion	Yes	6,901	C1 Fracture	C1−2 Post fusion	E	E	Yes	Yes	−12	Mild symptom
15	35	F	Beach	1.5	Flexion	Yes	11,276	C1 Fracture	C1−2 Post fusion	E	E	None	None	8	Mild symptom
16	18	M	Beach	1.3	Flexion	Yes	432	C7 Bursting fracture	C7 Corpectomy	A	D	None	None	0	
17	38	M	Beach	1.5	Flexion	Yes	-	C3−4 Cord contusion	None	C	C	Yes	None	3	
18	28	M	Beach	1	Flexion	Yes	154	C5 Bursting fracture	C5 Corpectomy	A	A	None	None	−20	
19	22	M	Beach	1.5	Flexion	Yes	-	C3−4 Cord contusion	None	D	E	Yes	Yes	−8	
20	24	M	Beach	1	Flexion	Yes	-	C7 Bursting fracture	None	E	E	None	Yes	−8	
21	44	M	Pool	1	Flexion	Yes	95	C4−5 BID	C3−4−5−6 Laminectomy +Posterior fusion	A	C	None	Yes	33	
22	54	M	Beach	1	Flexion	No	165	C3,4,5 Cord contusion	C3−4−5 Laminoplasty	B	D	None	None	−15	
23	17	M	Pool	1.5	Flexion	Yes	162	C6 Bursting fracture	C6 Corpectomy	B	D	None	None	−6	
24	23	M	Beach	1.5	Flexion	Yes	221	C4−5 BID	C3−4−5−6 Laminectomy +Posterior fusion	A	A	Yes	Yes	−7	
25	43	M	Beach	1.5	Extension	Yes	255	C1 Fracture	C1−2 Post fusion	B	E	Yes	Yes	−9	
26	21	M	Beach	1.3	Flexion	Yes	-	C567 Cord contusion	None	E	E	None	Yes	−7	

(continued to the next page)

TABLE 2. (Continued) Demographic characteristics of the patients

No	Age	Sex	Site	Injury mechanism			Duration to operation (minutes)	Diagnosis	Name of operation	AIS		Smoking	Alcohol	Osmolar gap >10	Remarks
				Depth (m)	Mechanism	Axial loading				Initial	6-month				
27	21	M	Bathroom	1	Flexion	Yes	188	C1 Fracture	C1–2 Post fusion	D	E	Yes	Yes	4	
28	21	M	Beach	2	Flexion	Yes	-	C5 Bursting fracture	Halo Vest	D	E	Yes	Yes	6	
29	22	M	Beach	1.3	Flexion	Yes	286	C5 Bursting fracture	C5 Corpectomy	A	A	None	Yes	2	
30	25	M	Beach	1.5	Flexion	Yes	-	C4–5 BID	None	A	Expire	None	Yes	35	Expire
31	31	M	Pool	1.5	Flexion	Yes	-	Cervical sprain	None	E	E	None	Yes	13	
32	43	M	Beach	1.5	Extension	Yes	-	C4 Spinous process fracture	None	A	C	Yes	Yes	−2	Transfer
33	16	M	Pool	1.2	Flexion	No	-	C45 Spinous process fracture	None	D	E	None	None	6	
34	34	M	Pool	1	Flexion	Yes	189	C6 Bursting fracture	C6 Corpectomy	A	C	Yes	Yes	42	

AIS: American Spinal Injury Association Impairment Scale.

The types of cervical spine injuries were as follows: bursting fractures in 15 patients (44.1%), spinous process fractures in 2 patients (5.9%), transverse process fractures in 1 patient (2.9%), articular process fractures in 1 patient (2.9%), and C1 fractures (Jefferson fractures) in 4 patients (11.8%). Unilateral interfacetal dislocation (UID) was observed in 2 patients (5.9%), bilateral interfacetal dislocation in 3 patients (8.82%), cervical cord injury without spinal fracture in 6 patients (17.6%), and cervical sprain in 2 patients (5.9%). Among these, 1 patient (2.9%) had a C1 fracture with a cervical cord injury not related to a bony structure, and 1 patient (2.9%) had both a vertebral body bursting fracture and UID (**TABLE 2**).

The mechanism at the time of the injury was more commonly associated with flexion injury (n=27, 79.4%) than extension injury (n=7, 20.6%) (flexion:extension=3.9:1). In cases of axial loading, it was defined by the presence of an external wound or swelling at the vertex, or by a history of impact to the top of the head upon hitting the ground while diving. Most cases of flexion and extension injuries were accompanied by axial loading (n=30, 88.2%), while in the remaining cases without axial loading (n=4, 11.7%), the impact occurred on the face or forehead (**TABLE 2**).

A total of 20 patients (58.8%) underwent surgery after presenting to our hospital, while 14 patients (41.2%) did not. The reasons for not undergoing surgery included mild symptoms (n=10, 29.4%), death (n=1, 2.9%), transfer to a hospital at the patient's place of residence without surgery (n=2, 5.9%) or undergoing Halo skull traction instead (n=1, 2.9%) (**TABLE 2**).

Nine patients (45.0%) were treated with anterior cervical corpectomy and fusion, while 1 patient (5.0%) underwent anterior cervical discectomy and fusion followed by posterior fusion. Five patients (25.0%) were treated with posterior fusion combined with decompressive laminectomy, and 1 patient (5.0%) received decompressive laminoplasty. Four patients (20.0%) underwent C1–C2 posterior fusion, while the remaining 14 patients were treated conservatively. Conservative treatment consisted of steroid administration or Halo skull traction (**TABLE 1**).

Among the patients who underwent surgery, the time from the injury caused by diving to the time of surgery ranged from a minimum of 95 minutes to a maximum of 8 days, with an average of 1.25 days. Although it may seem there is a lot of variation, excluding cases where surgery was not immediately performed due to unstable vital signs (1 case, 1.9 days) or very mild symptom (3 cases, mean 4.6 days), the remaining 16 patients (80%) underwent surgery with a mean time of 3.3 hours. Therefore, in most cases, emergency surgery was performed almost immediately, within 2 to 8 hours after the injury (**TABLE 2**).

Prognosis and related factors

A patient's prognosis was quantified by comparing the status at the time of initial admission with the status 6 months later, based on the AIS. Statistical tools, such as correlation analysis and multiple regression analysis, were used to identify factors that may influence changes in prognosis.

Among the various variables investigated, only the MCC, MSCC, and lesion length (the length of signal change in the spinal cord) satisfied the assumption of normality. Therefore, Pearson's correlation analysis was performed for MCC, MSCC, and lesion length, while Spearman's rank correlation analysis was used for the other variables.

First, the relationship between the change in the AIS and the time from injury to surgery was examined, but no statistical significance was found. No significant correlations were observed with other variables, except for the near-significant *p*-value of 0.055 between the change in AIS and MCC. However, indirectly, when examining the relationship between MCC and other variables, statistical significance was found in the correlation between MCC, MSCC, and lesion length (MCC vs. MSCC, p=0.021 and MCC vs. lesion length, p=0.007, respectively). Additionally, a positive correlation was observed between MCC and the grade of spinal stenosis, the grade of cervical soft tissue injury, and the type and grade of SCI. This same correlation was also found in the lesion length with these variables (p<0.001 for all), but not in MSCC (**TABLE 3**).

Considering these findings, it is expected that with a larger sample size, further statistical analysis could help reveal meaningful correlations regarding the prognosis of cervical spinal injuries resulting from shallow diving injuries.

Next, a multiple regression analysis was conducted to investigate variables related to the change in the AIS. Both entry method and stepwise method were used for analysis.

TABLE 3. The correlation among various variables, including the Δ ASIA Scale (Pearson's/Spearman's rank correlation analysis)

Tool	Pearson correlation coefficient (*p*-value)			Spearman correlation coefficient (*p*-value)					
Variant	MCC	Lesion length*	MSCC	Stenosis grade†	Soft tissue‡	T1/T2 MRI§	SCI grade	SCI type	Injury to OR‖
Δ ASIA Scale	0.361 (0.055)	−0.13 (0.948)	0.155 (0.421)	0.212 (0.270)	0.038 (0.846)	−0.262 (0.169)	−0.080 (0.681)	−0.086 (0.658)	0.096 (0.715)
MCC	-	0.491 (0.007)¶	0.426 (0.021)¶	-	-	-	-	-	-
Lesion length*	0.491 (0.007)¶	-	0.251 (0.188)	-	-	-	-	-	-
MSCC	0.421 (0.021)¶	0.251 (0.188)	-	-	-	-	-	-	-
Stenosis grade†	0.618 (<0.001)¶	0.697 (<0.001)¶	0.100 (0.606)	-	0.596 (<0.001)¶	−0.108 (0.577)	0.626 (<0.001)¶	0.584 (<0.001)¶	−0.410 (0.102)
Soft tissue‡	0.591 (<0.001)¶	0.550 (0.002)¶	0.087 (0.655)	0.596 (<0.001)¶	-	0.260 (0.172)	0.711 (<0.001)¶	0.697 (<0.001)¶	−0.146 (0.577)
T1/T2 MRI§	0.302 (0.111)	−0.025 (0.896)	0.403 (0.030)¶	−0.108 (0.577)	0.260 (0.172)	-	0.299 (0.115)	0.220 (<0.250)	−0.112 (0.669)
SCI grade	0.655 (<0.001)¶	0.691 (<0.001)¶	0.274 (0.150)	0.626 (<0.001)¶	0.711 (<0.001)¶	-	-	0.944 (<0.001)¶	−0.381 (0.132)
SCI type	0.578 (0.001)¶	0.701 (<0.001)¶	0.235 (0.220)	0.584 (<0.001)¶	0.697 (<0.001)¶	0.220 (<0.250)	0.944 (<0.001)¶	-	−0.097 (0.713)
Injury to OR‖	−0.638 (0.006)¶	−0.184 (0.479)	−0.012 (0.964)	-	-	-	-	-	-

ASIA: American Spinal Injury Association, Δ ASIA Scale: the change in ASIA Scale from the time of spinal cord injury to 6 months later, MCC: mean canal compromise, MSCC: mean spinal cord compression, MRI: magnetic resonance imaging, SCI: spinal cord injury.

*Lesion length: the maximum length of SCI on MRI sagittal image; †Stenosis grade: the grade of spinal canal stenosis on MRI sagittal image; ‡Soft tissue: the grade of soft tissue damage around the spinal cord caused by trauma; §T1/T2 MRI: the changes in cord signal on MRI T1-weighted and T2-weighted images; ‖Injury to OR: the time taken from the onset of SCI to arrival at the operating room for surgery.

¶Statistically significant.

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The multiple regression analysis using the enter method was conducted using a null hypothesis that the variance in the changes in ASIA scale from the time of spinal cord injury to 6 months later (Δ ASIA Scale) is not correlated with the variance in the group of independent variables. The multiple regression analysis returned a *p*-value of 0.091. Thus, we could not determine a direct correlation between the group of independent variables and Δ ASIA Scale as we had to accept the null hypothesis. However, in the entry method, it was confirmed that an increase in the grade of MRI signal changes, according to a classification system that accommodates both T1-weighted image (T1WI) and T2-weighted image (T2WI), was associated with a smaller change in the AIS (*p*=0.034, unstandardized coefficient=−1.98). No other variables showed a significant relationship with the change in the Δ ASIA Scale (**TABLE 4**).

In the stepwise method, in addition to the signal change pattern of T1WI/T2WI that was previously identified, MCC (unstandardized coefficient=0.034) and the type of SCI (cord edema, cord contusion, cord hemorrhage, unstandardized coefficient=−0.355) were also found to be related (*p*=0.008). That is, the larger the MCC, the greater the change in the AIS, and the more severe the type of SCI (edema < contusion < hemorrhage), the more significant the change in the AIS (**TABLE 5**).

TABLE 4. Variables related to the Δ ASIA scale (multiple regression analysis – enter method)

Independent variable	B	SE B	β	*p*-value
MCC	0.024	0.013	0.506	0.085
Lesion length*	−0.018	0.014	−0.368	0.214
MSCC	0.013	0.010	0.269	0.219
Stenosis grade†	0.124	0.253	0.145	0.629
Soft tissue‡	0.131	0.128	0.273	0.318
T1/T2 MRI§	−1.976	0.866	−0.504	0.034
SCI grade	0.135	0.763	0.000	0.859
SCI type	−0.380	0.480	−0.418	0.438
R^2		0.452		
F		2.060		
p-value		0.091		
Dubin-Watson		1.936		

ASIA: American Spinal Injury Association, Δ ASIA Scale: the changes in ASIA scale from the time of spinal cord injury to 6 months later, MCC: mean canal compromise, MSCC: mean spinal cord compression, MRI: magnetic resonance imaging, SCI: spinal cord injury.
*Lesion length: the maximum length of SCI on MRI sagittal image; †Stenosis grade: the grade of spinal canal stenosis on MRI sagittal image; ‡Soft tissue: the grade of soft tissue damage around the spinal cord caused by trauma; §T1/T2 MRI: the changes in cord signal on MRI T1-weighted and T2-weighted images.

TABLE 5. Variables related to the Δ ASIA Scale (multiple regression analysis – Stepwise method)

Independent variable	Model – (I)			Model – (II)		
	B	SE B	β	B	SE B	β
MCC	0.023	0.009	0.479	0.034	0.010	0.699
T1/T2 MRI*	−1.530	0.691	−0.390	−1.456	0.655	−0.371
SCI type	-	-	-	−0.355	0.177	−0.391
R^2		0.268			0.370	
F		4.766			4.885	
p-value		0.017			0.008	
Dubin-Watson			2.057			

ASIA: American Spinal Injury Association, Δ ASIA Scale: the changes in ASIA scale from the time of spinal cord injury to 6 months later, MCC: mean canal compromise, SCI: spinal cord injury.
*T1/T2 MRI: the changes in cord signal on MRI T1-weighted and T2-weighted images.

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DISCUSSION

Diving injury is one of the leading causes of severe trauma to the spine.[35] the incidence of SCI following diving or shallow-water falls ranges from 1.2% to 21%,[11,35] predominantly in young, healthy, male individuals.[29,35,37] The actual incidence of diving related spinal injuries may be underestimated, as some fatalities are reported as drowning deaths without postmortem investigation.[34]

From an epidemiological perspective, more than 75% of patients with a SCI due to diving are less than 30 years old and the median age is estimated to be between 15 and 19 years old.[11] The majority (88%) of spinal injuries take place between June and September, significantly increasing in frequency during this period.[11,18] In contrast, as mentioned in our study, the majority of cases occurred in the age group with an average age of 30.61±10.02 years, and temporally, the highest occurrences were reported in July (28.6%) and August (31.4%).

Most individuals, who sustain such injuries, were unaware of the possibility of such an injury prior to the accident, and both unawareness and careless behavior are key contributors to these accidents.[18] The majority of victims are those unfamiliar with the swimming area or the depth of the water.[11] Therefore, research on diving-related spinal injuries is valuable, especially in tourist destinations like Jeju Island, where marine and water leisure activities are popular, as tourists may be unfamiliar with the environment.

Besides negligence and reckless behavior of the patient, alcohol consumption and narcotic drugs are found 38% to 47% of cases,[11,29] and known as an important risk factor of injuries in diving induced SCI. But in our study, as mentioned earlier, alcohol consumption was suspected in only 16.7% and there was no use of narcotic drugs in our study.

Diving-related spinal injury is a disease group with various influencing factors. Due to the diversity in mechanisms, injury levels and types, severity of symptom, and prognosis, there are inherent limitations in deriving statistical conclusions under a single research theme. However shallow-water diving injuries have catastrophic neurological sequelae especially in the younger population, at enormous personal cost with a socio-economic burden to society.[35] A comprehensive analysis of diving-related spinal injuries and an investigation into the factors affecting their prognosis would provide valuable insights.

From the perspective of diving related spinal injury mechanisms, their head strikes an obstacle or the floor, abruptly stopping and resulting in the full body weight being transmitted to the spine, adversely affecting it. The head striking the bottom or an obstacle causes sudden deceleration, and the body weight impacts the cervical spine.[24,34,35] This axial force is usually accompanied by a flexion force,[9,29,33] but other mechanisms, such as lateral flexion or hyperextension, may also cause injury, though less frequently.[11,17,35] In our study, flexion injuries were observed in 79.4% of cases, and axial loading was observed in 88.2%. When axial force is applied to the neck during flexion, it can result in a crush fracture of the cervical vertebrae, and the displacement of bone fragments may injure the spinal cord.[17,34]

The most commonly affected area is the cervical spine,[9] although thoracolumbar injuries, particularly upper lumbar vertebral fractures, can also occur.[35] The most fractures occur at the C5–C7 vertebral levels most frequently. In particular, the C5 vertebra is more prone to fractures due to its larger range of motion and relatively smaller vertebral canal size.[3,18,34]

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In some cases, Jefferson fractures (C1) or odontoid process fractures have been noted,[7,8] though these cases emphasize the relative rarity of upper cervical spine diving injuries.[7] In our study, the most frequent injuries were observed in the lower cervical spine (C5–C7) with a prevalence of 55.9%, whereas the upper cervical spine (C1–C2) had the lowest prevalence at 5.9%, demonstrating overall consistency in findings.

The severity of the trauma and secondary injuries are directly proportional to the speed and the degree of flexion or extension experienced during the impact.[11] As a result, depending on the factors at the time of injury, such as impact speed, angle, and other conditions, the severity of the patient's symptoms can vary widely, ranging from extremely severe to relatively mild. However, diving injuries predominantly occur in the cervical spine, often leading to significant injuries such as tetraplegia or quadriplegia.[18,32,33]

In this study, an investigation was conducted to examine factors related to prognosis amidst various variables as mentioned above. In particular, statistical analysis was performed to assess the correlation with the timing of surgery.

As previously mentioned, in this study, the time from the injury caused by diving to the time of surgery ranged from 2 to 8 hours after the injury with 3 cases of exception. Therefore, in most cases, emergency surgery was performed almost immediately after the injury. However, the relationship between the prognosis and timing of surgery was not found to have significant statistical significance. In terms of correlation, no variables were directly correlated with timing of surgery. On the other hand, in the case of MCC, although statistical significance was not reached, a correlation with a similar degree of statistical relevance was observed (p=0.055).

In multiple regression analysis, although there were no variables directly correlated with timing of surgery, it was confirmed that prognosis, MCC, and changes in the signal pattern on T1WI/T2WI, as well as the grade and type (edema, contusion, hemorrhage) of cervical cord injury, significantly affect the outcomes. As the grade of MCC increases, indicating a greater degree of spinal canal stenosis due to trauma, the degree of change in AIS also increases. Moreover, as the cord injury grade on MRI increases, specifically with the appearance of hemorrhagic injury, and as the severity of the injury increases, the degree of change in AIS decreases (p0.008).

Therefore, for patients with cervical spinal injuries resulting from shallow-water diving treated at our trauma regional center, those with a higher MCC grade but with a lower grade of SCI or without hemorrhagic contusion may have the potential for AIS improvement if appropriate treatment is provided. Furthermore, considering that 16 (80%) out of the 20 patients who underwent surgery received it within 2 to 8 hours, Although a direct correlation or statistically significant association between the timing of surgery and prognosis could not be established, it is anticipated that in patients with less severe SCI, timely surgical intervention—even in cases of severe trauma-related spinal canal compromise—may potentially contribute to a better prognosis.

CONCLUSION

Cervical spine injury resulting from diving into shallow water often occurs due to negligence in unfamiliar environments, such as tourist destinations. It predominantly affects young

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males and can lead to severe disability, necessitating appropriate treatment. This study investigated various prognostic factors, with a particular focus on the timing of surgical intervention. While statistical analysis did not establish a direct correlation between surgical timing and prognosis, factors such as MCC, the severity of SCI on MRI, and the presence of hemorrhagic injury were more strongly associated with neurological outcomes. Notably, patients with significant spinal canal compromise but without extensive spinal cord damage exhibited a greater potential for neurological recovery when timely and appropriate intervention was provided.

As previously mentioned, diving-related cervical spinal injuries involve a broad range of variables, including injury mechanism, injury level, type, treatment approach, and patient prognosis. Controlling for these factors in a simple retrospective analysis is challenging, making it difficult to draw statistically meaningful conclusions regarding optimal treatment strategies. Additionally, the study's limited sample size further constrains the generalizability of its findings.

Nevertheless, research on diving-related spinal injuries remains highly valuable. Given their frequency, predominant occurrence in young individuals, and the severity of their outcomes, further investigation is warranted. Moreover, considering that Jeju Island is a major tourist destination where such injuries occur annually, continued research is essential to improve the proper management and clinical outcomes.

Future studies incorporating data from multiple regional trauma centers and hospitals, with larger patient populations and appropriate variable control, are expected to yield more definitive and robust conclusions. Furthermore, this study is inherently limited by its retrospective design, which is susceptible to selection bias. These findings underscore the need for validation through prospective observational studies or randomized clinical trials.

REFERENCES

1. Aarabi B, Sansur C, Ibrahimi D, Hersh D, Le E, Akhtar-Danesh N, et al. Intramedullary lesion length has a negative effect on neurological recovery in cervical spinal cord injury patients with AIS grades A-C. **Global Spine J 6:**s-0036-1582936, 2017 CROSSREF
2. Aarabi B, Sansur CA, Ibrahimi DM, Simard JM, Hersh DS, Le E, et al. Intramedullary lesion length on postoperative magnetic resonance imaging is a strong predictor of ASIA Impairment Scale grade conversion following decompressive surgery in cervical spinal cord injury. **Neurosurgery 80:**610-620, 2017 PUBMED | CROSSREF
3. Aito S, D'Andrea M, Werhagen L. Spinal cord injuries due to diving accidents. **Spinal Cord 43:**109-116, 2005 PUBMED | CROSSREF
4. Alizadeh A, Dyck SM, Karimi-Abdolrezaee S. Traumatic spinal cord injury: an overview of pathophysiology, models and acute injury mechanisms. **Front Neurol 10:**282, 2019 PUBMED | CROSSREF
5. Anthes DL, Theriault E, Tator CH. Ultrastructural evidence for arteriolar vasospasm after spinal cord trauma. **Neurosurgery 39:**804-814, 1996 PUBMED | CROSSREF
6. Avadhani A, Rajasekaran S, Shetty AP. Comparison of prognostic value of different MRI classifications of signal intensity change in cervical spondylotic myelopathy. **Spine J 10:**475-485, 2010 PUBMED | CROSSREF
7. Bailes JE, Herman JM, Quigley MR, Cerullo LJ, Meyer PR Jr. Diving injuries of the cervical spine. **Surg Neurol 34:**155-158, 1990 PUBMED | CROSSREF
8. Blackmore ME, Goswami T, Chancey C. Chapter 7. Cervical spinal injuries and risk assessment in Goswami T (ed): Injury and Skeletal Biomechanics. London: IntechOpen, 2012
9. Blanksby BA, Wearne FK, Elliott BC, Blitvich JD. Aetiology and occurrence of diving injuries. A review of diving safety. **Sports Med 23:**228-246, 1997 PUBMED | CROSSREF

 https://doi.org/10.13004/kjnt.2025.21.e16

10. Burke JF, Yue JK, Ngwenya LB, Winkler EA, Talbott JF, Pan JZ, et al. Ultra-early (<12 hours) surgery correlates with higher rate of American Spinal Injury Association Impairment Scale conversion after cervical spinal cord injury. **Neurosurgery 85:**199-203, 2019 PUBMED | CROSSREF
11. Chan-Seng E, Perrin FE, Segnarbieux F, Lonjon N. Cervical spine injuries from diving accident: a 10-year retrospective descriptive study on 64 patients. **Orthop Traumatol Surg Res 99:**607-613, 2013 PUBMED | CROSSREF
12. Chopra N, Menounos S, Choi JP, Hansbro PM, Diwan AD, Das A. Blood-spinal cord barrier: its role in spinal disorders and emerging therapeutic strategies. **NeuroSci 3:**1-27, 2021 PUBMED | CROSSREF
13. Fehlings MG, Hachem LD, Tetreault LA, Skelly AC, Dettori JR, Brodt ED, et al. Timing of decompressive surgery in patients with acute spinal cord injury: systematic review update. **Global Spine J 14:**38S-57S, 2024 PUBMED | CROSSREF
14. Jin LY, Li J, Wang KF, Xia WW, Zhu ZQ, Wang CR, et al. The blood-spinal cord barrier in spinal cord injury: a review. **J Neurotrauma 38:**1203-1224, 2021 PUBMED | CROSSREF
15. Kamal R, Verma H, Narasimhaiah S, Chopra S. Predicting the role of preoperative intramedullary lesion length and early decompressive surgery in ASIA Impairment Scale grade improvement following subaxial traumatic cervical spinal cord injury. **J Neurol Surg A Cent Eur Neurosurg 84:**144-156, 2023 PUBMED | CROSSREF
16. Kang Y, Lee JW, Koh YH, Hur S, Kim SJ, Chai JW, et al. New MRI grading system for the cervical canal stenosis. **AJR Am J Roentgenol 197:**W134-40, 2011 PUBMED | CROSSREF
17. Kiwerski J. Cervical spine injuries caused by diving into water. **Paraplegia 18:**101-105, 1980 PUBMED | CROSSREF
18. Korres DS, Benetos IS, Themistocleous GS, Mavrogenis AF, Nikolakakos L, Liantis PT. Diving injuries of the cervical spine in amateur divers. **Spine J 6:**44-49, 2006 PUBMED | CROSSREF
19. Kwon WK, Ham CH, Byun J, Jeong JH, Ko MJ, Lee S, et al. Surgical and neurointensive management for acute spinal cord injury: a narrative review. **Korean J Neurotrauma 20:**225-233, 2024 PUBMED | CROSSREF
20. Liontos A, Samanidou V, Athanasiou L, Filippas-Ntekouan S, Milionis C. Acute ethanol intoxication: an overlooked cause of high anion gap metabolic acidosis with a marked increase in serum osmolal gap. **Cureus 15:**e37292, 2023 PUBMED | CROSSREF
21. Lu K, Liang CL, Chen HJ, Chen SD, Hsu HC, Liliang PC, et al. Injury severity and cell death mechanisms: effects of concomitant hypovolemic hypotension on spinal cord ischemia-reperfusion in rats. **Exp Neurol 185:**120-132, 2004 PUBMED | CROSSREF
22. Magu S, Singh D, Yadav RK, Bala M. Evaluation of traumatic spine by magnetic resonance imaging and correlation with neurological recovery. **Asian Spine J 9:**748-756, 2015 PUBMED | CROSSREF
23. Marts LT, Hsu DJ, Clardy PF. Mind the gap. **Ann Am Thorac Soc 11:**671-674, 2014 PUBMED | CROSSREF
24. Pandey A, Yuk J, Chang B, Fish FE, Jung S. Slamming dynamics of diving and its implications for diving-related injuries. **Sci Adv 8:**eabo5888, 2022 PUBMED | CROSSREF
25. Papadopoulos SM, Selden NR, Quint DJ, Patel N, Gillespie B, Grube S. Immediate spinal cord decompression for cervical spinal cord injury: feasibility and outcome. **J Trauma 52:**323-332, 2002 PUBMED | CROSSREF
26. Ramakonar H, Fehlings MG. 'Time is Spine': new evidence supports decompression within 24 h for acute spinal cord injury. **Spinal Cord 59:**933-934, 2021 PUBMED | CROSSREF
27. Roberts TT, Leonard GR, Cepela DJ. Classifications in brief: American Spinal Injury Association (ASIA) Impairment Scale. **Clin Orthop Relat Res 475:**1499-1504, 2017 PUBMED | CROSSREF
28. Seo J, Lee JW. Magnetic resonance imaging grading systems for central canal and neural foraminal stenoses of the lumbar and cervical spines with a focus on the lee grading system. **Korean J Radiol 24:**224-234, 2023 PUBMED | CROSSREF
29. Siedlecki Z, Nowak K, Śniegocki M. Diving-related cervical spine injuries –a systematic review, treatment, and educational approach. **J Phys Educ Sport 20:**3684-3690, 2020 CROSSREF
30. Singh R. Prospective evaluation of relationship between MRI findings and ASIA score to predict neurological recovery in acute traumatic spinal cord injury. **Int J Spine Res 2:**8-13, 2020 CROSSREF
31. Song KJ, Kim GH, Wang SI, Lee JH. Soft tissue damage in cervical spine extension injury. **J Korean Orthop Assoc 42:**433-443, 2007 CROSSREF
32. Thom O, Roberts K, Leggat PA, Devine S, Peden AE, Franklin RC. Cervical spine injuries occurring at the beach: epidemiology, mechanism of injury and risk factors. **BMC Public Health 22:**1404, 2022 PUBMED | CROSSREF
33. Vlok AJ, Petersen J, Dunn RN, Stander J. Shallow-water spinal injuries--devastating but preventable. **S Afr Med J 100:**682-684, 2010 PUBMED | CROSSREF

https://doi.org/10.13004/kjnt.2025.21.e16

34. Voland C, Vilarino R, Grabherr S, Lobrinus JA, Palmiere C. Fatal cervical spine injury from diving accident. **Am J Forensic Med Pathol 36:**216-218, 2015 PUBMED | CROSSREF

35. Yılmaz M, Ikizoglu E, Arslan M, Ozgiray E, Calıskan KE, Erbayraktar RS. An overview of spinal injuries due to dive or fall into shallow water: our long-term, double-center experience from the Aegean coast. **Emerg Med Int 2021:**9937730, 2021 PUBMED | CROSSREF

36. Yousefifard M, Hashemi B, Forouzanfar MM, Khatamian Oskooi R, Madani Neishaboori A, Jalili Khoshnoud R. Ultra-early spinal decompression surgery can improve neurological outcome of complete cervical spinal cord injury; a systematic review and meta-analysis. **Arch Acad Emerg Med 10:**e11, 2022 PUBMED | CROSSREF

37. Zileli M, Osorio-Fonseca E, Konovalov N, Cardenas-Jalabe C, Kaprovoy S, Mlyavykh S, et al. Early management of cervical spine trauma: WFNS Spine Committee recommendations. **Neurospine 17:**710-722, 2020 PUBMED | CROSSREF