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ARTICLE

Rehabilitation outcome in people with spinal cord injuries resulting from diving in South Korea

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STUDY DESIGN: Retrospective electronic medical record review combined with a telephone interview.
OBJECTIVES: The purpose of this study was to describe the neurological and socio-professional outcomes of patients with diving injuries of the cervical spine.
SETTING: A tertiary hospital and its affiliated rehabilitation hospital in South Korea.
METHODS: Electronic medical records were reviewed for medical and neurological information. Telephone interviews were then conducted with questionnaire regarding specific circumstances at the time of injury and social status.
RESULTS: A total of 33 patients with spinal cord injury (SCI) due to diving accidents were analyzed, of which 27 responded to telephone interviews. Thirty-two (97%) participants were men and 27 (81.8%) were younger than 40 years at the time of injury. The American Spinal Injury Association grade A was the most common of all grades in 16 participants (48.5%), whereas C4 was the most common neurologic level of the injury ($n = 13$, 39.4%). SCI due to diving accidents most commonly occurred in swimming pools in holiday lodges ($n = 12$, 36.4%). Five out of 13 married couples with motor complete SCI were divorced or separated after injury. Eight persons resumed work or studies after the injury, with a mean return time of 33 (24.4) months.
CONCLUSIONS: SCI resulting from a diving accident not only causes severe functional impairment but can also result in changes in marital and employment status. This study may be used as a basic source of education and awareness to prevent further SCI due to diving accidents.

Spinal Cord Series and Cases (2022)8:40 ; https://doi.org/10.1038/s41394-022-00509-7

INTRODUCTION

Spinal cord injury (SCI) is the second most common serious traumatic event following traumatic brain injury, which causes devastating consequences, resulting in leaving various problems throughout the victim's life, including tetraplegia or paraplegia [1]. In particular, patients with SCI due to diving accidents usually have more severe disabilities than those with other etiology of SCI, such as motor vehicle accidents or falls, because most of them get injured in the higher levels of cervical vertebrae, resulting in tetraplegia than paraplegia [2–4].

Several studies in many countries have reported the regarding epidemiology of traumatic SCI, and the incidence of SCI due to diving varies depending on the region and country. The proportion of diving accidents in traumatic SCI was highest in Australia (9.4%), Brazil (9.3%), and Finland (9.2%), followed by the United States (8.5%), Canada (2.4%), and Japan (1.3%) [5–9]. In 2016, a systematic review of the epidemiology of sport-related SCI reported that diving is a common cause of sport-related SCI, ranging from 7.7% in Germany to 64.9% in China [10]. The difference in the natural environment and the number of people who enjoy diving was considered the reason why the rate of incidence of diving accidents varied from each country [11]. In contrast, several studies reported that the increase in SCI related to leisure activities and sports has been an emerging issue in countries transitioning from the "developing" to "developed" status [12, 13].

A few studies have been conducted on the epidemiology of SCI in South Korea although there are no national statistics regarding the cause of SCI in South Korea. In 1999, Park et al. reported that sport-related SCI ranked the fourth most common cause of traumatic SCI (4.1%), and diving accidents were the most common etiology (40.9%) of sport-related SCI [14]. In 2016, Lee et al. reported that diving-induced SCI accounted for 2.6% of traumatic SCI cases in South Korea, and ranked the fourth most common cause of traumatic SCI [15]. Therefore, diving accidents are not a rare cause of traumatic SCI in Korea, and prevention of diving accidents should be emphasized.

Since SCI due to diving accidents commonly occurs in young people and makes victims more disabled than other etiologies, it could lead to life-long severe disability for decades, thereby becoming catastrophic for patients and caregivers, especially due to high socioeconomic costs [2, 3, 16]. According to the 2010 report of the National Spinal Cord Injury Statistical Center, the life expectancy of people with cervical SCI occurring at the age of 20 is 41 years for neurologic level of injury between C5-8, and 37 years for between C1-4 [17]. However, developing countries have a much higher mortality rate for traumatic SCI than developed countries. For instance, mortality from cervical SCI is

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Received: 2 May 2021 Revised: 25 March 2022 Accepted: 29 March 2022
Published online: 09 April 2022

35% in a referral hospital in Tanzania [18, 19]. A study conducted in France regarding socioeconomic consequences of persons with SCI after diving injures reported that overall direct cost of treatment and hospitalization ranged from 14,000 to 364,000 dollars depending on their severity of injury [16]. If SCI caused by a diving accident can be prevented, not only the cost of healthcare but also the socio-economic burden could be reduced.

To date, studies on SCI due to diving accidents in South Korea are lacking. As South Korea's economy grows, the interest in leisure activities and sports has been increasing. Thus, the chances of SCI due to diving accidents are anticipated to increase. In the present study, we reviewed data of patients with diving injuries to describe their injuries and neurological outcomes. We interviewed patients with SCI to investigate the circumstances at the time of diving injuries to identify the risk factors for SCI due to diving accidents. In addition, marital and employment status were also investigated to examine socio-professional outcomes.

METHODS

Study location and population

This study included 33 patients with SCI due to diving accidents who visited Seoul National University Hospital (SNUH; 8 patients) from January 2000 to December 2019 and the National Traffic Injury Rehabilitation Hospital (NTIRH; 25 patients) from October 2014 to December 2019. SNUH is a tertiary hospital located in Seoul, the capital of South Korea, and has a population of approximately 9.7 million. NTIRH was established in 2015 by the Ministry of Land, Infrastructure, and Transport and is an affiliate of SNUH, which is located in Yangpyeong, Gyeonggi-do.

Study design

Retrospective electronic medical records were collected from patients with SCI due to diving injuries. Data on age, sex, date of injury, neurological status using the American Spinal Injury Association (ASIA) impairment scale at the date of admission and discharge, history of surgery, complications at hospitalization, and magnetic resonance imaging (MRI) findings were collected from medical records.

Telephone interviews were then conducted with patients with SCI due to diving accidents regarding circumstances at the time of injury and social status before and after SCI. Informed consent was obtained from the contacted patients after sufficient explanation of the purpose and specific details of the study on the phone. Of the 33 individuals, 27 responded to telephone interviews, three refused to answer, and three were not contacted. Participants were surveyed on 27 questions through a pre-written structured questionnaire. Specific circumstances of injury including the time and location of injury, the diving site, size and depth of the water, presence of depth indicator, presence of diving caution or prohibit sign, proficiency of diving and swimming, and frequency of swimming before injury, were investigated. We also surveyed the level of education, the job status before and after the injury, the amount of time to resume work, the degree of change in working ability, and marital status.

The study protocol was reviewed and approved by the Institutional Review Board of Seoul National University Hospital (IRB No. 1912-102-1089) and the National Traffic Injury Rehabilitation Hospital (IRB No. NTRH-19008).

RESULTS

Table 1 shows the characteristics of the individuals with SCI due to diving accidents. The mean (SD) age of the individuals with SCI was 31.4 (9.7) years and 81.8% ($n = 27$) were younger than 40 years at the time of injury. 97% ($n = 32$) participants were male. Burst fracture was the most common type of fracture in 23 participants, followed by dislocation or subluxation, with nine participants. Five participants were injured with both burst fractures and dislocations. The C5 vertebra was the most commonly involved fracture level in burst fracture in 13 cases, followed by C4 and C6 vertebra, in seven cases. Dislocation or subluxation occurred at the C4/5 level in five cases and C5/6 in four cases.

Table 1. Characteristics of the individuals with SCI due to diving accidents.

		n (%)
Gender	M	32 (97.0)
	F	1 (3.0)
Age in years at the time of injury	10–19	5 (15.2)
	20–29	11 (33.3)
	30–39	11 (33.3)
	40–49	5 (15.2)
	50–59	1 (3.0)
	≥60	0 (0.0)
Type of fracture	Burst	17 (51.5)
	Dislocation & Subluxation	4 (12.1)
	Burst & Teardrop	1 (3.0)
	Burst & Dislocation	5 (15.2)
	No fracture	2 (6.1)
	Etc.	1 (3.0)
	Unknown	3 (9.1)
Level of education at the time of injury	In high school	4 (12.1)
	In university or college	14 (42.4)
	University or college graduate	10 (30.3)
	Post-graduate or higher	2 (6.1)
	Unknown	3 (9.1)
Diving proficiency	Advanced	11 (33.3)
	Intermediate	7 (21.2)
	Beginner	9 (27.3)
	Unknown	6 (18.2)
Swimming proficiency	Advanced	13 (39.4)
	Intermediate	12 (36.4)
	Beginner	2 (6.1)
	Unknown	6 (18.2)
Safety education before injury	Yes	6 (18.2)
	No	21 (63.6)
	Unknown	6 (18.2)
Frequency of swimming	Daily	5 (15.2)
	1–2 times per week	2 (6.1)
	1–2 times per month	4 (12.1)
	several times in summer	16 (48.5)
	Unknown	6 (18.2)

SCI spinal cord injury.

The neurologic status of the patients at the time of discharge is shown in Table 2, with the ASIA grade and neurologic level of injury. The mean (SD) time of neurologic evaluation was 12.8 (9.8) months after injury. ASIA grade A was the most common in 16 people, followed by B ($n = 8$), C ($n = 4$), and D ($n = 5$), and 72.7% ($n = 24$) had motor complete injuries. C4 was the most common neurologic level of injury (39.4%, $n = 13$), followed by C5 (27.2%, $n = 9$), and C6 (18.2%, $n = 6$).

Table 3 shows the complications of people with SCI due to diving accidents during hospitalization. Among eighteen victims who had respiratory difficulty during hospitalization, five had

undergone tracheostomy and one experienced mechanical ventilation.

Figure 1 shows the distribution of locations where the SCI occurred due to diving and specific circumstances at the time of injury are analyzed in Tables 4 and 5. Diving accidents occurred in the swimming pool with 26 participants (78.8%) and in natural bodies of water with seven participants (21.2%). Moreover, the place where diving accidents occurred most was swimming pools in holiday lodges (36.4%, $n = 12$), followed by swimming pools in sports centers (15.2%, $n = 5$), and mountain valleys (12.1%, $n = 4$). More than half of accidents occurred during the day (63.6%, $n = 21$) compared with other time. As for swimming pools, 30.3% ($n = 10$) of the participants had SCI in small pools of <20 m, and 24.2% ($n = 8$) had accidents in pools >25 m. A total of 54.5% ($n = 18$) of diving accidents occurred at water levels lower than 1.4 m deep; further 27.3% ($n = 9$) of the accident sites had signs indicating the depth of the water and 21.2% ($n = 7$) had diving warning signs. There were 18 sites where the accidents occurred at a depth of <1.4 m, and only two of them had diving warning signs. In addition, six participants (18.2%) were in a drunken state at the time of injury. As shown in Fig. 2, most of the accidents occurred in summer (70%, $n = 23$), most commonly in August ($n = 10$), followed by July ($n = 9$).

More than half of the participants responded that their diving (54.5%, $n = 18$) and swimming skills (75.8%, $n = 25$) were above the intermediate level, and more than one-third responded that they had advanced levels of diving (33.3%, $n = 11$) and swimming (39.4%, $n = 13$) skills. Sixteen (48.5%) participants responded that they swam several times only in the summer, and only six (18.2%) reported that they ($n = 6$) received safety education before the diving accident.

Tables 6 and 7 show the changes in marital and employment status after SCI due to diving accidents. The mean (SD) time of the telephone interview was 46.2 (28.2) months after SCI. Of the 20 people with motor complete injury, 13 were married before SCI due to diving, but five of them were divorced or separated after SCI. There were no changes in marital status before and after SCI in participants with ASIA grade C and D, except one person with ASIA grade D who was married after the SCI.

As for employment status, in the ASIA grade A group, five participants were students and two of them continued their studies, 24 and 60 months after SCI, respectively. Eleven participants had jobs at the time of SCI, and only one person resumed work 30 months after SCI, in a job different from his previous job before SCI. In the ASIA grade B group, one participant was a student and seven had jobs at the time of SCI. Two of them returned to work, with one returning to the same job 84 months after SCI, and the other changed his job 14 months after SCI. There were four participants with ASIA grade C; two of them were students and others had jobs at the time of injury. One student continued his study, and one who had a job when injured was unemployed since SCI. In the ASIA grade D group, one participant was a student and four had a job at the time of injury. The student discontinued his study since SCI and two participants returned to the same job as before SCI, while the others were unemployed.

Table 2. Neurologic status at the time of discharge.

ASIA grade	*n*	Neurologic level of injury						
		C2	C3	C4	C5	C6	C7	C8
A	16	2	2	7	3	2	0	0
B	8	0	0	3	3	2	0	0
C	4	0	0	2	1	0	0	1
D	5	0	0	1	2	2	0	0
E	0	0	0	0	0	0	0	0
Total	33	2	2	13	9	6	0	1

ASIA American Spinal Injury Association.

Table 3. Complications of people with spinal cord injury during hospitalization.

Complication	Number
Neurogenic bladder	33
Neurogenic bowel	31
Neuropathic pain	20
Respiratory difficulty	18
Spasticity	18
Orthostatic hypotension	17
Sore	7
Urinary tract infection	7
Autonomic dysreflexia	6
Heterotopic ossification	6
Dysphagia	5
Pneumonia	4
Cardiac arrest	1
Thrombosis (DVT or PE)	1

DVT deep vein thrombosis, *PE* pulmonary embolism.

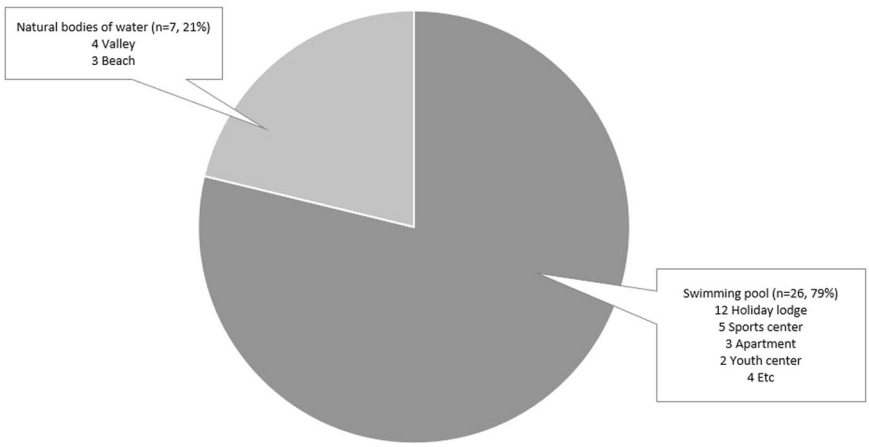

Fig. 1 Distribution of the location where diving accident occurred.

Eight out of 33 persons returned to their job, with a mean (SD) return time of 33 (24.4) months.

DISCUSSION

In this study, SCI due to diving accidents occurred most frequently in young men, and approximately one-third of them had advanced swimming or diving skills. The C5 vertebra was the most commonly involved fracture level and C4 was the most neurologic level of injury. Swimming pools in holiday lodges were the most common place-diving accidents. The depth of the water was mostly <1.4 m; however, there were no depth indicators or diving warning signs in more than half of the accident sites. Five out of 13 married participants with motor complete injury were divorced or separated after a diving accident, and 24% ($n = 8$) of all participants returned to study or work after an average of 33 months after SCI, while the rate of returning to work was lower in participants with motor complete SCI.

In this study, 97% of the SCIs due to diving accidents occurred in men and 81.8% occurred under 40 of age, which is consistent with the results of previous studies. Most victims had skills above intermediate levels and even one-third of them had advanced levels of diving and swimming skills; however, they had no experience taking water safety education before diving, and were not aware of the danger of SCI associated with diving before the injury.

As for the site of diving injury, the results from previous studies vary in each region: 49% of the individuals were injured in swimming pools in Quebec, Canada, and 17% in Canary Island [2, 20]. A study conducted in Pyrenees in France reported that diving accidents occurred 100% in swimming pools; however, another study conducted in Montpellier in France reported that only 15% of accidents took place in swimming pools [16, 17]. In our study, 79% ($n = 26$) of diving accidents occurred in swimming pools, which is a relatively higher rate than in other studies. These results can be explained by the geographic characteristics of South Korea, which has more than 70% of mountainous land, and the natural bodies of water where people can swim are a only small part of the entire coastline.

In our study, most injuries occurred in swimming pools in the holiday lodge, followed by the swimming pool in the sports center. The specific circumstances at the time of injury at these two sites were different. There is usually a swimming pool in the holiday lodge in South Korea, and its depth is shallow, mostly below the navel of an adult. Most shallow swimming pools in the holiday lodge had no sign of depth or diving caution. Therefore, environmental risk factors have a major impact on diving accidents. Specific circumstances of the injuries in the swimming pool in the sports center were different from those in the holiday lodge. The swimming pool in the sports center was >1.4 m deep, with depth indicators, and the swimming skills of all patients were above the intermediate level. Four of the five people injured in sports centers had accidents during diving lessons. Most of them were not educated about the safety of diving and were unaware that diving could cause devastating results. Personal risk factors were relatively more important than environmental risk factors in sports centers.

In this study, C5 was the most involved fractured vertebra, which is consistent with previous studies [4, 16, 18–22]. However, the exact neurological level of injury (NLI) varied from study to study. Many studies have reported C6 as the most common NLI, while some have reported it as C4 or C5 [2, 17–20, 22]. In our study, C4 was the most common NLI ($n = 12$). We investigated the sensory and motor levels of participants with C4 NLI, and two-thirds of them had a C5 ($n = 5$) or C6 ($n = 3$) motor level with a C4 sensory level. Only one-third of them had C4 levels at both motor and sensory levels. When considering only the motor level, C5 was the most common motor level (42%, $n = 14$), followed by C6 (27%, $n = 9$).

Regarding socio-professional outcomes, we investigated marriage and employment changes before and after SCI due to diving accidents. Most patients were relatively young, more than half (52%, $n = 17$) were single, and 27% ($n = 9$) were students when injured. As for people with motor complete injury, 13 were married before the injury, but five of them divorced or separated after SCI. However, there was no change in the marital status of people with motor incomplete injury, except for one who was married after the injury. This result was consistent with previous reports that the rate of divorce status increased after SCI, and patients with motor functional injuries had a lower divorce rate than those with non-motor functional injuries [16, 23, 24].

Nine percent of the ASIA grade A participants, 29% of the ASIA grade B participants, and 50% of the ASIA grade D participants

Table 4. Circumstances at the time of injury.

		Number	%
Time of day	Early morning & evening	4	12.1
	Day	21	63.6
	Night & dawn	4	12.1
	Unknown	4	12.1
Depth of the water	<1.4 m	18	54.5
	>1.4 m	13	39.4
	Unknown	2	6.1
Drunken state	Yes	6	18.2
	No	21	63.6
	Unknown	6	18.2
Presence of depth indicator	Yes	9	27.3
	No	18	54.5
	Unknown	6	18.2
Presence of diving caution sign	Yes	7	21.2
	No	20	60.6
	Unknown	6	18.2

Table 5. Distribution of circumstances at the time of SCI due to diving accident according to the injury site.

		Depth <1.4 m	Drunken state (+)	Depth indicator (+)	Diving caution sign (+)	Safety education (+)
Swimming pool	Holiday lodge ($n = 12$)	11	4	1	1	3
	Sports center ($n = 5$)	0	0	3	1	2
	Apartment ($n = 3$)	0	1	3	3	0
	Youth center ($n = 2$)	1	0	2	0	0
	Etc ($n = 4$)	4	1	0	0	0
Natural bodies of water	Valley ($n = 4$)	1	0	0	1	0
	Beach ($n = 3$)	1	0	0	1	2
Total		18	6	9	7	7

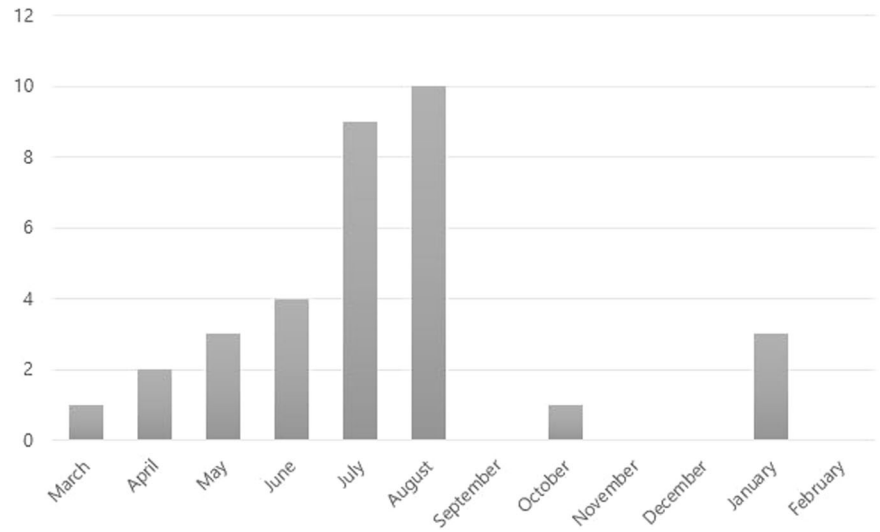

Fig. 2 Distribution of people with SCI due to diving accident according to month.

Table 6. Change of marital status after spinal cord injury.

ASIA grade	Marital status	
	Before SCI	After SCI
A ($n = 16$)	9 married	4 divorced or separated 4 married 1 unknown
	7 unmarried	6 unmarried 1 unknown
B ($n = 8$)	4 married	1 separated 2 married 1 unknown
	4 unmarried	3 unmarried 1 unknown
C ($n = 4$)	1 married	1 unknown
	3 unmarried	1 unmarried 2 unknown
D ($n = 5$)	1 married	1 married
	4 unmarried	1 married 3 unmarried

Table 7. Change of employment status after spinal cord injury.

ASIA grade	Employment status	
	Before SCI	After SCI (taken time)
A ($n = 16$)	11 employed	1 employed (30 months)
		8 unemployed
		2 unknown
	5 students	2 student (24 and 60 months)
		3 unemployed
B ($n = 8$)	7 employed	2 employed (14 and 84 months)
		3 unemployed
		2 unknown
	1 student	1 unemployed
C ($n = 4$)	2 employed	1 unemployed
		1 unknown
	2 students	1 student (30 months)
		1 unknown
D ($n = 5$)	4 employed	2 employed (8 and 14 months)
		2 unemployed
	1 student	1 unemployed

returned to work after SCI. The changes in the employment of patients in the ASIA grade C group were not investigated because they could not be contacted. Among the nine students who were injured, three persons had continued their studies. Persons with motor complete injury had a lower rate of returning back to work; the rate was lower in those with ASIA grade A than in those with ASIA grade B. This result was consistent with previous studies that reported severe repercussions on careers, including job losses in higher ASIA grades [16, 17]. Experiencing respiratory difficulty was an important factor in determining whether people with SCI could return to work [25, 26]. Among the 18 patients who had respiratory difficulty during hospitalization, 13 did not return to their work (72%), while 7 of 15 people who did not experience respiratory difficulty did not return to their work (47%).

This study has several limitations. First, there was a time interval between the point of retrospective chart review and the point of telephone interview. Neurologic level and severity were investigated by reviewing the electrical medical records, which averaged 12.8 months after the injury; however, the survey was conducted 46.2 months on average after the injury, and we investigated people who had respiratory difficulty as a problem during hospitalization and not after discharge. We did not investigate whether people had respiratory difficulties at the time of the telephone interview. Second, participants were not admitted to our hospital immediately after the injury. Most of patients were transferred from other hospitals where they underwent surgery and rehabilitation immediately after the injury. Therefore, some examination results, including MRI, were missed, and it was difficult to determine the medical and neurologic progression from the day of injury to the time of the investigation. Third, the sample size was relatively small; thus, further research is be needed, for example, based on the national statistics of SCI. Nevertheless, our study has several strengths. To the best of our knowledge, this is the first study to report the status of SCI caused by diving accidents in South Korea. Changes in employment and marital status after SCI were also studied which could be referred to as general rehabilitation outcomes.

To prevent further SCI due to diving accidents, people must be actively educated about the dangers of diving, especially young populations, regardless of their swimming or diving skills. Moreover diving warning signs should be placed beside swimming pools in holiday lodges and sports centers, and natural bodies of water such as valleys and beaches. Our study can be used as a source of education and awareness to prevent further SCI due to diving accidents, and has implications for the prevention of SCI due to diving in countries transitioning from the "developing" to "developed" status.

DATA AVAILABILITY

All datasets generated or analyzed in this study are available from the corresponding authors on responsible request.

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ACKNOWLEDGEMENTS

We would like to express our sincere gratitude to the individuals with spinal cord injury who participated in the study.

AUTHOR CONTRIBUTIONS

JHY was responsible designing the study, writing the protocol, collecting data, extracting and analyzing data, interpreting results, creating figures and tables, and writing the report. YGY was responsible for designing the study, writing the initial protocol, and interpreting results. She contributed to collecting data and writing the report. JYL contributed to collecting data. MSB was responsible for designing the study, collecting data, interpreting the results. He provided feedback on the report and approved the final version.

FUNDING

This study was funded by SNUH biomedical research institute.

COMPETING INTERESTS

The authors declare no competing interests.

ETHICS

The study was approved by the Institutional Review Board of SNUH (IRB No. 1912-102-1089) and NTIRH (IRB No. NTRH-19008). We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during the course of this research.

ADDITIONAL INFORMATION

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