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ORIGINAL ARTICLE

Cervical spine injuries from diving accident: A 10-year retrospective descriptive study on 64 patients

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KEYWORDS
Cervical spine injury;
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Surgical treatment;
Outcome;
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Diving accidents

Summary
Introduction: Ninety percent of the lesions resulting from diving injuries affect the cervical spine and are potentially associated with spinal cord injuries. The objective is to determine the most frequent lesion mechanisms. Evaluate the therapeutic alternatives and the biomechanical evolution (kyphotic deformation) of diving-induced cervical spine injuries. Define epidemiological characteristics of diving injuries.
Materials and methods: A retrospective analysis over a period of 10 years was undertaken for patients admitted to the Department of Neurosurgery of Montpellier, France, with cervical spinal injuries due to a diving accident. Patients were re-evaluated and clinical and radiological evaluation follow-ups were done.
Results: This study included 64 patients. Cervical spine injuries resulting from diving predominantly affect young male subjects. They represent 9.5% of all the cervical spine injuries. In 22% of cases, patients presented severe neurological troubles (ASIA A, B, C) at the time of admission. A surgical treatment was done in 85% of cases, mostly using an anterior cervical approach.
Discussion: This is a retrospective study (type IV) with some limitations. The incidence of diving injuries in our region is one of the highest as compared to reports in the literature. Despite an increase of our surgical indications, 55% of these cases end up with a residual kyphotic deformation but there is no relationship between the severity of late vertebral deformity and high Neck Pain and Disability Scale (NPDS) scores.
Level of evidence: Level IV, retrospective study.

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Introduction

Spinal cord injuries resulting from trauma during recreational or sports activities represent 10.4% of spinal cord injuries. More than 75% of patients with a spinal cord injury due to sports are less than 30 years old (National Spinal Cord Injury Statistical Center, NSCISC, https://www.nscisc.uab.edu). Most of these lesions were induced by diving accidents (6.3% of all spinal cord injuries). Spine trauma from a diving-related injury can cause severe lesions and most of them affect young healthy male amateur divers (97%). The median age is estimated between 15 and 19 years old [1—4]. The incidence of diving injuries increases during the summer with 88% of the cases occurring between June and September. The use of narcotic drugs and alcohol is found in 38 to 47% of cases [5—7]. In general, the victims are unfamiliar with the swimming area, the environment or the depth of the water. Impact often causes a benign head injury but may be associated with cervical spine trauma resulting from compression and hyperflexion.

The southeast part of France is located next to the sea and owns a high number of private swimming pools, rivers and lakes. Almost all of spinal injured patients of this region are systematically taken to our unit (Neurosurgery Department, Montpellier, France). Our purpose is to describe and analyze the nature of these spinal injuries. We also examine the neurological and socio-professional outcomes. We then discuss the importance of preventive measures in conjunction with a literature review.

Materials and methods

A retrospective analysis over a period of 10 years was undertaken for patients admitted to our department with cervical spinal injuries due to diving injury. Patients with benign disco-ligamentous lesion and/or with vertebral contusions without fracture were excluded.

We considered for each patient: gender, age at the time of injury, month of injury, vertebral injury, American Spinal Injury Association (ASIA) impairment scale at admission [8], spinal cord MRI findings, spinal treatment, length of stay in the Neurosurgery Unit, neurological outcomes and complications.

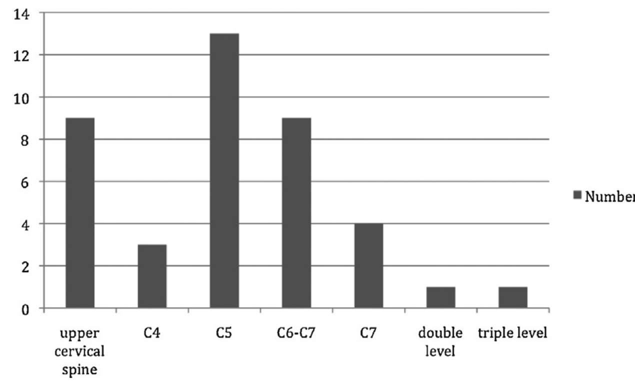

Figure 2 ASIA Impairment Scale classification at admission and at follow-up.

Sixty-four patients were cared for diving cervical spine trauma in the neurosurgical emergency unit in the University Hospital of Montpellier (France) between August 2000 and August 2010. This corresponds to 9.5% of all admitted cervical spine injuries (676 cervical spine trauma patients received care in our unit over the same period). Ninety-five percent of traumas occurring in males. Eighty-five percent of the accidents occurred in natural places (sea, rivers and torrents) as compared to 15% in private swimming pools. Three patients were drowned (4%) immediately after the accident. Most of the spinal traumas (59 cases, 93%) occurred between April and August with a peak frequency in July (32%) and August (43%). The age distribution at traumatism and the injury vertebral level are presented in the Fig. 1 (A, B). Mean and the median ages are 26.4 and 22 years respectively. At admission, 14 patients (22%) had been neurologically evaluated with an ASIA A, B or C scores (or Frankel scale A, B or C). Among these patients, seven patients presented a burst fracture, five a tear-drop fracture and two a dislocation. ASIA impairment scale classification at admission and at follow-up is indicated in the Fig. 2. Distribution of vertebral injury according to the type of fracture and neurological level is presented in the Fig. 3.

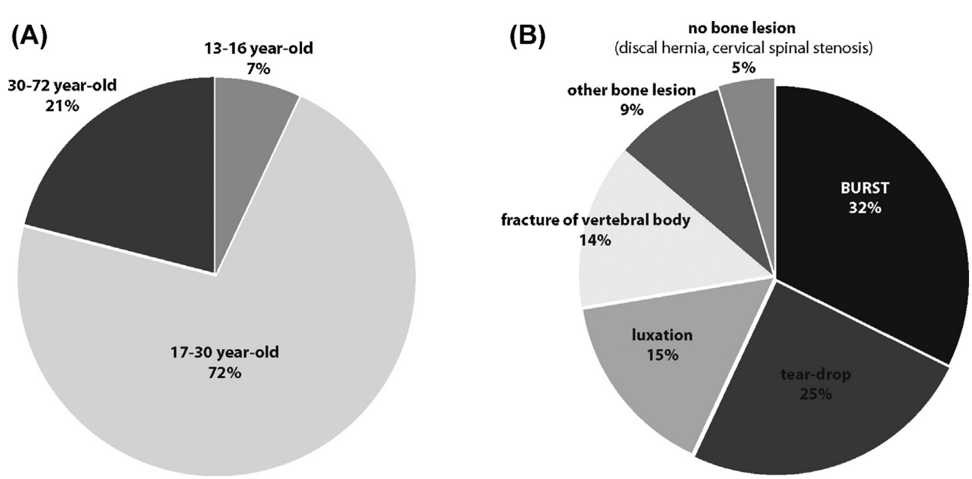

Figure 1 Age distribution at traumatism (A) and vertebral level (B).

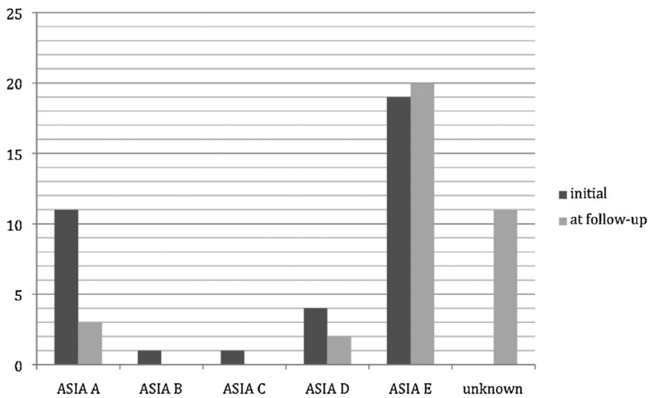

Figure 3 Distribution of vertebral injury according to the type of fracture.

Treatment

Surgical procedure was performed for 54 patients. Before surgery a cervical traction with a Müller's cranial screw was used for nine patients. A reduction was obtained for seven patients. An anterior decompression and interbody arthrodesis with autologous iliac bone graft was performed for 52 patients (84.4%). Surgical procedures included a simple discectomy or corporectomy with Screw-plate fixation. An arthrodesis with a Poly Ether Ether Ketone (PEEK) intersomatic cage and an anterior cervical plate was realized for two patients. Ten patients (15.6%) were treated conservatively with the use of a neck brace (four-poster bracing).

These patients were reviewed to assess neurological evolution with ASIA impairment scale, Frankel scale and bladder function. A quality of life assessment was performed. The French adaptation of the Neck Pain and Disability Scale was used to evaluate discomfort and chronic cervical pain [9,10]. We evaluated the complications after treatment, the link between MRI and neurological recovery, the sagittal balance parameters and lesion type, the repercussion on professional and social life, including daily activities, work and sports.

At the follow-up, a cervical computed tomography scan was obtained with a GE Yokogawa Medical Systems scanner (Japan) and images analyzed with the software advantage Workstation (General Electric Company, 2006). The degree of cervical kyphosis was measured by evaluating, on sagittal CT-Scan views, the angle from the line drawn parallel to the inferior end plate of the most cephalad vertebra in the sagittal kyphotic curvature and the line parallel to the inferior end plate of the most caudal vertebra of the sagittal curvature.

Results

Patient re-examination ($n = 34$)

Among the 64 patients, 26 patients (40.5%) were lost to follow-up, as a result of geographic remoteness from the referral center. Four patients died (6.25%). Two occurred during the initial hospitalization in the intensive care unit. The other two tetraplegic patients died from secondary pulmonary infectious.

We performed clinical examinations of 34 patients (53.25%) and evaluated their American Spinal Injury Association (ASIA) score at the time of the consultation. The mean follow-up was of 44.7 months (range, 5—120 months). Twenty-nine patients were surgically treated and five with a conservative treatment. The average length of hospital stay was of 14 days (range, 4—60 days). Baseline and monitoring characteristics of patients are detailed in the Table 1.

Neurologic outcome

At the follow-up, 14 patients (41%, $n = 34$) remain neurogically unchanged. Three ASIA A patients (9%) presented a complete neurological recovery: an 18-year-old woman with a C6 tear-drop fracture, a 23-year-old man with a C4-C5 dislocation and a 17-year-old man with a C7 burst fracture. Four ASIA D patients (12%) improved neurologically to ASIA E. Two patients (6%) progressed through two ASIA states. Among the four ASIA A patients, three regained partial sphincter control. Their bladder function was induced by percutaneous reflex stimulation. One patient required uretero-cystoplasty.

Complications

Seven patients (11%) developed complications during the initial hospitalization: four patients developed a pulmonary atelectasias, one patient a vertebral artery dissection, one a respiratory failure that required a tracheostomy implantation and one an infection of the iliac region (site of sample graft).

Relationship between initial MRI and neurological recovery

An initial MRI scan of the cervical spine was performed in 31 cases ($n = 64$). Among the 16 patients with an initial intramedullary hyper-intense lesion on T2-weighted MRI, 10 presented a sentivo-motor deficit (ASIA A, B, C), and six a single sensitive deficit (ASIA D). Among patients [11] with a normal initial MRI, one presented a deficit and 14 were neurologically non-symptomatic. In our series, the sensitivity of MRI on neurological impairment is of 0.9 and the specificity of 0.67. The positive predictive value of MRI is 0.065 and the negative one of 0.92. We were unable to establish any reliable conclusions regarding the prognostic value of MRI for neurological outcome.

Relationship between kyphotis deformity and vertebral lesion type

A conservative treated patient (brace) did not show initial vertebral deformation. At the follow-up, among the surgically-treated patient ($n = 29$), a late kyphotic deformity was present in 16 cases (55%). Kyphosis is in between 1—10° in seven cases, between 11—20° in seven cases and greater than 20° in two cases. Despite surgical treatment, kyphosis deformity increased in six cases (20%). Among these cases (3 burst fractures, 2 tear-drop fractures and one discal hernia), a severe kyphosis (> 20°) was present in two cases. Kyphotic

Table 1 Correlation between the type of fracture, the type of treatment, the neurologic status and kyphotic deformity.

Type of fracture	No. of cases	Initial ASIA		ASIA at follow-up		Initial kyphotic deformation	
Burst fracture, diabolo	12	A	4 (33%)	A	2 (17%)	None	2
		B	0	B	0	0–10°	1
		C	2 (17%)	C	0	11–20°	1
		D	1 (8%)	D	2 (17%)	> 20°	1
		E	5 (42%)	E	8 (67%)		
Tear-drop fracture	7	A	5 (71%)	A	4 (57%)	None	
		B	1 (14%)	B	0	0–10°	
		C	0	C	0	11–20°	
		D	0	D	1 (14%)	> 20°	
		E	1 (14%)	E	2 (29%)		
Luxation	5	A	1 (20%)	A	0	None	3
		B	0	B	0	0–10°	
		C	0	C	0	11–20°	
		D	2 (40%)	D	0	> 20°	
		E	2 (40%)	E	5 (100%)		
Fracture of vertebral body	3	A	0	A	0	None	2 (66%)
		B	0	B	0	0–10°	1 (33%)
		C	0	C	0	11–20°	0
		D	1 (33%)	D	0	> 20°	0
		E	2 (66%)	E	3 (100%)		
Bipedicular fracture, Jefferson's fracture, fracture of odontoid	5	A	0	A	0	None	4
		B	0	B	0	0–10°	
		C	0	C	0	11–20°	
		D	0	D	0	> 20°	
		E	5 (100%)	E	5 (100%)		
No bony lesion (cervical stenosis, discal hernia)	2	A	1 (50%)	A	0	None	1 (50%)
		B	0	B	0	0–10°	1 (50%)
		C	0	C	0	11–20°	0
		D	0	D	0	> 20°	0
		E	1 (50%)	E	2 (100%)		

Type of fracture	Surgical treatment (S)	Neurological improvement after S		Kyphotic deformation after S	
Burst fracture, diabolo	12 (100%)	Yes	4 (33%)	None	5 (42%)
				0–10°	4 (33%)
		No	8 (67%)	11–20°	2 (17%)
				> 20°	1 (8%)
Tear-drop fracture	7 (100%)	Yes	1 (14%)	None	0
				0–10°	1 (14%)
		No	6 (86%)	11–20°	3 (43%)
				> 20°	1 (14%)
Luxation	5 (100%)	Yes	2 (40%)	None	2 (40%)
				0–10°	1 (20%)
		No	3 (60%)	11–20°	1 (20%)
				> 20°	0
Fracture of vertebral body	1 (33%)	Yes	1 (100%)	None	0
				0–10°	0
		No	0	11–20°	1 (100%)
				> 20°	0
Bipedicular fracture, Jefferson's fracture, fracture of odontoid	3 (60%)	Yes	0	None	3 (100%)
				0–10°	0
		No	3 (100%)		

Table 1 (*Continued*)

	Surgical treatment (S)	Neurological improvement after S		Kyphotic deformation after S	
	11—20°	0			
				> 20°	0
No bony lesion (cervical stenosis, discal hernia)	1 (50%)	Yes	1 (50%)	None	0
				0—10°	1 (100%)
		No	1 (50%)	11—20°	0
				> 20°	0

Type of fracture	Conservative treatment (C)	Neurological improvement after C		Kyphotic deformation after C		Initial MRI		Death
Burst fracture, diabolo	0	Yes		None		N	1 (8%)	1 (8%)
				0—10°				
		No		11—20°		H	7 (58%)	
				> 20°				
						Undone	4 (33%)	
Tear-drop fracture	0	Yes		None		N	0	2 (29%)
				0—10°				
		No		11—20°		H	5 (71%)	
				> 20°				
						Undone	2 (29%)	
Luxation	0	Yes		None		N	1 (20%)	1 (20%)
				0—10°				
		No		11—20°		H	3 (60%)	
				> 20°				
						Undone	1 (20%)	
Fracture of vertebral body	2 (66%)	Yes		None	2 (100%)	N	0	0
				0—10°	0			
		No	2 (100%)	11—20°	0	H	0	
				> 20°	0			
						Undone	3 (100%)	
Bipedicular fracture, Jefferson's fracture, fracture of odontoid	2 (40%)	Yes	0	None	2 (100%)	N	0	0
				0—10°	0			
		No	2 (100%)	11—20°	0	H	0	
				> 20°	0			
						Undone	5 (100%)	
No bony lesion (cervical stenosis, discal hernia)	1 (50%)	Yes	1 (100%)	None	1 (100%)	N	0	0
				0—10°	0			
		No	0	11—20°	0	H	2 (100%)	
				> 20°	0			
						Undone	0	

deformity was reduced after surgical treatment for seven patients (23%). Patients without initial deformity (50%) kept a physiological cervical lordosis.

Repercussion on professional activity

Twenty-eight patients (82%) returned to their work or studies. ASIA A patients did not return to their previous activities.

Neck Pain and Disability Scale (NPDS) — French adaptation

In the group of patients that had undergone a surgery ($n = 29$), seven did not present disability (NPDS from 0 to 100), 16 had a slight disability (NPDS from 101 to 300), three showed a moderate disability (NPDS from 301 to 500), one had been classified as severe disability (NDPS from 501 to 700) and three were completely handicapped (NDPS > 701). Among patients preventively treated ($n = 5$), one patient had no disability, two a slight disability, one a moderate disability and one presented a major disability.

Discussion

This study has some limitations. This a retrospective study (type IV) and there is significant loss to follow-up (40.5%). The small sample size cannot conclude on the prognostic value of MRI. Despite surgical treatment, a kyphotic deformity persists in 55% of cases but without direct correlation with disability. However, the study is documented on many parameters (clinical, functional and radiological data) and the epidemiological findings are carefully described.

Diving injuries are in the fourth position in the international ranking of the aetiologies of spinal cord injuries. According to the 2010 National Spinal Cord Injury Statistical Center (NSCISC), this represents 6.3% of all spinal cord injuries. The incidence is estimated between 6 and 21% (Quebec 6% [5], USA 7% [12], Australia 10% [13]). This disparity is overall explained by the local geography [14]. The site of the diving injury varies according to the studies: 15% of these injuries occur by diving in swimming pools in our region, 49% in the Quebec province [5] and exclusively in swimming pools in Midi-Pyrénées's region [3]. Eighty-five percent of injuries in our study and 51% in the Quebec study [5] occurred in a natural environment (seaside, torrent, and river). Moreover, Barss et al. defined the time of the occurrence of accidents: 70% during the day, 14% during the evening and 16% during the night (alcohol consumption is often associated with night time traumas [5]). The diving location was unfamiliar to the amateur divers or was not a usual swimming place in 42% of the cases. Eighty-nine percent of the traumas occurred at a water depth of less than 1.52 m [13]. DeVivo et al. reported that 57% of the lesions occurred at a depth of less than 1 or 2 m [15]. In all series, these injuries mostly occur in the male population: between 74.8% and 97% [1,3,5]. In these series, 72% of our population was between 17 and 30 years old at the time of the incidents with a peak at 19 years old (23%) [1,3,5,7]. Ninety-three percent of the cases occur between April and August, with a peak in July and August (73%) [1].

Neurological deficits due to diving account for 20 to 45% of spinal injuries [1,7]. The evaluation of life expectancy according to the lesional level and the age at trauma has been reported by the NSCISC (statistical report 2010). A tetraplegic patient with neurological damage level between C5-C8 aged 20 at the trauma has a life expectancy of 41 years and 37 years if the level concerned is C1-C4. This type of trauma necessitates an average hospital stay of 12 to 25.6 days [3,11]. Initial hospitalisation for a diving injury represents an average expense of $48,264 per patient. The cost per patient for support in a physical therapy centre is estimated at $268,103 on average. The need for preventive action has been clearly demonstrated, a prevention campaign should be reinforced for the population [16]. For example, simple safety reminders are encouraged by Albrand and Walter [16], and should be extensively communicated: do not dive in shallow water when the depth is not more than twice the height of the person; do not drink and dive; do not dive in unfamiliar water [16].

The diving injury mechanism generates an indirect force to the cervical spine as result loading on impact. The head and cervical position (extension, flexion, rotation, neutral position of the cervical spine) on impact determines the different mechanisms of lesion (as luxation, tear-drop fracture, articular fracture). A diver accelerates in velocity as he/she dives into water, and acceleration ceases abruptly on impact. The body's weight also affects the cervical spine. In an extreme movement (hyperextension, hyperflexion), the compressive force is non-homogenously absorbed by the cervical structures. The severity of the trauma and the secondary lesions are also directly proportional to the speed and the degree of flexion or extension experienced during the impact. They are inversely proportional to the intrinsic resistance of the individual. A speed of greater than 3 m/s is sufficient for a diver to develop lesions upon impact. Most fractures occur at the fifth, sixth and seventh cervical vertebras, the level that controls a higher mobility [7,14].

Cervical spine trauma due to diving is responsible for 35% of burst fractures (mechanism in flexion-compression) [17,18]. This lesion type is the most frequently found (88% for Burke and al., 1982, 21% for Aito) [1,19]. Tear-drop fractures are the second most frequent type of fracture (20.6% for our study, up to 61% for Aito [1]), with dislocations (from 12 and 23.5%) being the third most frequent. It is clear that tear-drop fractures are predictive of the severity of the neurological deficit (91% of tear-drop fractures are ASIA A [20]). In our study, 57% of ASIA A, B, C patients had a tear-drop fracture, 17% a burst fractures, 29% a dislocation and 6% a spinal cord contusion without bone lesions. Distraction is the main mechanism of cervical spine injury. Leucht et al. [21] in the description of spine fractures found that both lesions in the anterior and posterior columns are caused by distraction type B in 59% of cases, by rotation type C in 27% of cases, and by compression type A in 14%, according to AO's classification [22,23]. Eighty-five percent of traumas involve the lower cervical spine (C3-C7), with 49% occurring at the C5-C6 level.

Mortality resulting from a diving-related spinal injury is associated with an upper cervical trauma with spinal cord injury. The NSCISC reports that 8% of deaths for patients with spinal cord injuries are a consequence of diving lesions.

In our study, patients with a neurological evaluation ASIA or Frankel A have better recovery than patients evaluated ASIA or Frankel B or C. It is worth noting that our neurological status through ASIA scale or Frankel scale is done during the first day after trauma. Neurological status after spinal sideration improves in the following days.

The functional prognostic value of MRI at the initial taking-care remains controversial. In our study, we cannot conclude that there is a prognostic value for MRI. However, there is a relationship between the neurological deficit and the presence of anomalies in the MRI scan of the spinal cord. The presence of a hemorrhage (hypointense lesion in T1-weighted MRI) or images evoking transection on MRI correlate with a severe injury and a poor prognostic. However, this relationship is not unanimously accepted, and some insist that a clinical examination is of primary importance and remains more effective than an MRI for the prevision of a clinical prognostic [24,25].

Surgical treatment was performed for 85% of the traumas in our series, as compared with 55% and 20% of the traumas in the series of Aito and Korres respectively [1,7]. Their series began in 1970 and at that time preventive treatment with immobilization using a neck brace or halo vest and bed rest was largely recommended. Since, the benefit of surgical treatment had been well recognized. As well as the need for only minimum external fixation, and the possibility for early mobilization clearly decreased nursing problems [1].

Acquired kyphosis seems to be due to an initial kyphotic deformation and lesional type more so than the treatment. In recent years, surgical indications have increased, particularly in an attempt to correct the cervical sagittal balance. Aito noted a vertebral deformation in 47% of the surgical treatments as compared to 62% for those patients that had received a preventive treatment [1]. Some burst and teardrop fractures were treated by preventive treatment. In our series, we have a higher level of kyphotic deformation after a surgical procedure than after preventive treatment. Moreover, in our series, there is no relationship between the severity of late vertebral deformation and high NPDS scores. No relationship between the NPDS and the effects on daily and professional activities was observed.

Conclusion

Cervical spine injuries due to diving are purveyor of severe individual damages. Consequences could be disastrous. Amelioration of medical support allows limiting biomechanical troubles secondary to disco-ligamentous lesions. Concerning neurological consequences, our expectations are based on the development of therapeutics strategies emanating from basic research. So the actual priority is to reinforce primary prevention. Target population is identified and accessible. In our region, places of accidents are mainly in public domain, thus they should be selected for preventive recommendations. It still remains to sensitize and get aware of the situation.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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