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ORIGINAL ARTICLE

Prognostic Factors of Spinal Cord Decompression Sickness in Recreational Diving: Retrospective and Multicentric Analysis of 279 Cases

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Abstract

Background This study aims to determine the potential risk factors associated with the development of severe diving-related spinal cord decompression sickness (DCS).

Methods Two hundred and seventy nine injured recreational divers (42 ± 12 years; 53 women) presenting symptoms of spinal cord DCS were retrospectively included from seven hyperbaric centers in France and Belgium. Diving information, symptom latency after surfacing, time interval between symptom onset and hyperbaric treatment were studied. The initial severity of spinal cord DCS was rated with the Boussuges severity score, and the presence of sequelae was evaluated at 1 month. Initial recompression treatment at 2.8 ATA with 100% oxygen breathing or deeper recompression up to 4 or 6 ATA with nitrogen or helium–oxygen breathing mixture were also recorded.

Results Twenty six percent of DCS had incomplete resolution after 1 month. Multivariate analysis revealed several independent factors associated with a bad recovery: age ≥ 42 [OR 1.04 (1–1.07)], depth ≥ 39 m [OR 1.04 (1–1.07)], bladder dysfunction [OR 3.8 (1.3–11.15)], persistence or worsening of clinical symptoms before recompression [OR 2.07 (1.23–3.48)], and a Boussuges severity score >7 [OR 1.16 (1.03–1.31)]. However, the time to recompression and the choice of initial hyperbaric procedure did not significantly influence recovery after statistical adjustment.

Conclusions Clinical symptoms of spinal cord DCS and their initial course before admission to the hyperbaric center should be considered as major prognostic factors in recovery. A new severity score is proposed to optimize the initial clinical evaluation for spinal cord DCS.

Keywords Diving · Hyperbaric · Decompression sickness · Spinal cord

Introduction

Decompression sickness (DCS) affecting divers are due to the development of bubbles of inert gas initially dissolved in the tissues during hyperbaric exposure. The incidence of DCS is relatively small if appropriate decompression procedures are observed, ranging from 0.01 to 0.019% for recreational divers. Neurological symptoms are dominant

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in DCS, and the most commonly affected area is the spinal cord. The great majority of spinal cord DCS involves subjective sensory abnormalities rarely distributed according to dermatomes. A less frequent but more characteristic presentation corresponds to numbness in the limbs with a progressive ascending level of both sensory and motor deficits, often accompanied by a disturbance of bladder function [1, 2]. The pathophysiological mechanisms of spinal cord DCS have not yet been fully identified: several hypotheses have been raised such as the embolisation of arterial bubbles via a right-to-left shunt, the development of native bubbles within nervous tissue of the spinal cord, or the onset of a venous infarction generated by bubbles [3]. This third hypothesis is the best-documented since the alteration of spinal cord venous draining resulting from the obstruction of the epidural venous system has been shown experimentally [4]. Secondary immuno-inflammatory processes on endothelial activation as well as the start of blood platelet aggregation and coagulation would contribute to worsening of the phenomenon. Actually, spinal cord DCS lesions are scattered throughout the white matter with no real segmental distribution as typically observed in spinal cord acute trauma [3].

Hyperbaric oxygen therapy (HBO) is considered to be the reference treatment for DCS since it reduces the bubble volume and increases the concentration of dissolved oxygen in ischaemized tissues.

Based on historical experience, recompression at 2.8 ATA with 100% oxygen breathing (US Navy Tables 5 or 6) is the most commonly used procedure worldwide, with a high efficiency rate and a low side effect impact [5, 6]. However, only a few studies that compare 100% oxygen tables at 2.8 ATA to other treatment tables using extended and deeper recompression at 4–6 ATA with oxygen–helium or oxygen–nitrogen mixtures, are available [7–9], and do not lead to conclusions on the optimal DCS recompression strategy.

Many surveys were conducted in the past, to identify factors influencing the prognosis of neurological DCS [10–13], especially the clinical presentation before treatment [10, 14], the symptom latency after surfacing [10, 15–17], and the time elapsed between the first signs and recompression [10, 13, 16, 18–23]. Nevertheless, dominant factors have not yet been identified due to methodological biases and the limited number of surveyed cases.

The purpose of this survey was to investigate the influence of potential risk factors associated with poor recovery from spinal cord DCS, pointing out different environmental or individual factors that may affect the prognosis. The purpose was also to assess the efficiency of the different recompression procedures used in French and Belgian hyperbaric centers.

Materials and Methods

A shared data file that includes data from seven hyperbaric centers (Hôpital d'Instruction des Armées Sainte-Anne Toulon, Hôpital Sainte-Marguerite Marseille, Hôpital Pasteur CHU Nice, Hôpital Edouard Herriot Lyon, CHU Angers, CHU la Cavale Blanche Brest, Hôpital militaire Reine Astrid Bruxelles) was used to complete a retrospective and multicentric analysis on consecutive spinal cord DCS treated between 2000 and 2007.

Inclusion Criteria

Patients admitted in a hyperbaric center within 24 h after dive completion presenting with bilateral neurological signs affecting long tracts were included, specifying whether they were affected by isolated paresthesia, objective sensory deficiency, or motor deficiency. The survey also included cases of DCS with unilateral neurological signs presenting a sphincter dysfunction and/or back pain, suggesting a spinal cord injury.

Patients believed to have isolated symptoms of cerebral DCS or pulmonary barotrauma with cerebral air embolism including altered speech, visual disturbance, and deterioration of higher functions were excluded from clinical, dive history, or imaging.

Data Collection

An anonymous data collection file of spinal cord DCS was proposed to most French hyperbaric centers via MEDSUBHYP (French society of undersea and hyperbaric medicine). This file includes information on the concerned dive: total diving time, maximum depth, inadequate decompression (rapid ascent, omitted decompression stop), and repetitive dives within 12 h. The following clinical data were also analyzed: age, gender, time elapsed between surfacing and the first signs, characteristics of clinical signs (isolated paresthesia, sensory deficiency ± paresthesia, motor deficiency ± sensory deficiency, or paresthesia), distribution of lesion area in spinal cord (lumbar, thoracic, or cervical), back pain, bladder dysfunction (defined when urinary retention was noted initially with subsequent drainage), combination of DCS, evolution of symptoms before recompression, recompression delay, initial hyperbaric treatment and additional sessions and medical treatment. The ASIA scale and the voluntary control of the external anal sphincter were not systematically assessed in the centers participating to this study, thus limiting the use of these data in the precise clinical evaluation of the neurological deficit.

Primary outcome after initial treatment table was not evaluated in this study. After neurological examination, clinical outcome was grossly determined by the recovery status 1 month post-injury, i.e., full recovery or presence of residual neurological manifestations defined as persistent objective sensory, motor, or bladder dysfunction.

The study design was approved by the scientific committee of the French society of undersea and hyperbaric medicine and was in accordance with the ethical standards laid down in the declaration of Helsinki.

Initial Severity Assessment

The Boussuges score was used to assess the initial severity of spinal cord injuries upon admission to the hyperbaric center. The score is calculated from five weighted clinical variables as follows: repetitive dive, clinical course before HBO treatment, objective sensory deficit, motor impairment, and bladder dysfunction (Table 1). The prognostic value of this score was prospectively validated and it has been demonstrated that cases with scores >7 predict more severe sequelae than those of cases with scores of 7 or less [24].

Initial Hyperbaric Treatment [25]

The tables used in the initial treatment for spinal cord DCS included "short 100% oxygen tables" at 2.5 m ATA for 90 min, at 2.8 ATA not exceeding 3 h (USN Table 5 tables or equivalent) or "long oxygen tables" exceeding 4 h (USN Table 6 or equivalent). Long deep tables were also used at 4 ATA for 7–8 h with 50% nitrox or 50% heliox mixtures (COMEX-CX 30 or French navy tables GERS), and finally tables at 6 ATA for 8 h (D50) with nitrox or heliox mixtures [26]. The choice of treatment regimen depended on the availability of gas mixture and the practice of the hyperbaric center.

Table 1 Parameters used in the Boussuges scoring system and their numerical weightings

Boussuges score	0	1	2	3	4	5	6
Repetitive dive							
No	X						
Yes			X				
Clinical course before recompression							
Better	X						
Stable				X			
Worse						X	
Objective sensory deficit							
No	X						
Yes					X		
Motor impairment							
No	X						
Paresis					X		
Paraplegia							X
Hemiplegia				X			
Bladder dysfunction							
No	X						
Yes						X	

Medical Treatment

Patients included in this survey were given medical treatment that complies with the European consensus conference on hyperbaric medicine in 1996 [27], including standardized fluid intravenous therapy, use of vasodilator drugs, e.g., pentoxyfilline (200 mg), buflomedil (400 mg), and/or corticosteroids, e.g., methylprednisolone (60–120 mg). Aspirin (250–500 mg) was also given mostly before the patient's arrival at the hyperbaric center, according to the French federation of diving procedures.

Additional Hyperbaric Treatment

In most centers, one or two additional HBO sessions per day with HBO at 2.5 ATA for 90 min completed the initial session. Additional HBO would continue until no further improvement could be observed after three further sessions. One center (Lyon) used a specific protocol of additional tables for 3 days including another heliox D50 table followed by 2 USN Table 6.

Statistic Analysis

The statistic analysis was conducted with the software Sigmastat 3.0 (SYSTAT Inc., Richmond, California). Data were entered as an average ± standard deviation or a median (range) for non-parametric variables. Clinical recovery after 1 month (complete or incomplete) was considered as a dependent variable, whereas characteristics related to the dive and clinical parameters were analyzed as independent variables. Receiver operating characteristic (ROC) curves were used to find the optimal cut-off level for the continuous variables, i.e., the level that can discriminate between divers with sequelae and those without sequelae. Univariate analysis used χ^2 tests or Fisher tests to identify significant predictive variables for incomplete recovery ($P < 0.05$). Variables whose P is less than 0.20 were retained for the multivariate analysis with backward elimination logistic regression to control for potential confounders and to determine independent predictors of severe spinal cord DCS. In this model, highly inter-correlated independent variables ($r > 0.7$) were avoided. Odds ratios (OR) with confidence intervals (CI) of 95% were specified for the univariate and multivariate analysis. Additional comparisons between groups for a given variable were completed using the Mann–Whitney test. ROC curves were also used to distinguish a new scoring system derived from the Boussuges score with subsequent determination of sensitivity, specificity, predictive positive and negative values. We compared paired-ROC curves, with one-tailed analysis, using the method described by Hanley and Mac Neil [28].

Results

The survey retained 279 cases of spinal cord DCS ($n = 101$, Marseille; $n = 63$, Toulon; $n = 41$, Nice; $n = 23$, Lyon; $n = 22$, Bruxelles; $n = 17$, Brest; and $n = 12$, Angers), including 226 men (81%) and 53 women (19%) with an average age of 42 ± 12 years. Seventy five percent were experienced divers, according to the French federation of diving. These 279 DCS divers include 63 patients from Toulon reported elsewhere in a recent study [2].

The average maximum depth was 39 ± 12 m for 33 ± 14 min total diving time. Seventy five patients (27%) performed an inadequate decompression profile (rapid ascent or omitted decompression stop); 61 repetitive dives (22%) were recorded.

The median time from surfacing to onset of initial symptoms was 30 (1–1400) min. Concerning the time to recompression (after the first symptoms), the median was 4 (0.5–336) h, with 124 patients (44.4%) recompressed within 3 h, 73 (26.2%) between 3 and 6 h, and 82 (29.4%) after 6 h.

Among the 279 divers affected by spinal cord DCS, 73 (26%) showed neurological sequelae after 1 month. Twenty five patients had symptoms of combined DCS suggesting cutaneous ($n = 5$), vestibular ($n = 6$), or cerebral ($n = 14$) injury.

For 126 patients (45%), the criteria of initial clinical severity assessed by the Boussuges score exceeded 7. The median number of additional HBO sessions was 3 (0–43) with 22 patients (8%) who received more than 20 sessions. No patients with cervical spinal cord DCS (29%) required intubation and intensive care. Additionally, none of them presented cardiorespiratory disorders.

The univariate analysis showed that several variables were significantly related to incomplete clinical recovery (Table 2). The number of additional HBO sessions was not retained for the multivariate analysis due to its close intercorrelation with the dependent variable ($r = 0.78$). After adjustment through logistic regression analysis, only five independent variables were significantly related to poor neurological recovery: age ≥42 [OR 1.04 (1–1.07); $P = 0.042$], depth ≥39 m [OR 1.04 (1–1.07); $P = 0.031$], bladder dysfunction [OR 3.8 (1.3–11.15); $P = 0.014$], persistence or worsening of signs before recompression [OR 2.07 (1.23–3.48); $P = 0.006$], and a Boussuges score exceeding 7 [OR 1.16 (1.03–1.31); $P = 0.016$].

Concerning the recompression delay, only the univariate analysis showed a statistical difference with clinical outcome (Table 3). Additional analysis revealed that 28% of DCS patients presented sequelae when time to recompression was <6 h versus 37.5% of divers treated after 6 h ($P = 0.012$). Moreover, treatment time for the group of patients suffering sequelae did not significantly differ from that of the group of healed patients (medians of 4 ± 9 and 3.5 ± 3 h, respectively, $P = 0.45$). Further, in the group of patients whose Boussuges score exceeded 7, there was no statistic difference in the recompression delay between patients with or without sequelae ($P = 0.23$).

The univariate analysis of the initial hyperbaric treatment did not show any statistic difference between the tables used in the group of patients with a Boussuges score <7 ($P = 0.2$). For DCS cases whose score exceeded 7, there was a statistic difference in the univariate analysis ($P = 0.01$) which no longer appeared after adjustment (Table 3).

A modified score based on the present analysis and expert opinion (French society of undersea and hyperbaric medicine) was proposed with new selected predictors and weights (Table 4). The analysis of area under the ROC curves (0.88 ± 0.02; 95% CI 0.84–0.93; $P < 0.0001$) showed that the new scoring system can accurately predict the divers with residual deficit. The discrimination between the two scores is statistically different, when comparing the areas under the curves ($P = 0.047$). The optimal cut-off for the new score was determined for values >8 instead of >7 with the Boussuges score (Fig. 1). Patients with scores >8 predict more severe sequelae than scores of 8 or less, with 87% positive predictive value and 74% negative predictive value.

Discussion

In our survey, 26% of the divers affected by spinal cord DCS suffered from neurological sequelae after 1 month. This result is consistent with the major series which showed that 20–30% of patients had incomplete recovery after a neurological DCS [29, 30] or a spinal cord DCS [17]. Our results show that age, depth, bladder dysfunction, persistence or worsening of signs before recompression, and finally a Boussuges score more than 7 are independent predictive variables for poor clinical recovery.

Age and depth were mainly described as risk factors of a DCS onset rather than prognostic factors [3, 31]. For example, it has been demonstrated that the risk of spinal cord DCS was minimal when the dives were conducted

Table 2 Analysis of clinical outcome at 1 month in divers with spinal cord DCS according to diving information, clinical characteristics, and treatment procedures

Variables	Full recovery	Sequelae	Univariate analysis		Multivariate analysis	
			P value	OR (95% CI)	*P* value	Adj OR (95% CI)
Total ($n = 279$)						
Age (years)						
<42	117	25				
>42	89	48	0.001	2.5 (1.4–4.4)	0.042	1.04 (1–1.07)
Dive time (min)						
<33	103	39				
>33	103	34	0.71	NA		
Depth (meters of sea water)						
<39	110	25				
>39	96	48	0.007	2.2 (1.3–3.8)	0.031	1.04 (1–1.07)
Inadequate decompression						
No	150	54				
Yes	56	19	0.97	NA		
Repetitive dive						
No	158	60				
Yes	48	13	0.417	NA		
Delay onset of symptom (min)						
>30	53	8				
<30	153	65	0.014	2.8 (1.3–6)	0.987	
Recompression delay (h)						
<3	94	30		1		
3–6	60	13		0.7 (0.3–1.4)		
>6	52	30	0.024	1.8 (1–3.3)	0.191	
Initial symptoms						
Paresthesia	127	13		1		
Sensory deficit	38	9		2.3 (0.9–5.8)		
Motor deficit	41	51	<0.001	12 (6–24.5)	0.177	
Lesion level						
Lombar	117	30		1		
Thoracic	29	22		2.96 (1.5–5.9)		
Cervical	60	21	0.006	1.37 (0.7–2.6)	0.309	
Back pain						
No	141	34				
Yes	65	39	0.001	2.5 (1.4–4.3)	0.218	
Bladder dysfunction						
No	189	24				
Yes	17	49	<0.001	22.7 (11.3–41.4)	0.014	3.8 (1.3–11.15)
Evolution before recompression						
Symptom disappearance	98	15		1		
Stable	61	29		3 (1.55–6.3)		
Worsening	37	29	<0.001	5 (2.5–10.6)	0.006	2.07 (1.23–3.48)
Boussuges score						
<7	146	7				
>7	60	66	<0.001	22.9 (11.6–45.2)	0.016	1.16 (1.03–1.31)
Initial treatment table						
Short tables < 2.8 ATA	118	25		1		
Long tables at 2.8 ATA	25	24		4.53 (2.2–9.2)		
Tables at 4 ATA	43	23		2.52 (1.3–4.9)		
Tables at 6 ATA	20	1	<0.001	0.24 (0.03–1.9)	0.533	
Additional HBO						
<5	161	2				
>5	45	71	<0.001	NA		

Table 3 Distribution of clinical outcome as a function of treatment table according to the initial severity score of Boussuges

Treatment table	Full recovery	Sequelae	*P*	OR (95% CI)
High severity				
Short tables ≤ 2.8 ATA	24	22		1
Long tables at 2.8 ATA	14	22		1.7 (0.7–4.1)
Tables at 4 ATA	12	21		1.9 (0.8–4.8)
Tables at 6 ATA	10	1	0.01	0.11 (0.01–0.9)
Low severity				
Short tables ≤ 2.8 ATA	94	3		1
Long tables at 2.8 ATA	11	2		5.7 (0.9–37.9)
Tables at 4 ATA	31	2		2 (0.3–12.6)
Tables at 6 ATA	10	0	0.2	NA

High severity defined as a score >7 and low severity as a score ≤7. "Short tables" means not exceeding 3 h and "long tables" more than 4 h

Table 4 Parameters used in the new scoring system and their numerical weightings for spinal cord DCS

Spinal cord DCS score	0	1	2	3	4	5	6
Age ≥ 42							
No	X						
Yes		X					
Back pain							
No	X						
Yes		X					
Clinical course before recompression							
Better	X						
Stable				X			
Worse						X	
Objective sensory deficit							
No	X						
Yes					X		
Motor impairment							
None	X						
Paresis					X		
Paraplegia						X	
Bladder dysfunction							
No	X						
Yes							X

within the diving depth range 0–40 m [31]. Our data would show that age ≥42 and depth ≥39 m are also associated with the development of sequelae, although the increased risk has been assessed as weak in both cases.

Some symptoms such as bladder dysfunction and the persistence or worsening of signs before reaching the chamber seem to have a greater prognostic value. Therefore, it comes as no surprise that the Boussuges severity score, which integrates these two clinical elements, is also associated with a poorer recovery when it exceeds the threshold value of 7. Other surveys, using clinical scores other than the Boussuges score, also connect the initial clinical signs of neurological DCS to the long-term result, and confirm the idea that persistent or worsening objective symptoms on admission represent a bad prognosis factor [10, 14, 19, 20]. Using a clinical score on admission seems interesting [32] and our survey confirms that the Boussuges score can be used for the prognostic assessment. However, it does not seem appropriate to maintain the "repetitive dive" criterion, which is not statistically related to the occurring of long-term sequelae and, moreover, does not correspond to a clinical criterion. We suggest replacing it with two low-weight criteria: age ≥42 and the presence of back pain. The "age" criterion is indeed found in our multivariate analysis, while the "back pain" criterion seems significant in the univariate analysis, and it is described as a major symptom in other studies [17, 33]. Although depth >39 m was noted as an independent risk factor, this variable, however, do not correspond to a clinical criterion and was finally not retained in our new scoring system. It also seems relevant to increase bladder dysfunction weight since this factor has the highest OR. Given that bladder dysfunction often appears latently, it seems appropriate to integrate this symptom whenever it appears within the first 12 h. The "motor signs" criterion must be given a lesser weight since the multivariate analysis does not express it and the "hemiplegic disorder" concerning cerebral DCS must be removed from this score, which is specific to spinal cord DCS. Although there seems to be little statistical difference between the new DCS score and the Boussuge score, we consider that the proposed modifications increased the accuracy of the initial clinical assessment of spinal cord DCS on admission. The validation of this modified score must undergo prospective clinical survey.

Our survey does not retain the time to recompression as an independent predictive variable for poor recovery. The literature review on this subject is rather controversial: some authors find no connection between the time to recompression and long-term neurological sequelae, others admit a poorer recovery when the hyperbaric treatment is applied late, i.e., after 12 to 24 h [18–23]. Based on mostly theoretical arguments, certain authors consider that applying an extremely early recompression, i.e., a few minutes, could be favorable [34]. Unfortunately, none of the experimental surveys on animals [35] or the epidemiological surveys conducted on military divers having chambers on the diving site allowed to confirm this statement [16].

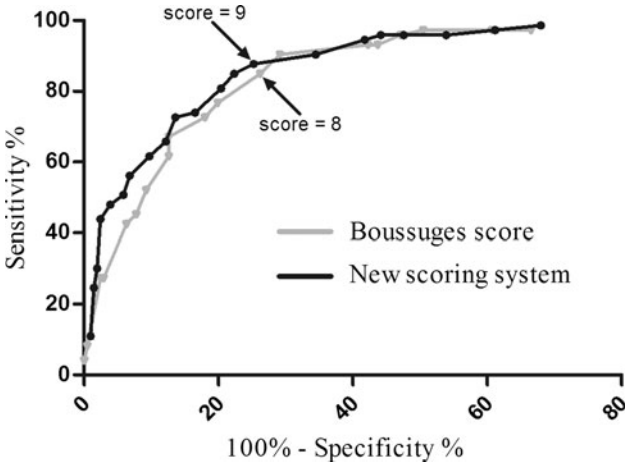

Fig. 1 ROC curves, comparing the new scoring system (in *black*) and Boussuges score (in *gray*)

The last surveys run on major series of DCS divers in Scotland seem to show that the optimal time to recompression should be <6 h [21]. This result is consistent with our series which shows the same threshold value in the univariate analysis.

The initial hyperbaric treatment influence on the long-term clinical recovery is also a controversial subject. Long tables at 2.8 ATA (US Navy Table 6) are the most commonly used procedures in the world for neurological DCS, with a sequelae rate of 20–30% in major series [29, 30]. In France, many hyperbaric centers also use longer and deeper recompression at 4 ATA for this type of DCS (CX 30 table). The efficiency of these tables seems similar to that of the US Table 6 when a nitrox or heliox mixture is used [2]. For Shupak et al., clinical recovery after the first hyperbaric treatment would tend to be better with a heliox CX30 table, compared to a US Navy Table 6, but final outcome at discharge was not different between these two procedures [7]. Several surveys showed also that deeper recompression at 6 ATA, initially completed with air, was not more successful than USN Table 6 [8, 9]. However, the later use of oxygen-enriched mixtures (oxygen–nitrogen) at this depth allowed results to be improved [36]. In a double-blind randomised prospective survey, Drewry and Gorman noted that using a table at 2.8 ATA with a 50% oxygen–50% helium mixture reduced the number of additional HBO sessions compared to an equivalent table with pure oxygen [37]. The literature review shows that it is necessary to integrate both the depth and time of the initial table as well as the applied breathing mixture, where heliox is likely to have specific effects on the kinetics of tissue nitrogen bubble elimination. Indeed, when heliox (50% oxygen and 50% helium) is breathed, previous experiments found that bubbles in adipose tissue and spinal white matter shrink at a rate faster than that seen during 100% oxygen or air breathing at the same pressure [38]. Interestingly, no divers presented sequelae after recompression with heliox tables at 6 ATA in our study. This result merits further consideration in future studies including a larger population of injured divers.

In our survey, all tested tables seem efficient to treat patients with a Boussuges score ≤ 7. The great majority of DCS divers treated with short oxygen tables ≤ 2.8 ATA (used in 62% of the cases in our series) were healed with a recovery rate of 97%. These results are consistent with those of Cianci and Slade, even if the time before the first symptoms and recompression were much longer in this series [39]. In the group of the most severely affected patients on admission (i.e., Boussuges score more than 7), it seems that the DCS deemed most severe were treated with the more aggressive therapy, however, it seems difficult to come to conclusions regarding the choice of initial recompression strategy due to the disparity in table profiles and gas mixtures used by the various centers. Continuing comparative prospective surveys should help defining the significance of deep tables and the use of oxygen–helium mixtures in severe neurological DCS.

In conclusion, the initial clinical assessment of spinal cord DCS upon arrival at the hyperbaric center is critical. The completion of a simple clinical score should make it possible to optimize this approach by identifying symptoms having the greatest prognostic value.

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