Factors influencing the severity of long-term sequelae in fishermen-divers with neurological decompression sickness

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Abstract
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Introduction: Numerous studies have been conducted to identify the factors influencing the short-term prognosis for neurological decompression sickness (DCS). However, the long-term sequelae are rarely assessed. The purpose of this study to investigate the factors likely to influence the long-term prognosis.

Methods: Twenty-seven Vietnamese fishermen-divers who on average 9 (SD 6) years beforehand had presented with neurological DCS and ongoing sequelae, were questioned and examined. The severity of the initial clinical profile was quantified using a severity score. The long-term sequelae were clinically evaluated by looking for a motor or sensory deficit or muscular spasticity, and by applying a severity score for the sequelae which focussed on gait and sphincter disorders.

Results: An initial severity score of ≥ 15 is significantly associated with a risk of serious long-term sequelae [OR = 13.7 (95% CI 2.4 to 79.5)]. Furthermore, certain treatment practices such as in-water recompression to depths > 17 metres' seawater breathing air are significantly associated with more serious sequelae. The practice of intensive non-standardised hyperbaric oxygen sessions over prolonged durations (median 30 days [IQR 19.5]) delayed after the initial accident (median 4 days [IQR 6]) also seems unfavourable.

Conclusion: This study establishes a link between the initial DCS severity and the long-term sequelae causing severe gait disorders and sphincter incontinence. Furthermore, this work suggests that certain detrimental treatment practices should be modified. During this field study, we also found that it was possible to reduce sequelae of these divers by offering them an individual programme of self-rehabilitation.

Introduction

Decompression sickness (DCS) in scuba diving is the consequence of bubbles linked to the presence of dissolved gas, especially nitrogen, in the various tissues of the body during exposure in a hyperbaric atmosphere.[1,2] The neurological form of these diving accidents is common and particularly feared because of its prognosis. The initial clinical profile is polymorphous starting with the presence of subjective neurological signs and moving on to the appearance of signs of motor and sensory deficit that could go as far as tetraplegia. Cognitive disorders are also possible if the brain is affected.[3]

In the past, numerous studies have been conducted with the aim of identifying the factors influencing the short-term prognosis for neurological DCS. The initial clinical presentation before treatment,[4–6] the symptom latency after surfacing[3,7,8] and the time elapsed between the first signs and recompression[9–16] are all factors to be taken into consideration. The severity of the initial clinical impairment seems to be one of the dominant factors in the prognosis and the presence of short-term neurological sequelae after the treatment in hyperbaric centre.[16] However, to date there are no studies considering the long-term sequelae of neurological DCS and, in particular, the factors likely to influence the severity of sequelae over the long term, which should be studied.

For many years an NGO, AFEPS [French-Speaking Association for Mutual Aid and the Promotion of Life Sciences], has organised a programme of humanitarian aid for Vietnamese fishermen-divers in order to prevent and treat DCS.[17] However, not all fishermen have access to this training and the populations of fishermen-divers continue to be affected by many cases of DCS. An assignment devoted to the evaluation and treatment of long-term sequelae from neurological DCS was organised in April 2015 in central

Table 1
Characteristics of the 27 injured divers studied

Characteristics of divers (*n* = 27)	Mean (SD)
Age (years)	38 (8)
Weight (kg)	59.7 (0.6)
Height (cm)	166 (6)
BMI (kg·m^2)	22 (2.5)
Years of diving before the accident	12.7 (7)
Years since the accident	9 (6)

Vietnam, in Quang Ngai province. During this assignment we studied a group of 27 randomly recruited Vietnamese fishermen-divers, by attempting to retrace the clinical history of the initial DCS until the fixation of long-term sequelae.

This work pursued several objectives. Firstly, we questioned the divers about the initial symptoms and the methods of therapeutic management. We then sought to identify the main clinical and functional sequelae responsible for a change in the quality of life of injured divers. Finally, we sought to individualise the factors that could influence the severity of these sequelae in the long term. Ultimately, a self-rehabilitation programme was proposed for each patient, under the guidance of a team made up of French and Vietnamese practitioners, doctors, physiotherapists, occupational therapists, and orthotists. The aim of this programme was to enable former fishermen-divers to regain, over the long term, a certain amount of independence, a place in society and optimum standard of living, particularly due to pain reduction.

Methods

POPULATION STUDIED

The study was approved by the institutional review board of the health department from Qhang Ngai province.

The medical observations for 27 fishermen-divers who presented a neurological DCS (diver characteristics in Table 1) were performed after random recruitment organised by the local people's committees on the island of Ly Son (*n* = 13) and in the village of Binh Chau (*n* = 14). It is a community of fishermen-divers in Central Vietnam, homogeneous both geographically and for lifestyle or diving operating methods. Participation was voluntary without commander involvement, and all provided informed consent prior to participation.

Dives are organised from 10 to 15-metre-long boats, capable of embarking eight to 10 divers, and equipped for open sea navigation (Figure 1). Fishing seasons are mostly spent around the Paracel Archipelago, several days sailing from the Vietnamese coast.

The divers' equipment is rudimentary, with some clothing, a lead belt and, very rarely, a neoprene wetsuit and fins (Figure 2). The water temperature varies from 22 to 30°C, depending on the season. The divers breathe compressed air from a hose placed directly in the mouth (Figure 3). The boat is equipped with a compressor, the drive belt of which is coupled to that of the boat's engine. The compressed air is sent to a small buffer tank from which four 60 to 70-metre hoses exit and are placed in the diver's mouth with a pressure of 6–8 bars.

During these fishing seasons dives are carried out at a depth between 40 and 60 metres' sea water (msw). The diving depth is known through use of a boat depth sounder. The divers carry out two to four dives a day with two to three-hour intervals between each dive. The dive time is in the order of 30 to 40 minutes. The return to the surface takes place slowly, between 10 and 15 minutes. Decompression stops are carried out completely empirically with inadequate depths and durations.

INITIAL CLINICAL PROFILE

All the fishermen-divers presented initial clinical signs suggesting neurological DCS with spinal and/or cerebral topography. The presence of a motor and sensory deficit of the upper and/or lower limbs has been reported in all the study subjects. Back pain that appeared early and of severe intensity occurred in 45% of cases. The appearance of urinary retention was reported in 70% of cases. There was initial loss of consciousness in 27.5% of cases, with spontaneous regaining of consciousness. The initial clinical severity was assessed by a severity score validated for neurological DCS,[6] especially the spinal forms (Table 2). The scores were calculated retrospectively by the investigators based on interviews with the divers. In this study, the calculated score took into consideration the development of symptoms during the six hours after the appearance of the first signs. None of the divers received normobaric oxygen after surfacing, but many divers carried out in-water recompression (breathing air) at variable depths. The final score took into account the evolution of symptoms after in-water recompression.

LONG-TERM SEQUELAE

Long-term sequelae were evaluated clinically by quantifying the extent of the actual deficit (motor and sensory) by an ASIA score,[18] looking for spasticity, tone disorders, the presence of tendon retraction, and by evaluating gait disorders. For these evaluations, the investigating doctors performed neurological exams. Injured divers were also questioned about functional aspects, trying to determine the level of change in the activities of daily life and the extent of sphincter disorders.

The severity of the long-term sequelae was evaluated based on the Rankin score,[18] modified and adapted to the population studied, by taking into account gait disorders and/or sphincter disorders; sequelae that are particularly frequent in divers suffering neurological DCS (Table 3).

Figure 1
Typical boats of the Vietnamese fisherman diver fleet

Figure 3
Diver with air supply hose. Note the lack of a demand valve

Figure 2
Diver about to enter the water. Note the rudimentary equipment and lack of fins

Different clinical factors such as the severity of the initial clinical presentation, the presence of motor and sensory deficits, spasticity, or factors linked to the initial management, such as in-water recompression or delayed hyperbaric oxygen treatment (HBOT) were analysed to study their relationship with the extent of the long-term sequelae.

STATISTICS

The statistical analysis was done with the Sigmastat 3.0 software program (SYSTAT Inc, Richmond CA, USA). Parametric data are presented as mean (standard deviation [SD]) and non-parametric data as median (interquartile range [IQR] or range). Receiver operating characteristic (ROC) curves were used to find the optimal cut-off levels. Chi-square or Fisher tests were used to identify significant predictive variables for intermediate or high grades of long-term sequelae. Additional analysis with the Mann-Whitney U-test or the unpaired *t*-test were also carried out to compare continuous variables. Odds ratios (OR) with 95% confidence intervals (95% CI) were calculated to estimate the relative risks between groups. We also used the Spearman correlation for the initial severity score and the long-term sequelae score. Alpha for statistical significance was set at $P < 0.05$.

Results

DESCRIPTION OF LONG-TERM SEQUELAE

Of the 27 subjects examined, 70.4% exhibited a motor deficit. The deficit remained moderate with an average ASIA score of 91.5/100. Eighty-nine percent of subjects presented a sensory deficit for all modes, with an average ASIA score of 184/224. Muscular spasticity in the lower limbs was objectively present in 52% of subjects. Eighty-nine percent of injured divers had gait disorders to a greater or less extent compatible with proprioceptive ataxia i.e. spinal cord lesions affecting deep sensitivity. Twenty subjects (74%) exhibited gait changes that did not need external aid, but which were augmented when subjects closed their eyes. Seven subjects (26%) exhibited severe gait impairment necessitating external aid, related to the presence of spasticity, hypertonia, tendon retraction or motor and sensory deficit in the lower limbs. Finally, 70% of subjects had urinary sphincter

Table 2
Initial clinical severity scoring system for neurologic DCS

Clinical parameter	Descriptor	Score 0	1	2	3	4	5	6
Age ≥ 42 y	no	*						
	yes		*					
Back pain	no	*						
	yes		*					
Evolution before recompression	better	*						
	stable				*			
	worsen						*	
Sensory deficit	no	*						
	yes					*		
Motor deficit	no	*						
	paresis					*		
	paraplegia						*	
Bladder dysfunction	no	*						
	yes							*

Table 3
Adapted Rankin Score for long-term sequelae for neurologic DCS

Score	Activities of daily life	Gait disorders	Sphincter disorders
1	No limitation, minor symptoms	No alteration at rest, tiredness during physical activities	No
2	Slightly limited, restrictions of certain past activities	Altered, but possible without external assistance	Forced urination possible, partial control of intestinal transit
3	Limited	Limited, but possible with crutches	Partial urinary or anal incontinence
4	Requiring frequent external assistance	Significantly limited, requiring walking frame or external assistance	Permanent urinary or anal incontinence
5	Bedridden, requiring permanent external assistance	Impossible to get out of bed without external assistance	Permanent urinary or anal incontinence requiring external assistance

disorders and 48% anal sphincter disorders, with problems of partial incontinence in the majority of cases.

INITIAL TREATMENT METHODS

Seventy-eight percent of divers underwent early in-water recompression (breathing air) after the appearance of the first symptoms: the injured divers were sent back under the water for a median duration of 50 min (range 10–480) and to a median depth of 20 msw (range 8–50). Thirty-eight percent of divers were sent to a remotely located hyperbaric centre. The median time for access to a hyperbaric centre was four days (range 3 h–30 d). The HBOT sessions were particularly intensive with a median 30 days of HBOT (range 8 d–6 months) with daily sessions lasting 3 h (SD 1.2) on 100% oxygen at 283.6 kPa (2.8 atmospheres absolute [atm abs]). Treatment with rehabilitation, often combined with acupuncture, was only performed in 48% of cases over a period from several weeks to several months after the accident.

FACTORS DETERMINING SEVERITY OF SEQUELAE

Clinical factors

The median modified Rankin score for sequelae was 2 (range 1–4). For the statistical analysis, two groups were distinguished taking into account the extent of the change in activities of daily life and the need for an external aid: intermediate grade sequelae being scores of 1 to 2; high grade sequelae being scores of 3 to 4 (no subjects achieved a score of 5).

Table 4
Clinical parameter association with the severity of long-term sequelae based on the adapted Rankin score (Intermediate grade = scores 1–2; High grade = scores 3–4). Data are number of subjects unless otherwise specified. M-W = Mann-Whitney U test

Clinical parameter	Intermediate *n* = 15	High grade *n* = 12	*P*-value (statistical test)
Initial severity score Median (IQR)	10 (5.7)	16 (1.5)	*P* = 0.023 (M-W)
Initial severity score ≥ 15	4	10	*P* = 0.011 (Chi-square)
Presence of a motor deficit	10	8	*P* = 1 (Fisher)
ASIA motor score Mean (SD)	95.5 (5.4)	92.5 (6.7)	*P* = 0.2 (*t*-test)
Bilateral motor deficit	3	5	*P* = 0.4 (Fisher)
Presence of a sensory deficit	13	11	*P* = 1 (Fisher)
ASIA sensory score Mean (SD)	186.3 (28.6)	189.3 (29.3)	*P* = 0.8 (*t*-test)
Bilateral sensory deficit	7	8	*P* = 0.5 (Fisher)
Presence of spasticity	7	8	*P* = 0.5 (Fisher)
Bilateral Spasticity	2	8	*P* = 0.007 (Fisher)

Table 5
Treatment parameters significantly associated with the severity of long-term sequelae based on the adapted Rankin score (Intermediate grade = scores 1–2; High grade = scores 3–4). M-W = Mann-Whitney U test

Treatment parameter	Intermediate *n* = 15	High grade *n* = 12	*P*-values (statistical test)
In-water recompression (Number of subjects)	9	12	0.02 (Fisher)
Depth (msw) of IWR (Median (IQR))	10 (13.7)	22.5 (16)	0.004 (M-W)
HBOT (Number of subjects)	2	9	0.002 (Fisher)

Table 4 shows the results concerning the association between the various clinical parameters and the severity of the sequelae, split into intermediate and high-grade sequelae.

Furthermore, the presence of a sensory deficit was significantly associated with the presence of proprioceptive ataxia revealed by a gait disorder that was increased when divers closed their eyes ($P = 0.025$, Chi-square test).

An initial clinical severity score of ≥ 15 (threshold identified by ROC analysis) was significantly associated with a risk of serious long-term sequelae (OR 13.7 [95% CI 2.4 to 79.5]). We also found a positive correlation (Spearman correlation coefficient 0.4, $P = 0.02$) between the initial severity score and the long-term sequelae score (Figure 4).

Factors linked to the initial treatment

Table 5 shows the analysis of the association between the different methods of treating the initial DCS and the severity of the sequelae. With an ROC analysis, we identified that an in-water recompression depth threshold of ≥ 17 msw was significantly associated with a higher number of high grade long-term sequelae (OR 20 [95% CI 3.3 to 120.3]). A higher number of serious long-term sequelae for subjects who received HBOT was found (OR 19.5 (95% CI 3.2 to 117.6); HBOT sessions over prolonged periods greater than or equal to 30 days were performed in 72.7% of the cases.

Furthermore, the data given in Table 6 shows the absence of a significant relationship between the severity of the initial clinical profile and the performance of recompression in water or HBOT sessions (Table 6).

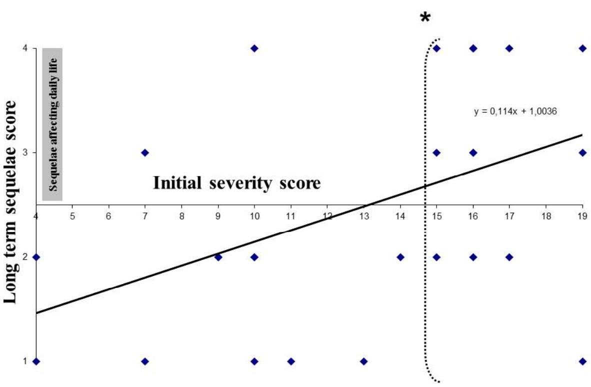
Discussion

Due to the use of specific scores this study has made it possible to establish a link between the initial clinical presentation and the severity of the long-term neurological sequelae. The score for the initial clinical profile has been validated in the framework of a multi-centre study.[6] That study showed that patients with an initial severity score higher than eight presented a higher risk of neurological sequelae at one month (positive predictive value of 87%). However, only the presence or absence of sequelae were considered without quantification of the impairment. On the other hand, clinical recovery was taken into account at one month after the accident without necessarily assessing the level of the impairment at one year or more. So, the present study using a ROC analysis is the first to demonstrate a significant link between an initial clinical score higher than 15 and the risk of developing sequelae with a major effect on the patient's quality of life several years after the accident. According to the Rankin classification we used and adapted for the sequelae observed in the divers, the main sequelae affecting the daily life of the divers are the loss of independence in walking with the need to use a technical

Table 6
Relation between the initial severity score and the number of subjects receiving in-water recompression and hyperbaric oxygen treatment

Treatment parameter	Score < 15 *n* = 13	Score ≥ 15 *n* = 14	*P*-value
Number receiving in-water recompression *n* (%)	8 (61.5)	13 (92.8)	*P* = 0.08
Number receiving HBOT *n* (%)	4 (30.7)	7 (50.0%)	*P* = 0.53

Figure 4
Relationship between the initial severity score and the long-term sequelae score. There is a positive correlation between initial severity score (especially when greater than or equal to 15) and a risk of severe sequelae affecting daily life (score > 2), especially when the **P* < 0.05



aid (crutches or walking frame), recurrent pain in the lower limbs and back, and the problems of urinary and faecal incontinence.

For gait disorders we have shown that these were mainly linked to proprioceptive ataxia of variable extent observed in 89% of cases, and routinely associated with the presence of a deficit in the deep sensitivity of the lower limbs. For subjects with severe gait disorders requiring an external aid we observed that the change in gait did not seem to be influenced by the extent of the motor and/or sensory deficit, moderate in most cases, but rather by the presence of lower limb spasticity, particularly when this was bilateral.

We have been able to put in place a rehabilitation programme targeted at gait disorders and improvement in living standards: pain reduction, increase in joint suppleness and amplitude, stabilisation of deformations, etc. For subjects who retained some independence in walking (*n* = 20), the programme included learning specific exercises, in the form of laminated sheets with demonstration photos and explanation translated into Vietnamese. The exercises involved muscle strengthening and stretching, and exercises for proprioception and posture. Collective learning sessions were organised as well as individual sessions, depending on the specific needs of each patient.

For the most severely affected fishermen-divers with major limitations in walking (*n* = 7), treatment was concentrated on the use of and training in distributed technical aids (walking frame, crutches). Exercises for rebalancing the pelvis, lumbar relaxation and active or passive mobilisation of the lower limbs, associated with specific muscle strengthening, have been proposed. Finally, the advice of an occupational therapy specialist has made it possible to promote lifestyle and living environment and optimisation of movements in particular.

An important aspect of this study concerns the assessment of the traditional practice of in-water recompression on air after the appearance of the first symptoms of DCS. The practice of recompression is quite frequent in the communities of fishermen-divers in emerging countries, which do not have hyperbaric installations. However, the non-standardised practice of in-water recompression is debatable, because a number of complications are possible like drowning, hypothermia or dehydration, and also its efficacy is difficult to establish if there is no reproducible, uniform protocol.[19–21] Although some studies performed in different isolated communities of fishermen-divers are in favour of in-water recompression,[22,23] the results of our study demonstrate a factor that aggravates and increases the risks of long-term neurological sequelae. In fact, the practice of recompression in very deep water breathing air over a long duration contributes to an increase in dissolved gas (nitrogen) and the formation of bubbles during decompression. Our study shows a significant relationship between the in-water recompression depth and the severity of the long-term neurological sequelae. The number of high-grade sequelae is greater for recompression depths ≥ 17 msw.

These results are consistent with the prevention programme initiated several years ago in these fishermen-diver communities, proposing to perform in-water recompressions with oxygen breathing at a shallow depth instead of deep air recompressions for neurological DCS.[17,19,24]

An unexpected result concerns the practice of HBOT sessions. Our study seems to show a potentially detrimental effect of these HBOT sessions if they are delayed after the initial accident (median time to HBOT of 4 ± 6 days), without a standardised protocol. In fact, a higher number of serious long-term sequelae for subjects who received HBOT are observed, and this result seems minimally influenced by the degree of severity in the initial clinical profile. There are very few studies, which have evaluated the efficacy of HBOT sessions performed late after a DCS (median four days in our study). Some studies seem inclined towards a worse clinical recovery when the delay is more than 24 hours.[10–12,14] However, other studies show a definite benefit in performing late recompressions after more than 48 hours.[25–27] In these studies the HBOT was short with an average total number of one to two sessions,[25,26] or more if residual symptoms existed.[27] It involved a majority of Type 2 accidents with about only 20% to 40% of severe forms and a cure rate greater than 60%. Thus, it is difficult to compare these results with our series, which only concerns neurological DCS with high initial clinical severity and sequelae. However, the benefit of repeated HBOT sessions over an extended period may be questioned. In our study the HBOT was continued over prolonged periods greater than or equal to 30 days in 72.7% of the cases with daily sessions of 3 ± 1.2 hours with 100% O_2 at 2.8 atm abs. This intense, prolonged practice does not correspond to western standards, which generally recommend no more than ten additional HBOT sessions after DCS, with the implementation of early rehabilitation by physiotherapy. In our study the repeated sessions probably caused tiredness and lower efficacy of rehabilitation, often considered to be optional or forgotten.

Seriously injured fishermen-divers should be subjected to an early, adapted rehabilitation programme with physiotherapy and occupational therapy. We think that it is also possible to improve the sequelae of DCS in these patients later by offering them a personalised programme of self-rehabilitation. To be effective this programme should target exercises adapted to each subject by combining muscle strengthening and stretching with proprioception exercises.

We acknowledge that the results should be interpreted with caution. Indeed, the number of subjects included is small and does not allow for a multivariate analysis. Moreover, it is a retrospective study, which consequently may be a source of selection bias. The in-water recompression depths and times were obtained by interviewing the divers and thus subject to memory error. Because the outcome of serious DCS is highly variable even in the absence of treatment, it is possible there is a significant population of previously injured divers who resolved completely, which were not captured by this study. We hope that the analysis performed on two different sites, using standardised clinical scores has reduced these potential biases a little.

Conclusion

For the first time this study has made it possible to establish a link between the initial DCS clinical severity and the presence of long-term neurological sequelae, which have an impact on the patients' quality of life. The most frequent long-term sequelae are gait disorders related to proprioceptive ataxia. The change in the quality of daily life is linked to the presence of urinary or faecal incontinence and severe walking impairment often linked to bilateral spasticity.

Furthermore, our study suggests changing certain practices, which could aggravate the prognosis for these diving accidents, in early and later treatment. We support the firm and definitive abandonment of deep in-water recompressions in favour of shallow in-water recompressions with oxygen.[17,20,21]

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