Review articles

Evidence-based guidelines for long-term care in spinal cord-related decompression illness

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Abstract
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Introduction: The aim of this review was to synthesise current knowledge and propose structured evidence-based recommendations for long-term care of individuals with spinal cord decompression illness (scDCI) drawing on experience from French clinical settings and the international literature.
Methods: We conducted a systematic search of international and French guidelines for decompression illness (DCI) and spinal cord injury (SCI), including systematic reviews and consensus statements. Additional literature searches were performed in PubMed Central® (1996–2025) to identify evidence relevant to long-term care. Key domains were predefined based on SCI guidelines: lower urinary tract and gastrointestinal function, thromboembolic, autonomic dysreflexia, pulmonary function, pain, and spasticity.
Results: Our findings confirmed the absence of specific long-term follow-up protocols for scDCI. Evidence from SCI guidelines was therefore adapted to this population. We propose structured, evidence-based recommendations that include systematic neurological and urological screening even in apparently recovered patients and risk-adapted follow-up during the first two years.
Conclusions: Long-term outcomes after scDCI remain poorly defined, but sequelae are frequent and may be underdiagnosed. Structured follow-up based on adapted SCI guidelines may improve prognosis, harmonise care, and generate robust data for future prospective studies.

Introduction

Decompression illness (DCI) refers to a group of clinical syndromes caused by the pathophysiological response to the formation of gas bubbles within the body following a decrease in ambient pressure. In diving, DCI occurs when inert gas, primarily nitrogen, dissolved in tissues and blood under pressure forms bubbles during ascent. These bubbles trigger a complex cascade of pathophysiological responses that may affect multiple organ systems. Clinical manifestations range from mild symptoms such as skin itching or joint pain to severe neurological impairment, cardiovascular instability, or even death. The incidence of DCI varies across diving populations, ranging from 1 to 4 per 10,000 person-dives for recreational diving. Among severe cases, neurological symptoms are predominant, affecting up to 50% of individuals, with clinical features often consistent with spinal cord injury (SCI). Spinal cord decompression illness (scDCI) is thought to result from a combination of these mechanisms, including extravascular bubble formation in the spinal white matter and venous or arteriolar gas embolism, leading to spinal ischaemia or infarction.[1,2] Intravascular bubbles can obstruct vessels and activate coagulation pathways through platelet aggregation, leukocyte activation, and fibrin deposition. Concurrently, endothelial injury increases capillary permeability, exacerbating oedema and ischaemia. Once activated, inflammatory and coagulation cascades persist even after bubble resolution, which may explain why recompression therapy is not immediately and uniformly effective.

Prognosis is primarily determined by initial clinical severity, the time to recompression and early neurologic deterioration within the first 24 hours.[3] Nevertheless, despite timely hyperbaric treatment, studies report persistent sequelae in 20–30% of individuals at one month, primarily involving sensorimotor deficit and bladder dysfunction.[4] Given the specific pathophysiological consequences of scDCI, early prevention of secondary complications, particularly neurogenic bladder dysfunction, is essential to minimise long-term morbidity and mortality.[5]

To our knowledge, no prospective long-term study has systematically evaluated the outcomes of scDCI. As a result, follow-up strategies remain heterogeneous, and late complications may be under-recognised. The aim of this work was to conduct a systematic search of the literature and existing guidelines to propose evidence-based recommendations for long-term follow-up in this population.

Methods

RECOMMENDATIONS FOR DCI

We searched for international guidelines regarding post-acute care after diving-related DCI.

To identify relevant recommendations, we searched for publications from January 1996 to July 2025 in the PubMed Central® database using the keywords: "*scuba diving*", "*decompression sickness OR decompression illness*", and "*recommendation OR guideline*".

Inclusion criteria were: (1) evidence-based recommendations or clinical guidelines; (2) specific relevance to decompression illness; (3) applicability to long-term care; and (4) focus on spinal cord involvement.

RECOMMENDATIONS FOR SCI

We searched for both international and French recommendations about the long-term follow-up of individuals with SCI, unrelated to diving or DCI.

To identify updates, we performed a systematic search of the literature using the PubMed Central® database from January 2015 to July 2025. The following keywords were used: "*spinal cord injury*", "*recommendation OR guideline*", and "*long-term*".

Inclusion criteria were: (1) evidence-based recommendations or clinical guidelines; (2) relevance to acquired SCI; (3) general recommendations covering main secondary health conditions of people with SCI; and (4) applicability to long-term care.

When necessary, targeted searches were then undertaken on specific topics, for instance, the recommended minimum duration of hospitalisation following an episode of DCI or the post-void residual volume threshold prompting intermittent catheterisation in a neurogenic bladder.

EVIDENCE-BASED RECOMMENDATIONS

Based on the collected data, we proposed evidence-based recommendations for the long-term follow-up of individuals with scDCI.

To individualise post-discharge care, patients were stratified into two groups: those with full recovery or isolated sensory deficit at discharge, in whom follow-up aims to detect subtle or delayed impairments, and those with persistent motor deficit or neurogenic bladder dysfunction, for whom follow-up focuses on monitoring and preventing secondary complications associated with SCI.

A large language model was used to enhance readability and language during manuscript preparation. All authors reviewed, revised, and take full responsibility for the final content.

Results

RESULTS OF THE SYSTEMATIC SEARCH

The article selection process is summarised in the PRISMA flow diagrams, including the reasons for exclusion of articles.[6]

DCI recommendations

Reference documents included the clinical practice guidelines of the Undersea and Hyperbaric Medical Society (UHMS) and the 1996 European consensus statement on diving-related injuries. The UHMS clinical practice guidelines do not address post-acute care for scDCI.[7] The 1996 European consensus provides limited guidance, recommending at least two years of clinical follow-up for spinal cord-injured divers, without further specification.[8]

Our literature search on follow-up care in DCI identified 53 articles as of July 15, 2025; none met the inclusion criteria after title and abstract screening (Figure1).

SCI recommendations

Reference documents included French national recommendations for the long-term management of individuals with SCI published by the *Haute Autorité de Santé* in 2007 based on the Consortium of Spinal Cord Medicine guidelines published by the Paralyzed Veterans of America between 1999 and 2006.[5] In line with these recommendations, we then chose to focus on seven key areas: lower urinary tract function, gastrointestinal function, thromboembolic complications, autonomic dysreflexia, pulmonary function, pain and spasticity.

Our supplementary literature search on follow-up care for individuals with SCI yielded 173 articles as of July 15, 2025.

Figure 1

PRISMA flow diagram for our literature search on follow-up care in spinal cord decompression illness; no references were found using alternative methods

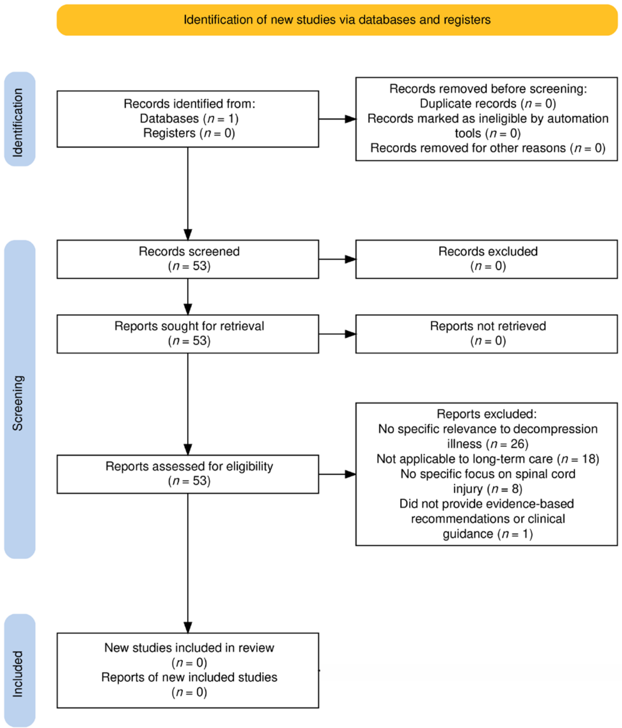
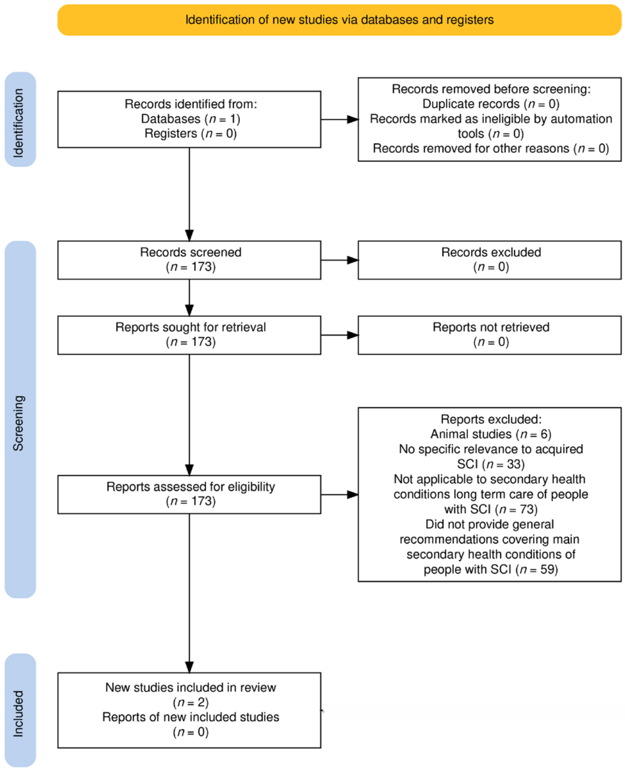


Figure 2

PRISMA flow diagram for our literature search on recommendations and guidelines for general long-term care in spinal cord injury; no references were found using alternative methods



Based on title and abstract screening, only two articles met the inclusion criteria (Figure 2).[9,10]

PROPOSAL FOR EVIDENCE-BASED RECOMMENDATIONS AFTER SCDCI

The proposed follow-up protocol is summarised in Tables 1 and 2.

Day 0 (admission) to discharge management

Before emergency recompression therapy the following should occur.

1. Neurological assessment: SCI is characterised by the neurological level of injury, the lowest segment with preserved motor and sensory function, and by its completeness. Neurological and functional status should be classified according to the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI), including the ASIA Impairment Scale (AIS), which ranges from grade A (complete injury) to grade E (normal function). This scale is the international gold standard for SCI assessment and strongly predicts outcome, with grade A injuries rarely and grade D injuries commonly regaining independent ambulation at one year.[11]

2. Lower urinary tract assessment: In the acute phase, spinal shock is associated with a high risk of urinary retention, often due to detrusor areflexia or hypocontractility. The duration of spinal shock can vary from a few days to several months, as observed in traumatic SCI, though its course remains undocumented in DCI-related cases.[12] In 2025, international consensus has defined a 150 mL post-void residual volume threshold for initiating intermittent catheterisation in individuals with neurogenic bladder dysfunction, based on associated risks of urinary tract infections, bladder stone formation and upper urinary tract deterioration.[13]

For practical guidance, we propose:

- A spontaneous void attempted prior to hyperbaric chamber entry, with immediate post-void residual volume assessment using ultrasound.
- In cases of acute urinary retention, defined as the inability to void despite a full bladder, or elevated post-void residual volume (> 150 ml), external bladder drainage using indwelling catheterisation is recommended before entering the hyperbaric chamber. The catheter should then be removed as soon as clinically feasible and, if spontaneous voiding does not resume, replaced by intermittent catheterisation.

3. Prognosis scoring: Prognosis is primarily driven by initial clinical severity, time to recompression and the

occurrence of neurological deterioration within the first 24 hours following the accident.[3] Initial severity can be assessed using the MedSubHyp score, developed by the Société de Médecine et de Physiologie Subaquatiques et Hyperbares (MedSubHyp). This score is based on the following parameters: age > 42 (0 or 1); back pain (0 or 1); clinical course before recompression (better = 0; stable = 3; worse = 5); objective sensory deficit (0 or 4); motor impairment (none = 0; paresis = 4; paraplegia = 5) and neurogenic bladder dysfunction (0 or 6). The total score ranges from 0 to 22, with higher scores (≥ 6) associated with significantly worse neurological outcomes at discharge.[14]

After emergency recompression therapy the following should occur.

1. Surveillance: In cases of incomplete recovery after initial recompression, additional hyperbaric sessions may be considered, as this phase may coincide with peak post-ischaemic inflammatory processes.[3]

For practical guidance, we propose:

- » Even in cases of apparent full recovery, a minimum of 48–72 hours hospitalisation to monitor for potential secondary deterioration, which may necessitate additional hyperbaric treatment.
- » In symptomatic individuals, length of stay should be determined by clinical evolution and therapeutic requirements.

2. Diving-specific considerations – screening for right-to-left shunt: According to recent South Pacific Underwater Medicine Society (SPUMS) and the United Kingdom Diving Medical Committee (UKDMC) guidelines, screening for a right-to-left shunt is recommended in cases of DCI with cerebral, spinal, vestibulocochlear, cardiovascular and cutaneous manifestations.[15]

For practical guidance, we propose:

- » Screening for right-to-left shunt when clinically feasible using either transcranial Doppler ultrasound or trans-thoracic echocardiogram, depending on local expertise and equipment availability, with bubble contrast techniques and use of provocation manoeuvres (Vasalva and sniffing test).

3. Imaging strategy in early management: In scDCI, lesions revealed by magnetic resonance imaging (MRI) usually correlate with clinical findings, but a normal MRI does not exclude the diagnosis. Clinical-radiological dissociation is recognised in scDCI. While MRI has limited sensitivity, acute findings may inform prognosis: haemorrhage predicts poorer outcome, whereas oedema or normal imaging are generally associated with better recovery, although sequelae remain possible (negative predictive value ~77%). MRI also identifies compressive factors, such as cervical spondylosis, that may predispose to severe scDCI.[16]

For practical guidance, we propose:

- » Spinal MRI may be performed after emergency recompression therapy, within the first days following the accident, to assist in prognostic evaluation.

4. Lower urinary tract management: All individuals with SCI remain at risk for neurogenic bladder dysfunction, including those with apparent recovery, as bladder dynamics may change over time. With the return of spinal reflexes, detrusor overactivity and detrusor-sphincter dyssynergia may develop, leading to incomplete emptying, elevated voiding pressures and potential upper urinary tract deterioration if untreated.[17] In traumatic SCI, up to 50% of individuals who initially void with low-pressure storage and adequate emptying later develop neurogenic bladder dysfunction requiring changes in management.[18] Urinary symptoms should be actively assessed at discharge, for example using the validated Urinary Symptom Profile questionnaire.[19]

For all individuals, the following should be performed:

- » If acute urinary retention initially requires an indwelling catheter, it should be removed as soon as medical stabilisation allows (within 48–72 hours), and replaced with intermittent catheterisation if needed, which significantly reduces the risk of complications (e.g., infections, bladder stones, urethral damage). Long-term use of an indwelling catheter should be strictly avoided at all stages following SCI.
- » Screening for signs of overactive bladder (urgency and urinary urgency incontinence), combined with daily post-void residual volume assessment using ultrasound to identify significant urinary retention should be performed. An average post-void residual volume > 150 mL should prompt the initiation of intermittent catheterisation, along with a therapeutic educational program to support patient training in self-catheterisation.
- » If neurogenic bladder is suspected (urgency, urinary urgency incontinence, voiding difficulties): renal function should be assessed through blood testing to estimate the glomerular filtration rate, as well as bladder and kidney imaging, including ultrasound measurement of post-void residual volume.

5. Gastrointestinal management: Neurogenic bowel dysfunction is a common and burdensome consequence of SCI, significantly affecting psychological well-being and social participation. If inadequately managed, it may lead to serious complications. Constipation is the most frequent symptom, reported in up to 95% of individuals with complete SCI. Pharmacological management includes several options, such as osmotic agents, bulk-forming agents, oral laxatives, prokinetics, and rectal therapies including

suppositories, but no treatment has demonstrated clear superiority. Management therefore relies on individualised bowel programmes tailored to the person's autonomy and preferences, as rigid protocols are rarely appropriate.[20]

6. Venous thromboembolism complications: Venous thromboembolism is a serious complication of SCI that may go unnoticed due to limb swelling and sensory impairment. Early thromboprophylaxis is therefore crucial to minimise morbidity and mortality.[21]

For practical guidance, for all individuals with lower limb motor dysfunction, the following should be performed:

» If walking dysfunction persists after emergency recompression therapy, anticoagulant thromboprophylaxis should be initiated once the patient is clinically stabilised and continued for 8–12 weeks in combination with mechanical compression methods (e.g., compression stockings). However, treatment may be discontinued earlier if ambulation improves before this period.

7. Autonomic complications in high spinal cord injuries: In individuals with SCI at or above T6, loss of sympathetic control may result in autonomic instability, affecting cardiovascular responses and catecholamine regulation. Autonomic dysreflexia, triggered by stimuli below the level of injury, is defined as a systolic blood pressure increase > 20 mmHg above baseline and may present with headache, flushing, sweating above the lesion, nasal congestion, or arrhythmia; and can be life-threatening.[22]

For practical guidance, for all individuals with lesions at or above T6, the following should be performed:

» Baseline electrocardiogram.
» Orthostatic hypotension test when clinically feasible.
» If autonomic dysreflexia or cardiac dysfunction is suspected: blood tests including B-type natriuretic peptide, troponin, lipid profile, and echocardiography.

8. Respiratory complications in high spinal cord injuries: Pulmonary complications are the leading cause of death within the first year following SCI. The degree of respiratory dysfunction following SCI depends on the neurological level, severity (AIS grade), and resulting impairment of ventilatory effort and cough effectiveness, increasing the risk of respiratory complications such as pneumonia, atelectasis, pleural effusion, sleep-disordered breathing, and dyspnoea.[23]

For practical guidance, for all individuals with lesions at or above T8 with motor deficit, the following should be performed:

» Pulmonary function tests within the first month.
» Morning arterial blood gas testing and polysomnography within the first month.

Discharge to two-years follow-up

According to recommendations in SCI guidelines and to the European consensus on the management of recreational diving accidents, clinical follow-up should continue for a minimum of two years post-injury.[8]

1. Return to scuba-diving: Current guidance on resuming diving after DCI is based primarily on expert consensus and policies issued by major organisations (e.g., US Navy, Diving Medical Advisory Committee [DMAC], UHMS), rather than on robust scientific evidence. Among these, the MedSubHyp society proposes the following minimum intervals before return to diving:

» For individuals with isolated sensory deficit that resolves completely after recompression therapy: Three months.
» For individuals with bladder or motor dysfunction with full recovery after recompression therapy: Six months.
» For individuals with neurological sequelae, except for isolated superficial sensory deficit, return to diving is not recommended.

In all circumstances, clearance to resume diving should be provided by a physician experienced in diving and hyperbaric medicine, considering individual risk factors such as recurrent DCI or the presence of a right-to-left shunt.

2. Rehabilitation program: The need for a rehabilitation program depends on the presence and severity of sequelae.

For practical guidance, we propose:

» Individuals with no residual deficit (AIS E) may be discharged without a structured rehabilitation program.
» Referring individuals with persistent neurological deficits (AIS grades D to A) to a Physical and Rehabilitation Medicine physician to establish a rehabilitation program – either inpatient, day-hospital-based, or outpatient physiotherapy, depending on functional independence at discharge.

3. Neuropathic pain: Pain is a major contributor to functional limitation in individuals with SCI, with a reported prevalence of 60–70% in traumatic SCI. The 2021 CanPainSCI Clinical Practice Guidelines formalised a series of recommendations for the management of neuropathic pain after SCI.[24]

For practical guidance, the following should be performed:

» Use of a validated questionnaire for neuropathic pain screening (as for example the DN4 questionnaire).
» Encourage the use of self-management strategies that help reduce pain intensity, improve function, and address sleep, mood, or activity-related pain exacerbation.
» First-line treatment: Pregabalin is the preferred option, supported by the strongest evidence for below-level neuropathic pain. Gabapentin is a recommended

alternative if pregabalin is contraindicated or ineffective.

» In cases of treatment resistance, individuals should be referred to a specialised interdisciplinary pain management center.

4. Spasticity: Spasticity is a frequent complication of SCI, presenting with increased tone and exaggerated reflexes due to impaired sensorimotor control. Treatment includes medication, physical measures and, in selected cases, surgery.[25]

For practical guidance:

» Given its complexity and functional implications, spasticity management should be initiated and supervised by a physical and rehabilitation medicine physician.

5. Follow-up spinal MRI at 3–6 months: Follow-up spinal MRIs are recommended for all individuals, including those with a normal initial imaging and complete neurological recovery, to screen for delayed-onset spinal lesions.

6. Individualised clinical follow-up: To individualise post-discharge care, we have stratified patients into two groups; those with full recovery or isolated sensory deficit at discharge, in whom follow-up aims to detect subtle or delayed impairments, and those with persistent motor deficit or neurogenic bladder dysfunction, for whom follow-up focuses on monitoring and preventing secondary complications associated with spinal cord injury.

For individuals with full clinical recovery or isolated sensory deficit at discharge, we propose (Table 1):

» Follow-up at six, 12 and 24 months post-injury with a physician experienced in diving and hyperbaric medicine. Each visit should include a full neurological examination, screening for neurogenic bladder dysfunction (using the Urinary Symptom Profile questionnaire), and bladder ultrasound with post-void residual measurement, with uroflowmetry where available.

» If clinical examination is entirely normal, with a Urinary Symptom Profile score of 0, normal spinal MRI, and normal renal and bladder ultrasound ± uroflowmetry, follow-up may be discontinued after the 24-month visit.

» At any time, the emergence of symptoms such as spasticity, neurogenic bladder dysfunction or motor deficit should prompt management according to the symptomatic care pathway.

For individuals with persistent neurogenic bladder dysfunction or motor deficit at discharge, we propose (Table 2):

» Coordinated follow-up with a Physical and Rehabilitation Medicine physician at one month, every three months during the first year and then at least annually.

Table 1

Proposed follow-up schedule for individuals with full clinical recovery or isolated sensory deficit at discharge; items that are shaded in gray are not mandatory and recommended assessments are indicated by an 'X'. DN4 – Douleur Neuropathique 4 (questionnaire); MRI – magnetic resonance imaging; N/A – not applicable; PVR– post-void residual; R-L – right-to-Left; USP – urinary symptom profile

Consideration	Admission to discharge	3 months	6 months	12 months	24 months
Diving and hyperbaric medicine physician follow-up	N/A	If return to diving considered	X	X	X
Screening for R-L shunt	If indicated, e.g., to inform return to diving decision				
Return to diving	Contraindicated	Clearance to resume diving provided by a physician experienced in diving and hyperbaric medicine			
Spinal MRI	X	X			
Lower urinary tract assessment	Daily PVR measurement				
	USP questionnaire		X	X	X
	Renal-bladder imaging with PVR measurement ± uroflowmetry		X	X	X
In cases of neuropathic pain	DN4 questionnaire	First-line treatment: pregabalin / gabapentin Or refer to interdisciplinary pain management centre			

Table 2

Proposed follow-up schedule for individuals with neurogenic bladder dysfunction or motor deficit at discharge; items that are shaded in gray are not mandatory and recommended assessments are indicated by an 'X'. ABG – arterial blood gas; BNP – B-type natriuretic peptide; CI – contraindication; ECG – electrocardiogram; eGFR – estimated glomerular filtration rate; MRI – magnetic resonance imaging; N/A – not applicable; PRM – physical and rehabilitation medicine; PVR – post-void residual; R-L – right-to-left

Consideration		Admission to discharge	1 month	3 months	6 months	9 months	12 months	24 months
PRM physician Follow-up		N/A	X	X	X	X	X	X
Screening for RLS		If indicated						
Return to diving		Contraindicated			Clearance to resume diving provided by a physician experienced in diving and hyperbaric medicine			
Spinal cord	Spinal MRI			X			X	X
Neurogenic bladder dysfunction	eGFR				X		X	X
	Renal-bladder imaging with PVR measurement				X		X	X
	Urodynamic testing		X		X		X	Every six months
Cardio-vascular function if lesion ≥ T6	ECG		If needed (e.g., autonomic complications)					
	Screening for autonomic complications		If needed: blood testing with BNP, troponin, lipid panel + echocardiography may be useful					
Respiratory function if motor deficit ≥ T8	Chest X-ray		If needed					
	Morning ABG testing		X				X	X
	Pulmonary function tests		X				X	X
	Polysomnography		X	Depending on initial evaluation				

» Complete neuro-urological evaluation every six months for the first two years, then adapted based on individual uro-nephrological risk.
» Screening for autonomic complications for individuals with a neurological level of injury at or above T6.
» Annual respiratory assessment for individuals with a neurological level of injury at or above T8.

Discussion

Changes in diver demographics, including older age, less experience, and a higher prevalence of comorbidities, likely contribute to a greater risk of severe outcomes.[26] In parallel, the rise of technical diving, involving greater depths, longer bottom times, and the use of mixed gas, has also been associated with more complex and severe cases of DCI, as supported by recent epidemiological data.[27] Despite advances in acute management, including early recompression protocols and wider access to hyperbaric facilities, long-term follow-up remains poorly standardised. Moreover, recent studies have raised concern over the potential for delayed neurological sequelae in individuals initially classified as having "*non-neurological*" DCI, thus challenging the conventional dichotomy between "*neurological*" and "*non-neurological*" forms.[28] The absence of specific guidance for post-acute management of scDCI underscores the need for a coordinated long-term follow-up strategy. This study aimed to propose structured, evidence-based recommendations drawing on international and national SCI recommendations as well as diving medicine consensus statements, to address the dual specificity of this population: individuals with SCI resulting from diving-related DCI. Beyond improving clinical care, such an approach may also facilitate harmonised data collection and contribute to a clearer understanding of recovery trajectories.

Conclusions

Spinal cord DCI remains a complex condition, with limited data available on its long-term outcomes. While acute management is well established, post-acute care lacks standardised protocols, and delayed complications may be underdiagnosed or insufficiently addressed. This work proposes structured, evidence-based recommendations for long-term care, aiming to improve early detection of sequelae and optimise patient outcomes. Standardising follow-up may also support consistent data collection and contribute to a better understanding of the condition's natural history. Further prospective studies are needed to validate this follow-up strategy and inform future recommendations.

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