REVIEW ARTICLE

Delayed Treatment of Decompression Sickness with Short, No-Air-Break Tables: Review of 140 Cases

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Introduction: Most cases of decompression sickness (DCS) in the U.S. are treated with hyperbaric oxygen using U.S. Navy Treatment Tables 5 and 6, although detailed analysis shows that those tables were based on limited data. We reviewed the development of these protocols and offer an alternative treatment table more suitable for monoplace chambers that has proven effective in the treatment of DCS in patients presenting to our facility. ***Methods:*** We reviewed the outcomes for 140 cases of DCS in civilian divers treated with the shorter tables at our facility from January 1983 through December 2002. ***Results:*** Onset of symptoms averaged 9.3 h after surfacing. At presentation, 44% of the patients demonstrated mental aberration. The average delay from onset of symptoms to treatment was 93.5 h; median delay was 48 h. Complete recovery in the total group of 140 patients was 87%. When 30 patients with low probability of DCS were excluded, the recovery rate was 98%. All patients with cerebral symptoms recovered. Patients with the highest severity scores showed a high rate of complete recovery (97.5%). ***Discussion:*** Short oxygen treatment tables as originally described by Hart are effective in the treatment of DCS, even with long delays to definitive recompression that often occur among civilian divers presenting to a major Divers Alert Network referral center.

Keywords: decompression sickness, short oxygen treatment tables.

THE STANDARD TREATMENT for decompression sickness (DCS) in divers is hyperbaric oxygen. In the United States, such cases are generally treated using U.S. Navy (USN) Treatment Tables 5 and 6, which were developed in the late 1960s for use in multiplace chambers. Detailed review of the development process indicates that they were based on a limited number of cases and contain a number of paradoxical features. Reported outcomes of therapy using USN Treatment Tables 5 and 6 have varied widely. More recently, some treatment centers have used shorter tables suitable for monoplace chambers.

USN Treatment Table 6 has been the standard of care in most of the diving community since its promulgation by the U.S. Navy in August 1967, yet few practitioners are aware of the factors relating to its development. Based on the work of Behnke and Shaw in 1937 (3) and a later report by Yarborough and Behnke (30), the U.S. Navy undertook a retrospective analysis of 79 cases presenting to various USN recompression facilities in 1963 and 1964 using short O_2 tables then in development (9). This action was prompted by a high degree of failure with the USN Tables 3 and 4 in use at that time. Some of these failures were ascribed to the fact that civilian divers were presenting to USN facilities with increasing frequency, often having dived very provocative profiles, many suffering from severe DCS, and with long delays to treatment.

In 1963 and 1964, the Navy Experimental Dive Unit received reports of 133 cases of DCS in which the standard USN tables at the time were used (28). Full relief did not result in 24% of initial recompressions. When outcomes using USN Tables 3 and 4 were analyzed, a 47% incidence of failure of the first treatment was noted. However, there were no instances of treatment failure when DCS had occurred following rigid USN diving protocols.

Noteworthy in the initial report of Goodman and Workman (9) was that of the 79 cases submitted using the shorter O_2 tables, only 50 had adequate documentation to determine speed of relief. Yet these new tables were based on obtaining complete relief within 10 min of pressurization at only 33 ft, which was their initial compression procedure, or at 60 ft, which was recommended later. If relief was obtained within 10 min at 33 ft, the patient was maintained at that depth for 30 min and then brought to the surface at the rate of 1 ft $\cdot$ min^{-1}. If relief was not obtained within 10 min at 33 ft, the patient was compressed to 60 ft and observed. If relief was then not complete at 60 ft within 10 min, a compression to 165 ft was recommended.

An analysis of the data showed that for the shorter, shallower table, total treatment time could vary between 64 and 74 min and, for the deeper 60-ft excursion, between 103 and 112 min. These cases were then subjected to retrospective statistical analysis, and it was determined that depth of treatment and oxygen exposure were the major factors contributing to recovery. Arbitrarily, the U. S. Navy established USN Treatment Tables 5 and 6 by multiplying the minimal adequate treatment protocol (60 ft for 30 min on 100% oxygen with a slow ascent to the surface for a total treatment time of 90 min) by a factor of 1.5 and 3.0, respectively.

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TABLE I. RESULTS OF TREATMENT OF DECOMPRESSION SICKNESS.

	Total (n = 150)	Military (n = 110)	Civilian (n = 40)
Results of First Treatment			
Relief Complete	127 (84.7%)	102 (92.6%)	25 (62.5%)
Relief Substantial	8 (5.3%)	4 (3.7%)	4 (10.0%)
Residual Substantial	5 (3.3%)	0 (0.0%)	5 (12.5%)
Recurrent Symptoms	10 (6.7)	4 (3.7%)	6 (15.0%)
Treated at 33′ only	5 (3.3%)	3 (3.7%)	1 (2.5%)
Failure of Initial Treatment			
Total Cases	23 (15.4%)	8 (7.3%)	15 (27.5%)
Pain Only	4 (17.4%)	3 (37.5%)	1 (6.6%)
Serious Symptoms	29 (82.6%)	5 (62.5%)	14 (93.4%)
Results of Second Treatment			
Relief Complete	134 (89.3%)	106 (96.3%)	28 (70.0%)
Relief Substantial	9 (6.0%)	4 (3.7%)	5 (12.5%)
Residual Substantial	7 (4.7%)	0 (0.0%)	7 (17.5%)
Recurrent Symptoms	0 (0.0%)	0 (0.0%)	0 (0.0%)
Number Re-Treated	10 (6.7%)	4 (3.7%)	6 (15.0%)

Modified from Workman (28), with permission.

Because of the concern for oxygen toxicity, air breaks were added. Thus, USN Table 5 (total time 135 min) and USN Table 6 (total time 285 min) were promulgated to the USN fleet in August 1967.

In 1968 Workman reported on the experience with the new USN tables (28). By now, there were 150 patients in the series: 110 military and 40 civilians. Symptoms appeared within 60 min of surfacing in 66 military divers (60%) and in 36 (96%) of the civilians. Pain-only DCS was suffered by 64% of the military cohort and 15% of the civilians, leaving 36% of the USN divers and 85% of the civilians with more serious signs and symptoms. Of USN divers, 71% were under treatment within 6 h of symptoms, and 50% were treated within 1 h. Only 10% of civilians were treated within 1 h of symptom onset.

Relief of symptoms with the first treatment was noted in 93% of military cases, but in only 62.5% of civilians. With a second treatment, this improved to 96.3% of USN divers and 70% in the civilians. Failure of initial treatment to provide complete relief predominated in the most seriously injured civilian divers and was 93.4% (**Table I**). All of the substantial residuals were in the civilian population. We can infer from these data that USN Tables 5 and 6 were much more effective in the treatment of military divers, who overall were less severely injured and more promptly treated. Civilian cases were more serious, presented for treatment later, and had a less than optimal outcome despite being treated with the longer USN Table 6.

In 1996, Thalmann reported subsequent experience with USN Tables 5 and 6 (25). Pearson and Leitch (23) reported 28 cases with the Royal Navy (RN) equivalent of USN Table 5 (RN Table 61) or 6 (RN Table 62). There were eight failures, six with mild and two with major residual symptoms, for an overall failure rate of 28%. Erde and Edmonds (8) reported on 100 cases of DCS in sport and civilian divers and a success rate of 80% with 20 failures. Of note, there was a significant delay in presentation, but 10 of 11 cases treated after 24 h had "substantial benefit."

Bayne reported on 50 cases of DCS from the USN School of Salvage, of which 92% of treatments began within 2 h of onset (2). Only one case did not obtain complete relief at 60 ft. Kizer reported 157 cases treated by the USN hyperbaric chamber at Pearl Harbor from 1977–1979 (17). Of these cases, 78% were nonmilitary. A total of 58% of patients obtained complete relief, 25% substantial relief, and 17% had significant residual symptoms. In 58 cases of DCS reported by Yap, 50% enjoyed complete relief, with a mean delay to treatment of 48 h (29). All 11 Type I (pain only) cases obtained complete relief or more than 50% recovery, but 3 Type II (neurological) cases showed no response. Gray, reporting on 812 DCS cases treated by the U. S. Navy between 1971 and 1981, showed an 81% chance of complete relief on the first treatment, with an overall final success rate of 94% (10). It was noted that "substantial relief" was a subjective term, which may have meant residual soreness or neurologic deficit. Green et al., showed a 96% overall success rate at the USN Experimental Dive Unit in 208 cases treated between 1976 and 1988 (11). They noticed no difference in efficacy between USN Tables 5 and 6.

Van Hulst analyzed 10 yr of recompression treatments from the Netherlands (26). USN Table 6 was used in 88% of the 65 cases, and complete recovery was obtained in 77% of cases with delays to treatment of less than 12 h and in 43% of cases with delays of 24 h or more. Kovacevic et al. analyzed 154 cases of DCS treated by the Yugoslavian Navy from 1967 to 1988 (20). USN Table 6 was used most of the time. All Type I cases showed complete recovery, but 30 cases of Type II had residual symptoms. Ball (1) published a study in which USN procedures were strictly followed. Of the 49 cases he reported, 67% required re-treatment. A total of 93% of mild cases eventually obtained complete relief regardless of the treatment delay. Only 36% of moderately severe and 8% of severe cases obtained complete relief. In these latter cases the treatment delay was felt to have had a large impact on the outcome. Koch reported 72 cases from Toronto using USN Tables 5, 6, or 6A (19). Most cases were considerably delayed. There were 28 failures in the 40 Type I cases (62%), 12 failures in the 20 Type II cases (60%), and 4 failures in the 7 cases (57%) of arterial gas embolism (AGE).

In his report on USN Tables 5 and 6 (25), Thalmann further commented that "given the slim experimental evidence and the small number of cases in the initial clinical trial, the final success of the USN Minimal-Recompression Oxygen-Breathing Treatment Tables (Tables 5 and 6) could be ascribed to either good fortune or the insight and experience of the investigators. In reality it was probably a combination of both." Thus, in most reports where military and commercial divers are treated promptly, usually at the site of the diving operation, prompt and complete relief is the expected norm. In sport divers, where there often are provocative dive profiles and/or long delays to treatment, either due to ignorance of signs and symptoms or delayed referral or both, outcomes may not be as good. These data are supported by the recent Divers Alert Network report for the year 2005, where only 70% of divers obtained complete relief at discharge and 29.7% had residual symptoms (27).

In 1974 Hart reported a series of cases of DCS and AGE treated with short oxygen tables essentially based on the "minimally adequate" tables described earlier by Goodman and Workman (13). Hart's protocol involved compression to 3.0 ATA for 30 min followed by 60 min at 2.5 ATA and then a slow ascent to the surface:

Hart-Kindwall Protocol

- Descent rate—as quickly as tolerated
- Compress to 26 lb · in^{-2} gauge pressure (2.8 ATA) breathing 100% oxygen for 30 min
- Decompress to 14.7 psig (2.0 ATA) over 30 min
- Maintain 14.7 psig (2.0 ATA) for 60 min
- Decompress to surface over 30 min
- Total elapsed time, not counting descent: 150 min
- Total oxygen dose: 401.7 unit dose pulmonary toxicity (UDPT)

There were 14 cases of DCS in this series. All patients had complete relief with this recompression schedule. In 1986 Hart and colleagues reported their continued experience in 51 patients treated for Type II DCS or AGE and 26 cases of Type I DCS (14). After one or more treatments, 95% of the Type I cases were asymptomatic. There were 35 patients who were only treated in a monoplace (single-person) chamber. Of these, 33 patients (94%) had no residual, and 2 had a slight residual. Some 17 patients had been treated elsewhere in multiplace chambers and had not resolved and/or had residuals or recurrences. Of these 17 patients, 11 (64%) recovered.

In 1999 Cianci and colleagues (5) reported a series of patients with DCS treated by a modification of the Hart protocol as described by Kindwall (16). Overall success rate was 79%. The average number of treatments necessary for resolution was 1.77. We have used this method of treatment continuously since 1983. We now report 140 cases over a 20-yr period using this short, no-air-break oxygen protocol.

METHODS

The records of 140 patients treated from January 1983 through December 2002 were obtained from the hospital and department database. Most patients were referred by the Divers Alert Network medical advice service. The original charts were reviewed by the authors, both of whom were among the treating physicians. All patients receiving treatment for suspected DCS or those given a trial of recompression were included in this study. Carefully noted were age, gender, signs, symptoms, classification of DCS, time to symptoms, time to treatment, number and total time of treatments rendered, and outcomes. Severity of DCS was assigned using a scale of 0 to 4:

Severity Scale

0: No signs or symptoms
1: Joint pain, malaise, skin or lymphatic complaints
2: Paresthesias, numbness, mild neurological complaints
3: Significant motor weakness, major sensory deficits, balance or gait disturbances and/or mental impairment
4: Paresis, paralysis, bladder, bowel, or erectile dysfunction, or evidence of other severe central nervous system involvement

Evaluation of outcomes was carried out at the completion of each treatment and by follow-up telephone interview or return visit.

RESULTS

From January 1983 through December 2002, 140 patients were recompressed at our facility; 44 were women. There were 30 cases that had weak diagnostic criteria for DCS and were excluded from the definitive analysis of data. Criteria for exclusion included cervical or lumbar disk disease, musculoskeletal problems, seizures, transient ischemic attacks, labrynthitis, migratory or fleeting symptoms, symptoms appearing well outside the accepted window for DCS or AGE, drug-seeking behavior, no symptoms at presentation for treatment, or poor follow-up. These criteria are similar to those used in the 2005 Divers Alert Network Case Reclassification (27). Noteworthy was a 35% improvement in this excluded group. In the remaining 110 patients, all strongly felt to be suffering from DCS or AGE, presenting complaints included pain, numbness, muscular weakness, frank neuropathy, gait disturbances, and spinal or CNS signs.

Mental aberration was present in 49 divers (44.5%). This was noted as a major complaint of the patient or brought to our attention by the patient's family, friends, or co-workers. Many of these patients had previously enjoyed a very high level of executive function, but at presentation to our facility were severely mentally impaired and exhibited significant difficulties in the performance of activities of daily living or work, e.g., operating their computers, reading street signs, following driving directions to our facility, etc. Some patients demonstrated marked apathy, belligerence, or antisocial behavior. The average age was 35.1 (range 16–67 yr). There were 21 patients (19%) who had DCS I, 73 patients who had DCS II (66%), and 7 patients who had DCS III (6%) as described by Neuman and Bove (22). Five patients had AGE (4.5%), and four patients suffered altitude DCS (3.6%).

Average time to symptoms for the entire group was 9.3 h after surfacing or exposure; the median time was 1.5 h. Of the patients, 92% developed symptoms in the first 24 h (**Fig. 1**). The average delay from initial symptoms to treatment was 93.5 h; the median was 48 h (**Fig. 2**). Of the divers, 79% received one to three treatments. The median number of treatments was 2, and the highest was 20 (1 patient). A summary of the number of treatments relating to diagnosis is seen in **Fig. 3**. There were 13 patients (11.8%) who received more than 5 treatments (range 6–20). All 13 patients receiving more than 5 treatments were very seriously injured (average severity score 3.7), and all had received initial or mul-

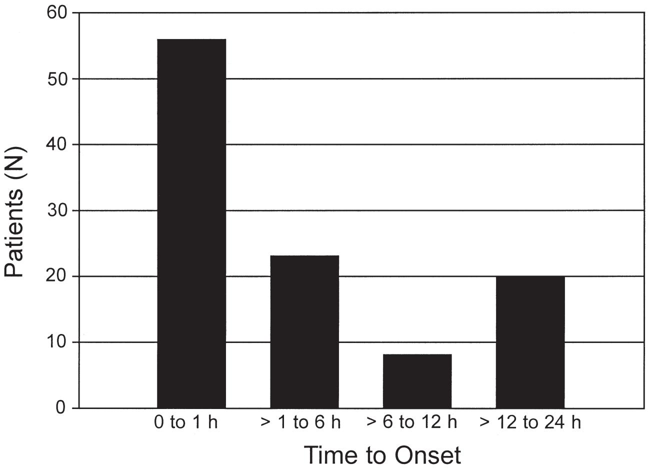

Fig. 1. Number of patients vs. time to onset in hours. Time is the interval from when the patient surfaced to onset of first symptom as reported by the patient and recorded in the medical files. Times were grouped as follows: 0–1; > 1–6; > 6–12; > 12–24.

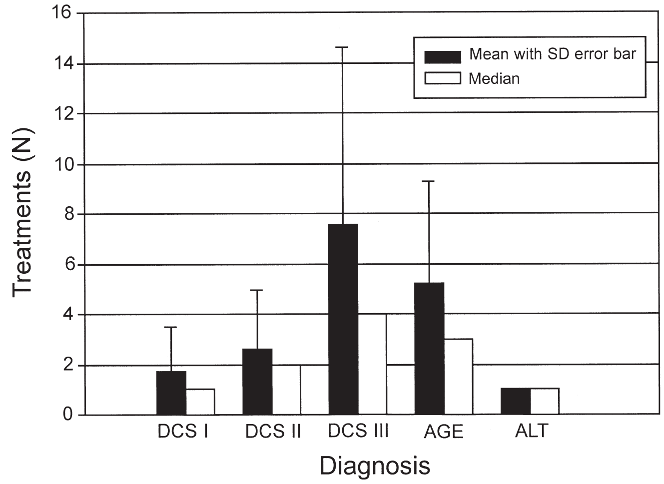

Fig. 3. Median number of treatments vs. diagnostic category. DCS 1 = pain only; DCS 2 = neurologic decompression sickness; DCS 3 = combined arterial gas embolism and decompression sickness; AGE = arterial gas embolism; ALT = altitude decompression sickness.

tiple treatments (usually USN Table 6) elsewhere. They were referred to our facility because of lack of resolution or recrudescence of symptoms. This subset of 13 patients received a total of 110 treatments, averaging 10 per case. The remaining 97 patients had a total of 191 treatments, averaging 1.96 per case. Treatment times for the more seriously injured patients averaged 1107 min or 18.45 h. In the remaining 97 patients the average total treatment time was 253 min or 4.22 h.

Overall recovery for the entire group of 110 patients was 98%. Recovery for Type I DCS was 98%, Type II was 95%, Type III was 100%, and AGE was 94%. Of the altitude decompression patients, 100% made a complete recovery (**Fig. 4**). Mental aberration was associated with a 100% recovery. Recovery of patients relating to severity score at presentation was: 1 (32 patients, mean 98%), 2 (38 patients, mean 93%), 3 (32 patients, mean 94.3%), 4 (8 patients, mean 97.5%) (**Fig. 5**).

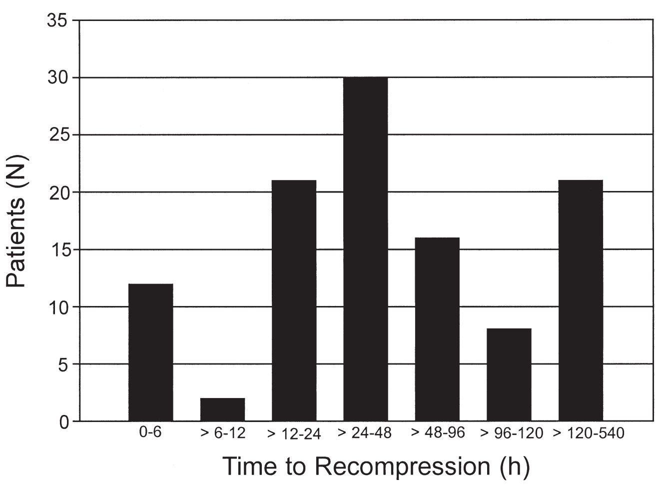

Fig. 2. Number of patients vs. time to treatment in hours, where the latter is the interval from the patient-reported time of first symptom to initiation of hyperbaric oxygen treatment (recompression) as recorded in the medical files.

DISCUSSION

While USN Table 6 has become the most common protocol used for the treatment of DCS, the evidence for its superiority is scant. In pain-only DCS, the shorter USN Table 5 has proven quite effective (11). Kindwall analyzed data from the Divers Alert Network, comparing outcomes between the longer USN tables and the shorter monoplace protocols. He found no difference in outcomes in any category. There was a suggestion that the shorter tables were not as effective in the treatment of serious cases of AGE. However, a comparison of Hart's later report with Kindwall's data showed no significant difference in outcomes (15).

The high success rate attained in our patients is not unusual. Indeed, Smerz recently reported a 91.3% success rate in DCS II and a 92.4% resolution rate in AGE using a deep treatment protocol developed at the University of Hawaii (24). There remains, however, considerable variability in outcomes as noted by Bond's 1990 multicenter study (4) of 327 cases reported to the Divers Alert Network, which found no apparent benefit from

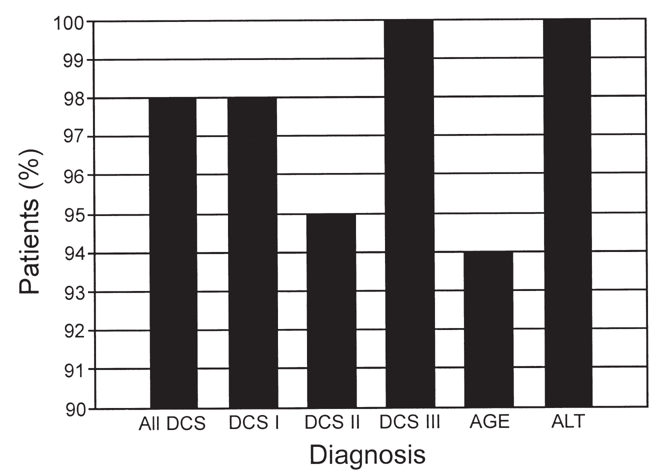

Fig. 4. Percentage of patients who made a full recovery vs. diagnostic category. Abbreviations are as in Fig. 3.

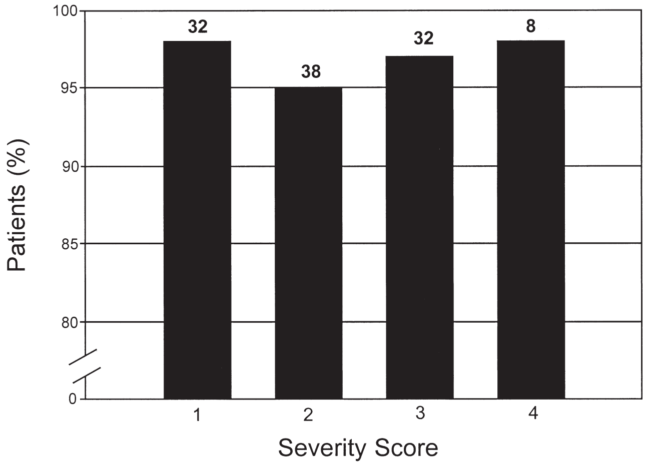

Fig. 5. Percentage of patients who made a full recovery vs. severity score for presenting signs and symptoms. The numeral over each bar shows the number of patients in each group.

the longer (extended) or deeper tables, but severity seemed to correlate with the number of re-treatments in the enhanced treatment group; that is, more severely injured divers would be most likely to undergo the longer tables. Only 58% of recreational divers were symptom free 24 h after treatment (4).

Delay to treatment seems to have a definite deleterious effect on outcome (1,18). Despite an average delay to treatment in our series of 93.5 h (median 48), our results were quite good and compare favorably to national statistics (27). These outcomes lend further credence to the view that treatment should not be withheld because of long delays in presentation for therapy (1,6,7,18).

It is interesting to speculate that the high degree of mental aberration, confusion, or clouded judgment experienced by our patients may have contributed to the delays in recognition of the problem and thus obtaining therapy in a more timely fashion. The recent report by Gronning et al. (12) suggests that cerebral involvement in DCS may be more common than presently appreciated.

One of the difficulties encountered in the treatment of DCS is the marginal case with equivocal or ambiguous findings. Indeed, five patients whose signs and symptoms did not improve were later found to have cervical or lumbar disk disease. We do not have the absolute ability to make a definitive diagnosis in all cases. Thus, treatment is sometimes rendered when signs, symptoms, and dive profiles are not consistent with injury. A "test of pressure" or a complete treatment is often administered in these situations because of prior recommendations by referring physicians, patient pressure, or an "abundance of caution" in the current highly litigious environment. Perhaps the diagnostic criteria described by Neuman (21), akin to the Jones criteria for diagnosis of rheumatic fever, will better enable us to refine our diagnostic accuracy.

Economic considerations may also favor the shorter tables. The average total duration of treatment(s) in our series was 357 min or 5.95 h (range 95–1925 min, median 253). However, this number included 13 very seriously injured patients who were treated for an average of 1107 min (range 540–1925) or 18.45 h. When this group of patients is excluded from the series, we note a total average treatment time of 253 min or 4.22 h. Most treatment facilities charge by half-hour segments, with a range from $175 to $900 per segment (Cianci P, Slade JB Jr. Personal communication; national survey of 46 hyperbaric facilities in the continental United States; 2006). The average number of hours of treatment submitted for payment to an international insurance carrier in the United States was recently noted to be 12.5 (Cianci P, Slade JB Jr. Personal communication; 2006).

While we make no claim for the economic advantage of the short, no-air-break oxygen tables, it would appear that the shorter treatment times we have noted may well be less expensive than the more traditional treatment protocols used to treat most scuba-diving-induced DCS.

In conclusion, the use of these short, no-air-break treatment tables, as originally described by Hart and Kindwall, provide 62% of the oxygen dose of USN Table 6 and are 47% shorter. This short oxygen protocol has proven highly effective for the type of patients presenting to our hospital, a major Divers Alert Network referral center, for decompression sickness. Many of these patients had long delays to recompression. This short treatment protocol may additionally be an economical approach to the treatment of DCS.

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