A prospective field study of reverse dive profiles in UK female recreational divers

Marguerite St Leger Dowse, Alex Gunby, Richard Moncad, Caroline Fife and Philip Bryson

Key words
Reverse dive profiles, decompression sickness, diving, women

Abstract

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Everyday diving habits of a large group of female recreational divers were observed for up to three years. Reverse dive profiles (RDPs) were compared with the conclusions of the Smithsonian Institution Reverse Dive Profiles Workshop. Volunteers did not know RDPs would be scrutinised, making changes to their diving habits unlikely. 570 participants returned 'diaries'; 62% for three consecutive years, reporting 30,480 dive days (16,706 multiple-dive days). The majority of dive depths ranged from 15 m to 89 m. In 29.7% of the multiple-dive days the second dives were of greater depth than the first dives, with 0.25% outside the Smithsonian conclusions for RDPs (depth differentials between the first and second dive of the day were >12 m, and the second dive was deeper than the first and deeper than 40 m). Rates of self-assessed symptom data of possible decompression sickness (DCS) were analysed by RDP with no significant correlation found (minimum P = 0.18). Maximum depth ever dived and total dives logged at the start of the study (surrogates for diving experience) were both significantly correlated with percentage of RDPs (P <0.0001 and P = 0.0008). There were significantly fewer RDPs for one dive training organisation (P = 0.0005). This work suggests future studies should consider carefully the type and amount of data necessary to address these issues, with power calculations demonstrating 30,000 to 180,000 multiple-dive days from 1,000 to 6,000 women needed for any significant effect (at the 5% level) to show. More complex physiologically based studies are possibly required.

Introduction

Within the recreational diving industry the tradition that it is safest to make the deepest dive first has evolved from interpretations of decompression modelling and historical custom.[1] The question of whether reverse dive profiles (RDPs) incur a higher risk of decompression sickness (DCS) than non-reverse dive profiles is the subject of frequent debate.[2] In a review of the literature it was found that there was no theoretical or experimental evidence to indicate a repetitive dive must be shallower than the dive that precedes it.[3] The exception was direct ascent from deep repetitive dives that have been shown to produce a high incidence of DCS.

Theoretical predictions have tended to 'suggest' safe limits with regard to 'no-decompression' dives for forward and reverse dive profiles.[4] Anecdotal observations indicate that within the recreational diving industry it is widely believed the practice of RDPs makes for an increased risk of DCS, and so are not always consistent with scientific and diving medicine literatures.[5,6] When asked to substantiate this belief, however, educators cannot always evidence the argument. Additionally, educators within the industry acknowledge that the practice of RDPs does take place but have no means of quantifying the activity.

In the Smithsonian Reverse Dive Profiles Workshop it was observed that the use of the physiological model serves to draw attention to the complexities of the problem and generates the need for clearer thinking regarding the evaluation of the risks involved.[7] Current assessment of the risks therefore cannot be regarded as hard science, and there is a clear need for additional studies and the gathering of more field data.[4,8] The Workshop concluded, "*We find no reason for the diving communities to prohibit reverse dive profiles for no-decompression dives less than 40 msw (130 fsw) and depth differentials less than 12 msw (40 fsw)*."

We have prospectively observed the everyday diving habits of a large group of female recreational divers over a prolonged period of time. The primary goal of the study being to observe respondent-reported scuba-diving problems and the menstrual cycle. As part of this study the prevalence of RDPs was recorded and compared with the Workshop conclusions. Respondent-reported self-assessed symptoms of possible DCS were also examined. This paper communicates the information gathered.

Methods

From 1997 female recreational divers had volunteered to keep diving 'diaries' for up to three consecutive years as part of a project designed to observe ordinary diving habits, respondent-reported scuba-diving problems, and the menstrual cycle. Publicity for the project was generated via United Kingdom (UK) dive clubs, dive shows and press releases in the diving journals. Volunteers did not know

that reverse-dive-profile data would be scrutinised and therefore made no changes to their diving habits as a result. Volunteers recorded basic dive information (maximum depth, total dive time, and if a mandatory decompression stop was added). Respondents were also given the option to record any possible signs and symptoms of DCS from a fixed option list (lower limb or joint pain, upper limb or joint pain, dizziness/disorientation, visual disturbance, inappropriate fatigue/weakness, difficulty in speaking, skin itching, tingling, skin rash, chest pain or breathlessness, partial paralysis, loss of sensation/numbness, problems with thinking, memory or performance). They were also asked to record any further information not included in the fixed options they felt appropriate. Additionally volunteers were asked if they had reported the possible symptoms of DCS to a diving physician, whether diagnosis was confirmed, and if so to detail their subsequent treatment.

Social and demographic data were gathered (age, weight, smoking and alcohol consumption) together with diving histories (training grade and affiliation, years diving, number of dives and maximum depth ever dived at the start of the study, use and type of dive computers and tables). Respondents were also asked if, in their opinion, they used dive computers/tables exactly as written, conservatively, or if they "took risks" by shaving times and depths.

All participants initially completed the comprehensive background questionnaire. From then on they completed and returned update questionnaires with monthly 'diary' charts, returning them on a six-monthly basis. Questionnaires and specifically designed charts were developed in conjunction with a psychologist. Volunteers were offered no incentive to participate and were free to leave the project at any time.

Data were categorised into multiple-dive day data and by whether or not the second dive of the day was deeper than the first dive of the day. When more than two dives were performed in a day only the first and second dives of the day were used for statistical analysis. Data were also categorised by whether or not they were within the Smithsonian Reverse Dive Profiles Workshop conclusions. We did not restrict the definition to no-decompression dives since there was insufficient granularity in the data to do this. We used the following interpretation of dives outside of the conclusions of the Workshop: the second dive is deeper than the first dive and deeper than 40 metres seawater (msw), with the depth differential between first and second dives greater than 12 msw. We used 30 msw as a marker (second dive is deeper than the first dive and is deeper than 30 msw) when analysing the relationship between experience (at the start of the study) and percentage of respondents doing RDPs (during the study), and training organisations and RDPs (during the study).

Trained operators entered all data, with data quality checks carried out against hard copy. All data were recorded anonymously.

STATISTICAL ANALYSIS

The dive days outside of the Smithsonian Workshop conclusions were analysed, together with untreated, self-assessed symptom data of possible DCS. Self-assessed symptoms were considered only if occurring after the second dive. For each method of categorising the data, the rate of untreated, self-assessed symptoms per 1,000 dive days is given. The self-assessed symptom rates were compared with the symptom rates for dive days within the Workshop conclusions using z-tests.

Power calculations were performed to estimate the size of study sample needed to be able to detect possible differences in self-assessed symptom rates between RDP and non-RDP dives. The calculations assumed that the proportion of RDP dives and the self-assessed symptom rate for non-RDP dives would both be as observed in this study. The calculations were performed for the cases where the self-assessed symptom rate for RDP dives was 33% of the observed value and 125% of the observed value, thus giving a range of sample sizes.

We analysed the relationship between the proportion of dives that were RDPs and diving experience. The proportions of RDP dives were arcsin-transformed before applying linear regression. The explanatory variable of experience was surrogated in two ways: as the number of dives logged at start of study; and as maximum depth ever dived at start of study. A linear regression was performed for each of the two explanatory variables.

Table 1
Profiles of dive days with numbers of dive days, dives, self-assessed symptoms of possible DCS, and rates of symptoms per 1000 dive days

Profile of dive day	Dives days	Dives	Symptoms	Rates
Outside Workshop conclusions	41	82	2	48.78
Inside Workshop conclusions	4,928	9,856	19	3.86
Second dive shallower than first dive	11,737	23,474	46	3.92
Only 1 dive in day	13,774	13,774	54	3.92
Total	30,480	47,186	121	3.97

Chi-square tests were used to examine the relationship between RDP frequency and training organisation.

Results

A total of 570 women returned data for a minimum of six months, with 62% continuing to return data for three consecutive years. At the start of the study the age range was 14 to 63 years (mean 35, SE 0.37).

DIVING BACKGROUND AT START OF STUDY

Prior to the study the number of years of diving experience per person ranged from 1 to 34 years, with the number of dives reported per person ranging from 1 to 3,000 (mean 208, SE 4.14), and a collective experience recorded of 117,919 dives. Also prior to the study 49% had dived to 40 m and deeper (1.9% >70 m) during their diving career, and had already recorded more than 100 dives each.

Fifty-eight per cent of women dived all the year round, though not always evenly throughout the months. Addition of extra stops over those demanded by the tables and computers was reported by 67%. Few women (1%) admitted to taking risks, with 60% reporting they dived conservatively, and 37% using tables and computers exactly as written; 2% declined to give this information.

Table 2
Reported first and second dives from the 41 dive days outside Smithsonian Workshop conclusions

1st dive of day	2nd dive of day	1st dive of day	2nd dive of day
14	51	8	41
30	46	11	46
28	45	20	43
25	42	20	46
26	61	12	46
22	42	30	58
8	41	47	68
28	46	28	40
15	44	28	40
6	48	23	52
32	48	36	58
25	40	22	43
11	51	6	42
10	46	25	45
10	42	21	58
22	61	26	40
33	59	15	42
34	60	41	56
15	40	35	50
13	53	30	57
		17	55

Figure 1
Relationship between RDPs during the study and maximum depth (msw) ever dived at start of study

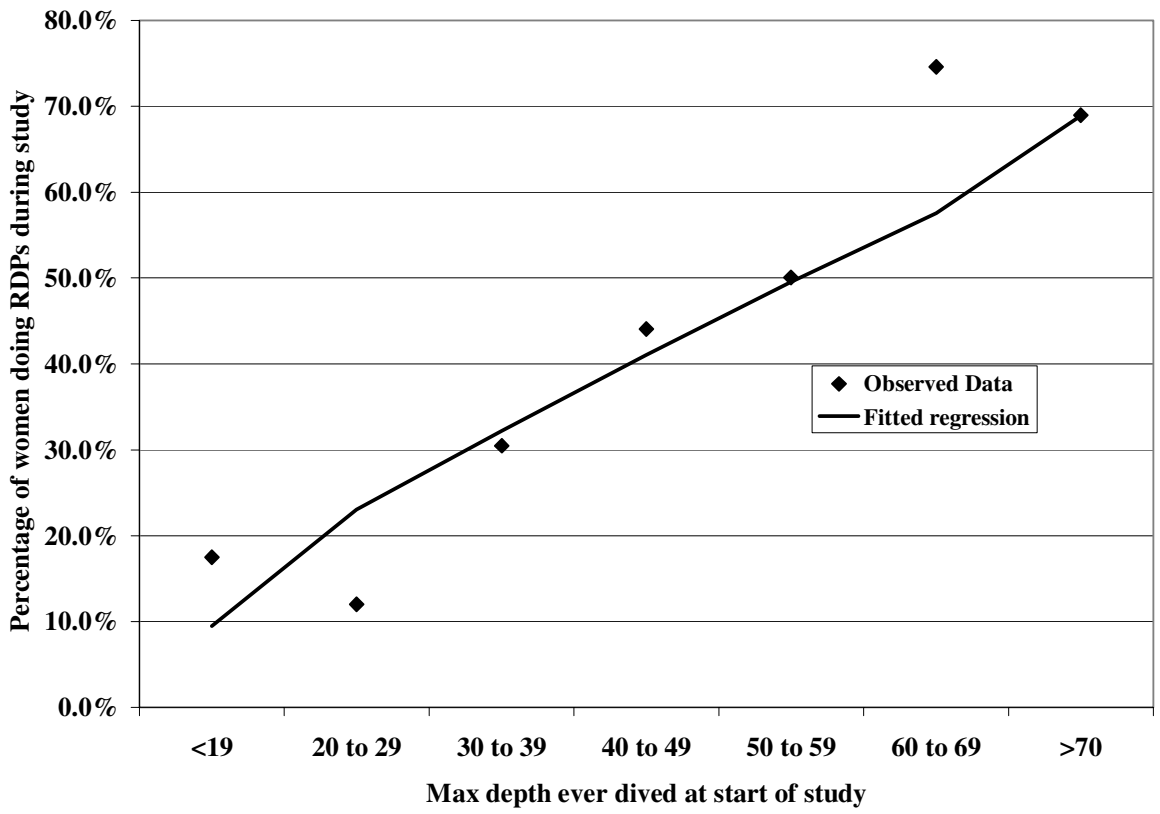
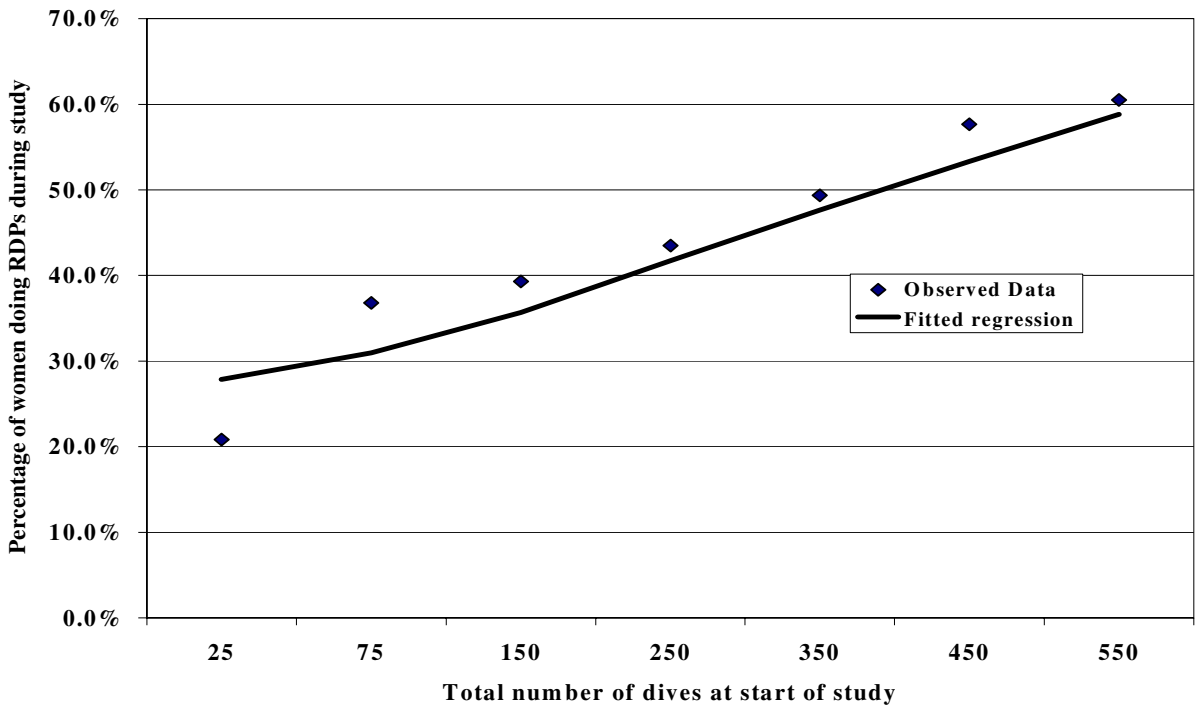


Figure 2
Relationship between RDPs during the study and total number of dives recorded at start of study



DIVES RECORDED DURING THE PERIOD OF THE STUDY

During the period of the study the women recorded a total of 50,261 dives (including third dives of the day) from 30,480 dive days. Also during the study 44% dived to 40 m or more, with a 174 m mixed gas dive being the deepest dive recorded; this depth was verified with the subject concerned. With the exception of this dive, taken overall, the deepest first, second and third dives of any day were 89 m, 68 m and 57 m respectively, performed by different respondents recorded on separate days. Eighty-four per cent of women added mandatory decompression stops to 31% of the dives. The 62% of women who had returned diaries for three consecutive years accounted for 83% of the dives and averaged 40 dives each per year.

REVERSE DIVE PROFILE DIVES

There were 16,706 multiple-dive days recorded (Table 1). Of these there were 4,969 days (29.7%) with second dives of the day to a depth greater than or equal to that of the first dive of the day. Only 41 (0.25%) dive days fell outside the Smithsonian conclusions. There were 3,074 multiple-dive days (18.40%) with three dives recorded.

Untreated, self-assessed symptom rates are far higher for the dive days outside our interpretation of the Smithsonian conclusions than all other dive-day profiles, but these differences are not statistically significant (minimum P = 0.18). Two women reported untreated, self-assessed symptoms of possible DCS outside the Smithsonian conclusions. The first woman reported itching, tingling, and "strange sensations in the left part of the body", with the first dive to 47 m and the second dive to 68 m. The second woman reported skin rash and itching right shoulder, with the first dive to 28 m followed by a dive to 45 m. First and second dives from the dive days outside the Workshop conclusions are shown in Table 2. There were no treated cases of DCS in this study.

REVERSE DIVE PROFILES, AND EXPERIENCE AT THE START OF THE STUDY

We used the maximum depth ever dived, and the total number of dives reported by each respondent at the start of the study as surrogates for experience. The percentage of respondents performing RDP dives during the study (as defined by the second dive being deeper than the first dive and being deeper than 30 m) is shown in Figures 1 and 2. The correlation between percentage of respondents doing RDP dives during the study and each surrogate for experience at the start of the study is significant (linear regression of arcsin percentage RDP dives against maximum depth has a P-value of <0.0001 and against number of dives has a P-value of 0.0008).

RDPs and training organisations

When RDPs (as defined by the second dive being deeper than the first dive and being deeper than 30 m) were analysed by training organisation, there were significantly

fewer RDP dives done by members of one particular organisation (P = 0.0005) when compared with all others.

Discussion

Our data give a unique insight into female-specific, everyday recreational diving, documenting more than 50,000 dives from 570 women over three years. The women were from a wide range of experience levels and from across different training organisations. Attrition was evenly distributed over the time of the study, with 10.7% in the second six months of the study falling to 8.2% at 30 months. In the first eighteen months of the study 12% of women changed address, with 8% in that group moving more than once, emphasising the problems of tracking a large group of the population over a prolonged period of time. Where possible, reasons for ceasing to participate were established, and these ranged from changes in marital status (7% married during the course of the study) to not wanting to commit further time to the study.

The women kept normal diving records for long periods of time, 62% for up to three years, and so it is reasonable to conclude that they did not conduct their diving in line with any preconceived criteria or restraints. The prevalence of RDP dives, in one form or another, has been demonstrated by these study data and therefore may lend support to anecdotal observations that RDPs are indeed regularly taking place. Around 30% of multiple-dive days within the study population involved some combination of RDP, even though only 0.25% of multiple-dive days fall outside our interpretation of the Smithsonian Reverse Dive Profiles Workshop conclusions (Table 1). Studies have shown women may dive with more caution than men,[9] and therefore it is likely that a greater number of RDPs are taking place amongst male recreational divers.

Previous studies have implied that there are a large number of divers who never report their symptoms of possible DCS to a physician, and our data might be considered to support those studies.[9–11] Untreated, self-assessed symptoms of possible DCS in this study were not reported to a physician. In addition to those described outside the Smithsonian conclusions (Table 1) other unreported symptoms of possible DCS within the Smithsonian conclusions included skin rash, visual disturbance, loss of sensation, and inappropriate fatigue. When analysing the symptom rates in relation to dive days outside the Smithsonian conclusions, no significant effect was discernable even though the observed rate is far higher than for other dive-day profiles. This can be explained by the tiny number of dive days seen outside the Smithsonian conclusions, which makes the estimated symptom rate for that category subject to a large standard error.

This study was not specifically designed to observe the incidence of RDP dives and any definitive association with possible signs and symptoms of DCS. If there truly is an underlying correlation, power calculations based on our study data indicate that we would need to observe in the order of 30,000 to 180,000 multiple-dive days (giving 60,000 to 400,000 dives) in order to detect a significant effect at the 5% level. This translates to between 1,000 and 6,000 women in total taking part in the study.

When attempting to analyse any correlation between RDPs and experience, we used the 30 m marker (second dive is deeper than first dive and deeper than 30 m) given that diving to depths over 30 m has been traditionally defined as 'deep' by some training organisations. Additionally, 30 m is the depth limit beyond which many dive operators will not take divers, particularly in holiday destinations. The diving practices of the study group outline a possible need for training agencies to promote a clearer policy message with regard to RDPs. The exact policies and type of reverse-dive-profile recommendations by training organisations are not always clear to instructors and the grass-roots diver. The significantly lower number of RDP dives performed by one particular training agency is evidence of this.

The use of dive computers, which has largely overtaken the use of traditional dive tables, could also be a contributory factor in clouding the issue and understanding of RDPs, with divers relying on the culture of dependence and trust in technology. Within the study group as a whole more than 50% used computers only or computers in conjunction with dive tables. In the group where the second dive of the day was greater than the first dive and also greater than 40 metres, 73% of women used computers. The clear link between performing RDP dives and the experience of the diver may, on the other hand, indicate that initially divers pay heed to advice given during training. Subsequently divers become either more empirical in their approach, or more distant from the training, and so develop their own ideas about what is and is not safe.

The concern surrounding the risks associated with RDP dives and DCS, which may or may not exist, is ongoing and generates controversy. It is beyond the scope of this study to analyse or discuss a definitive relationship between RDPs and DCS. Problems identified with field data and self-assessment symptomatology have been reported.[12] Although in our study the more aggressive RDP categories were associated with a higher rate of self-assessed symptoms of possible DCS per thousand dive days, these differences were not statistically significant. The availability to date of so few field data on which to draw any understanding has allowed much of the debate and recommendations of safe limits to be substantiated by statistical modelling, with some conclusions drawn from hyperbaric chamber records and limited field data.[8,13] Our study data provide a 'real-world' insight into the everyday diving practices of a large population of female divers over a long period of time, and should therefore be useful in formulating more definitive studies, and as an indicator to teams collecting field data in the future.

Conclusions

The question of whether RDPs are 'safe' is complex. Our data are not entirely conclusive despite the large numbers and the time scale involved. However, this work indicates to other bodies and organisations wanting to take this work further the problems associated with this type of study. For example, to answer this question many more participants would need to be studied over a longer period of time. Additionally, a study would need to take into account such factors as biological variables and the anomalies of self-assessed symptoms.[12] Any future study would need to consider carefully the type and amount of data required to show any possible significant effect. It may be that these questions cannot be answered by a field-study approach and will require a more complex physiologically based study.

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Marguerite St Leger Dowse is a research co-ordinator at the Diving Diseases Research Centre, Hyperbaric Medical Centre, Tamar Science Park, Plymouth, United Kingdom.
Alex Gunby, DPhil, is a professional statistician with the Diving Diseases Research Centre, Plymouth.
Richard Moncad is a computer programmer with the Diving Diseases Research Centre, Plymouth.
Caroline Fife, MD, is Medical Director, Houston Chamber, The University of Texas Health Science Center, Memorial Hermann Center for Hyperbaric Medicine, Houston, Texas, USA.
Philip Bryson, MRCGP, is Medical Director at the Diving Diseases Research Centre, Plymouth.

Address for correspondence:
Marguerite St Leger Dowse,
Hyperbaric Medical Centre,
Tamar Science Park,
Research Way,
Plymouth PL6 8BU,
Devon, United Kingdom
***Phone:** +44-(0)1752-209999*
***Fax:** +44-(0)1752-209115*
***E-mail:** <mstld@eurobell.co.uk>*

The database of randomised controlled trials in hyperbaric medicine developed by Dr Michael Bennett and colleagues at the Prince of Wales Diving and Hyperbaric Medicine Unit is at:

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