explain the higher incidence of decompression illness in Queensland diving instructors. However, in the absence of further data, one can speculate or use deductive reasoning. The authors believe that the main difference between the two groups is in diving practice, in that only the instructors regularly perform multiple ascents and descents.

Recreational diving authorities must recognise that diving training procedures put instructors at a higher risk of decompression illness than the general diving population. Further research is needed in this area and recommendations should be developed by the training agencies to avoid continued hardship, disability or, in the extreme, death of the unfortunate diving instructor who is hit by decompression illness.

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Key Words

Ascents, decompression illness, diving industry, safety, recreational diving, reprints.

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SAFE LIMITS: ASSESSING THE RISKS

Harry F Oxer

This paper examines “Safe Limits: assessing the risks” with respect to our experience of almost five years of managing dive accidents in Western Australia. The areas we examined include:

Multiple dives on successive days
Rapid ascents
Multiple ascents
Flying after diving or decompression illness

In Western Australia 175 divers presented with possible decompression illness over a four and a half year period. This is in the context of an estimated 40,000 certified divers in this state, though the number of dives carried out is unknown. We see between 30 and 35 cases who are treated each year, of which usually only one is serious. There are few cases of arterial gas embolism.

We looked at our cases and examined 114 in detail, for which we had very complete records, and follow up. The aim of this paper is to examine our statistics and to cite some cases which illustrate our experience in the categories we are examining in this Symposium. Statistical analysis was carried out using the χ^2 test.

Multi-day diving

Divers are often advised to take a break every third or fourth day, particularly during a diving holiday. However many instructors dive daily without problem, as do many professional divers. Rogers[1] and his co-workers, when testing the algorithm for the PADI Wheel, carried out a large number of multi-day tests, albeit mostly in a dry chamber, and did not find evidence of decompression illness occurring under these circumstances. However statistical analysis of our cases indicates that repetitive diving is predictive of decompression illness in Western Australia (P=0.027).

It is widely believed that one can acclimatise to multi-day diving. There are many reports in the literature, and pearl divers in particular do large series of repetitive dives, and some feel that acclimatisation at the beginning of the dive series is very important.

There may be some scientific basis for this. Ward et al.[2] carried out some experiments, mostly in rabbits, on a substance in the blood called "complement". This substance appears to be involved when symptoms of decompression illness present. They showed that either chemically or by using tiny bubbles they can "de-complement" the blood of rabbits, which are then a much harder to "bend" when subjected again to decompression stress. We know that tiny bubbles are often generated by dives, one suggestion is that these micro-bubbles may be involved in reducing the amount of complement in the blood and thus the likelihood of decompression illness.

Some divers bend despite having apparently complied with the rules, following multi-day diving. The following cases were all treated by us and responded to recompression with remission of their presenting signs and symptoms.

CASE 1

A 17 year old male was carrying out an Advanced Sport Diver Course. He carried out 4 days of diving with all stops and within tables. Three to four hours after his last dive he was tired, lethargic, with joint pains and nausea; on presentation still had these symptoms and was unable to study.

CASE 2

A 17 year old male with considerable experience carried out twelve dives in 7 days at the Abrolhos Islands, diving on his buddy's computer. The next day he was extremely tired and apathetic and presented with pains in his back, wrists and ankles and with balance problems.

CASE 3

A male 33 years old, who had had previous decompression illness at the same dive site, was diving again at the Abrolhos Islands and carried out 6 dives in 3 days within tables and with safety stops. That evening he developed pain in the knees, right shoulder, had difficulty coordinating movements and had numb feet, poor balance, headache and poor concentration.

CASE 4

A 25 year old female with one year diving experience had three, two and one dive on three successive days within the tables with all safety stops. She presented the next day with extreme tiredness, headache, pains in the left shoulder and neck, her hands were tingling and she had blurred vision.

CASE 5

A 25 year old male was diving at Exmouth, and carried out one, two, and three dives over four days. All were within tables, and he did five minutes at five m for each dive. The next day presented with pain in the right shoulder, elbow, thigh and fleeting pains in all joints.

Each of these cases responded to recompression treatment.

Rapid ascent

Rapid ascent is a problem which frequently shows up in our series. Ascent rates are most important. Ascending at the rate of bubbles is a useless exercise. Recommended ascent rates vary but appear to be getting slower. In our series, rapid ascent was significantly associated with dive accidents (P=0.014).

Various ascent rates are recommended. The US Navy recommends 18 m (60 ft) a minute, though this is reported to be a compromise between the 30m (100 ft) per minute ascent rate requested by their SCUBA divers, and the rate at which the US Navy could haul up a tethered surface supplied diver! The Royal Navy and Royal Australian Navy use a 15 m (50 ft) per minute ascent rate. Bühlmann, after careful study, recommended 10 m (33 ft) per minute; most modern computers use this rate.

All ascent rates and stops are really compromises, as ascent should be exponential, getting slower as you near the surface. Decompression stops are a practical way of achieving a similar result. However the problems of maintaining a stop or slow controlled ascent near the surface, when there may be a swell running, make this impracticable at shallow depths. It is common for divers, when they have made their stop, to then ascend rapidly to

the surface, although this is the zone where volume increases most with with pressure reduction.

The British Sub-Aqua Club (BS-AC) recommends differing ascent rates which slow as you near the surface. Western Australian pearl divers use 3 m per minute from below 20 m to 8 m. They then perform their stop at this depth and then use 3 m per minute to the surface.[3] One metre in 20 seconds is a very much slower ascent rate than is used by most recreational divers!

In our experience, if a diver has a nitrogen load, i.e. some time has already been spent at depth, then this is followed by rapid ascent even from 10 m or less, it can cause problems.

CASE 1

Three females all with professional backgrounds were carrying out a training course. On their third open water dive in the same day they dived to 22 m (74 ft). It should have been 18 m (60 ft) but the instructor got the depth wrong. They practiced buddy breathing on the bottom for 30 minutes then each was taken up on an individual buddy-breathing ascent. All were anxious and all did this rapidly. None sustained an embolism but all three were seriously bent, and required several treatments, one returning for follow up treatment on a later occasion.

CASE 2

A 29 year old male was carrying out a photographic dive 22 m (74 ft) for 40 minutes when he ran out of air. He buddy-breathed half way to the surface then found he could breathe, so surfaced fast. He later carried out a further 8 m (27 ft) dive for 62 minutes but the next day found he was weak, with a numb left arm and had headache, nausea, and difficulty concentrating.

CASE 3

A 27 year old female on an initial course, carried out a dive at 18 m (60 ft) for 30 minutes, then, as briefed, carried out an unsupervised free ascent to the surface!

She developed aches and pains and difficulty in speaking and rang the Dive Emergency Service. They sent her to a local Perth Hospital where she received oxygen and fluids, and her symptoms resolved overnight. She declined recompression treatment, was advised to take a month off and report immediately if she had any problems.

One week later she continued her dive course, dived to 8 m (27 ft) for 30 minutes and developed severe pain in her knee. She came to us, and when seen was apathetic, could not carry out serial 7's, and in her job as a teacher said she could not concentrate all week.

CASE 4

A 32 year old female was undertaking a Divemaster Course and carried out a dive to 17 m (57 ft) for 54 minutes. She tried to stop at 5 m (15 ft) but ran out of air and surfaced rapidly, exhaling properly.

She developed lethargy, problems with concentration, headaches, aches and pains in her joints, and found she was doing silly things at work. She presented some four days later referred by her general practitioner when she presented looking for a tonic.

Multiple ascents

A number of diving styles require people to make multiple ascents to the surface. In our experience this can cause problems especially if the diver or instructor has acquired a nitrogen load, then is carrying out the ascents later in the dive. We have found that it seems to be a requirement in some forms of training; whether this is in accordance with the organisations recommendations or not, it is being done. Even if the dives are within tables, repeated ascents cause problems presumably by causing gas separation, which is then not reabsorbed even if safety stops are done at the end of the dive.

CASE 1

A male diver had been a professional for 2-1/2 years and a recreational diver for 13 years. He dived for 6 hours, mostly, at 1 to 1.5 m but with bounces to 15 m, and including 15 to 20 ascents. Three hours later he complained of fatigue, headache and tingling with pains in his wrists, ankles, weak legs, apathy, difficulty walking, double vision and balance problems. He needed three treatments, the symptoms recurred and he required a further four treatments.

CASE 2

A male dive instructor carried out 2 dives on a Saturday to 4 m with students, then on the Sunday carried out 4 dives. On the third of these he did multiple ascents to 5 m. At the end of the dive they did 5 minutes at 5 m. Two hours later he had severe lethargy, chest pain, weak arms with tingling and was very apathetic. He came to us the next day.

CASE 3

A 37 year old male undertaking a Dive Master Course dived to 12 m for 45 minutes then did a stop for 5 minutes for 5 m. His surface interval was 2-1/4 hours after which he did 12 m for 75 minutes, but with 7 ascents at the end. That night he developed a headache. The next day he had joint pains, tingling in his back, and pains in his joints with lethargy and slowness of thought.

CASE 4

A 40 year old male carried out a multi-level dive with many ascents to the surface from a maximum of 17 m for 2 hours total time. That night he had pain in his elbows and took analgesics.

He presented to us 10 days later when he was apathetic and withdrawn, had a weak right arm and was unable to balance effectively.

CASE 5

An instructor working out of Exmouth had been treated by us for decompression illness two weeks before. Contrary to our advice he was instructing again and carried out two 9 metre dives totalling 16 minutes, then had a surface interval of 4 hours followed by a 12 metre dive for 45 minutes with a 5 minute stop at 5 m. He then carried out a 9 metre dive totalling 71 minutes and including 6 ascents with free ascent trainees. That evening he developed pain in his elbow with tingling and a heavy sensation. He was apathetic, excessively tired and developed hot and cold flushes.

CASE 6

A 26 year old male dive instructor dived to 16 m for 50 minutes then carried out multiple ascents to 5 m because of student problems. During a surface interval of 2-1/2 hours he developed extreme lethargy and tingling, but carried on with the next dive and went to 10 m for 45 minutes and felt much better at depth. Since then he had found he was unmotivated, lethargic with various tinglings, his balance was terrible and he had numbness in the left arm and leg.

Flying after diving

Hypobaric exposure during flying can be seen as an extreme of the tables, and tables are unreliable at the extremes. Flying after diving seems to show that divers are exquisitely sensitive to small reductions in pressure at this lower oxygen partial pressure. The reasons are not well understood.

Our experience gives us mixed signals about flying after diving. It seems that if it is over 48 hours since the diving it is probably safer to fly, and also after 100% oxygen treatment of decompression illness symptoms, it may be safer. We have evacuated patients from remote islands by commercial flights after treating them, with oxygen, and have not had a recurrence of symptoms. However if the dive is marginal, and flying is undertaken within the first 24 to 48 hours, it certainly appears to be able to bring on or exacerbate the symptoms.

CASE 1

A 25 year old female was diving on the Great Barrier Reef in Queensland on a PADI Advanced Divers Course. She carried out 11 dives in 49 hours. The next day she developed headache, was tired and lethargic, with pain and tingling in the left arm and leg. She flew to Perth the following day and had no changes in flight, and presented to us two days later for treatment.

CASE 2

A 25 year old male was diving in Thailand, he carried out an 18 metre dive for 50 minutes with much swimming up and down then, after a surface interval of 70 minutes, dived to 15 m for 45 minutes again with many ascents. Following this he towed a buddy 50 m to the boat against the wind. Later he felt very unwell, light headed, tingling and lethargy. He went to a doctor and was checked for Dengue Fever. He flew back to Perth the next day as he felt too ill to continue his holiday, and there were no changes in flight. He presented to his doctor still with possible tropical fever. He was referred to us for treatment.

CASE 3

A 25 year old female diving at Bali carried out a series of dives well outside the tables resulting in nausea, feeling desperately tired, mentally slow, tingling. She subsequently climbed a 1700 ft volcano, at the top of which she could not stand! She improved on descent of the mountain, but in the 747 flying back to Perth was too weak to get out of her seat and go to the toilet. She improved on descent and was able to walk out of the aircraft.

CASE 4

A 22 year old male accountant diving at the Abrolhos Islands carried out a series of dives within tables. However within 24 hours he flew to Melbourne and developed symptoms on flight and was treated at the Alfred Hospital.

CASE 5

A 30 year old male was diving in the Solomon Islands, he carried out 8 dives in 3 days including one to 42 m. He did all stops and safety stops, but then suffered several hours of what was termed seasickness with nausea and vertigo.

He flew to Perth the next day with no change in his symptoms, but sought treatment with us.

CASE 6

A 25 year old female diving at the Cook Islands on somebody else's computer, flew out 30 hours later on a Boeing 747 and developed symptoms during flight.

CASE 7

A diver from the Abrolhos Islands who had previously been treated by us found that his tingling recurred two weeks later whilst on a flight to Sydney, the tingling disappeared on descent. We retreated him, however he still had this recurrence of tingling each time he flew for several months later. There were no other problems.

We have treated several cases from Christmas Island and Cocos Islands where the treatment facilities are limited. However they are usually flown after being treated by 100% oxygen and usually more than 48 hours. So far although mostly flying them back on commercial aircraft we have had no changes in symptoms.

Multi-day or rapid ascent?

This case may fall into either category!

A 23 year old female had just completed an initial dive course with four open water dives then went on holiday on the Cocos Islands. Her daily dive profile was:

50 m for 30 minutes
40 m for 40 minutes
45 m for 30 minutes
43 m for 45 minutes. The last five m of this dive had a rapid ascent as she had buoyancy problems.

After this she was too weak to stand, exhausted, chest pain, withdrawn, apathetic and had pain in the left arm, elbow, and right knee. On consultation there was no cylinder of oxygen, and no aircraft on the island, and we were unable to find an available aircraft in the immediate future to evacuate her. On the island they had an oxygen concentrator which will generate about 90% oxygen and she was treated with equipment designed jointly over the telephone. She flew out on a commercial flight two days later and was treated by us. Further symptoms were revealed as her affect improved. She required four treatments, then later three more, and never got rid of all of her residual tinglings, particularly in the legs.

Rapid ascent

The ultimate rapid ascent was perhaps exemplified by a pearl farm diver who did 13 m for 22 minutes then a 30 minute surface interval followed by a 13 m for 18 minutes.

A boat supplying shell to him, having delivered the shell did a fast circle and accelerated away. The propeller caught his hose resulting in instant surfacing. Thereafter the hose was cut, following an instant return to the bottom. He then used his bail out bottle and rapidly surfaced again. It is a tribute to the diver's training that he did not sustain a serious embolism, but certainly did get decompression illness.

Summary

Our experience in Western Australia of patients presenting at Fremantle Hospital Hyperbaric Unit for treatment seems to show that for non professional divers, doing multiple dives on successive days is a factor increasing the danger of sustaining decompression illness.

It seems that ascent rates are particularly important. Rapid ascents are a problem even within tables and even at shallower than 10 m. Once again ascent rates and appropriate stops appear to be the vital factor.

Multiple ascents particularly seem to cause problems in our experience, even in shallow diving and especially late in a dive after taking on a nitrogen load.

Flying after diving can cause a problem, though this seems to be worse in the first 24 to 48 hours and, as reported by others, is related to the depth and severity of the dive. In our experience, patients who have developed decompression illness, and have been initially treated with 100% oxygen usually seem to be able to fly safely, when this becomes operationally essential. We have the one case who got recurrence of minor symptoms every time he flew for some months after otherwise successful treatment.

The message we perceive is that slow ascent rates make for safer diving, and it seems that they will facilitate problem free multi-day, multi-dive situations. The pearl industry has developed this method of enabling their divers to do repetitive dives on repetitive days throughout the pearling season with extremely low incidence of decompression illness. (Slow ascent rates are only one facet of the pearl divers' safe practises, but appear to be of critical significance.)

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Key Words

Ascent, decompression illness, flying, reprints, risk, treatment.

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