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High altitude dives in the Nepali Himalaya

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Leach J, McLean A, Mee FB. High altitude dives in the Nepali Himalaya. Undersea Hyperbaric Med 1994; 21(4):459–466.—British divers undertook no-stop decompression dives at altitudes of 15,700 and 16,000 ft (4,785 and 5,33 m) in the Everest region of the Nepali Himalaya. They performed 23 dives on oxygen and two on nitrox (60% N_2:50% O_2. The dives took place under ice in two lakes, Gokyo Tsho and Donag Tsho. The maximum depth achieved was 98 feet fresh water (29.32 msw), maximum duration was 39 min in water, 44 min on gas.

altitude diving, oxygen, Everest region, nitrox, acclimatization

Diving at high altitude in remote areas is beset by problems of reduced ambient pressure, breathing gases, unproven decompression schedules, low temperatures and other extreme climatic conditions, and often difficult access to diving sites. These problems affect both divers and equipment (1). Recent attempts have shown various degrees of success: in 1968 Jacques Cousteau carried out an underwater exploration of Lake Titicaca in Bolivia at an altitude of 12,500 ft (3,810 m); in the 1980s an American-led expedition to the South American Andes performed a series of successful shallow-water dives (<30 ft, 9 m) at 19,450 ft (5,928 m) (2); and the Indian Navy reported conducting diving operations in the northern tip of Lakdeh in the Himalaya between 7,000 ft (2,134 m) and 14,200 ft (4,328 m) (3).

The aim of our expedition was to explore three lakes lying along the Khumbu glacier in the Everest region of the Himalaya. These lakes were Gokyo Tsho at 15,700 ft (4,785 m), Donag Tscho at 16,000 ft (4,877 m), and Tshomoche at 17,500 ft (5,332 m). The expedition left Kathmandu in February 1989 with the purpose of reaching the target area after the breakup of the lakes' surface ice and before the onset of the monsoon period. Movement to Jiri was over 7 h by four-wheel Landrover and thereafter on foot to Gokyo and higher altitudes. Arrival at Gokyo Tsho was achieved after a 15-day march plus an extra 4 days for acclimatization at Namche Bazar (11,300 ft, 3,444 m), typical acclimatization routines for mountaineering expeditions in this area. The conditions beyond Namche were harsher than normal for the season, with blizzards, deep snow drifts, stormforce winds, and surface temperatures down to −40°C at times. Conditions at the lakes were also difficult, with ice coverings varying from a few inches to 2.5 ft (0.76 m) at Gokyo Tsho and a uniform ice thickness of 4 ft (1.2 m) at Donag Tsho. Operationally, 18 dives were completed at 15,700 ft (4,785 m) on 100% oxygen in Gokyo Tsho (maximum depth 33 ft, 10 m) and five O_2 and two nitrox (60% N_2:40% O_2) dives were done at 16,000 ft (4,877 m) in Donag Tsho (maximum depth 98 ft, 30 m). Unfortunately, during the expedition the weather and ground conditions deteriorated so that an attempt on Tshomoche at 17,500 ft (5,332 m) was abandoned because access to it involved a glacier crossing, which under the prevailing conditions was too treacherous.

At Donag Tsho the atmospheric pressure was 0.5 bar. This reduction in atmospheric pressure meant that 100% O_2 could be used safely below the limiting depths found at sea level. In this instance, O_2 diving was restricted to 50 feet of freshwater (ffw) (14.96 msw). Below 50 ffw, the O_2 content was reduced and replaced with N_2 to give a nitrox mixture (60:40)

METHODS

Divers

Three experienced professional (military and commercial) divers, aged 30, 34, and 39 yr, participated. All were physically fit, held in-date diving medical certificates, and had experience with rebreathing apparatus and with breathing mixed gases. Two members had previously been to altitudes of 15,000 ft (4,572 m); all were qualified as diving paramedics and were familiar with symptoms of hypoxia and acute mountain sickness.

Apparatus

Divers used a closed-circuit rebreathing apparatus (Special Duty Oxygen Breathing Apparatus SDBA Mk V, Life Support Engineering Ltd, Sussex, UK). The gas was contained in two slim, aluminum alloy, high-pressure cylinders and supplied on demand with a regulating valve and counterlung; gas was set to 3 liter/min. This system is comfortable for the diver, compact, lightweight (10 kg when fully charged with gas and sodasorb scrubbing chemical), and especially robust, being designed primarily for activities such as combat diving, canoe patrol, and submarine exit.

Breathing gases were 100% O_2 for use to depths of 50 ffw (14.96 m) and nitrox for depths below 50 ffw. Carbon dioxide was scrubbed by SofnoLime sodasorb (MP United Drug Ltd, Thaxted, Essex, UK). Diving suits were commercial neoprene unisuits with separate neoprene hoods worn above woolly-bear undersuits and Damart thermal underwear.

Procedure

Our main concern was acclimatization to extreme altitude. Five simultaneous approaches were adopted: a) A high degree of initial physical fitness was required from each diver. b) Work-up dives were done in the United Kingdom both at sea level and at an altitude of 2,000 ft (610 m), which also enabled specialist training and experimental trials to be conducted. c) Fitness was increased by the 15-day walk, the usual procedures being to "climb high—sleep low." Divers started from a valley early in the morning, climbed to a mountainous pass by afternoon, and descended into a neighboring valley by early evening. More than one mountain pass was often crossed in a day. d) A planned 48-h acclimatization stop at Namche Bazar at 11,300 ft (3,444 m) was scheduled to allow time for both rest and maintenance of equipment. However, the expedition was cut off by snow for 4 days at Namche. e) Twenty-four hours was spent at the dive site before diving operations began. Moderate exercise was undertaken during this period consistent with normal duties and activities in a mountain camp.

The team was supported as far as Namche by a Sirdar, six Sherpas, and 30 low-level porters. Thereafter the porters were replaced by high-altitude Sherpas supported by yaks. This core team provided excellent logistics, backup, and safety support.

High-altitude decompression tables were originally calculated using equations by Hennessy (4 and Hennessy, personal communication, 1989). However, we found a close correspondence between the resultant calculations and the U.S. Navy (USN) diving tables (5), such that an operational table depth could be obtained from doubling the actual diving depth (e.g., for a dive to 30 ffw the table would be at the 60-ft level, whereas for a dive to 92 ffw the table would be entered at 190 ft). This procedure was adopted.

All divers took on roles as dive supervisor/tender, standby diver, and diver. When operating under ice (which happened in most cases), one diver would enter the water tended via a lifeline by the dive supervisor, with the standby diver fully dressed but with his mask off for comfort. When diving in ice-free water, two divers would enter the water using the "buddy" system and linked by a buddy line. Apart from operations conducted immediately beneath the ice, all dives involved a straight descent to the bottom of the lake where the diver worked until completion of the dive, whereupon he undertook a final, steady ascent to the surface.

RESULTS AND OBSERVATIONS

Acclimatization and health

Overall, the 15-day march-in proved effective in acclimatizing to altitude. One diver suffered from mild altitude sickness above 12,000 ft (3,658 m) with feelings of continual fatigue, sleeplessness, headaches, and a general slowing in performance. Nonetheless, this diver was able to keep up with the schedule demanded by the exigencies of the expedition, and at Gokyo Tsho most of the symptoms disappeared and he managed the successful climb to over 18,000 ft (5,846 m) at Gokyo Khala Patar. The other two divers showed no overt symptoms of altitude sickness. However, there was some temporary enteritis, and one diver showed an influenza-type illness that lasted for 72 h including 12 h confined to his tent at Namche. One diver sustained frostnip in his toes, and two Sherpas experienced mild snow blindness. All showed full functional recovery.

Preventive measures against the possibility of sunburn included high-altitude glacier cream (Piz Buin ski combi) and normal covering of otherwise exposed body areas. These measures were quite effective, but extreme discomfort from sunburn was still experienced during diving operations, most notably around the neck when dressing into the rubber neck seal, and around the nose when using nose clips beneath full face masks.

Diving procedures

By Day 3 of diving, some initial technical and operational problems were overcome and a routine was effectively established. Key points are:

- To save time, the dive plan for the day was established and agreed the day before and was as simple as possible. This is normal procedure for most military and commercial diving operations but its importance is even greater at altitude where problems are magnified.
- The whole diving procedure, from dressing-in to recovery, was done at a slower pace than at sea level. Divers sometimes became fatigued simply by putting on the suit and equipment. Dressing-in the diver while he was seated was found to be the most effective and comfortable method.
- We found it useful to erect a large, separate tent dedicated as a diving workshop and changing area for protection from the elements.
- Dives were conducted around midday, allowing the forenoon sun to warm the equipment, including suits and woolly bears which had frozen during the night. Toward the end of the expedition it was necessary to defrost woolly bears over open fires before diving.
- After a few days the team of Sherpas grasped the diving procedures and performed basic tendering duties under supervision and anticipated the equipment needs of the divers.
- Immediately after the dive, the diver was dressed-out and provided with warm clothes, a hot drink, and food.
- A stand-by tent contained sleeping bags and medical equipment in case of an accident or hypothermia.
- After diving operations, all equipment was laid out to dry in afternoon sun, which lasted until about 1800 h.

A summary of dives is given in Table 1 (Gokyo Tsho) and Table 2 (Donag Tsho).

Diving health

No diving-related diseases were encountered. All dives were non-stop dives calculated on a modified USN dive table. We had originally intended to conduct some decompression dives, but after pilot dives to 100 ffw (29.93 msw) in Donag Tsho we realized that our supply of nitrox would not be sufficient for a full decompression protocol, which could have caused serious problems if an accident had arisen; so plans for decompression dives were aborted. No incident of hypothermia was reported despite surface temperature reaching −35°C and continual under-ice diving with leaking suits. After a few days the divers and Sherpas perceived themselves to be continually cold but nonetheless were operationally effective.

Equipment

The four SDBA Mk V rebreather sets stood up well under rough handling by men and portage by animals, high altitude, poor weather, and extremes of temperature. Problems were encountered with O-rings which, despite being designed for low temperature, began to crumble. A high-pressure hose exploded due to inappropriate handling in the early stages of diving. Nevertheless it was possible to maintain three fully functioning sets, out of the original four, throughout the operation. Field maintenance was particularly easy

Table 1: Dives at 15,700 ft Gokyo Tsho[a]

Diver ID	Operating Depth ffw	Operating Depth msw	On Gas	Left Surface	Arrived Surface	Off Gas	Total Time in Water, min	Total Time on Gas, min
A	20	5.98	1500	1503	1512	1513	9	13
B	10	1.50	1520	1522	1529	1530	5	10
C	3	0.89	1550	1551	1552	1553	1	3
C	16	4.79	1605	1607	1614	1615	7	10
B	33	9.87	1134	1135	1143	1144	8	10
C	3	0.89	1200	1203	1205	1206	2	6
A	20	5.95	1245	1248	1307	1309	19	24
C	30	8.97	1325	1327	1332	1333	5	8
B	13	3.89	1031	1032	1054	1055	22	24
C	13	3.89	1036	1039	1054	1056	15	20
B	20	5.98	1113	1122	1132	1134	10	21
C	13	3.89	1120	1124	1130	1133	6	13
A	30	8.97	1424	1430	1504	1506	34	42
C	30	8.97	1130	1135	1155	1158	20	28
B	30	8.97	1218	1220	1238	1240	18	22
A	20	5.98	1029	1031	1110	1113	39	44
B	30	8.97	1232	1236	1304	1305	29	33
C	30	8.97	1235	1236	1309	1310	33	35

[a] All dives on 100% oxygen.

Table 2: Dives at 16,000 ft Donag Tsho

Diver ID	Operating Depth ffw	Operating Depth msw	On Gas	Left Surface	Arrived Surface	Off Gas	Total Time in Water, min	Total Time on Gas, min
C	20	5.98	0957	0959	1038	1040	39	43
B	10	1.50	1120	1122	1129	1130	7	10
B	33	9.87	1132	1132	1155	1157	23	25
A	33	9.87	1513	1515	1537	1538	22	25
C	20	5.98	1603	1614	1628	1629	14	26
B	10	1.50	1613	1621	1628	1629	7	16
B[a]	98	29.32	1050	1051	1055	1057	4	7
A[a]	98	29.32	1123	1125	1130	1131	5	8

[a]Dives using 60% O_2: 40% N_2; all other dives on 100% O_2.

because all routine tasks were designed around hand-tight adjustments, which avoided the need for tools. SofnoLime sodasorb proved effective. It was necessary to crack open the tops of the polythene cartons every 2 days during the march-in to release the pressure built up by the increase in altitude, but this did not impair the effectiveness of the sodasorb.

The neoprene in our unisuits began to perish quite quickly due to a combination of rough treatment in transit and wide variation in temperatures. Toward the end of the expedition, one suit was abandoned completely and all the others leaked. The woolly-bear undersuits and other thermal underwear served well, although at the top lake they never fully defrosted.

DISCUSSION

We believe that the key to success was the easing of both men and equipment into the diving operation. Rushed movements quickly fatigued the divers and risked damage to equipment, and it was important to establish a routine and adhere to it.

The SDBA Mk V rebreather functioned extremely well and the design of the sets for field maintenance without tools was a notable benefit. We suggest that future operations be conducted with rubber "skin suits" instead of neoprene suits. Woolly bears and thermal underwear provided adequate protection for the length of dives undertaken. Although all divers reported feeling cold, there was no evidence of clinical hypothermia, possibly because of the good supply of high caloric food and hot drinks, as well as an acceptance by everyone that they were going to be cold anyway, above and below the water.

The USN diving tables for no-stop dives worked well, with no diving illnesses being encountered. It was not possible to test these tables during decompression stops but such trials are planned for future operations. Sahni et al. (3) review two approaches to the use of decompression tables at altitude, one in which tables are specifically calculated for altitude diving, and the other which uses sea-level tables after applying a correction for altitude. Both these approaches have drawbacks: For example, many of the specifically designed tables were inadequate for our purposes because they are calculated only to altitudes of 10,500 ft (3,200 m). Modification from sea-level tables tends to work for no-stop diving but can falter if stops are required. We looked at both approaches before establishing a hybrid whereby an altitude diving profile was established from the model developed by Hennessy (4 and Hennessy, personal communication, 1989), and this was overlaid on the USN tables. These modified tables fit very closely with those adopted for use by the Indian Navy's high altitude diving expedition (3), which was based on the British Royal Navy diving tables (6). Our approach of doubling the actual diving depth to give table depth worked well within the model and provided an increased safety margin for lower altitudes.

All dives were conducted on 100% O_2, except the last two which used 60:40 nitrox. A previous expedition reported difficulties with O_2 at an altitude of 14,200 ft (4,328 m), where O_2 diving was abandoned due to diver discomfort (3). Sahni et al. (3) argued that when surfacing, air starvation and breathing difficulty can occur due to the change from high partial pressure of O_2 during diving to very low partial pressures in the atmosphere at high altitudes, but the change from high to low partial pressure of O_2 on surfacing presented no problems to our expedition. Sahni et al. (3) further speculated that after adapting to low partial pressure of O_2 on the surface, changing over to 100% O_2 under pressure may cause O_2 toxicity at much shallower depths and that this may underlie the inability of the divers to carry out O_2 diving at 14,200 ft (4,328 m). However, the symptoms described by these authors do not correspond to O_2 toxicity, and no problem or discomfort was found by any diver on our expedition through breathing 100% O_2 at either Gokyo Tsho (15,700 ft, 4,785 m) or Donag Tsho (16,000 ft, 4,877 m) on any of the 23 O_2 dives that were completed. Subjectively, both comfort and performance improved on O_2, so O_2 toxicity at such shallow depths seems unlikely. Although discomfort was reported by the divers on the two final nitrox dives, this was not attributed to mixture but was considered a result of the combination of general fatigue, altitude effects, deep diving, and deteriorating suits. Although diving at extreme altitude is still an exploratory endeavor with unique problems and few documented dives above 9,000 ft (2,734 m) on which to build an operational understanding, it is being shown that exploration of waters at extreme altitude is achievable within the constraints of equipment and technology available today.

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