Clinical observation: Beau's lines on fingernails after deep saturation dives.

H. SCHWARTZ

Hyperbaric Treatment Center, University of Hawaii, John A. Burns School of Medicine
347 N. Kuakini Street, Honolulu, HI 96817

Schwartz H. Clinical observation: Beau's lines on fingernails after deep saturation dives.Undersea Hyperb Med 2006; 33(1):5-10. Transverse furrows, or Beau's lines, were noted in the fingernails of all 6 divers following a deep saturation dive to a pressure equal to 1100 feet (335 meters) of sea water (3,370 kPa), and in 2 of 6 divers following a similar dive to 1000 feet (305 meters) of sea water (3,164 kPa). Both dives took place at the Ocean Simulation Facility of the Navy Experimental Diving Unit in Panama City, Florida. The divers breathed a partial pressure of 0.40 - 0.44 atm abs (40.5 – 44.6 kPa) oxygen, with the balance helium, during most of the time under pressure. All divers performed hard work on bicycle ergometers during the dives. Four of the divers on the first dive were treated during the dive for pain-only decompression sickness. Beau's lines have been reported in numerous medical conditions such as typhus, rheumatic fever, malaria, myocardial infarction, and other severe metabolic stresses. To the author's knowledge this is the first report of Beau's lines associated with saturation diving.

INTRODUCTION

Underwater diving is associated with a number of risks and stresses. In addition to the risks of physical injury and drowning there are additional stresses due to the increased pressure or to changes in pressure. Increased partial pressure of oxygen leads to pulmonary or central nervous system oxygen toxicity. Increased partial pressure of nitrogen causes a narcotic effect. Increased pressure of inert gasses including nitrogen or helium (used in deeper dives to avoid the narcotic effect of nitrogen) results in an increased quantity of inert gas in the body. These gasses must be released gradually to avoid the generation of bubbles in tissues, thought to be the principal abnormality in decompression sickness (1). Arterial gas embolism is the result of over-expansion of pulmonary alveoli during rapid ascent, and may be produced by voluntary closure of the epiglottis or by unrecognized blockages in the bronchial system. Underwater diving typically involves a relatively rapid descent, short stay at depth usually measured in minutes, followed by ascent to the surface according to various decompression schedules.

Saturation diving on the other hand is characterized by slower descents, often to much deeper depths. Durations at depth can be measured in days or weeks, and instead of being in the water for the entire time, saturation divers typically spend most of their time in pressure vessels on board ships or other craft, entering the water for several hours at a time to work. Decompression is slow, and in general takes place at a rate of approximately 100 feet of sea water (fsw), or 33 meters of sea water (msw), per day. Certain risks and stresses are unique to deep saturation diving. High pressure nervous syndrome (HPNS), a constellation of tremors, nausea, and dizziness, is seen with rapid compression, using helium as the inert gas, beyond about 500 fsw (160 msw), and may be ameliorated by slow compression and the addition of a small quantity of nitrogen to the breathing mixture (2). Compression arthralgias have been noted during saturation compressions, particularly when the compression is too rapid (3). Neuropsychological sequelae of deep saturation diving have been reported and include minor problems with sustained attention, concentration, and cognition (4). Prior to the present observation there have been no reports of physical markers of physiologic stress caused by diving, including saturation diving.

Transverse sulci, or Beau's lines, are transversely-directed furrows in the fingernails or toenails that begin at the lunula and gradually move distally with nail growth (Figure 1). They have been attributed to a variety of local and systemic conditions, including severe infectious diseases, or severe malnutrition, and are thought to represent a temporary arrest of nail growth. Table 1 lists specific conditions in which Beau's lines have been observed (5, 6, 7, 8). Transverse white bands, but not furrows, were observed in the fingernails of a 34-year-old man who spent approximately 6 weeks at or above 5,500 meters on Mt. Everest (9).

Fig. 1. Diagram of a Beau's line in a fingernail

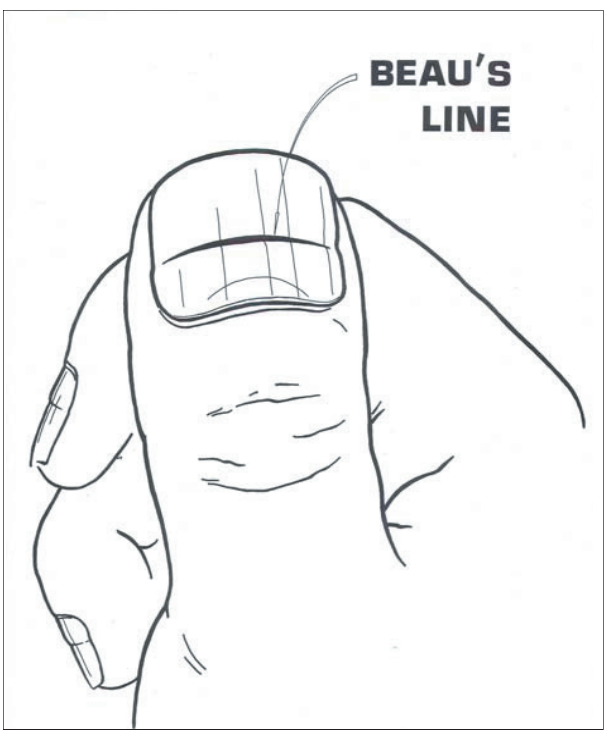


Table 1. Partial list of conditions associated with Beau's lines.

Typhus
Acute rheumatic fever
Diphtheria
Syphilis
Malaria
Vitamin deficiencies
Myocardial infarction
Subacute and chronic pancreatitis with malabsorption
Chemotherapy
Acute gastrointestinal bleeding
Other severe metabolic stresses

To this author's knowledge Beau's lines have never been reported following deep helium-oxygen saturation diving. Saturation diving to 165 fsw (606 kPa) for 10 days using nitrogen-oxygen mixes in 1982 may have been associated with Beau's lines (Morgan Wells, personal communication, 1989).

Following a helium-oxygen deep saturation chamber dive in 1986 to a pressure equal to 1,100 fsw (3,370 kPa) all six divers noted depressions in their fingernails, and brought them to the attention of the medical officer. This report describes Beau's lines noted in these six divers, and in two of six other divers following a deep saturation dive in 1988 to 1,000 fsw (3,164 kPa).

METHODS

Both dives took place in the Ocean Simulation Facility at the Navy Experimental Diving Unit in Panama City, Florida. Navy divers lived in dry chambers and typically made daily excursions into a wet chamber to perform underwater equipment testing, at moderate to heavy exercise rates. The chamber complex was pressurized initially with air to achieve the desired oxygen partial pressure and to add a small percentage of nitrogen to the gas mixture, followed by pressurization to the desired depths with helium. Table 2 gives the compression rates for the dives. The oxygen partial pressure was maintained throughout the dives between 0.40 and 0.44 atm abs (40.5 – 44.6 kPa), until the final two days of decompression when it was allowed to decrease to normoxic. Daily gas analysis samples were analyzed for helium, nitrogen, oxygen, carbon dioxide, and contaminants. Carbon dioxide levels were maintained between 0 and 3.8 mmHg (0.51 kPa). Chamber temperatures were kept at diver comfort from 25.5 to 32° C. The wet chamber water temperature was 2 to 6° C, and the divers wore hot water suits while in the water. Relative humidity in the living spaces was 50 to 60 per cent.

Table 2. Compression rates

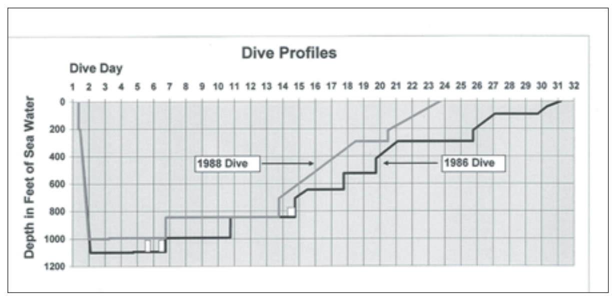
Depth Feet of sea water	Rate Feet per minute	Depth Meters of Sea water	Rate Meters per minute
0-33	60	0-10	18.2
33-200	3	10-61	0.92
200	2-hour hold to check equipment	61	
200-500	2	61-152	0.61
500-1000	1	152-306	0.31
1000-1100	0.5	306-337	0.15

The 1986 dive lasted 31 days, and the maximum pressure was equal to 1,100 fsw (335 msw) (3,370 kPa). Total compression time was 17 hours 7 minutes. The 1988 dive lasted 23 days, and the maximum pressure was equal to 1,000 fsw (304.9 msw) (3,164 kPa). Total compression time was 13 hours 46 minutes. During each dive there were several stays of at least 48 hours at various storage depths. Several short upward or downward excursions were made for equipment testing. This testing typically involved heavy exercise performed by a diver in the water on a bicycle ergometer. When leaving one storage depth for a shallower storage depth, an initial upward excursion was made as permitted by the Navy Diving Manual (3).

The decompression rate during the 1986 dive was constant at 3.8 fsw per hour until reaching 40 fsw, when the rate slowed. The decompression rate during the 1988 dive was 3.8 fsw per hour until reaching 190 fsw, when the rate slowed.

Figure 2 shows the two dive profiles. Divers tested equipment in water 6 feet (2 meters) deep, and these additional depths are not shown on the profiles. Brief upward excursions beyond 6 feet in the 1986 dive are shown as clear boxes.

Fig. 2. Dive profiles

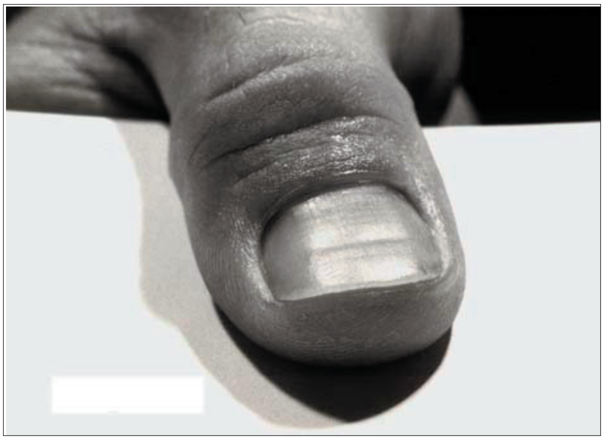


RESULTS

All 12 divers had mild compression pains and mild symptoms of HPNS during the compression phases of both dives. During the 1986 dive several divers noted mild abdominal cramps, loose stools, and nasal congestion, and mild tinea pedis or tinea cruris. One was treated for external otitis, and another was treated for cellulitis of the elbow. During this dive four divers were treated for pain-only decompression sickness. No divers were treated for decompression sickness during the 1988 dive.

Following the 1986 dive all six divers were observed to have Beau's lines. An example from this dive is illustrated in Figure 3. Following the 1988 dive two of the six divers were observed to have Beau's lines. One of the two noted a transient onychodystrophy of two fingernails.

Fig. 3. Example of a Beau's line in a saturation diver



The distances from the middle finger eponychium to the center of the Beau's line on both hands of the divers were measured and are listed with the number of days after surfacing from the dive in Table 3. No new abnormalities in the fingernails were observed during the periods after the dives. The toenails were examined and appeared to show Beau's lines, but were not as easily identified and were not measured. The growth rate of toenails is known to be much slower, from one half to one third that of fingernails (10). Observation of the growth rate of the fingernails fixed the origin of the Beau's lines as occurring during the time of the deep dives.

All divers had physical exams before and after the dives. Weight changes and ages of all divers are shown in Table 4. There were no chamber atmosphere contaminants reported during the dive. All gas mixes remained within specifications. With the exception of the diver who had a mild cellulitis that responded to antibiotics, none of the divers reported any condition previously associated in the medical literature with Beau's lines. All divers performed periods of hard work in the wet chamber during the dive.

Table 3. Greatest distance from the eponychium to the center of the Beau's line in the middle finger

1986 dive			
Diver	Days after dive	Right (mm)	Left (mm)
1	69	5.5	5.5
1	103	10.5	9.0
2	91	10.0	10.0
2	126	12.7	12.7
3	69	5.0	5.0
4	70	5.5	5.0
4	133	12.0	11.0
5	69	6.0	5.0
5	99	8.0	8.0
5	103	9.5	10.5
6	95	12.7	19.0

Table 3. continued

1988 dive			
4	34	3	4
5	34	8	0

Table 4. Ages and weights of divers

1986 Diver number	Age	Weight change Pounds (kilograms)
1	26	-9.5 (-4.6)
2	32	-2.5 (-1.1)
3	25	+4.5 (+2.1)
4	28	+7 (+3.1)
5	34	+3 (+1.3)
6	28	-3 (-1.3)
Average	28.8	-0.5 (-0.2)

1988 Diver number	Age	Weight change Pounds (kilograms)
1	30	-3 (-1.3)
2	26	+5 (+2.3)
3	29	-8 (-3.6)
4	29	-5 (-2.3)
5	32	-1 (-0.6)
6	28	-4 (-1.8)
Average	29	-2.7 (-1.2)

DISCUSSION

It has been estimated that the fingernails grow at a rate of between 0.5 and 1.2 mm per week in normal adults, and require about 5 ½ months to grow from the eponychium to the free edge (10). The nail is pushed distally from the matrix where it is formed. Thus when Beau's lines are observed it is possible to estimate the date of the presumed stress. The measurements indicate that the periods of growth arrest occurred during the time of the saturation dives. What is not so clear is what caused this arrest during relatively routine working exposures to increased pressures for prolonged periods.

Beau's lines have been reported in diverse conditions best summarized as severe physiologic stress. This report is the first time this condition has been noted in saturation divers, and is the first documentation of a sign of physiologic stress in diving. Beau's lines have not been reported in association with the obvious stressors encountered in these dives: brief periods of hard work, brief exposure to cold water, or very brief exposure to cold breathing gases. Other environmental factors are peculiar to this type of diving such as long exposures to helium and increased partial pressures of oxygen. Hyperbaric helium may have had an effect on nail growth that is not related to physiologic stress, and there are no reports that helium is harmful to mammals when breathed for a prolonged period. Oxygen in slightly increased partial pressures similar to these dives has been used in many other settings, and is part of the treatment for many illnesses. Except for the underlying diseases which may have caused severe stress, Beau's lines have never been attributed to increased oxygen exposure. If pressure itself is the cause for the arrest in nail growth, a mechanism is not apparent.

Following the 1986 dive all divers showed Beau's lines. Only two of the six divers in the 1988 dive showed them. The 1988 divers had somewhat less exposure to the conditions associated with diving stress, that is, deep depth and long duration. The decompression schedule was also adjusted to be less stressful. The divers had no decompression sickness during the 1988 dive.

Additional observations may be useful in discovering the mechanism for producing Beau's lines in otherwise healthy saturation divers. Shallower dives using helium could show whether pressure is a contributing factor. Deeper saturation dives to the practical limit of nitrogen as the inert gas, compared with similar profiles using helium, could show whether helium is an important contributor to the growth arrest. While deep saturation diving has not been shown to be harmful in the absence of physical injury or decompression sickness, the appearance of a physiologic stress should be of great interest to those interested in the safety and health of these divers.

ACKNOWLEDGMENTS

1. The United States Navy provided the funding for these studies.
2. Substantially the same data was reported in a poster session at the 1989 Undersea and Hyperbaric Medical Society Annual Scientific Meeting, Honolulu, HI, 7-11 June 1989, Schwartz HJC, Tucker PE, Clinical observation: Beau's lines on fingernails after deep saturation dives.
3. The author wishes to acknowledge the enormous contribution to diving knowledge and safety made by the Navy divers who volunteered for these dives, as well as the military and civilian staff of the Navy Experimental Diving Unit.
4. The views expressed in this report are solely those of the author and do not represent the official views of the Navy Experimental Diving Unit, the United States Navy, or the Department of Defense.

REFERENCES

1. Dutka AJ, Francis TJ. Pathophysiology of Decompression Sickness. In: Bove, ed. Bove and Davis' Diving Medicine. Philadelphia: WB Saunders, 1997:159.
2. Bennett PB. Inert gas narcosis and high pressure nervous syndrome. In: Bove, ed. Bove and Davis' Diving Medicine. Philadelphia: WB Saunders, 1997:117-130.
3. U.S. Navy Diving Manual, Rev 4, change A. Washington, DC: Commander, Naval Sea Systems Command, 2001:chap.3:29-45.
4. Becker B. Neuropsychologic sequelae of a deep saturation dive: a three-year follow-up. In: Bachrach

J, Matzen MM, eds. Underwater physiology VIII. Bethesda, MD: Undersea Medical Society, 1984:707-712.

5. De Nicola P, Morsiani M, Zavagli G. Nail diseases in internal medicine. Springfield, IL: CC Thomas, 1974:44-45.
6. Sauer G. Manual of Skin Diseases, 4th ed. Philadelphia, PA: JB Lippincott, 1980:245.
7. Slee P. Nail changes after chemotherapy. *New England Journal of Med* 1997; 337:168.
8. Lebwohl MG. Atlas of the skin and systemic disease. New York: Churchill Livingston, 1995:57.
9. Hutchinson S, Amin S. Everest nails. *New England Journal of Med*, 1997; 336:229.
10. Samman PD. The Nails in Disease, 3rd ed. Chicago: Year Book Medical Publishers, 1978.