Evaluation of Static Work Load in a Helium-Oxygen Saturation Dive at 31 ATA

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Abstract. The purpose of the present study is to evaluate the static work load as a model work in Submersible Decompression Chamber (SDC) during a deep sea saturation dive with helium-oxygen gas mixture. Heart rate (HR) and electromyogram (EMG) power spectrum changes were studied during a 7-minute static work, half-rising posture or flexed knee posture in four healthy male subjects. During the static work, EMG of the rectus femoris was recorded with surface electrodes, and changes in the EMG power spectrum were presented in the ratio of a high-frequency to low-frequency band (H/L ratio) after the Fourier transform analysis.

The HR decreased at 31 ATA and increased remarkably after the decompression to 1 ATA. HR at post-decompression was higher than pre-compression. The lowering phenomena of EMG presented by H/L ratios during the static work were similarly observed in all three conditions. But the changes of the high and low frequency components were different in the post-decompression condition from the pre-compression and 31 ATA conditions.

HR as a parameter of static work load might underestimate the work load at the hyperbaric environment due to hyperbaric bradycardia and overestimate it after decompression by "decompression tachycardia." The EMG lowering phenomenon observed after decompression might not be caused by the same mechanism as seen in the pre-compression and hyperbaric environments. Extreme care must be taken to evaluate the static work load not only at hyperbaric helium-oxygen environments but after decompression from a deep saturation dive.

(*Appl Human Sci*, 15(2): 81-86, 1996)

Keywords: saturation dive, helium, static work load, EMG, fatigue

Introduction

During saturation diving, the divers' work can be

divided into the three phases: at 1) Deck Decompression Chamber (DDC) for a prolonged diving operation and decompression, 2) Submersible Decompression Chamber (SDC) traveling between the DDC and work site (in the sea or on the sea floor), and 3) the work site (Fig.1). The heaviest work for divers and tender who assists lock-out divers in the SDC has been reported by tend to be the work in the SDC based on their subjective evaluation and heart rate (HR) trends recorded with a portable HR recorder during an open-sea saturation dive (Fig.2). The

Fig. 1 Major components of saturation diving system of JAMSTEC. Surface support vessel KAIYO (semi-submerged catamaran type), DDC (Deck Decompression Chamber), SDC (Submersible Decompression Chamber)

Fig. 2 Heart rate changes of deep divers during the open-sea saturation dive to the depth of 300m.

SDCi: Transfer from DDC to SDC,

SDCo: Transfer from SDC to DDC

L.O.: Lock-out from SDC (swim-out from SDC),

L.I.: Lock-in to SDC (return into SDC)

H.O.: Tender opens the Hatch of SDC

H.C.: Tender closes the hatch of SDC

| : SDC arrived to the sea surface from DDC or from sea floor

total weight of the diver's equipment sums up to 30-40 kg in air and 5-10 kg in water. The spherical SDC working space with an internal diameter of only 2.2 m is extremely limited, and the SDC inside space is further reduced due to the equipment. Divers and tender are also forced to work with a half-rising posture. We employed a static work in the leaning posture as a model of SDC work.

We studied the effects of compression and decompression on muscle fatigue during static work in the deep saturation dive environments. The most useful physiological parameter for a dynamic work load is HR. HR, however, tends to decrease under a helium hyperbaric atmosphere; the phenomenon known as "hyperbaric bradycardia" (Hong et al., 1973; Moore et al., 1976; Conn et al., 1981). Significant changes in oxygen con-

sumption and ventilatory volume for a given work load have not been found in hyperbaric helium environments when compared with 1 ATA air (Overfield et al., 1969; Lambertsen et al., 1977; Salzano et al., 1981). For the static work, we chose not to use the same parameters as the respiratory and circulatory parameters often used to assess a dynamic work (Bezucha et al., 1982). Instead, we evaluated the static work load under a hyperbaric helium-oxygen environment with two parameters: HR and electromyogram (EMG). Studies of the static work in a hyperbaric helium-oxygen environment have not been reported to our best knowledge.

Methods

Dive profile

A simulated saturation dive to an equivalent depth of 300 m (31 ATA) with excursion dives to 270 m (28 ATA) were conducted in a diving chamber located at the Japan Marine Science and Technology Center (JAMSTEC). The dive profile consisted of 5 consecutive periods: 3 days of pre-compression control observation period at 1 ATA air, a half-day of compression with helium from 1 to 31 ATA at rate of 2.5 ATA per hour (one-hour compression stop at 16 and at 26 ATA), 6 days of pressure held at 31 ATA, 11 days of decompression to 1 ATA, and 3 days of post-decompression at 1 ATA in air. Every other day in the period of the pressure held at 31 ATA, the wet chamber that is attached to the DDC was decompressed with the divers to 28 ATA for 8 to 9 hours as a simulated excursion dive. We measured the static work load on the day without the excursion dives. The partial pressure of oxygen was maintained to be 0.4 ATA during the hold of pressure of 31 ATA and 0.5 ATA during the decompression (Fig.3).

Experimental procedures

The protocol of the experiment consisted of 7

Fig. 3 Dive profile of 31 ATA simulated saturation dive with excursion dives to 28 ATA.

Fig. 4 Power spectra of the EMG recording each minute during the half-rising posture. A and H indicate the beginning and the end of half-rising posture for 7 minutes, respectively.

minutes of sitting rest, 1 minute of standing, 7 minutes of the static work (half-rising posture with the knee joint at an angle of 120° and the erect trunk), and 3 minutes sitting at rest in recovery, totaling 18 minutes. HR was obtained every minute throughout the experiment.

EMG of the rectus femoris was recorded directly on the digital recorder (SONY: DR-F1, with a 1 MB floppy disk) for 15 seconds of a 1-minute interval during the half-rising posture work. Two surface electrodes were placed in lengthwise parallel to the muscle fibers. Each 15 seconds of EMG recording was divided into 60 sample records of 256 msec which were digitized at a sampling rate of 2 kHz. These data underwent power spectral analysis using a fast Fourier transform (Lindstrom et al., 1977; Boxtel et al., 1983). Power spectra were computed in the frequency range 0-1000 Hz, with a resolution bandwidth of 3.906 Hz so that each spectrum contained 256 estimates. Then the 60 spectra were averaged (Fig.4). As an indicator of spectral shape, we calculated the ratio between the energy in the high (130-238 Hz) and low (20-40 Hz) frequency range to generate H/L ratio (Gross et al., 1979; Bigland-Ritchie et al., 1981; Harry et al., 1982; Lenoir et al., 1990; Naraki et al., 1991). The H/L ratios were also computed for the

Fig. 5 Heart rate changes during static exercise.

Vertical lines indicate standard error of the mean values. open circle: 1 ATA air pre-compression (8 data), open square: 31 ATA helium (12 data), closed circle: 1 ATA air post-decompression (8 data).

first 15 seconds of the half-rising posture maintained from 5th to 20th second. Also, the H/L ratio index was obtained to present the relative changes from the beginning of the static work. The H/L ratio index at the start of exercise was always 1.00.

Subjects

Four 26 or 27 years old and well-trained male divers in excellent physical condition participated as subjects in the experiment. One week before the study, the subjects began training several times a day for the 7-minute half-rising posture. The static work test was carried out twice at pre-compression, three times at 31 ATA, and twice at post-decompression period for each subject.

Results & Discussion

The subjects reported pain in the rectus femoris region within a few minutes after the half-rising posture began. The pain became nearly unbearable at 4th or 5th minute, although all subjects maintained the static work for 7 minutes at all measurements.

Heart rate changes

HR decreased at 31 ATA after compression and increased 1 ATA after decompression (Fig. 5). At the same 1 ATA air, HR at post-decompression exceeded that of pre-compression. The atmosphere in the hyperbaric chamber was hyperoxic, with 0.40 ATA of oxygen. We speculate that the decrease in HR at 31 ATA was caused not only by the hyperbaric environment with high pressure and high density of respiratory gas (Salzano et al., 1970) but also by the hyperoxic breathing gas (Fagraeus and Linnarson, 1973; Shida and Lin, 1981). Changes in resting HR for compression and decompression

Fig. 6 Mean values of the H/L ratio index of the EMG power spectrum during static exercise at 1 ATA pre-compression and post decompression and 31 ATA helium (mean and standard error).

L low frequency component (20 - 40 Hz) and
H high frequency component (130 - 238 Hz)

sion phases showed a similar tendency that has been reported (Ohta et al., 1981; Lin et al., 1987).

Hyperbaric bradycardia eventually returns to the pre-compression level when divers were maintained at a given maximal hyperbaric pressure for a certain time (Gosovic et al., 1981). The hyperbaric effect on the circulatory function is changed by the HR level (Doubt and Evans 1982). When assessing the static work load using circulatory indices, the pressure holding time period, a subject who is exposed to the hyperbaric conditions, as well as subject's work load and work time must be taken into account.

Electromyogram changes

The peaks in the EMG spectrum increased and shifted to a lower frequency with work time (Fig.4). We could not find any significant difference between environments on the H/L ratio. Then the H/L ratio index was calculated to present the relative change of the H/L ratio. The H/L ratio index changes in the fatiguing run showed an exponential decline, and the decrease of the H/L ratio index at 31 ATA was very similar to that of 1 ATA pre-compression and post-decompression (Fig. 6). But the changes of high and low frequency components of EMG at post-decompression were different from those of pre-compression and 31 ATA as seen as in Figure 7. The reduction of the H/L ratio index for the first two minutes of the static work at pre-compression and 31 ATA was caused by the decreased high frequency component and the slightly increased or constant low frequency component. At post-decompression, however, the H/L ratio index reduction was attributed to the greater decrease in high frequency component than the low frequency component. The lowering phenomenon of

Fig. 7 Changes of high and low frequency components of the EMG power spectrum during static work from the start of static work (mean and standard error).

the EMG power spectrum presented by the H/L ratio could not show each of the frequency component changes. If our observation indicates a true phenomenon, we must consider the reasons for the low frequency component decrease at post-decompression at the onset of muscle fatigue.

EMG analysis, which generally permits an assessment of muscle fatigue during voluntary contraction, shows a shift toward the lower frequencies in the power spectrum (Sato, 1963). This change is mainly caused by an increase in the amplitude of the low frequency in the EMG power spectrum (Boxtel et al., 1983). Various spectral estimates are used for "fatigue indices" such as the centroid frequency, median frequency, and the high/low frequency ratio. We used the H/L ratio to minimize the noise interference. Our results showed a similar shift of the H/L ratio as a function of time in the half-rising posture (Lindstrom et al., 1977; Gross et al., 1979; Bigland-Ritchie et al., 1981; Harry et al., 1982; Lenoir et al., 1990).

The changes in EMG of muscle fatigue at hyperbaric helium-oxygen environments were discussed (Lenoir et al., 1990). The mechanical failure of an exercising skeletal muscle during fatiguing contraction is preceded by an increase in the low frequency component of the EMG (Lindstrom et al., 1970 and 1977; Kadefors et al., 1968). This shift in the EMG power spectrum during fatiguing contraction is caused by the reduction in neuromuscular conduction velocity (Lindstrom et al., 1970). This reduction could be attributed to an inade-

quate blood flow to the contracting muscle in relation to its power output, which in turn results in lactic acid accumulation.

Synchronizing action potentials also increases the power of the low-frequency component of EMG during sustained maximum isometric voluntary contraction of limb muscles. Finally, a fall in the discharge frequency of motoneurons is also observed during prolonged maximal voluntary contraction, reducing the power of the high-frequency band. Low frequency component reduction of the EMG power spectrum in the muscle fatigue was not reported. Extrinsic factors of the lowering phenomenon of the EMG may be induced by muscle cooling, a decrease in muscle thickness, the position of the recording electrodes of the skin, and the operating length of the passive stretched muscle during the isometric contraction.

We have no proven explanation for the different reduction of high and low frequency components of the EMG power spectrum in muscle fatigue at post-decompression when compared with pre-compression and hyperbaric helium environments. We propose a hypothesis that these results were caused by adaptation to the long hyperoxic condition during pressure held at 31 ATA and decompression, and gradually lowering respiratory gas density during decompression, the respiratory gas density at the end of decompression was lower than that of 1 ATA air, and then the oxygen transfer capacity to the tissues decreased under the easy gas exchange conditions. After the decompression, the gas exchanges system must take time for readaptation to the normoxic 1 ATA air condition.

When studying hyperbaric physiology, we have a tendency to look for the differences in the results between at pre-compression and those of the hyperbaric environment. Even when studying the decompression phase, most of the research is addressed on the safety of the decompression procedures. As we have shown in the present study, without decompression sickness, the effects of slow decompression on physiological phenomena could be more severe than the effects of compression.

We must take extreme care when we evaluate the static work load in 1 ATA air pre-compression and post-decompression conditions and at the hyperbaric helium-oxygen environments.

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Received: September 14, 1995

Accepted: January 9, 1996

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