[Case Report]

Effects of Hyperbaric Environment on Human Brain Stem Function with Specific Reference to Auditory Brain Stem Responses

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Abstract : Hyperbaric chamber dives at 31 ATA with helium-oxygen were performed at the Japan Marine Science and Technology Center in 1987. During simulated underwater experiments, auditory brain stem responses were recorded in 4 professional divers for assessment of brain stem function. All divers had no clinical symptoms at 150 m below sea level, and their ABRs also showed no significant changes. During the 150–250 m depth saturation dives, all divers complained of various symptoms such as euphoria, ataxia, joint pain, tremor and dyspnea, while, I – III and I – V interpeak latencies on their ABRs increased with a tendency of recovery. Furthermore, the changes of both interpeak latency were independent of each other. These results indicate that transient dysfunction clinically or subclinically occurred at the processes between 150–300 m below sea level. Moreover, independent changes of I – III and I – V interpeak latencies in this study may mean that the pathways reached to the generation sites of wave III and V were different.

Key words : hyperbaric environment, brain stem function, ABR.

(Received 16 May 1988)

Introduction

The short-latency auditory evoked potentials, commonly referred as auditory brain stem responses (ABRs), consist of 7 vertex-positive peaks within the first 10 msec after stimulus onset (Jewett & Williston, 1971; Leb & Sohmer, 1972). The short latencies of the ABR peaks implicate origins in peripheral and brain stem portions of the auditory system.

Recently, the ABR has proven to be an effective clinical tool for assessing the integrity of brain stem function in clinical populations because of its insensitivity to state variables such as level of consciousness (Amadeo & Shagass, 1973; Zollner *et al.*, 1977), variation in arousal (Picton & Hillyard, 1974) and directed attention (Wood & Hillyard, 1978).

On the other hand, it has been known that various hyperbaric environments of over 21 absolute atmosphere (ATA) cause high pressure nervous syndrome (HPNS) whose clinical signs are characterized by headache, nausea, tremor, ataxia, disturbance of attention, euphoria and joint pain. We had opportunities to participate in experiments of deep dive

in Japan Marine Science Technology Center (JAMSTEC), and have already reported the effects of hyperbaric environment of electroencephalography (EEG) (Matsuoka *et al.*, 1987). The aim of this study is to clarify the effects of a hyperbaric environment at the 300 m below sea level with helium-oxygen on the human brain stem function by using ABR as an objective tool for assessment of its function.

Materials and Methods

Four professional divers, ages 34, 22, 21 and 24 years old, participated in the dives to 300 m. All of them were examined in detail and were found to have no clinical disease including hearing before the experiment. The experiment in a hyperbaric environment was performed in a human diving simulator at JAMSTEC in 1987. The hyperbaric dive took place according to the schedule and environmental parameters shown in Fig. 1.

Brain electrical activity was recorded from silver-silver chloride disk electrodes affixed to the vertex (Cz) and bilateral mastoids. Recordings were obtained from the vertex referred to as ipsi-lateral mastoid (Cz-Mi) with a gain of 200,000 and a bandpass of 100 Hz to 3 kHz (6 dB down). The responses were analyzed for 10 msec after stimulus onset, with a resolution of 20 μ sec per data point. Each trial consisted of 2,000 stimuli and at least 2 trials were obtained to confirm reproducibility of results. Stimuli consisted of alternating rarefaction and condensation clicks, and 100 μ sec duration monaurally delivered at 10/sec at an intensity of 80 dB normal hearing level (nHL) through a couple of TDH-39 headphones. The ABR data were stored on a disk for subsequent off-line analysis. Total compression time including twice one hour pressure holding time was 14 hours, and

Fig. 1. Dive profile: During the compression, pressure holding time (PH = 1 hour) was given twice at the 150 and 250 m below sea level.

ABRs were recorded as 9 epochs in all divers during the compression period (compression rate 25 m/h; see Fig. 1). During the experiment the divers rectal temperature was monitored and their clinical symptoms were recorded in detail. From obtained data I – III and I – V interpeak latencies, which are considered to mean mainly central conduction time of auditory pathway in the brain stem, were analyzed and compared with their symptoms, equivalent depth etc.

Results

Auditory brain stem responses of humans (Fig. 2), recorded between 'Cz' electrode referenced to a mastoid electrode and stimulated by an ipsi-lateral ear, consist of 7 vertex positive waves in the first 10 msec after stimulation. Five early components of them, which are considered to be generated by peripheral and brain stem portions in the auditory system, were designated by their polarity at the vertex (P for positivity and N for negativity) and their approximate latency in msec. Moreover, wave I, II, III, IV and V were regarded as combining the peak to the following trough, i. e., P1-N1, P2-N2, P3-N3, P4-N4 and P5-N5 respectively (Wada *et al.* 1988).

Figure 3 shows the hyperbaric effects on I – III and I – V interpeak latencies, body temperature (rectal temperature) and clinical symptoms in each diver during the compression period. In all divers, both I – III and I – V interpeak latencies showed no significant effect due to the hyperbaric environment until 150 m below sea level as well as their clinical symptoms. At a hyperbaric environment of over 150 m below sea level the divers began to reveal various complaints such as joint pain, euphoria, tremor, ataxia and/or dyspnea. Of these symptoms joint pain, euphoria and ataxia occurred comparatively earlier than tremor and dyspnea. I – III and I – V interpeak latencies were affected at a

Fig. 2. ABRs in a normal adult subject to monaural stimulation. Wave I, II, III, IV and V were regarded as combining the peak to the following trough, i. e., P1-N1, P2-N2, P3-N3, P4-N4 and P5-N5 respectively.

hyperbaric environment corresponding to over 150 m below sea level with individual variation. The I – V interpeak latency in 3 cases (Case YS, NM and F M) was prolonged between 150–250 m below sea level and showed a tendency to recover once, while the remaining case (YK) increased in latency only at the final stage of the compression period. On the other hand, I – III interpeak latency gradually increased from over 150 m below sea level with a tendency of recovery once, except for one case (YS) which continuously increased in I – III interpeak latency. These I – III and I – V interpeak

Fig. 3. Symptoms, body temperature (BT) and changes of I – III (◆) and I – V (▼) interpeak latencies. A, case YS; B, case NM; C, case FM and D, case YK.

latency changes were individually variable and there was no correlation between these interpeak latencies. Moreover, there was no correlation between these changes and body temperature.

Discussion

Saturation dives in a 31 ATA helium oxygen environment have been performed at the JAMSTEC since 1984 to insure human health and safety in similar operations at the bottom of the open sea at around 300 m which corresponds to the depth of the continental shelf in the neighboring sea of Japan. In addition, the detection of HPNS and its prevention have been an important problem for working safety at the bottom of the sea. On the other hand, there are many electrophysiological studies on such hyperbaric environments (Hock *et al.*, 1986; Frost *et al.*, 1970; Naquet *et al.*, 1984; Thorn *et al.*, 1986; Matsuoka *et al.*, 1987). Therefore, this study was conducted to discover the hyperbaric effects on brain stem by using ABRs as one part of the research series. There has been little objective study about brain stem dysfunction caused by hyperbaric environment because of technical difficulty of ABR recordings under such a condition. Only I – III and I – V interpeak latencies were employed in this study for assessment of the integrity of the brain stem function, because these interpeak latencies showed reliable reproducibility in comparison with the amplitudes.

The results in this study clearly indicated that the hyperbaric environment corresponding to up to 150 m below sea level caused an increase of I – III and I – V interpeak latencies on ABRs. According to recent studies about intra-subject, interscorer and intrascorer ABR reliabilities by Lasky *et al.* (1987), mean (SD) differences in msec by wave III and V latencies by successive records (62 dB nHL, 20/sec) were 0.0217 and 0.0166 respectively in adult normal subjects, while the latency changes of these components in this study were much over their 2.5 S. D. with little wave I latency changes. In addition to organic lesions of the brain stem, it has been well-known that some factors influence ABR latencies. Of these influencing factors, body temperature (Jones *et al.* 1977; Stockard & Sharbrough, 1980; Achor & Starr, 1980) and stimulus conditions (Starr & Achor, 1975; Pratt & Sohmer, 1976; Stephens & Thornton, 1976; Huang & Buchwald, 1978) were also important in this study. However, it is clear that changes of the body temperature were not a cause of the increasing of ABR components in this study because there was no correlation between them, e. g., increase in the interpeak latency in spite of rising temperature. The stimulus conditions were fixed during the experiments, but influence of He-O₂ gas or pressure on the stimulus condition can not be overlooked. Both He-O₂ gas and pressure were applied at constant speed, and if I – III or I – V interpeak latency had been influenced by a changing sound stimulus caused by such gas or pressure, the latency changes must be linear (Wada & Starr, 1983a). However, the increasing of interpeak latency in this study was transient and individual. Moreover, if the body temperature or stimulus condition influ-

Fig. 4. ABR changes during the compression period in case FM.

enced the ABRs, not only I – III or I – V interpeak latency but also wave I latency should have changed. However, wave I was always stable as shown in Fig. 4. That is, the increasing of the interpeak latencies in this study means that some brain stem dysfunction occurred at the hyperbaric environments. According to these results the brain stem dysfunction produced by hyperbaric environment corresponding to 300 m below sea level was probably transient because of the recovery of the increased interpeak latency. Moreover, it is an interesting result that I – III and I – V interpeak latencies were individually influenced. These results may mean that stimuli passes through separate pathways from the cochlear nucleus to the generation sites of waves III and V in human ABR. These different pathways to generation sites of wave III and V in animals have been already reported (Buchwald, 1983; Wada & Starr, 1983b).

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高圧環境下における聴性脳幹反応を用いた脳幹機能の評価

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要 旨： 大陸棚開発に必要な水深 300 m での海中作業技術の確立と安全を目的とした海洋技術センターでの潜水シュミレーターを用いて実施された実験に参加し、加圧経過中、聴性脳幹反応 (ABR) を 4 人の被験者 (プロダイバー) に記録する機会を得た。被験者は全員水深 150 m までは何ら異常を示さず、ABR も変化なかったが、水深 150–250 m で関節痛、多幸、振戦、運動失調、呼吸困難等を次々と訴え、ABR の I–III, I–V 頂点間潜時も有意に延長した。この頂点間潜時の延長は水深 300 m までに一旦回復する傾向がみられた。また、これらの ABR の変化は体温変動と相関性はなく、刺激条件等の影響も考えられず、He-O₂ ガスの加圧による脳幹機能の一過性の機能低下によるものと考えられた。さらに、I–III, I–V 頂点間潜時は互いに独立しており、このことは ABR の III 波、V 波の発生源へ達する刺激が独立した別々の伝導路を通る可能性を示唆する所見と考えられた。

J. UOEH (産業医大誌), 10 (3): 317–324 (1988)