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Case Report

A Case of Hyperbaric Therapy Interrupted Due To Ear Pain during Pressurization and Sudden Drop in Muscle Oxygen Saturation in Inactive Muscles

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Abstract

During a session of hyperbaric environmental therapy at the Fukuoka University Faculty of Sports and Health Science Clinic, a student athlete experienced ear pain upon chamber pressurization, leading to interruption of the therapy approximately 5 minutes after reaching 1.3 atmospheres. The interruption was due to pain in the ear and onset of mental anxiety. Throughout the incident, the student athlete maintained a supine position in the chamber and refrained from engaging in any limb or trunk muscle activities. A near-infrared spectrometer was attached to the student's right forearm, enabling continuous monitoring of local muscle oxygenation by the therapist via wireless connection. Within approximately 5 minutes of chamber pressurization, muscle oxygen saturation was observed in the forearm flexor muscle group, registering a significant decrease by approximately 16.4 % compared to resting levels. Analysis of oxygen dynamics, indicating rapid decline in oxygenated hemoglobin and concurrent increase in deoxygenated hemoglobin within the forearm flexor muscles over a brief period of time, led to the inference that intramuscular vascular occlusion had occurred, resulting in impaired blood supply. Despite the mild hyperbaric environment of the chamber, the combined factors of ear pain and heightened psychological distress may have contributed to an exaggerated activation of the sympathetic nervous system.

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Keywords: Hyperbaric Therapy, Ear Pain, Muscle StO_2

Introduction

In recent years, hyperbaric therapy has gained popularity among athletes as a means of promoting early recovery from sports injuries and reduction of training fatigue [1,2]. The duration of this therapy typically ranges from 60 to 90 minutes in a mild hyperbaric environment of approximately 1.3 atmospheres. Therapy at this level of mild hyperbaric environment has only been associated with minor psychological or biological effects [3-7]. Currently, there is no strong evidence confirming significant physiological effects at this pressure level. Clinically, it is recommended that hyperbaric therapy be conducted at pressures of 1.4 atmospheres or higher [8]. In Japan, the standard treatment at medical institutions involves pure oxygen inhalation at pressures ranging from 2.0 to 2.8 atmospheres for 60 to 90 minutes [9,10]. Because of its safety profile, hyperbaric chambers up to 1.3 atmospheres are commonly utilized in private medical institutions, private therapies, and sports-related facilities. At the Fukuoka University Faculty of Sports and Health Science Clinic, hyperbaric therapy is administered to athletes with various sports injuries or those seeking relief from fatigue. This therapy is conducted under the supervision of medical professionals including doctors, sports acupuncturists, and sports trainers. Concurrently, the clinic engages in collection of experimental and practical data using specialized measurement equipment to investigate the effects of hyperbaric therapy on muscle tissue circulation, autonomic nervous system activity, and exercise performance. During data collection, we encountered a case involving a student athlete who experienced ear pain during the pressurization phase within a hyperbaric chamber, subsequently manifesting symptoms of anxiety and mild panic, leading to the interruption of the hyperbaric therapy session. In this case, we conducted observations on the oxygen dynamics within the subject's forearm flexor muscle group before and after pressurization in the chamber using near-infrared spectroscopy (NIRS). The findings are reported here.

Case

This case involved a 20-year-old male ball game player (referred to as Subject A), who had been consistently engaging in weight training and endurance exercises. Subject A did not present with any chronic orthopedic or respiratory-cardiovascular conditions, and he did not report any subjective symptoms at the time of the therapy session. However, he did have a history of past psychiatric consultations related to "depressive tendencies." On the day of the hyperbaric therapy session, he reported no physical issues and was not using any supplements or medications. Prior to the session, the therapist at the clinic provided Subject A with detailed explanations regarding the precautions to be observed during his time in the hyperbaric therapy capsule. Specifically, the therapist highlighted the confined nature of the environment, its enclosed structure, and the possibility of temporary discomfort in the eardrums during pressurization. Subject A confirmed his understanding regarding the instructions provided. Subsequently, a near-infrared spectrometer was attached to the right forearm flexor muscle group, and he was positioned supine in the hyperbaric therapy capsule. At that time, the therapist emphasized the importance of keeping the right arm with the spectrometer attached and refraining from exerting any force on it.

Hyperbaric environment and its interruptions

For the hyperbaric environment therapy, an O_2 chamber (Time World Co., Ltd, Japan) was used. This device was programmed to increase atmospheric pressure by approximately 1.0 kPa within 10 seconds, rising to 1.3 atmospheres in approximately 4 minutes and 30 seconds. There was no change in the oxygen concentration in the chamber, maintaining a level of 20.9% O_2, similar to that of the surrounding atmosphere. Upon entering the chamber, the user lies down in the chamber and the hatch is securely closed. Communication is facilitated through a small reinforced plastic window. Once Subject A was settled in the chamber, the therapist closed the hatch and confirmed the readiness of Subject A before proceeding with the pressurization process. Subsequently, the therapist activated the pressurization switch and monitored the changes in chamber pressure from outside the chamber. Throughout the pressurization process, the therapist maintained continuous communication with Subject A, inquiring about any changes in his physical condition, especially focusing on any issues related to his ears. Shortly after the initiation of pressurization, Subject A began to experience discomfort in his ears and attempted the swallowing method and the Valsalva maneuver. The Valsalva maneuver, commonly used in activities such as scuba diving, involves gently pinching the nose while exhaling with the mouth closed, with the image of biting the nose. Subject A frequently performed ear clearing maneuvers by pinching his nose with his left hand, which was not attached to any measurement device, starting approximately 1 minute into the pressurization process. Until the 2-minute mark following pressurization, Subject A indicated no issues in response to the therapist's inquiries about his physical condition. However, around the 3-minute mark, when the chamber pressure increased to approximately 1.2 bar, Subject A continues to experience ear discomfort despite repeated attempts at the Valsalva maneuver. The therapist suspected that Subject A might be experiencing "ear squeezing," a condition characterized by ear pain due to the inability to equalize pressure in the tympanic chamber cavity of the ear. The therapist noted that there was a possibility for the ear squeeze to improve and stabilize by the 4-minute mark of the process. However, Subject A conveyed through gestures that the ear discomfort was not improving and showed an extremely anxious expression. Consequently, the pressurization process was halted, and the chamber was switched off at the 5-minute mark.

Noninvasive Measurement of Muscle Oxygen Dynamics

Muscle oxygenation of the forearm was non-invasively measured using an NIRS (ASTEM, Co., Ltd, Japan). The device was positioned at the proximal 1/3 point of the forearm flexor muscle group along the line connecting the medial humeral epicondyle and the center of the wrist joint. Data obtained from the NIRS included estimates of total hemoglobin (To-Hb), oxygenated hemoglobin (Oxy-Hb), and deoxygenated hemoglobin (DeOxy-Hb) at a depth of approximately 1.5 cm subcutaneously. These measurements were used to calculate muscle oxygen saturation (StO_2), which served as a reliable indicator of oxygen dynamics in the local muscle groups.

Data acquisition, Analysis, and Statistics

The data obtained through the NIRS included estimates of To-Hb, Oxy-Hb and DeOxy-Hb. The StO_2 was expressed as a percentage from the ratio of Oxy-Hb to To-Hb. These data were transmitted wirelessly from inside the hyperbaric chamber to a computer outside the chamber every second. The StO_2 levels presented in the graphs are represented as mean ± standard deviation (SD) over a 10-second interval. Statistical analysis was performed using one-way analysis of variance and Bonferroni's multiple comparisons test to assess differences in means for changes over time for each indicator.

Results

Figure 1 illustrates the changes in forearm StO_2 level during hyperbaric chamber pressurization. No significant change in forearm StO_2 level was observed until 2 minutes and 20 seconds following the start of pressurization. Subsequently, as the air pressure in the chamber exceeded +15 kPa, a linear decline was noted in the forearm StO_2 level of Subject A. The degree of this decrease ranged from 81.3 ± 0.003% to 64.9 ± 0.004%, indicating a significant StO_2 reduction of 16.4% over a span of 150 seconds ($p<0.01$). There was no overall change in forearm muscle To-Hb level throughout the entire 5-minute pressurization period. However, a detailed analysis of To-Hb values at 10-second intervals revealed a significant difference in mean values between 2 minutes and 00 seconds to 2 minutes and 10 seconds compared to values recorded prior to the 2-minute mark, with a significant decrease ($p<0.01$) in blood volume between 2 minutes and 20 seconds to 2 minutes and 30 seconds. In contrast, forearm muscle DeOxy-Hb level exhibited a significant increase from 2 minutes and 30 seconds to the 5-minute duration, with a 1.81-fold increase at the 150-second mark (Figure 2).

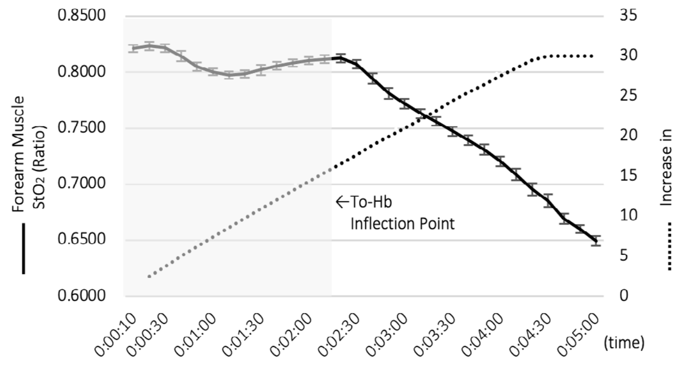

Figure 1 Linear decrease in forearm muscle oxygen saturation that occurred during chamber pressure increase

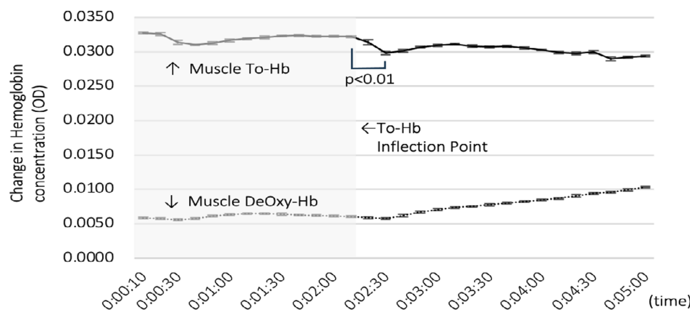

Figure 2 Dynamics of total and deoxygenated Hb in forearm flexor muscle groups during chamber pressurization

Discussion

This study presents a case analysis focusing on the dynamics of forearm muscle oxygenation during a mild hyperbaric therapy session, which was interrupted due to ear pain and anxiety experienced by the subject in the middle of pressurization. Despite the relatively mild pressure level of approximately +15 kPa above atmospheric pressure, Subject A reported discomfort, ear pain, and anxiety, prompting termination of the therapy session. Notably, the observed linear decrease in forearm StO_2 level during this period decreased linearly, with a decrease of 16.4% over a duration of 150 seconds, despite the absence of muscle activity. To the best of our knowledge, this is the first study examining the biological effects of high-pressure environments, reporting a significant decrease in StO_2 level during a hyperbaric therapy session. In this case, several factors such as the enclosed environment, pressurization, ear pain, anxiety, and individual psychological characteristics were assumed to have contributed to an excessive state of tension, resulting to heightened activity of the muscle sympathetic nervous system and consequent muscle vasoconstriction. Generally, mental stress signals are processed in the dorsomedial hypothalamus. These processed mental stress signals are then transmitted throughout the body as excitatory signals via the sympathetic nervous system, resulting in physical responses, which may include increased body temperature, vasoconstriction, and muscle tension [11]. According to a study conducted by Oyama, et al., mental stress induced by heightened mental workload increases sympathetic nerve activity, consequently increasing muscle tone [12]. Fadel, et al., through animal experimentation involving electrical stimulation, observed a decrease in muscle blood flow and oxygenated hemoglobin with increased sympathomimetic nerve activity [13]. Similarly, Ogata et al. reported a decrease in oxygenated hemoglobin levels within inactive muscle groups during exercise in humans, suggesting a correlation between muscle sympathetic nerve activity and muscle oxygenation dynamics [14]. Herein, we present a case wherein the decrease in forearm muscle To-Hb between 2 min 10 sec and 2 min 30 sec was attributed to vasoconstriction resulting from sympathetic nervous system activation induced by mental stress. The data depicted in Figure 2 illustrates a consistent decrease in forearm muscle To-Hb during this timeframe. Furthermore, the significant 1.81-fold increase in forearm muscle DeOxy-Hb observed between 2 min 30 sec and 5 min, similar to the StO_2 results, was interpreted as an increase in muscle metabolism due to increased muscle tone resulting from sympathetic nervous system activation induced by mental stress.

Saiki et al. reported otological issues commonly experienced by scuba divers, with more than 60% of cases reporting ear pain associated with changes in water pressure [15]. For safe diving, it is recommended to perform proper ear clearing at a depth of approximately 1 m, before ear pain escalates to the level of pain near the eardrum. During hyperbaric treatment, it is advisable to initiate ear clearing procedures around a pressure increase of +10 kpa in the chamber. It was presumed that Subject A, unable to undergo this procedure, experienced both physical pain and mental stress. Additionally, it has been shown that there is a general decline in autonomic nervous system function in individuals with depressive disorders, as well as an increase in peripheral vascular sympathetic nerve activity in those with panic disorders [16]. Therefore, prior health checks that consider the client's mental and developmental characteristics, as well as continuous monitoring during the therapy session, may be necessary.

Conclusion

Even in cases where a patient exhibits excellent physical health and lacks immediate physical or mental health concerns before undergoing hyperbaric therapy, a history of depressive tendencies or panic disorder may indicate susceptibility to experiencing mental stress. It has been suggested that pressure-induced ear pain and claustrophobic anxiety may activate the sympathetic nervous system, resulting in both muscular vasoconstriction and muscular tension.

Ethical Considerations and Conflicts of Interest

Approval for the use of forearm NIRS during hyperbaric therapy was obtained from the Ethics Review Committee of Fukuoka University (Approval No. 23-06-02). The therapist verbally explained to Subject A the purpose of hyperbaric therapy, its implementation, and side effects, and obtained verbal and written consent. There are no conflicts of interest to be disclosed in the reporting of this case.

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