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Research Progress on the Influence of Aerobic Exercise on Oxidative Stress in High-altitude Environments

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Abstract

In today's society, with the increasing public health awareness, people's attention to health and sports shows a continuous growth trend. Against this background, sports research in high-altitude environments has attracted more and more attention from all parties, and has gradually become a hot topic in the field of sports science. High-altitude areas have special environmental factors that distinguish them from plains, such as hypoxia, low temperature and strong ultraviolet rays. Among these factors, hypoxia plays a key role, which has a profound impact on the exercise performance and physiological response of the human body. As a popular exercise mode, when carried out in a high-altitude environment, aerobic exercise will promote a series of unique physiological changes in the human body, including oxidative stress. An extremely important aspect. This article aims to comprehensively and systematically review the relevant research results of the impact of aerobic exercise on oxidative stress in high-altitude environments, and to deeply explain the mechanism of oxidative stress in the process of high-altitude aerobic exercise, the characteristics of changes, and its specific impact on the body. At the same time, the forward-looking outlook for the future research direction in this field is expected to provide a solid theoretical basis for sports health protection and sports training optimization in high-altitude areas, and help the high-altitude sports field be better developed.

Keywords

high-altitude environment, aerobic exercise, oxidative stress, research progress

1. Introduction

Due to the unique geographical conditions in high-altitude areas, the atmospheric oxygen division is significantly lower than that of sea level. When the human body is in a high-altitude environment and engages in aerobic exercise, the body's demand for oxygen rises sharply, but the oxygen supply is difficult to meet synchronously. This imbalance of supply and demand triggers a series of intricate physiological reactions. As a key stress response of the body in the face of high-altitude special environments and motor stimuli, oxidative stress has a profound impact on human health and motor

ability. On the one hand, moderate oxidative stress may activate the body's self-protection mechanism and enhance its adaptability to the plateau environment; on the other hand, excessive oxidative stress may cause cell and tissue damage, damage health and affect exercise performance. In-depth exploration of the intrinsic relationship between aerobic exercise and oxidative stress in a high-altitude environment can not only provide effective guidance for residents in plateau areas to carry out sports and fitness scientifically and reasonably, and help athletes improve their performance in plateau training, but also have an indispensable significance for the prevention of various high-altitude-related diseases.

2. High-altitude Environment and Oxidative Stress

2.1 Characteristics of High-altitude Environment

The high-altitude environment has many unique characteristics, mainly covering hypoxia, low temperature, high ultraviolet radiation and low pressure. These characteristics are intertwined, forming special environmental conditions that distinguish them from the plains. Among these characteristics, hypoxia is undoubtedly the most prominent and critical feature. As the altitude continues to rise, the oxygen pressure in the atmosphere shows a gradual decreasing trend. Taking the actual data as an example, at an altitude of 3,000 meters, the oxygen division pressure is only about 70% of the sea level; and when the altitude reaches 5,000 meters, the oxygen division pressure drops to about 50% of the sea level. This obvious reduction in oxygen division pressure greatly reduces the amount of oxygen in the air that can be ingested by the human body. The hypoxic environment is like a double-edged sword, which has a wide and significant impact on many important systems of the human body. The first is the respiratory system. In order to obtain enough oxygen, the respiratory rate and depth will involuntarily increase to make up for the lack of oxygen intake as much as possible. However, in this state for a long time, the burden on the respiratory system will continue to increase, which is easy to cause respiratory diseases such as plateau pulmonary edema. The cardiovascular system is also facing serious challenges. In order to ensure the oxygen supply of all tissues and organs of the body, the heart has to work harder, accelerate the heart rate, and increase the contraction of the heart. However, if this compensatory mechanism is in a state of high-intensity operation for a long time, it will increase the load on the heart, which may lead to cardiovascular problems such as arrhythmia and myocardial hypertrophy. The nervous system is also difficult to escape. Hypoxia will affect the normal metabolism and function of nerve cells, resulting in a series of neurological symptoms such as dizziness, headache, insomnia, memory loss, etc. In severe cases, it may even cause plateau cerebral edema, threatening life safety. It can be said that the hypoxic environment is the core factor that causes a series of physiological and pathological changes in the body. It breaks the physiological balance that the human body has adapted to in the plain environment, forcing the body to activate a series of complex compensation and regulation mechanisms. However, these mechanisms cannot always effectively cope with the pressure caused by hypoxia. When the body's adaptation limit is exceeded, it will cause various plateau-related

diseases, which poses a serious threat to human health. Therefore, an in-depth understanding of the prominent characteristics of hypoxia in high-altitude environments and its impact on the human body are crucial for people living, working and exercising at high altitudes.

2.2 The Concept and Mechanism of Oxidative Stress

As a key physiological and pathological concept in the field of life sciences, oxidative stress refers to the breaking of the balance of oxidation and antioxidant systems that were originally finely maintained in the body when the body encounters all kinds of harmful stimuli. At this time, a large amount of reactive oxygen (ROS) is generated, which far exceeds the effective removal ability of the body's antioxidant defense system, which triggers the body's oxidative damage and presents a pathological state. Under normal physiological conditions, the production and removal of ROS in the body are in a fine dynamic balance. ROS is not just a substance harmful to the body. In fact, it plays an indispensable role in many important physiological processes. For example, in the process of cell signal transmission, an appropriate amount of ROS, as a signal molecule, participates in key activities such as regulating cell growth, differentiation and apoptosis, and ensures the orderly progress of cell functions. In terms of immune defense, ROS can help immune cells resist the invasion of pathogens and destroy the structure and function of pathogens through oxidation, thus protecting the body from disease. However, when the body is in a special stress state such as a high-altitude environment, the situation changes significantly. The peculiarity of the high-altitude environment is that low oxygen, low temperature, strong ultraviolet rays and other factors are intertwined with each other, which together have an impact on the body. In terms of oxidative stress, the hypoxic environment plays the first role. At high altitudes, the oxygen content is significantly reduced, and the respiratory chain function of mitochondria, the "energy factory" of cells, will be seriously affected. The mitochondrial respiratory chain is responsible for electron transfer and energy generation in the process of cell respiration. When it is in a hypoxic environment, the electron transfer process is abnormal and the electron leakage increases, resulting in a large number of ROS. In addition, low temperatures and strong ultraviolet rays in high altitudes should not be underestimated. The low-temperature environment can change the mobility of the cell membrane, affecting the metabolic pathway and signal transduction process in cells. Strong ultraviolet rays have high energy and can directly damage biological macromolecules, such as DNA, proteins, etc. Both of these factors can further increase the generation of intracellular ROS by activating the relevant signaling pathways. For example, low temperature may activate some cold stress-related signaling pathways, and strong ultraviolet rays can activate the light stress signaling pathways in cells. The activation of these pathways will eventually lead to a cascade reaction generated by ROS, causing the ROS level in the cell to rise sharply, breaking the original oxidation and antioxidant balance, and triggering oxidative stress, causing potential damage threats to the cells and tissues of the body.

3. The Influence of Aerobic Exercise on Oxidative Stress in High-altitude Environments

3.1 The Effect of Acute Aerobic Exercise

When the body is in a high-altitude environment and carries out acute aerobic exercise, it will immediately face the double severe challenges of hypoxia and exercise, which causes the level of oxidative stress to rise rapidly and significantly. High-altitude areas themselves have scarce oxygen content, and aerobic exercise greatly increases the body's demand for oxygen. This contradiction between supply and demand leads to rapid changes in the physiological state of the body. Many studies have strongly shown that after experiencing acute high-altitude exercise, the content of reactive oxygen (ROS) in the blood will show a significant growth trend. At the same time, the content of lipid peroxidation products such as propylene aldehyde (MDA) will also increase. Lipid peroxidation is a key process of oxidative stress damage to cell membranes. The increase in MDA content intuitively reflects the increasing degree of oxidative damage in the body. It is worth noting that antioxidant enzymes such as superoxide dismutase (SOD) and glutathione peroxidase (GSH - Px) play an important defensive role in this process. In the early stage of acute exercise, in the face of sharply increased oxidative stress, the activity of these antioxidant enzymes will increase rapidly in a short period of time. They are like the "defense guards" of the body, actively responding to the attack of ROS, trying to remove it to maintain the body's oxidation-oxidation balance. However, this kind of defense is not endless. With the continuous extension of exercise time and the gradual increase in exercise intensity, the activity of antioxidant enzymes may show a downward trend. This means that in the state of high-load exercise, the body's antioxidant ability is gradually consumed excessively, and it cannot sustainably and effectively cope with a large number of ROS, resulting in further aggravating the degree of oxidative stress. Take a study of a group of healthy men as an example, asking them to do 30 minutes of moderate-intensity aerobic exercise at a high altitude of 4,000 meters. After the exercise, it was found that the content of propaldehyde (MDA) increased by 30% compared with before the exercise, which clearly showed the increase in the degree of lipid peroxidation in the body, that is, the deepening of oxidative damage. At the same time, the activity of superoxide dismutase (SOD) increases immediately after the end of exercise, indicating that the body's antioxidant defense system has reacted quickly. However, it is worrying that after re-testing one hour after the end of exercise, the SOD activity is significantly lower than the pre-exercise level, which fully proves that with the passage of time after exercise, the activity of antioxidant enzymes decreases, the body's antioxidant ability weakens, and the degree of oxidative stress further deepens. This research example vividly demonstrates the dynamic impact of acute aerobic exercise in a high-altitude environment on the level of oxidative stress in the body, and also highlights the importance of understanding these changes for scientific guidance of high-altitude exercise.

3.2 The Influence of Long-term Aerobic Exercise

If you persist in aerobic exercise for a long time in a high-altitude environment, the body will continue to be stimulated by hypoxia and exercise, resulting in a series of adaptive changes. Among them, the

change in the level of oxidative stress is particularly complex and shows multifaceted. From a positive point of view, long-term aerobic exercise can induce an adaptively enhanced response to the body's antioxidant defense system. At the cellular level, this adaptability is manifested as an upregulation of antioxidant enzyme-related genes such as superoxide dismutase (SOD) and glutathione peroxidase (GSH-Px). Simply put, it is like receiving a danger signal inside the body, so the emergency "order" of the gene responsible for producing antioxidant enzymes to increase the "yield". With the increase in the expression of these antioxidant enzyme genes, the activity of enzymes will continue to increase. These antioxidant enzymes are like "clean guards" in the body. The enhancement of their activity greatly improves the body's ability to remove reactive oxygen (ROS), thus effectively reducing the damage caused by oxidative stress to the body. This process is like building a stronger "shield" for the body to resist the attack of the "enemy" ROS. However, things always have two sides. Excessive long-term high-altitude aerobic exercise may have negative effects on the body. Long-term and high-intensity exercise can easily lead to excessive fatigue, which will further damage the function of mitochondria. As the "energy factory" of cells, after the function of mitochondria is impaired, the electron transfer process will be disordered, resulting in a continuous increase in ROS. Even if the body's antioxidant enzyme activity is increased due to the previous adaptive reaction at this time, it is difficult to maintain the equilibrium state of redox in the body in the face of a large number of continuous ROS. It seems that although the "shield" is thickened, the enemy's attack is too fierce, and it will eventually break through the defense line, causing oxidative stress damage. A tracking observation study of people who live in high altitudes for a long time and insist on aerobic exercise clearly reveals this difference. The study divided the observed subjects into moderate exercise groups and excessive exercise groups. The exercise mode of the moderate exercise group is 3-5 times a week, and each exercise lasts 30-60 minutes. The results show that the oxidative stress index of this group of people is at a relatively stable and low level, indicating that their bodies can better maintain the redox balance during long-term exercise, and the oxidative stress damage is relatively small. The exercise intensity of the excessive exercise group is significantly higher, with more than 7 exercises a week, and each exercise lasts more than 90 minutes. In this group, the content of propaldehyde (MDA) continued to increase. As a product of lipid peroxidation, the increase in MDA means that the degree of oxidative damage to the body is aggravated. At the same time, although the antioxidant enzyme activity is high, the fluctuation is large, which indicates that the body's antioxidant defense system is trying its best to cope with it, but due to the excessive production of ROS, it is difficult to maintain a stable balance, suggesting that there is a potential risk of oxidative stress damage in this group of people. This study fully shows that when conducting long-term aerobic exercise at high altitude, it is very important to grasp the "degree" of exercise. Only moderate exercise can effectively avoid oxidative stress damage while enhancing the body's adaptability.

4. The Effect of Oxidative Stress on High-altitude Aerobic Exercise Bodies

4.1 Impact on Athletic Ability

When performing aerobic exercise at high altitude, there is a close and complex relationship between oxidative stress and motor ability, which plays a crucial role in sports performance. Moderate oxidative stress is not completely harmful. On the contrary, it can act as a special signal stimulus. When the body feels this moderate oxidative stress, it is like receiving an "alarm signal", and the associated signal pathway in the cell will be activated. This series of activated signal pathways is like the internal command system of the body, guiding the body to make a series of positive adaptive changes. For example, they will promote the production of red blood cells. Red blood cells are like a "van" that transports oxygen in the body. More red blood cells mean that they can transport more oxygen to various tissues and organs of the body, thus meeting the body's oxygen needs during exercise in high altitude and low oxygen environments. At the same time, these signaling pathways can also improve the respiratory function of mitochondria. As the "energy factory" of cells, the improvement of mitochondria's respiratory function means that it can generate more energy for cells, provide more sufficient motivation for movement, and thus improve motor ability to a certain extent. When oxidative stress exceeds a certain limit, that is, excessive oxidative stress occurs, the situation becomes unoptimistic. Excessive oxidative stress is like a destructive "destructor", which will cause damage to muscle tissue. Muscles are like the "engine" of exercise. When muscle tissue is damaged, its contractile function is bound to be affected, resulting in a decrease in muscle endurance and strength. Imagine that if the parts of the engine are damaged, the power output will naturally be greatly reduced. Not only that, oxidative stress will also "attack" cell membranes and destroy the integrity of cell membranes. For cells, cell membranes are like a solid wall, protecting various structures and substances inside the cells, and are also responsible for important functions such as ion transport and nerve conduction. Once the cell membrane is destroyed, ion transport will be disordered and nerve conduction will be hindered. This is like the paralysis of the transportation and communication systems in cities, which makes the body unable to coordinate movement normally, and fatigue will occur in advance, eventually leading to a decline in motor ability. Many studies show that under the special background of high-altitude environment, there is an obvious positive correlation between the level of oxidative stress and the degree of exercise fatigue. Specifically, when the content of MDA, an indicator that can reflect the degree of oxidative stress, exceeds a certain threshold, it is like a trigger of a danger signal, and the athlete's endurance performance and speed endurance will be significantly reduced. This fully shows that in high-altitude aerobic exercise, the impact of oxidative stress on athletic ability cannot be ignored, and maintaining a moderate level of oxidative stress is crucial to ensuring athletic ability.

4.2 Impact on Physical Health

When doing aerobic exercise in a high-altitude environment, if the oxidative stress caused by it is not controlled in a timely and effective manner, it will bring a series of negative effects to the body's health, like a hidden "time bomb", which threatens the various systems of the body. Oxidative stress has a

strong destructive power, which can directly damage Biological macromolecules such as wound cell membranes, proteins and DNA. As an important barrier for cells, once the cell membrane is damaged, the exchange of substances and information transmission inside and outside the cell will be disturbed, affecting the normal function of the cell. Proteins are the main bearers of life activities. If their structure and function are damaged by oxidative stress, many physiological processes will not be able to proceed normally. As a carrier of genetic information, DNA may cause genetic mutations after being damaged, burying hidden dangers for the occurrence of various diseases. This injury further increases the risk of cardiovascular disease, neurological disease and altitude sickness. Take the cardiovascular system as an example, oxidative stress causes damage to vascular endothelial cells, which is like "making a cure" in the inner wall of the blood vessels. Vascular endothelial cells can finely regulate the contraction and diastolic of blood vessels and maintain smooth blood circulation. However, after the damage, the contraction and diastolic function of the blood vessels will fall into disorder, which greatly increases the probability of high blood pressure and puts extra pressure on the cardiovascular system. The nervous system is also difficult to escape the "attack" of oxidative stress. The nervous system is extremely sensitive to oxidative stress. Once damaged, the symptoms of altitude sickness will be significantly aggravated. Common headaches, dizziness, insomnia and other symptoms will be more serious, affecting people's daily life and work. What's more serious is that if this damage accumulates for a long time, it may also lead to cognitive dysfunction, affecting memory, attention and thinking ability, and causing a heavy blow to personal physical and mental health. In addition, oxidative stress will also quietly weaken the body's immune function. The immune system is the "Great Wall of Steel" for the body to resist the invasion of pathogens. When the immune function is damaged, this line of defense will become fragile, and the body is more susceptible to infection by various pathogens. Imagine that there are holes in the originally strong defense line, and the germs from the outside will take the opportunity to enter and cause various diseases. Therefore, when doing aerobic exercise at high altitude, we must attach great importance to the impact of oxidative stress on physical health, and take effective measures to control it to maintain the health of the body.

5. Factors Affecting Aerobic Oxidative Stress in High-altitude Environments

5.1 Altitude

Altitude plays a crucial role in the process of oxidative stress caused by high-altitude aerobic exercise, which can be regarded as the core element affecting this process. As the altitude continues to rise, the oxygen content in the air decreases sharply, and the hypoxia becomes more serious. This change directly leads to an increasingly prominent imbalance between oxygen supply and demand faced by the body. We know that the demand for oxygen will increase significantly when the body is doing aerobic exercise. However, in a high-altitude environment, as the altitude rises, the oxygen supply cannot meet this demand growth. Therefore, in order to cope with the challenge of hypoxia, a series of changes will occur in the metabolic process in cells, one of which is the large amount of active oxygen (ROS) is

produced. ROS is like a "by-product" released by the body when dealing with low oxygen pressure. When hypoxia intensifies, that is, when the altitude rises, the amount of "by-product" generated will increase significantly, resulting in a significant increase in the level of oxidative stress. Many studies have deeply explored the relationship between altitude and oxidative stress, and have achieved valuable results. The research data clearly shows that when the altitude is within the range of 2000-3000 meters, the oxidation stress index shows a linear upward trend with the increase of altitude. This means that within this altitude range, each time a certain altitude is increased, the level of oxidative stress will increase at a relatively stable rate. When the altitude exceeds 3,000 meters, the situation becomes more obvious, and the upward trend of oxidative stress indicators becomes steeper. This shows that as the altitude rises further, the influence of the high-altitude environment on oxidative stress during aerobic exercise becomes stronger and more significant. Simply put, the higher the altitude, the greater the pressure caused by hypoxia on the body, which makes the oxidative stress reaction produced by the body more intense. This phenomenon warns us that when doing aerobic exercise at high altitudes, especially in high altitudes, we must fully consider the impact of altitude on oxidative stress, and reasonably plan the intensity and duration of exercise to avoid damage to the body caused by excessive oxidative stress. After all, only by fully understanding and respecting the physiological reactions of the body in different altitudes can we ensure that we enjoy the benefits of exercise while protecting our health to the greatest extent.

5.2 Exercise Intensity and Time

When doing aerobic exercise at high altitude, there is a close relationship between exercise intensity and time and oxidative stress. This connection is like an invisible net, which deeply affects the body's physiological response during movement. In high-altitude areas, the oxygen content itself is relatively low. When the intensity of movement increases and the time is extended, the body's demand for oxygen will soar like a rocket. At this time, hypoxic stress and motor stress are like two "superimposed burdens", pressing on the body at the same time, and this superposition effect is extremely significant. With the continuous rise of oxygen demand, the respiration of the intracellular mitochondria accelerates to meet the energy demand, but in this process, the electron transfer chain is prone to "disorder", resulting in a sharp increase in the production of reactive oxygen (ROS). Too much ROS exceeds the normal processing capacity of the body's antioxidant system, and the degree of oxidative stress is constantly aggravated. Especially in the state of high-intensity and long-term exercise, the body's antioxidant ability is like a constantly consumed "energy pool", which is gradually exhausted. Although the defensive "weapons" such as antioxidant enzymes will work hard at the beginning, in the face of the surging ROS for a long time, they will eventually be "powerless" and unable to remove too many ROS in a timely and effective manner. In this way, the oxidative damage will become more and more serious, just like a dike constantly hit by floods, gradually cracking and even collapsing. On the contrary, moderate exercise intensity and time can become a "benign stimulus" for the body. When the body is in this state, it is like receiving a gentle "signal", which will activate its own adaptation

mechanism. At the cellular level, this adaptation is manifested as the upward adjustment of the expression of antioxidant-related genes, which enhances the activity of antioxidant enzymes and improves the antioxidant ability of the body to a certain extent. In this way, the body can better maintain the redox balance, just like a skilled dancer, maintaining a beautiful and stable posture on the "stage" of oxidation and oxidation, not only enjoying the benefits of exercise, but also avoiding the damage caused by excessive oxidative stress.

5.3 Individual Differences

When doing aerobic exercise in a high-altitude environment, the impact of individual differences on the level of oxidative stress cannot be ignored. Many factors such as age, gender, physical fitness and plateau adaptability, like intricate silk threads, intertwine to affect the body's oxidative stress response in high-altitude movement. Age is one of the important influencing factors. Young people usually have vigorous metabolic ability, and their antioxidant system functions are stronger. It's like a car with excellent performance, with a more efficient "power system" and "protection device". During high-altitude exercise, young people have good resistance to oxidative stress with good metabolism and antioxidant ability, and can better cope with the double pressure caused by hypoxia and exercise. Gender differences also play a role in it. The study found that men's oxidative stress reaction is often slightly higher than that of women during high-altitude movement. This difference may be due to different levels of sex hormones. Sex hormones are like the "regulating knob" in the body, which plays a subtle regulating role on the body's antioxidant system. The difference in sex hormone levels between men and women makes them show different degrees of response when facing the oxidative stress caused by high-altitude exercise. Physical fitness is also a key factor affecting the level of oxidative stress. Individuals with good physical quality have better functions such as cardiopulmonary function and muscle strength. They can more effectively ingest and utilize oxygen during high-altitude exercise and reduce oxidative stress caused by hypoxia. Like well-trained athletes, they can better adapt to the environment and reduce the damage caused by oxidative stress on the special "field" at high altitudes. Plateau adaptability has a significant impact on the level of oxidative stress. Individuals who have undergone plateau adaptation training have gradually adapted to the hypoxia environment, just like the specially modified "equipment", and the tolerance to hypoxia has been greatly enhanced. During aerobic exercise, their bodies can regulate the metabolic process more rationally and reduce the production of reactive oxygen (ROS), resulting in a relatively low level of oxidative stress. Those who have just entered the plateau, because their bodies have not yet adapted to the low-oxygen environment of the plateau, are like recruits who have just entered a strange battlefield, are more susceptible to the impact of oxidative stress and oxidative damage.

6. Research Outlook

6.1 In-depth Exploration of Molecular Mechanisms

In a high-altitude environment, the relationship between aerobic exercise and oxidative stress has

attracted wide attention from the scientific community, and we have accumulated a certain amount of knowledge. However, just as only shallows have been explored in the vast scientific ocean, there are still large areas of unknown "deep-sea areas" waiting for us to explore in the key field of molecular mechanism. At present, although we know that high-altitude aerobic exercise can lead to changes in the level of oxidative stress, we have limited understanding of the precise molecular mechanisms behind it. As a key factor in oxidative stress, reactive oxygen (ROS) involves a series of complex molecular signaling pathways. At the same time, the body's antioxidant defense system will also be activated through specific molecular signaling pathways when dealing with ROS. However, the specific details of these pathways, including the various molecules, proteins and interactions between them, have not been fully clarified. In addition, the influence of related gene polymorphism on oxidative stress response is also a mysterious area. Genetic polymorphism is like a "personalized label" at the genetic level. There are subtle differences in each person's genes, which may cause individuals to have different oxidative stress reactions in the face of high-altitude aerobic exercise. For example, some genetic polymorphism may make individuals more active in antioxidant enzymes, thus responding more effectively to oxidative stress; while others may make individuals more sensitive to oxidative stress. However, the polymorphism of which genes is closely related to high-altitude motor oxidative stress, and how they work, need to be solved urgently. It is extremely important to study these molecular mechanisms in depth. It can not only help us fundamentally reveal the nature of high-altitude motion oxidative stress, but also open a door to the depths of the mystery of life for us, so that we can see more clearly the internal operation mechanism of this complex physiological process. More importantly, it will lay a solid theoretical foundation for the formulation of scientific and reasonable sports intervention strategies. By understanding the molecular mechanism, we can accurately design exercise schemes according to the genetic characteristics and molecular signaling pathways of individuals, such as adjusting the intensity, duration and frequency of exercise, so as to achieve the purpose of not only giving full play to the benefits of high-altitude exercise to the body, but also to minimize oxidative stress damage. This is of immeasurable value for ensuring the health of residents at high altitudes and guiding athletes to conduct scientific training in the plateau environment.

6.2 Formulation of Personalized Sports Programs

When doing aerobic exercise at high altitude, the impact of individual differences on oxidative stress should not be underestimated. Factors such as age, gender, physical condition and plateau adaptation are like a unique "key", each opening the door of the body's response to movement and oxidative stress in different ways. In view of this, the future research direction should focus on how to tailor personalized exercise plans according to these different individual characteristics. Age is one of the key factors. Young people have active physical function, vigorous metabolism, and relatively strong tolerance for high-altitude sports. However, this does not mean that they can exercise without restraint. For young people, exercise programs may focus on appropriately increasing the intensity and duration of exercise under the premise of ensuring safety to stimulate physical potential. For example, combined

with the characteristics of the plateau environment, design challenging aerobic endurance training to improve cardiopulmonary function.

Gender differences should not be ignored either. Men and women have different reactions to high-altitude sports due to different physiological structures and hormone levels. For women, when formulating exercise plans, it is necessary to consider the protective effect of estrogen on the body, and choose sports that are more gentle and focus on flexibility and coordination, such as plateau yoga. Men, on the other hand, can appropriately arrange some training that combines strength and aerobics according to their own muscle strength, such as mountaineering. Physical condition is an important basis for the formulation of exercise programs. Individuals with good physical fitness and adapted to the plateau environment can try more challenging sports to further improve their athletic ability. However, for people who are relatively weak or have not adapted to the plateau for the first time, they should start with low-intensity, short-term exercise, such as slow plateau hiking, and gradually adapt their bodies to changes in the environment. By comprehensively considering these individual differences and formulating a personalized exercise plan, it is expected to achieve the best sports effect and health benefits. It can not only give full play to the positive effects of high-altitude aerobic exercise on the body, such as enhancing cardiopulmonary function and improving endurance, but also minimize the damage caused by oxidative stress to the body, and provide a strong guarantee for the health and sports performance of residents and athletes at high altitudes.

6.3 Research and Development of New Antioxidant Interventions

When doing aerobic exercise at high altitude, the body faces more severe oxidative stress challenges. Therefore, exploring safe and effective new antioxidant interventions has undoubtedly become an important direction in the field of scientific research in the future. Traditional antioxidant supplementation can help the body resist oxidative stress damage to a certain extent. However, with the deepening of the research, its limitations have gradually emerged. Therefore, scientific researchers have set their sights on a wider field and strive to open up more innovative antioxidant pathways. Natural plant extracts are a direction with great potential. Nature is rich in plant resources, and many plants contain antioxidant-active ingredients. For example, flavonoids and polyphenols contained in some plants can efficiently remove free radicals in the body and reduce oxidative stress. Moreover, compared with artificially synthesized antioxidants, natural plant extracts often have better biocompatibility and safety, and have fewer side effects. Bioactive peptides have also attracted much attention. These small molecule peptides can not only directly play an antioxidant role, but also indirectly reduce the damage caused by oxidative stress to the body by regulating the body's immune function and promoting cell repair. They come from a wide range and can be extracted from animals, plants or microorganisms, providing new ideas for antioxidant intervention. In addition, emerging cell therapy and gene therapy technologies have also brought the dawn to regulate the level of oxidative stress during high-altitude aerobic exercise. Cell therapy delivers cells with antioxidant functions to the body, such as mesenchymal stem cells, which can endoculate a variety of antioxidant factors in the body, regulate the

immune microenvironment, and reduce oxidative stress damage. Gene therapy starts from the root cause and enhances the body's own antioxidant ability by changing the expression of relevant genes. Through the in-depth study and application of these new antioxidant interventions, it is expected to build a stronger defense line for high-altitude sports health. It can not only effectively reduce the damage caused by oxidative stress to the body in high-altitude aerobic exercise, but also improve the sports performance of athletes in high-altitude environments, so that people can enjoy the fun and benefits brought by high-altitude exercise while protecting their health to the greatest extent.

7. Conclusion

Carrying out aerobic exercise in a high-altitude environment, the relationship between it and oxidative stress shows an extremely complex situation. This complexity is reflected in multiple levels, especially during acute and long-term movements, changes in the level of oxidative stress follow different laws. In the acute motor stage, the body suddenly faces the dual stimulation of high-altitude and low-oxygen environment and exercise, and the level of oxidative stress rises rapidly. This is due to the sudden increase in exercise intensity, which greatly increases the body's oxygen demand in a short period of time, and the oxygen supply is relatively insufficient in high-altitude environments, resulting in a large amount of activated oxygen (ROS) generation, which leads to the intensification of oxidative stress. For example, after a short period of high-intensity mountaineering, the content of oxidative stress markers such as propylene glycol (MDA) in the blood will increase significantly. During long-term exercise, the change of oxidative stress level is more complicated. In the early stage, the body will try to cope with continuous hypoxia and exercise stress by enhancing the antioxidant defense system, increasing the activity of antioxidant enzymes such as superoxide dismutase (SOD) and glutathione peroxidase (GSH-Px) to maintain the balance of oxidation reduction. However, if the exercise intensity is too high or the time is too long, the body's antioxidant ability may be gradually exhausted, and the oxidative stress damage will be aggravated. Just like athletes who conduct high-intensity training at high altitudes for a long time, excessive fatigue and decreased athletic ability may occur, and the impact of oxidative stress behind this cannot be ignored. The impact of oxidative stress on high-altitude aerobic exercisers is two-sided. Moderate oxidative stress can act as a signal stimulus to promote the body's adaptation to exercise and low oxygen environment, and to a certain extent improve motor ability, such as enhancing red blood cell production to improve oxygen transport capacity. However, excessive oxidative stress will cause damage to the body, affect muscle contraction function, reduce exercise endurance, damage biological macromolecules such as cell membranes, proteins and DNA, and increase the risk of cardiovascular diseases, neurological diseases and altitude sickness. At the same time, factors such as altitude, exercise intensity and time, and individual differences are like intertwined silk threads, which further affect the development of oxidative stress. The higher the altitude, the more serious the hypoxia, and the higher the level of oxidative stress; the greater the exercise intensity and the longer the time, the degree of oxidative stress will often be aggravated;

individuals of different ages, genders, physical qualities and plateau adaptability have different reactions and tolerances to oxidative stress.

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