Training Muscle Capacities in Hypoxic Conditions

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Training muscle capacities in hypoxic conditions increases some manifestations, such as hypertrophy and muscle strength, due to a change in the muscle phenotype as a result of the activation of hypoxia-inducible factors (HIF). Despite the proven benefits of resistance training in hypoxic conditions that allow conjecture regarding the effectiveness in facilitating muscular capacities in different populations, there is still controversy regarding the difference between resistance training in hypoxia and normoxia.

Keywords: muscle development ; hypoxic conditions ; exercises

1. Introduction

Considering the current research developments related to sports and exercise medicine, it is crucial to explore new methods that improve sports performance and optimise health. Studying the novel methods of physical programming is key to proving its effectiveness and impact [1]. In this regard, some interventions focus on muscle strength training as a critical factor that allows the necessary neuromuscular adaptation to maintain optimal physical conditions. Consequently, research on muscle strength training methods and the understanding of adaptations have allowed exploring different interventions that manage intensity, volume, type of exercises, execution sequence, and velocity [2].

Previous evidence has found that even though resistance training in hypoxia increases muscle growth and strength, this modality does not provide additional benefits compared with normal oxygen availability.

Even though the muscle is adaptable to different training methods, it adapts to the type of stimulus to a greater or lesser extent. Among the available training methods in exercise and health sciences, exercising under hypoxic conditions has emerged as an alternative to improve strength. Altitude training facilitates physiological and biochemical adaptations in muscles [3][4]. Still, due to the lack of evidence, there is increasing interest in how hypoxia could boost exercise interventions. The challenge is to determine which hypoxic conditions are more suitable to achieve the necessary adaptations efficiently and effectively for a specific population [5].

Some research on hypoxia in sports and exercise medicine has evidenced an improvement in variables related to skeletal muscle function. This method has shown an increase in the maximum voluntary contraction, increased muscle size in the cross-sectional area, and improved muscular endurance and mitochondrial angiogenesis and biogenesis [6]. Hypoxia training also offers special conditions for strength training through muscle hypertrophy due to a change in muscle phenotype by activation of hypoxia-inducible factors (hypoxia-inducible factor, HIF), which in turn affects the expression of genes in charge of the functional part of skeletal muscle tissue, as well as the gene transcription related to erythropoiesis and angiogenesis [7].

The benefits and muscular adaptations to strength training under hypoxia vary from changes in blood volume leading to haemoconcentration (a reduction in plasma volume) to improved muscle mechanical function. Training muscle strength under hypoxic conditions has increased intramuscular metabolic stress, enhanced hypertrophic signalling and muscle hypertrophy, and increased anabolic hormone concentration. In the long term, this method causes improvements in oxygen transport and uptake, which expose the muscle to metabolic stress that facilitates adaptation and increases the recruitment of motor units so that a larger portion of the muscle is stimulated [8].

In addition, positive results have been explored using hypoxic low-intensity strength training, leading to an observed increase in motor unit recruitment and muscular endurance. [9][10]. One of the reasons why hypoxia can increase muscle hypertrophy at high rates compared to normoxia conditions is the greater amount of metabolic stress during training caused by the lack of oxygen availability [11]. This response can be associated with the higher hypoxic intramuscular environment that results from training; for that reason, there is greater dependence on anaerobic processes and, therefore, a greater accumulation of metabolic by-products, such as blood lactate, that stimulate muscle growth.

2. Training Muscle Capacities in Hypoxic Conditions

It is known that muscular strength training leads to structural or neural adaptations and that these improvements influence muscle growth and the effectiveness of the muscle in generating force [12][13]. In addition, strength training contributes to sports performance [6][14][15][16][17][18][19] and is also beneficial to health [20][21][22][23][24][25][26][27][28][29][30][31]. Resistance training leads to morphological muscle adaptations such as hypertrophy and increased strength due to changes in muscle fibre diameter, protein synthesis of myofibrils and increased anaerobic capacity [7][12][13]. In addition, it causes changes in metabolic characteristics such as mitochondrial synthesis, increases in lactate tolerance, and improvements in oxidative function and muscle endurance capacity [7].

Therefore, strength training induces these changes due to the metabolic stress it generates since the energy pathways used in this type of training generate an anabolic situation that, in turn, causes an increase in anabolic signalling proteins, giving way to the creation of metabolites that promote myofibrillar protein synthesis. Consequently, these muscle proteins balance with satellite cells and bind to the muscle fibre. This balance is only achieved when the protein synthesis rate exceeds its breakdown because of the work carried out by satellite cells in muscle hypertrophy [7][32].

Hypoxic training on muscle hypertrophy and strength development is an issue that has become relevant in recent years. Part of the theory is associated with greater metabolic stress than normoxic training since there is more dependence on the anaerobic metabolism, which contributes to muscular adaptations [15][33]. Training in hypoxia has been postulated as a factor that stimulates capillary growth through increased nitric oxide production and greater vasodilation, as well as increased expression of the vascular endothelial growth factor gene (VEGF). This factor is induced by HIF-1; these signals, due to the activation of the HIF factor, affect the expression of a greater number of genes. Most of these genes have functional relevance in muscle tissue adaptations and are related to erythropoiesis, angiogenesis, pH and glycolysis regulation [7][21].

2.1. Changes in Muscle Size Due to Hypoxia

Hypoxia was observed to provoke some positive results concerning muscle growth [14][15][16][17][20][24][25][26][27][28][29][30]. However, in some papers, no substantial change was proven between groups (normoxia vs. hypoxia), suggesting that one training method is neither more nor less effective. Those studies that presented statistically significant differences ($p < 0.05$) in the hypoxia group [14][17][24][25][26][27][29], can be due to methodological particularities, and no strong recommendations could be made so far based on this evidence.

Some documents found greater benefits in the hypoxic group. These studies share certain methodological characteristics, such as training programmes of between 4 to 7 weeks [14][27][28], which can be considered a relatively moderate training time. Evidence [27] suggests that chronic exposure to altitude could lead to an adverse effect on hypertrophy since prolonged exposure can generate a reduction in the cross-sectional area of the muscle (CSA), and a decrease in the size of the muscle fibres.

2.2. Changes in Muscle Strength Due to Hypoxia

Strength training in hypoxic conditions is a new horizon for training programmes to improve strength capacity, as proposed in some studies [26]. Furthermore, some contrasting evidence suggests that strength training under hypoxic conditions has or has not greater benefits than under normoxia [2].

Methodological consistency was found in the hypertrophy-selected variables. Regarding strength variables results, in some studies, a higher percentage of change was found [14][18][20][23][27][31]. These studies shared the duration of the intervention (4–8 weeks) [14][18][20][23][27] and reported a load intensity of 50–70%, considering a low-moderate load. Additionally, increased strength was reported when a low training load was applied under hypoxic conditions [14]. This can also be noted when intensities of 85–90% of 1RM were used [26].

The physiological mechanisms caused by the low load in strength training are not entirely understood. Type I muscle fibres are thought to fatigue earlier in a low-load, hypoxic environment and are highly recruited. The recruitment of type II fibres can cause growth hormone alterations and testosterone because of hypertrophy and muscle strength [24][30].

Finally, regarding the training volume, in those studies reporting the highest percentage of change, a total of three to four series and six to fifteen repetitions were programmed Falta algo. [14][18][20][23][27]. Another study used three sets to failure, and the results had a small impact on the hypoxia group compared to the control group [24]. In addition, there was a small impact on the percentage of change between groups, using >25 repetitions [22]. Concerning the body segments used, the highest rate of change was found in those studies where different body segments were involved [14][18][20][23][27][31].

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