INTRODUCTION: Training under hypoxic conditions is believed to be useful for improving aerobic performance by increasing erthropoietin and maximum oxygen intake (VO2 max) [1]. However, the effects of resistance training under hypoxic conditions with recovery in normoxia are mostly unknown. Takarada et al. [2] reported that low-intensity training (30-50% 1RM) with vascular occlusion not only increased electrophysiological muscle activities during exercise, but also significantly increased cross-sectional area (CSA) in normoxia. The brachialis and triceps brachii muscles increased after 16 weeks of training. These studies suggest that the restricted blood circulation caused an intermittent hypoxic and acidic muscular environment, which induces the recruitment of additional motor units and leads to greater muscle hypertrophy. We conducted the present study under the assumption that muscle hypertrophy could be efficiently achieved by resistance training under conditions of intermittent systemic hypoxia.

MATERIALS AND METHODS: Subjects: Subjects comprised 14 male university students (age (mean ± standard deviation): 21.4±1.1 years; height: 173.0±5.4 cm; body weight: 65.9±8.1 kg; percent body fat: 12.6±3.7%). Subjects were randomly divided into the following groups: hypoxia group (HC group, n=7); and normoxia group (NC group, n=7). Intensity of training was set based on the maximum weight that could be lifted in the entire range of motion (1RM) in normoxia. The constant hypoxic room (Alticube, USK, Nara, Japan) consists of a compressor, a hypoxia generator with a polymer membrane and a hypoxic chamber. During training, oxygen concentration was monitored and maintained at 16%. Training: Each subject was instructed to hold a dumbbell in the non-dominant hand and perform French press and arm curl in the standing position. For the hypoxia group, the subject was asked to rest in the sitting position inside the hypoxic chamber for 30 min before training. For the normoxia group, the subject was asked to rest in the sitting position in a normoxic environment for 30 min before training. During training, exercise intensity was set at 70% 1RM for both French press and arm curl. Each training session consisted of 4 sets of 10 repetitions each, with a 1-min break between sets. If a subject could not finish 10 repetitions, the set was finished at that point. A 3-min break was provided between sets of French press and arm curl. For the hypoxia group, after the end of each training session, the subject rested in the hypoxic chamber for 30 min and then left the chamber for the next bout of exercise. At 3 weeks after the start of training, muscle strength was again measured to adjust the intensity level of exercise as needed. Students trained twice a week for 6 consecutive weeks (total, 12 sessions). Subjects were instructed to raise or lower the dumbbell at comparable rates in about 3 s (1 s for concentric movement, 2 s for eccentric movement).

Magnetic resonance images (MRI): To measure CSA of the upper arm, a 1.5-T super coiling system (Excel ART, Toshiba, Tokyo, Japan) was used. CSA was measured for the exercise side of the NC group, the HC-E group (exercise-side for the HC group) and the HC-N group (non-exercise side for the HC group). Multislice sequences with a 6-mm interval were taken under the following conditions: 1.0 mm intersection gap; 20×20 cm field of view (FOV); spin echo T1-weighted pulse sequence; 500 ms repetition time; and 15 ms echo time. Of 11 slices, 3 images at the center of the upper arm were chosen to measure CSA of muscles. Determinations of tissue outlines and measurements of CSAs for muscles and other tissues were made by Image J (version 1.37v) software. CSA was measured 3 times and averaged. In relation to CSA before training, the percentage increase in CSA was calculated.

Muscle strength measurement: The 1RM was determined by 8-10 RM tests. In each subject, 1RM was measured 1 week before the start of training and was measured again 3 and 6 weeks after the start of training. SpO2: SpO2 was measured 10 min before and 0 and 30 min and 24 h after each training session using PULSOX-3i (Minolta, Osaka, Japan). SpO2 after 24 h of both groups were measured under normoxic conditions.

Rating of Perceived Exertion (RPE): Using the Borg’s 6-20 RPE scale [3], the level of perceived exertion was assessed after training. After each training session, the subject was asked “How hard was it?” The RPE score of each subject was determined based on grades ranging from “very, very light: 6 points” to “very, very heavy: 20 points”.

Statistical analysis: In comparisons among effects of HC-E, HC-N, and NC, examinations of statistical significance were based on one-way analysis of variance followed by Bonferroni post hoc testing. Differences between two variables within the same individual were examined with Student’s paired t-test. To examine differences between HC and NC in muscle strength (1RM), SpO2 and RPE, Student’s unpaired t-test was used. For all statistical analysis, p<0.05 with Bonferroni correction was regarded as significant.

RESULTS: Changes in CSA after training: For the HC-E group, compared to before training, percent increase of the elbow extensor and flexor significantly increased in size (p<0.05) (Fig. 1). For the HC-E group, the degree of increase for extensors and flexors at week 6 was 7.3% and 9.6%, respectively. Conversely, no significant increase was seen for NC or HC-N groups.

1RM: Significant increases were confirmed for both HC and NC groups (Fig. 2). The degree of increase in muscle strength following French press and arm curl for the HC group was 71.1% and 61.6%, respectively, and the NC group 56.4% and 38.9%, respectively. For both groups, a significant increase was seen between before training and 6 weeks after training, and between 0 and 3 weeks after training, but a significant increase in French press and arm curl was seen between before training and 3 weeks after training only for the HC group.

SpO2: For the HC group, SpO2 was significantly lower 10 min before and 0 and 30 min after training. At 24 h after training, no significant intergroup difference in SpO2 was apparent, as this measurement was made under normoxic conditions in both groups.

RPE: Figure 5 shows changes in RPE. For both French press and arm curl, no significant differences existed in RPE.

DISCUSSION: Compared to resistance training under normoxic conditions, resistance training under hypoxic conditions efficiently improves muscle strength and induces muscle hypertrophy faster without markedly elevating perceived exertion (RPE). While further studies are being carried out to investigate whether any harmful effects can be induced during training, resistance training under hypoxic conditions may be a new useful training method.


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