Changes in Total Work, Total Work Ratio, Heart Rate, and Blood Lactate during 75% 1-RM Bench Press Exercise

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Background and Objectives

This study was conducted to investigate the change of total work and total work ratio for each set, peak heart rate during exercise, and blood lactate for each set during the 5-set bench press exercise at 75% one repetition maximum test (1-RM).

Materials and Methods

Seven men in their 20s with more than 6 months of experience doing resistance exercises were selected as subjects, and their 1-RM bench press was measured two weeks before the experiment and 75% 1-RM was measured one week before the experiment. In this study, total work was measured for each set, and heart rate was measured during rest and set-by-set exercise. Blood lactate was measured during rest time after each set. The raw data were analyzed by repeated one-way ANOVA.

Results

Total work and total work ratio decreased from 1 set to 4 sets ($p < .05$), $p < .001$), heart rate increased from stable at the start of exercise ($p < .001$) and decreased between 3 sets and 4 sets ($p < .05$). Blood lactate increased continuously up to 2 sets ($p < .001$, $p < .01$).

Conclusion

In conclusion, total work and heart rate decreased with muscle fatigue during exercise, and blood lactate continuously increased. The results of this study are expected to be useful references for constructing resistance exercise programs in the future.

Key words

Bench press; Total work; Heart rate; Blood lactate; Exercise set

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INTRODUCTION

The purpose of resistance exercise is to stimulate the physiological system in the body to make adaptation.¹ It is known as a very effective method for improving strength, hypertrophy and endurance. This effect is influenced by intensity, set, number of repetition, rest time.² In particular, as a training method for skeletal muscle growth and hypertrophy, national strength and conditioning association (NSCA) recommends performing up to 3-6 sets with a weight of 67-85% one repetition maximum (1RM).³

In weight training, the total work is expressed as the product of the lifted weight and the number of repetitions, and since it is in inverse proportion to the weight load, the training effect may differ depending on the amount of exercise performed, so it must be configured according to the training purpose.³ Bompa said that exercise can change the metabolic temperament, endocrine response, and neuromuscular fatigue level, so it can be used as an indicator of training stress, and if too much or too little, the effect of exercise is decreased.⁴ Generally, resistance exercise is composed of several sets and the accumulated muscle fatigue as exercise performance continues leads to a decrease in power output and performance speed, which eventually leads to a set to failure, which reduces exercise volume.⁵ As such, resistance exercise performed to the point of failure of repetition is known to contribute to the increase of gene expression and activation of motor units related to muscle recovery due to the increase of mechanical stress, and it is reported that the effect increases as the number of sets is performed.⁶

Mechanical stress caused by resistance exercise stimulates the PI3K/Akt signaling pathway that causes assimilation by stimulating proteins that maintain the shape of myocytes such as integrin, cadherin, and cytoskeletal proteins, and metabolic stress caused⁷ by the anaerobic process contributes to the synthesis of muscle proteins by generating metabolic products such as hydrogen ions, inorganic phosphates, ammonia, etc.⁸

Peterson et al.⁹ reported that the effect size of each set was analyzed and significant effect was shown in 4-8 sets. Krieger¹⁰ showed a larger effect size as the number of sets increased when applying resistance exercise of muscle hypertrophy strength, and it showed a clear effect from 4-6 sets. In addition, Wernbom et al.¹¹ showed the greatest cross-sectional area in training for 4-6 set, and it was inconsistent with the researchers because it was ineffective in 3-3.5 sets and 9 sets.

The increase in afferent stimulation and venous return due to mechanical contraction of the muscles during

exercise inhibits the activity of the vagus nerve, which causes the heart rate to rise.^{12,13} Heart rate is used as an indicator of cardiopulmonary training strength,¹⁴ but it is necessary to investigate the change of heart rate according to resistance exercise because it includes factors such as accumulation of metabolic products and increase of plasma amount along with the release of catecholamine among the factors that increase heart rate.^{15,16} The heart rate during exercise shows a smaller increase in resistance exercise than in aerobic exercise, and increases as the intensity of exercise or duration of exercise increases.¹⁷ Pierce et al.¹⁸ reported that the heart rate during resistance exercise increased as the exercise intensity increased, but Lee et al.¹⁹ reported that the heart rate during resistance exercise increased at the beginning of exercise and decreased as the set continued.

The lactate generated as a product of the glycolysis during resistance exercise is used as an energy substrate in the state of sufficient aerobic, but in the state of anaerobic, the hydrogen ion emitted by oxidizing pyruvate reduces the pH in the muscle. The decrease in the pH level due to hypoxia inhibits nerve conduction in the muscle and decreases protein binding of calcium ions, thereby interfering with muscle contraction.²⁰ Rogatzki et al.¹ suggested that blood lactate in weight training can be used as an indicator of muscle fatigue and metabolic load as a marker of PCr depletion and glycogen use. And it is known that blood lactate during exercise increases as the reliance of Type II motor unit increases.^{21,22} Therefore, as the amount of exercise increases, the blood lactate is also affected. In previous studies, it was reported that the 3 set higher than 1 set at 12 RM weight,²³ and Alcaraz et al. reported²⁴ that the higher the number of sets, the higher the blood lactate.

As such, indicators for monitoring the perceived intensity and fatigue level during exercise in sports fields are used, but among them, heart rate and lactate have been mainly applied only to aerobic endurance training. In particular, most of the studies on resistance exercise were investigated only before and after exercise,²⁵ and even though there was a clear difference between the aerobic exercise method and the exercise progression pattern, which continued to perform exercise, it was only investigated over time.²³ Therefore, this study investigated changes in total workload, heart rate, and blood lactate during a 75% 1 RM 5-set bench press exercise to obtain data that can be used for future resistance exercise program composition.

MATERIALS AND METHODS

Subject

The subjects of this study consisted of 7 men who were enrolled in Dankook University of Chungnam and had experience in resistance exercise for more than 6 months. In accordance with the regulations of the institutional review board (IRB) based on the declaration of helsinki for the finally selected personnel, the purpose of the study, the contents and participation period of the study, risk factors, and the freedom to stop the experiment were explained, and then voluntary consent was obtained. In order to obtain accurate research results during the experimental period, the subjects were instructed to refrain from smoking, drinking alcohol, and moderate physical activity during the experiment. Table 1 shows the characteristics of the study subjects.

Study design

After selecting subjects, the maximum strength of the bench press was measured 2 weeks before the experiment, and then the weight of 75% 1 RM to be applied to the experiment was measured based on the 1RM measured 1 week before. On the day of the experiment, the subject arrived at 30 minutes before the experiment, rested, measured the heart rate and blood lactate, and performed bench press exercise with a maximum repetition of 5 sets with a weight load of 75% 1 RM determined in the preliminary test. Rest time between sets was set to 2 minutes. The total work and heart rate were measured during exercise, and the blood lactate was measured a rest time between each set.

Bench press exercise

The subjects of the study were to attach their head, shoulders, and hips on a flat bench, lie down in a five-part contact position in which the soles of the feet touch the floor, and then hold the barbell with a closed pronation grip that is at the width of the shoulders. At the beginning of the measurement, a signal was given to the assistant to lift the barbell onto the subject's chest, and the assistant gently released the lifted barbell while the subject was straightening his arm to start the exercise. The subjects were instructed to keep their wrists firmly when perform-

ing the bench press operation and to repeat the movement of pushing down the bar until the elbow was bent to 90°.

75% 1 RM testing

To determine the weight of 75% 1 RM of bench press, the Haff and Triplett³ literature was referred and then applied to the measurement environment to test the maximum weight of bench press once twice a week before the experiment, and 75% 1 RM was measured based on 1 RM measured a 1 week ago. The first set was prepared with a weight that can be repeated 5 to 10 times during 1 RM measurement, and the weight load of 5-10 kg was increased after 1 minute rest to lift it. After that, the rest time was provided for 2 minutes, and the weight of 5-10 kg was increased to determine the weight expected to be repeated 2-3 times, and then lifted and provided a 2-4 minute rest. Then, the weight of 5-10 kg was further increased to try 1 RM. When the bench press was successful, the weight was further increased after a 2-4 minute rest, and when the bench press failed, the weight of 2.5-5 kg was decreased after a 2-4 minute rest, and the 1 RM was determined by retrying. The weight was determined based on the number of times performed in the correct posture, and an assistant was placed to prevent the risk of injury during measurement.

Total work and total work ratio calculation

In order to measure the total work for each set, it was calculated by multiplying the number of successful lifting of the weight between each set (the number of repetitions) and the lifting weight. The total work ratio was calculated based on the total work of one set. Total work and total work ratio calculation is as follows.

Total work (kg) = [weight load (kg)] [number of repetition]

Total work ratio(%) = $\frac{[\text{total work each set}]}{[\text{total work of 1 set}]} \times 100$

Heart rate measurement

The heart rate for each period was measured using a wireless heart rate sensor (Polar, Finland) at rest, and the peak value during exercise for each set. The wireless heart rate sensor was measured by placing the sensor

Table 1. The characteristics of the subjects

N	Age (year)	Weight (kg)	Height (cm)	Career (year)	Bench press 1 RM (kg)
7	26.38 ± 3.02	79.13 ± 3.44	174.75 ± 4.20	2.88 ± 1.46	94.13 ± 10.68

on the xiphoid process of the chest and then interlocking with the polar beat software (ver. 3.3, Polar Electro). The heart rate measuring equipment shown in Fig. 1.

Blood lactate measurement

The lactate concentration of the whole capillary blood was measured at rest using a portable lactate analyzer (Lactate pro 2, Japan), 6 times each after exercise for each set, and blood was collected through the earlobe using a needle lancet-coupled. Before measurement, the blood collection area was sterilized with an alcohol cotton, dried, and then punched, and 3-5 μL of whole blood was buried in a strip connected to a blood lactate analyzer for analysis. Before the bench press, the experiment was conducted only when the blood lactate was less than 2 mmol during stability, and when it came out more than 2 mmol, the experiment was performed after rest for 30 minutes and then re-measured. The blood lactate measuring equipment shown in Fig. 2.

Statistical analysis

For data processing measured in this experiment, the mean and standard deviation of all variables were calculated using the IBM SPSS Statistics (ver 22.0) statistical program. Total work, heart rate, and blood lactate concentration by period were analyzed using the repeated

one-way ANOVA method, and if significant differences were found, post-comparison was performed using the repeated method. The statistical significance level was set $\alpha = .05$.

RESULTS

Change in total work

The total work showed a statistically significant change as the set continued. As a result of post-mortem comparison, it significantly decreased from set 1 to set 4, respectively, and after set 4, there was no statistical significance. The results of repeated measurement one-way variance analysis and post-comparison for total work and total work ratio during bench press exercise are as shown in Table 2. And the change in total work shown in Fig. 3 and 4.

Change in heart rate

Heart rate showed a statistically significant change as the set continued. As a result of the post-mortem comparison, it increased between rest and set 1, and decreased between sets 3 and 4. The results of repeated measurement one-way variance analysis and post-comparison for heart rate per time during bench press exercise are as shown in Table 3. And the change in heart rate shown in Fig. 5.

Fig. 1. Polar H10 heart rate sensor.

Fig. 2. Lactate pro 2.

Table 2. Changes in total work during 10 RM bench press exercise

	1 set	2 set	3 set	4 set	5 set	F	p	contrast
Total work (kg)	711.43 $\pm$ 49.14	*588.14 $\pm$ 111.87	***373.71 $\pm$ 93.04	***263.57 $\pm$ 97.84	235.57 $\pm$ 86.30	80.882	.000	① > ② > ③ > ④⑤
Total work ratio (%)	100.00 $\pm$ 00.00	*82.86 $\pm$ 16.04	***52.86 $\pm$ 13.80	***37.14 $\pm$ 13.80	32.86 $\pm$ 11.13	84.788	.000	① > ② > ③ > ④⑤

M $\pm$ SD, Significant differences between time of before: * $p < .05$, *** $p < .001$.

Change in blood lactate

The blood lactate showed a statistically significant change as the set continued. As a result of post-mortem comparison, there was a significant increase from rest to 2 sets, and there was no statistical significance after 2 sets. The results of repeated measurement one-way vari-

ance analysis and post-comparison for blood lactate per time during bench press exercise are as shown in Table 4. And the change in blood lactate shown in Fig. 6.

Fig. 3. Change in total work.

Fig. 5. Change in heart rate.

Fig. 4. Change in total work ratio.

Fig. 6. Change in blood lactate.

Table 3. Changes in heart rate during 10 RM bench press exercise

	Rest	1 set	2 set	3 set	4 set	5 set	F	p	contrast
Heart rate (bpm)	70.57 ± 9.48	***151.14 ± 16.30	144.43 ± 12.84	141.86 ± 15.59	*136.29 ± 13.03	136.28 ± 11.53	64.620	.000	⑧ < ①②③ > ④⑤

M ± SD, Significant differences between time of before: * $p < .05$, *** $p < .001$.

Table 4. Changes in blood lactate during 10 RM bench press exercise

	Rest	1 set	2 set	3 set	4 set	5 set	F	p	contrast
Blood lactate (mmol)	1.53 ± 0.28	5.04 ± 1.48	7.09 ± 2.01	7.90 ± 1.73	7.94 ± 1.50	8.90 ± 1.89	37.655	.000	⑧ < ①** < ②*③④⑤

M ± SD, Significant differences between time of before: * $p < .05$, ** $p < .01$.

DISCUSSION

Muscle fatigue that occurs during the duration of resistance exercise generates metabolites such as hydrogen ions and inorganic phosphoric acid, which occur at the same time as the blood lactate increases, which changes homeostasis in the human body.²⁰ Persistent local fatigue and intramuscular acidification cause fatigue of the central nervous system, which interferes with exercise performance and reaches the point of failure of exercise.⁶ Since continuous muscle contraction at the point of failure of exercise can contribute to additional stimulation for muscle growth, this study attempted to investigate changes in total exercise volume, heart rate, and blood lactate during 5-set bench press exercise of 75% 1 RM.

The total work is calculated by multiplying the weight performed, the number of repetitions, and the number of sets, and it is said that the training effect may appear differently depending on the amount of exercise performed.³ Bompa and Buzzichelli⁴ reported that exercise is related to metabolic temperament, endocrine response, and neuromuscular fatigue, so it can be used as an indicator of training stress. In this study, the total work showed a significant change between sets and decreased to 1-4 sets. Kim⁵ reported that performing several sets of constant intensity induces muscle fatigue and reduces the number of repetitions.

Simão et al.²⁶ reported that when the 80% 1 RM 3 set bench press was set to 2 minutes, it tended to decrease to 10.2 times in the first set, 8.2 times in the second set, and 6.7 times in the third set. The results of this study also showed that the total work of exercise gradually decreased as the muscle fatigue due to the preceding exercise accumulated even though the exercise performance using the same exercise intensity between the sets was performed. In particular, there was no significant difference in exercise amount after 4 sets. In this case, the mechanical and metabolic stress in the muscle accumulates, resulting in a failure point of exercise and the mobilization of Type II motor unit. A number of previous studies⁹⁻¹¹ reported that more than 4 sets showed a clear muscle hypertrophy effect, so even if the amount of exercise decreased to less than 40% compared to the first set, it would be necessary to continue training to the point of failure.

Heart rate is used as an indicator of the intensity of exercise given to the heart.¹⁴ During exercise, in response to an increase in muscle mechanical contraction and venous return, it rises as the activity of the vagus nerve decreases,¹³ and an increase in heart rate above 120 bpm

is said to have a greater effect of catecholamines.²⁷ In addition, Noakes et al.²⁸ reported that as the intensity of exercise increases or increases, the stress of the myocardium increases. Alcaraz et al.²⁴ reported that the heart rate during resistance exercise increased as the intensity increased or the duration increased, and Lee et al.²⁹ reported that the higher the weight intensity during resistance exercise by intensity, the higher the heart rate. In this study, heart rate increased between resting and set 1 and decreased between 3 and 4 sets. The lowered heart rate between 3 and 4 sets is believed to be due to a decrease in exercise volume due to muscle fatigue, and it is believed that the decreased muscle activity due to central fatigue due to nerve stimulation and metabolites generated by anaerobic training reduced afferent stimulation.

The blood lactate is a substance produced as a result of anaerobic metabolism of glucose and is known as a fatigue substance that acidifies tissue cells and blood. It is the final product of carbohydrate metabolism when oxygen is not properly supplied to the tissue during high intensity or long-term exercise.³⁰ As the moderate intensity, number of sets, and exercise time continue, the use ratio of Type II fiber increases. In general, it is known that the use of Type II fibers accelerates the production of blood lactate due to high fatigue.²¹ The exercise performed in this study was high in the recruitment ratio of Type II fibers with strength above the medium intensity, and in this case, the anaerobic energy system was applied to obtain energy depending on the ATP-PC system or the anaerobic process.³¹ The gradual increase in blood lactate according to the duration of the set is believed to be because the exercise type performed is a short-time high-intensity exercise that uses intramuscular glycogen as the main fuel, and lactate is produced at the same time as energy is supplied by the anaerobic metabolic process.³² There was no significant difference, but the increase in blood lactate in the 4-5 set was thought to be due to the accumulation of muscle fatigue and the recruitment of additional exercise units to maintain exercise performance.

CONCLUSION

The purpose of this study is to analyze the changes in total work, heart rate, and blood lactate according to the duration of the set during a bench press exercise of 75% 1 RM intensity, which is commonly performed. As a result, the total amount of exercise decreased to 4 sets, and the heart rate remained elevated during the duration of the exercise, and decreased slightly between 3-4 sets. It was confirmed that the blood lactate increased up to 2

sets, and after that, it was maintained at a similar level, so that muscle fatigue caused by continuing exercise decreases the amount of exercise and heart rate, maintains the increased blood lactate level. In conclusion, it is effective to proceed more than 4 sets as a stimulus for muscle growth during bench press maximum repetition exercise at 75% 1 RM intensity, and it is thought that the signs of muscle fatigue can be predicted by a significant decrease in total exercise amount and a decrease in heart rate during exercise. In summary, it is suggested that the total amount of exercise and heart rate decrease with the occurrence of muscle fatigue during exercise, and the blood lactate may be continuously increased. The results of this study may be a reference for constructing the resistance exercise program in the future.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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