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Comparative analysis of basal physical fitness and muscle function in relation to muscle balance pattern using rowing machines[1]

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Abstract. The purpose of this study was to evaluate muscle function and basal physical fitness in relation to muscle balance pattern using rowing machines. Twenty four subjects participated in this study, using three different rowing machines. Rowing exercises were performed for twenty-five times a set, four sets a day, 3 days a week, for 8 weeks. Biodex system 3(Biodex Medical Systems Co., New York, USA) was used to measure joint torques in the elbow, shoulder, lumbar and knee of subjects, for analyzing muscle function. The evaluation of basal physical fitness included body composition, muscle strength, muscle endurance, muscle reaction, agility, flexibility and explosive power. Before the experiment, significant differences of joint torques in the elbow, shoulder, lumbar and knee were present between subjects in the group. After the rowing exercise, significant improvement in every joint was witnessed. All aspects of basic fitness increased significantly, and the most improvement was observed in muscle strength from the joint torque results. As shown in the following results, every joint it was evident to have improved by more than 30% with the use of dependent load deviation type over the previously used water load method. This means that it is more effective for enhancing muscle strength and endurance to keep the muscle balance using dependent load deviation. The human body maintains motor coordination of muscle contraction during exercise. The muscle balances in the upper-lower and left-right arms could assist with effective activation of motor coordination. In this paper, an exercise method using dependent load deviation was demonstrated to be more efficient for improving muscle imbalance and strengthening muscles.

Keywords: Muscle function, basal physical fitness, muscle balance pattern, rowing exercise

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1. Introduction

Recently, areas of sports, healthcare, exercise and leisure have been in the spotlight. Consequently, many related technological and scientific studies are being performed; however, most of the studies concentrated solely on athletic performance enhancement for athletes, or on improving effects for average people. To date, none of the studies have focused on the balance of the human body considering the muscular system, while exercises at random can cause injuries or insufficient results in the human body. Muscle balance means that muscles are built with mutual and balanced strength, endurance and power between antagonist and agonist surrounding a joint situated in the middle. Presently, internal studies on muscle imbalance have been focused on people with injuries and patients who underwent surgery, in addition to external research using isokinetic systems [1–4].

Research on athletes has already progressed to a considerable level, but studies on muscle imbalance have not yet even been clearly defined [5,6]. Most studies have reported that a muscle strength difference of 8~15% between the left and right sides can cause muscle imbalance [7,8]. Many people have bad body positions or work-postures in their daily lives, due to spending too much time on computers or in generally improper environments. Many studies have reported these bad body positions or postures could be the major factors of work-related musculoskeletal disorders [9–15]. Although some reports indicated that there is no relation between exercise injuries and muscle imbalance [16–18], more current research reports have produced various results showing imbalance might be an important predictor of exercise injuries. Moreover, research on muscle imbalance demonstrated that muscle imbalance can be improved significantly in the upper and lower limbs by using the dependent load deviation method.

However, most of the research only mentioned a correlation between muscle imbalance and exercise injuries, for predicting injuries to the human body, without any suggestion on how to improve such imbalance. It is extremely important for athletes and average people to prevent exercise injuries due to muscle imbalance. Therefore, it is equally important to study methods of treating and improving such muscle imbalance.

Our research was performed to study the improvement of muscle function by comparing the levels of muscle balance achieved by dependent load deviation methods.

2. Experimental methods

2.1. Participants

In this study, we recruited one hundred individuals who had no medical history with muscle function and no experience with rowing exercise. We also measured joint torque of shoulder, elbow, lumbar and knee using isokinetic dynamometer in the pre-test. From the test, twenty-four subjects were recruited by muscle imbalance over 20% of muscle strength average at each plane. Also we divided into three groups with muscle imbalance at horizontal plane (upper and lower limbs) and transverse plane (left and right arm). The first group was the normal exercise load group (M1, age: 23±3.1 yrs, height: 175±3.3 cm, weight: 65±3.1 kg), the second group was exercise load deviation of horizontal plane group (M2, age: 23±1.8 yrs, height: 175±2.7 cm, weight: 65±3.4 kg), and the third group was exercise load deviation of horizontal and transverse plane (M3, age: 23±2.2 yrs, height: 175±3.1 cm, weight: 65±2.8 kg). Table 1 shows the physical information of the subjects included in this research.

Table 1

Information of participants

	Water Load(M1)	Electric Load(M2)	Load Deviation(M3)
Age(year)	23±3.1 yr	23±1.8 yr	23±2.2 yr
Height(cm)	175±3.3 cm	175±2.7 cm	175±3.1cm
Weight(kg)	65±3.1 kg	65±3.1 kg	65±2.8 kg

2.2. Experimental equipment and procedures

Three different types of rowing machines were used: a water load rowing machine (Naptune, Australia), an electric rowing machine with load deviation type in the upper and lower limbs, and one with load deviation in the left and right arms with upper and lower limbs. Presently, most rowing machines provide exercise loads by pulling a bar with the upper limbs; however, the electric rowing machine provided independent load patterns in the left-right arms and upper-lower limbs using deviation of the exercise load (Figure 1).

This study progressed in three steps. First, the rowing exercises were carried out twenty five times per set, four sets per day. The subjects performed the rowing exercises three days a week, for a total of eight weeks. Second, evaluations were done on the joint torques and basic fitness estimation. Joint torques in the elbow, shoulder, lumbar and knee were evaluated using Biodex system 3 (Biodex Medical Systems Co., New York, USA) for estimation of the improvement in muscle function. The basic fitness evaluation included analysis of body composition for percentage of fat, and fitness evaluation for muscle strength, muscular endurance, muscle reaction, agility, flexibility and exclusive power. Finally, the changes in joint torques and indexes of basic fitness during the eight weeks were calculated.

2.3. Exercise load and directions in rowing exercise

The subjects were provided each exercise load in three types. First, the original exercise load was provided without dependent load deviation, as per original rowing technique (M1). Second, dependent load deviation in the upper and lower limbs was carried out using one pulling bar (M2). Third, dependent load deviations in the upper-lower limbs and left-right arms were performed using two pulling bars (M3). Dependent load deviation indicates adaptation of the basic principle of exercise load to include the overload principle and the progressive principle, adding the deviation of the load to this research. In addition, we measured one resistance maximum (1RM), which was chosen as the initial exercise load based on the overload principle. The exercise load was then increased by 5kg every two weeks. As shown in Figure 2, after estimating 1RM using isokinetic evaluation of the electric rowing machine, 50% of 1RM was adapted. In this research, the deviation of exercise load was performed by providing an exercise load of 50% of 1RM to the dominant side. To the non-dominant side, 50% of 1RM plus the 1% of the deviation value of the muscle strength difference between the upper and lower or left and right side was applied [19].

2.4. Methodology of estimation

2.4.1. Basal physical fitness

Our study attempted to perform three types of tests to estimate the positive effect factor from rowing exercise. Evaluations included the following: basal physical fitness, for overall physical evaluation;

trunk flexibility, observing the variance in range of motion in the forward and backward directions of the trunk; isokinetic muscle functions, for estimation of muscle strength and power.

Measurement of basal physical fitness was performed before commencement, and after starting the exercise program, once a month. The basal fitness consisted of measurements of body composition, isometric muscle strength, muscular endurance, agility, explosive strength, and aerobic capacity. Body composition was measured as the amount of muscle increase and weight decrease, as detected by Inbody 2.0 (Biospace, Inc., Seoul, South Korea). For evaluating physical fitness, Helmas 2.0 was used (O2 Run, Inc., Seoul, South Korea). Isometric muscle strength tests evaluated grip power, back muscle strength and leg extension strength. The left and right hand grip power, strength of the back muscles and leg extension strength in both legs were measured twice, and the better score was recorded. In regards to muscular endurance, the number of sit-ups performed in 30 seconds was measured. Reaction time was tested twice in the entire body for agility, and the better score was recorded. For the agility test, the equipment provided the subject with visual and audio signals, which the subject followed. The surrounding environment was kept quiet during the test. The explosive strength test consisted of 3 meter shuttle runs and standing high jumps. The 3 meter shuttle runs were performed for 20 seconds, and the standing high jump was conducted twice, recording the better score. Maximum oxygen consumption was evaluated using a cycle ergometer to measure aerobic capacity. Subjects cycled until they were reaching their maximum heart rate.

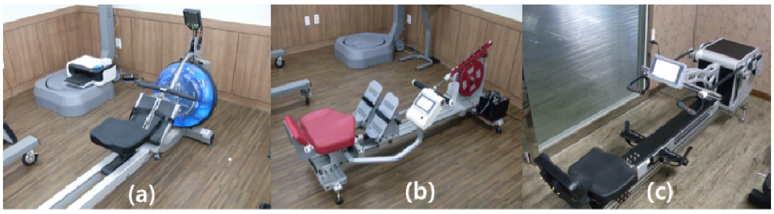

Fig. 1. Different types of rowing machines: (a) water load equipment, (b) dependent electric load in upper and lower limbs, (c) dependent electric load in upper/lower and left/right arms (ROBO Gym Series, Humonic Ltd. Korea).

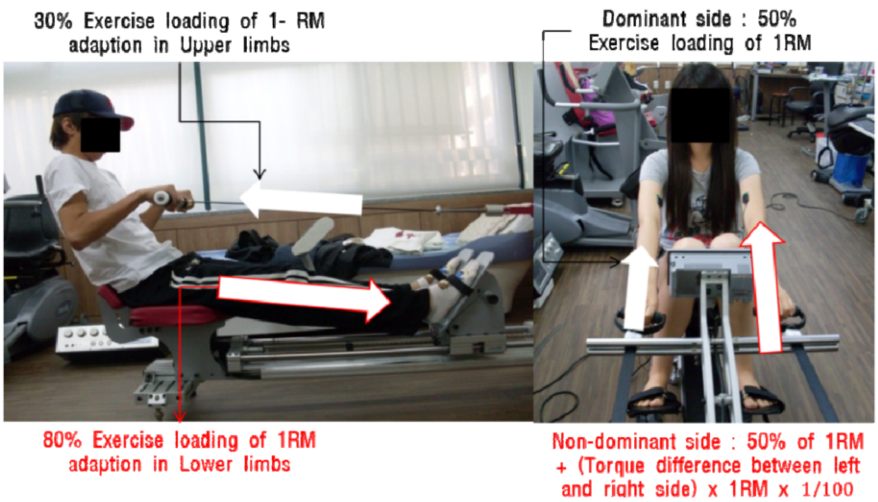

Fig. 2. Exercise load deviation method for muscle balance types during rowing exercise.

2.4.2. Muscle function

Joint torques in the elbow, shoulder, lumbar and knee were measured to observe variation of muscle strength before and after exercise. Biodex system 3 (Biodex Medical Systems Co., New York, USA) was used to observe the variance of muscle strength and muscle power. For muscle function, the lumbar joint peak torque for muscle strength and average power for muscle power time was measured. A semi-standing posture was adopted to reduce the error from the ground reaction force. Joint torque was evaluated by measuring the range of motion 60° from the vertical condition, with the waist forward. In addition, peak torque and average lumbar joint power were also evaluated.

3. Results

3.1. Variation of basic fitness components according to exercise load types

With regard to body composition, the percentage of body fat reduced significantly. Before the test, the average body fat percentage of all the groups was measured to be 17.5±1.32%. Through the rowing exercises, reductions in body fat by 5.4%, 16.1%, and 11.7% were observed in the M1, M2, and M3 groups, respectively, at four weeks. After eight weeks, a remarkable reduction of 7.4%, 23.6%, and 24.7% was observed in the groups, respectively (Table 2).

After completing the rowing exercises, all contents of basic fitness increased significantly, and muscle strength demonstrated great joint torque results. First of all, we considered the muscle strength pertaining to basic fitness to be divided into three components: grip power in the upper limbs, back muscle strength in the trunk and isokinetic strength in lower limbs. Differences of grip power, back muscle strength and isokinetic strength among the groups were minimal, at levels of 1.5%, 1.9% and 2.8%. After completing the rowing exercise with the different load types for eight weeks, the grip power showed increases by 11.1%, 30.8%, and 36.6% in groups M1, M2, and M3, respectively.

In the case of back muscle strength, dramatic increases of 10.4%, 33.4%, and 37.8% were observed in the respective groups. For isokinetic strength of the lower limbs, measured at eight weeks, increases of 29.7%, 34.5% and 38.7% were observed for M1, M2, and M3, respectively. For muscular endurance, there were slight differences in the number of sit-ups able to be performed by the different groups before the exercise treatment, at about 1.1%. After eight weeks, number of sit ups increased by 5.1%, 17.3%, and 22.7% in groups M1, M2, and M3, respectively (Table 3).

For flexion forward of trunk, measured for flexibility, there appeared to be a slight difference of 1.4% among the groups before the test. This also improved significantly, by 18.0%, 52.4%, and 38.9% in the three groups, respectively. These results demonstrated that dependent load deviation in the upper and lower limbs was better than the combination of upper-lower and left-right for improving flexibility. Next, we attempted to measure the reaction time between sensory stimulus and kinesthesia to measure agility. The results of reaction time showed that there was only slight difference between the groups of about 2.1% before commencing the exercise. After eight weeks, the reaction time reduced significantly by 12.4%, 24.2%, and 23.9% in the M1, M2, and M3 groups, respectively. These reaction time results demonstrated that use of the dependent load deviation method showed more than a 20% decrease, while use of the previous water load method only showed approximately 10% reduction (Table 4).

Finally, the results of standing high jump, to measure explosive power, also significantly improved during the eight weeks, although this area did not increase the greatest. Increases of 3.2%, 12.0%, and

13.9% were observed in M1, M2, and M3, respectively, whereas there was only a slight difference of 2.1% between the groups before conducting the exercise.

Table 2

Variation of body fat composition

	Group	pre-test	4-weeks	8-weeks
Percentage Body fat (%)	M1	17.3	16.4	16.1
		±1.62	±1.642	±1.41
	M2	17.77	15.3	14.375
		±1.57	±1.10	±1.08
	M3	17.651	15.8	14.15
		±1.82	±1.12	±1.30

Table 3

Variation in grip power, back muscle strength, isokinetic strength for evaluating muscle strength, and sit ups for evaluating muscular endurance

	Group	Grip Strength (kg)	Back Muscle Strength (kg)	Leg Extension Strength (kg)	Sit ups (times)
Pre-test	M1	46.49	100.50	80.37	26.00
		±3.47	±7.41	±5.5	±4.54
	M2	45.42	99.00	83.57	25.34
		±7.43	±8.28	±4.21	±4.99
	M3	43.98	102.00	84.00	24.65
		±3.58	±5.21	±3.40	±2.75
4-weeks	M1	50.37	107.75	90.55	26.75
		±7.75	±12.26	±5.40	±2.08
	M2	55.97	120.50	96.40	28.50
		±2.620	±10.59	±3.36	±2.30
	M3	56.40	126.30	94.96	28.65
		±3.58	±11.83	±7.40	±3.68
8-weeks	M1	51.63	110.96	103.85	26.1.34
		±4.26	±7.75	±12.26	±2.82
	M2	59.45	132.10	112.47	29.75
		±3.625	±10.59	±7.41	±1.32
	M3	60.10	140.60	116.54	30.25
		±1.06	±4.57	±8.28	±2.64

Table 4

Variation of flexibility, whole body reaction time and explosive power

	Group	Flexibility (cm)	Whole body reaction time (msec)	Explosive power (cm)
Pre-test	M1	9.82	210.50	37.00
		±1.40	±16.39	±1.69
	M2	9.17	217.25	37.60
		±2.23	±24.72	±1.70
	M3	9.50	209.54	36.50
		±1.58	±13.62	±1.41
4-weeks	M1	11.10	190.90	37.50
		±2.10	±14.57	±1.32
	M2	12.77	175.50	39.90
		±1.01	±23.82	±1.15
	M3	12.58	168.50	38.95
		±1.78	±13.64	±1.87
8-weeks	M1	11.6	184.32	38.22
		±2.62	±22.32	±1.56
	M2	13.99	164.65	42.12
		±2.83	±12.87	±1.15
	M3	13.20	159.46	41.59
		±1.82	±8.39	±1.60

3.2. Improvement of maximal torques in elbow, shoulder, lumbar and knee joints, depending on the exercise load types

Before the experiment, there were significant differences of joint torques in the elbow, shoulder, lumbar and knee among the groups. After the rowing exercise, significant improvement in each joint was witnessed. For the elbow joint, torque was measured as an average of 33.25±2.59 Nm between the groups, with 2.3% variation among the groups before commencing the rowing exercise. After exercising for eight weeks, the results of the muscle improvement were as shown below. Maximal peak torque in the elbow joint increased to by 68.7% to 53.15±1.45 Nm (M1), by 96.9% to 61.07±3.02 Nm (M2), and by 109.3% to 65.09±3.46 Nm (M3) (Figure 3). In the shoulder joint, initial values of 35.17±1.20 Nm were observed, varying by 1.7% among the groups. Eight weeks later, the shoulder joint demonstrated the greatest improvement in maximal peak torque, increasing by 25.7% to 44.32±2.12 Nm (M1), by 52.9% to 52.33±1.97 Nm (M2), and by 71.8% to 60.25±1.46 Nm (M3) (Figure 4).

For the lumbar joint, there appeared to be only very slight differences of maximal peak torque amongst the groups before commencing the rowing exercise, measured at 220.16±3.98 Nm with 1.5% variation. After the rowing exercise, the maximal peak torque among the groups improved by 31.2% to 275.36±5.98 Nm (M1), by 38.3% to 305.88±9.06 Nm (M2) and by 43.5% to 320.65±7.29 Nm (M3) (Figure 5). The knee joint results were also similar. Before commencing the exercise, there appeared to be a 3.3% difference between the groups. Improvement of the knee joint was observed to occur at

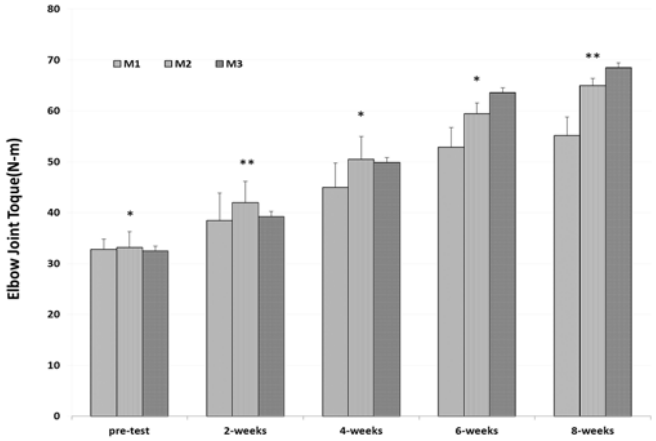

Fig. 3. Trend of maximal peak torques in elbow joint during eight weeks among the groups (means ± SE. *p < 0.05; **p < 0.01).

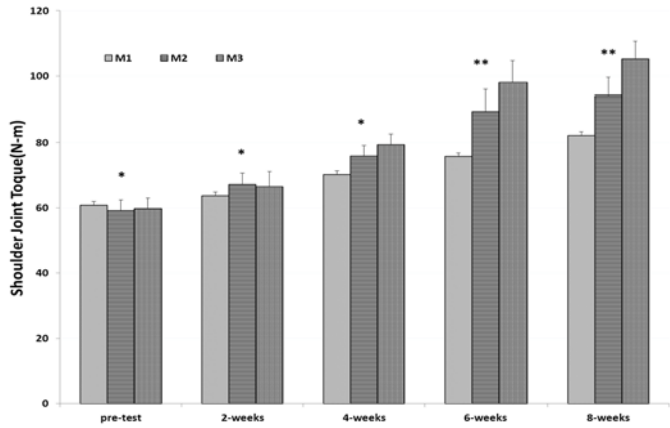

Fig. 4. Trend of maximal peak torques in shoulder joint during eight weeks among the groups (means ± SE. *p < 0.05; **p < 0.01).

35.5% to 135.27±6.42 Nm (M1), 52.1% to 155.97±3.99 Nm (M2), and 57.7% to 160.28±6.75 Nm (M3) (Figure 6).

4. Discussion

Our research was performed to compare the improving efficiency of the muscle function in relation to muscle balance types using dependent load deviation methods. We proposed new methods to be adopted for improving muscle imbalance, for comparing improvement of muscle function with quantification. Our study suggested three types of whole body exercise training with differential exercise load, divided into normal load as previous one, dependent load in upper-lower for its balance, and also dependent load in upper-lower with left-right for its balance. Rowing exercises as whole body exercise according to the different methods were performed for eight weeks.

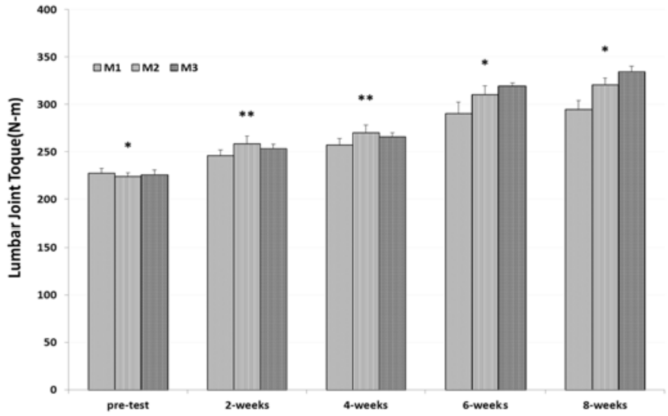

Fig. 5. Trend of maximal peak torques in lumbar joint during eight weeks among the groups (means ± SE. *p < 0.05; **p < 0.01).

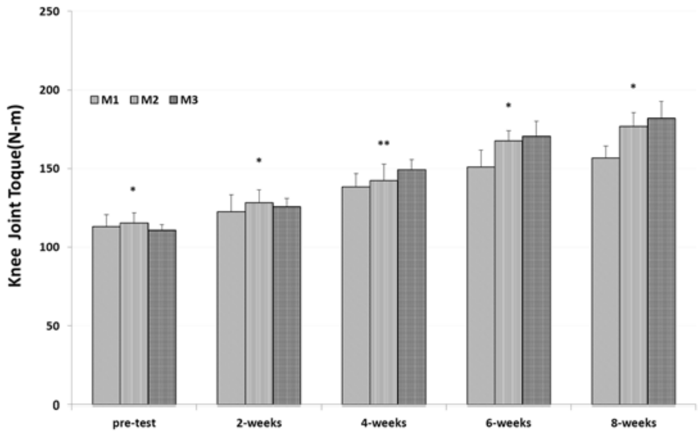

Fig. 6. Trend of maximal peak torques in knee joint during eight weeks among the groups (means ± SE. *p < 0.05; **p < 0.01).

As shown in our results, it was evident that an improvement of more than 30% more in every joint was obtained when adopting the dependent load deviation type, over the previously used water load method. This suggests that using dependent load deviation is more effective for providing muscle strength to non-dominant side and endurance exercise to dominant side at same time from one form exercise, by keeping muscle balance. Also, it could improve muscle imbalance according to balanced effect of muscle strengthen from neural adaption of muscles. The human body maintains motor coordination of muscle contraction during exercise. Therefore, achieving muscle balance in the upper-lower and left-right arms seems to be very effective for activating motor coordination. More specifically, we found that exercise considering the muscle balance in the upper-lower limbs and left-right arms was better for improving muscle strength than only balancing the upper and lower limbs. In this research, as shown above, the variation of joint torques and deviation of exercise loads provided improvement of muscular sensation and proprioception for efficient movement of the body in response to independent force patterns in the upper limbs.

This muscle balance could improve muscle strength more effective according to provide more efficient ATP consume, the bigger recruitment of motor unit and endurance exercise effect by causing slow muscle fiber's activation. This carries an important meaning for verifying its effect on muscle balance for both normal people and athletes. While most research and sports science place emphasis on muscle function and effectiveness during exercise, they seem to ignore the importance of muscle balance in motor coordination. Our research suggests that muscle balance in the whole body is the key factor to allow accurate motor coordination, to improve muscle function and effectiveness during exercise or in daily lives.

Recently, muscle imbalance has been designated as a new disease in the area of sports rehabilitation. Muscle imbalance has been shown by many studies to be responsible for causing sports injuries. They've found that it causes injury to joints and muscles during active sports and daily lives if muscle imbalance is neglected. It could cause problems in muscle function by causing leaning to one side. Many studies have reported that whole body exercise provides a significant effect on the improvement of muscle strength and muscular endurance, while balanced exercise to the whole body has also proved to be good for improving health. Muscle imbalance in expert athletes, as well as in average people for that matter, can result in diminished muscular performances. Balancing muscles will help to improve athletic performance for athletes by facilitating more efficient exercise. Herein, we were able to establish the importance of muscle balance, both in athletes as well as in average people. Further studies should progress to adapt muscle balance for verifying the effects of muscle improvement, as this research only tried to compare normal people. More studies should be performed to verify the effects of muscle balance on muscle improvement in athletes.

5. Conclusion

This research compared muscle function and improvement of muscle balance using a dependent load deviation method. We designed new methods to be adopted for the improvement of muscle balance. In addition, we analyzed effects on the human body by measuring joint torques, and the components of basic fitness. Based on our results, we arrived at the following conclusions.

First, the after rowing exercises, it was evident that dependent load deviation for the upper-lower and left-right arms gave the most significant improvement in each joint. For joints, test results indicated increases in the maximal peak torques at levels of 109.3% (elbow), 71.8% (shoulder), 43.5% (lumbar) and 57.7% (knee).

Second, considering body composition, the percentage of body fat reduced significantly more considering muscle balance in the upper-lower and left-right arms. Through rowing exercises, it reduced significantly down to 14.15±1.30%, with level of 24.7%.

Third, all contents of basic fitness increased significantly with the exercises. Muscle strength in particular showed the greatest improvement, as demonstrated by the joint torque results from the group with dependent load deviation. In the M3 group, respective increases of muscle strength (36.6%), muscular endurance (22.7%), flexibility (38.9%), muscle reaction time (23.9%) and explosive power (13.9%) were witnessed.

Our research suggests that training considering muscle balance, using dependent load deviation, is more effective for improving muscle strength, and hence to prevent exercise injuries in comparison to any other method. In addition, the results of our research can provide basic information for programs to sports or rehabilitation science, suitable for the treatment of muscle imbalance, by adopting dependent load deviation specific to the proposal, age and physical condition of people, whether they are average people or athletes. This can also be applied to customized rehabilitation programs for patients with special conditions of exercise injuries from muscle imbalance, as well as for elite athletes with muscle imbalance.

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