Effects of resistance combined with aerobic training on physical function and glucolipid metabolism in obese women after bariatric surgery

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Research Article

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Abstract

Background: bariatric surgery is one of the most popular weight-loss methods at present, which can significantly reduce the weight of obese patients and improve the complications. Through 4-week exercise intervention and routine postoperative management control, the changes of subjects' indexes were observed to provide reference for making scientific exercise plan.

Methods: 17 subjects were randomly divided into two groups, EG (n=8) and CG (n=9). The exercise group received online exercise intervention for 4 weeks, 3 times a week, while the CG did not participate in exercise. The related indexes of EG and control group before and after exercise intervention were detected and analyzed.

Results: The HC of the control group was better than that of the EG ($P < 0.05$). The improvement of WHR in EG is better than that in CG ($P < 0.01$). The decrease of TF in EG is better than that in CG ($P < 0.05$). The decrease of BMR was better than that of the CG ($P < 0.05$). The effect of lowering FBG in the CG is better than that in the EG ($P < 0.01$). EG improved HDL-C better than CG ($P < 0.01$).

Conclusion: (1) the CG has a greater effect on reducing WC, and exercise has a more significant effect on reducing WHR and TF and BMR. (2) the CG has a greater effect on reducing FBG, but exercise can adjust the relative stability of FBG level. Exercise can improve HDL-C obviously.

Key Points

1. bariatric surgery can result in significant weight loss in obese patients. However, most of this weight loss is accompanied by loss of skeletal muscle and development of complications.
2. Exercise has a role in the maintenance of muscle mass, increased metabolism, and improved cardiopulmonary function in weight-loss patients. However, whether exercise after bariatric surgery can provide better improvement in postoperative obesity and complications requires further validation.
3. To observe the differences in physical function and glycolipid metabolism in obese patients after bariatric surgery through exercise intervention and conventional postoperative management control.
4. To provide a reference for the development of a scientific exercise program for obese patients after bariatric surgery.

Background

Global overweight and obesity rates tripled between 1975 and 2016[1]. China, once considered one of the world's thinnest populations, has seen a rapid rise in the number of overweight and obese people. the rapid increase in China's obese population in 2016 led it to overtake the United States in ranking as the world's top obese population. At the same time, some diseases are also related to obesity, such as type 2 diabetes mellitus (T2DM), hypertension, sleep apnea, non-alcoholic fatty liver, etc. The occurrence of various diseases is related to obesity, which makes obesity the "source of all diseases".

Currently, there are many ways to improve obesity. For example, medication, surgery, diet and exercise interventions. Some studies have reported[2].Weight loss pills have side effects that cause anorexia and affect people's health. bariatric surgery can result in significant weight loss in obese patients. However, most of this weight loss is accompanied by loss of skeletal muscle. Some studies say that patients usually lose significant weight within the first year after bariatric surgery, about 70% of which is fat and 30% is muscle[3].This means that bariatric surgery alone may not be able to maintain long-term weight loss, and poor management of oneself in the later stages may result in regained weight[4]. bariatric surgery can lead to complications such as severe anemia, reduced bone mass, decreased basal metabolism, mineral deficiencies, lower HDL-C and low blood glucose[5–7].Since the slogan "exercise is a good doctor" was introduced, exercise has been proven to improve the symptoms associated with obesity[8–10].Exercise has a role in the maintenance of muscle mass, increased metabolism, and improved cardiopulmonary function in weight-loss patients [11]. However, whether exercise after bariatric surgery can provide better improvement in postoperative obesity and other "risk factors" (complications) requires further validation.

Methods

Patient Selection

The subjects were 17 obese women after bariatric surgery (laparoscopic sleeve gastrectomy patients) with the following requirements: 1. BMI:28-40kg/m2, age: 20–40 years old; 2. no heart disease, diabetes, gout, no bone, joint, muscle, or nervous system disease affecting physical activity, and no recent antibiotic medication; 3. no participation in any other form of post-bariatric surgery except this experiment 4. undergo the PAR-Q Physical Activity Readiness Questionnaire and medical screening for exercise risk before the experiment; 5. voluntarily participate in this experiment. Subjects who passed the above requirements were eligible for enrollment in the post-bariatric surgery intervention, informed of the details of this post-bariatric surgery experimental study and signed the informed consent form.

Table 1
Basic characteristics of the subjects

Group	Age(year)	Height(cm)	Weight(kg)	BMI(kg/m^2)
Control group(n = 9)	30.44 ± 5.10	166.89 ± 4.31	95.96 ± 13.37	34.42 ± 4.33
Exercise group(n = 8)	31.88 ± 6.49	166.50 ± 5.10	88.50 ± 6.16	31.93 ± 1.90
P	*P 0.05*	*P 0.05*	*P 0.05*	*P 0.05*

Exercise

Blackburn [12] and other bariatric surgery expert panels recommend encouraging patients to increase their physical activity from preoperative to postoperative, especially low to moderate intensity exercise. The exercise intervention in this study was: the exercise format took the form of online training, which lasted for 4 weeks throughout, with 3 sessions per week and required subjects to practice every other day for 70 min, with each session consisting of a 5 min pre-training warm-up, 30 min of strength training, 30 min of aerobic training, and a final 5 min of stretching and relaxation. The training intensity was 40% 1RM (strength training), 50% HRmax (aerobic), and the subjects were required to wear an exercise bracelet for heart rate monitoring during the aerobic training.

Diet Management

In the subject's diet, the dietitian developed a diet based on the subject's postoperative diet management. The daily intake was standardized at 600-800kcal. In order to give the subjects better control in terms of calories, the subjects used meal replacements and dietitian-recommended foods for their daily diet instead of choosing their own food. At the same time, the subjects' daily diets were sent to the dietitian through the dietary records to evaluate the caloric intake.

Statistics

In this paper, SPSS 22.0 statistical analysis software was used to statistically process the before and after data of obese women for 4 weeks. The test results of each index of the subjects were expressed as mean ± standard deviation ($x \pm SD$), and when the experimental data met normal distribution, the independent samples t-test was used for comparison between groups. Conversely, the non-parametric Mann-Whitney U test (Mann-Whitney U test) was used. Paired-samples t-test was used for comparison of pre-post changes within groups. The significance level was set at $P < 0.05$ and the very significant level was set at $P < 0.01$.

Results

Table 2
Changes in body morphology before and after the four-week intervention

	Control group			**Exercise group**		
Items	Pre-test	Post-test	Within-group change	Pre-test	Post-test	Within-group change
Weight(kg)	95.96 ± 13.37	85.96 ± 12.80**	-10 ± 2.31	88.50 ± 6.16	78.55 ± 6.54**	-9.95 ± 2.53
BMI(kg/m^2)	34.42 ± 4.33	30.84 ± 4.28**	-3.57 ± 0.75	31.93 ± 1.90	28.34 ± 2.21**	-3.71 ± 1.06
NC(cm)	37.79 ± 2.41	35.89 ± 2.46**	-1.9 ± 1.39	38.00 ± 2.27	35.81 ± 2.07**	-2.19 ± 0.92
WC(cm)	109.28 ± 13.94	100.61 ± 13.39**	-8.67 ± 4.93	101.63 ± 3.34	92.38 ± 4.03**	-9.25 ± 5.82
HC(cm)	120.06 ± 8.57	110.17 ± 5.41**	-9.89 ± 4.62	109.75 ± 5.09	105.31 ± 5.12**	-4.44 ± 3.54#
WHR	0.91 ± 0.08	0.91 ± 0.09	0.00 ± 0.04	0.93 ± 0.06	0.88 ± 0.04*	-9.25 ± 5.82##

Weight, BMI, NC, and WC in both the exercise and control groups showed significant decreases before and after 4 weeks ($P < 0.01$), however, the exercise group did not outperform the control group in improving the above indicators ($P > 0.05$). HC in both the control and exercise groups showed a significant decrease after 4 weeks ($P < 0.01$), however, the control group was superior to the exercise group in terms of HC decrease ($P < 0.05$). The indicator WHR of the control group did not change significantly after 4 weeks ($P > 0.05$), while the exercise group showed a significant decrease in the indicator WHR through 4 weeks of intervention ($P < 0.05$). The exercise group was better than the control group in improving WHR ($P < 0.05$).

Table 3
Changes in body composition before and after the four-week intervention

	Control group			Exercise group		
Items	Pre-test	Post-test	Within-group change	Pre-test	Post-test	Within-group change
TBW(L)	37.98 ± 2.84	34.97 ± 0.86**	−3.01 ± 1.92	38.18 ± 4.17	36.48 ± 3.11*	−1.70 ± 1.60
P(kg)	10.24 ± 0.71	9.34 ± 0.86**	−0.90 ± 0.49	10.29 ± 1.11	9.75 ± 0.80*	−0.54 ± 0.45
IS(kg)	3.58 ± 0.37	3.36 ± 0.37*	−0.21 ± 0.26	3.66 ± 0.39	3.52 ± 0.32	−0.14 ± 0.25
BF(kg)	44.18 ± 10.38	38.23 ± 9.89**	−5.94 ± 1.84	35.96 ± 4.03	28.81 ± 4.23**	−7.15 ± 1.70
BF(%)	45.54 ± 4.58	43.91 ± 5.59	−1.63 ± 2.45	40.88 ± 4.08a	36.29 ± 3.41**	−4.59 ± 1.51
VFA(cm2)	214.59 ± 47.26	194.11 ± 51.80**	−20.48 ± 10.29	178.85 ± 21.66a	138.31 ± 21.70**	−36.54 ± 10.54
RULF(kg)	4.44 ± 1.82	3.57 ± 1.49**	−0.88 ± 0.41	3.09 ± 0.58	2.24 ± 0.50**	−0.85 ± 0.25
LUEF(kg)	4.47 ± 1.82	3.58 ± 1.48**	−0.89 ± 0.41	3.11 ± 0.60	2.24 ± 0.51**	−0.88 ± 0.24
TF(kg)	21.70 ± 4.53	18.99 ± 4.73**	−2.71 ± 0.63	18.21 ± 1.47	14.73 ± 1.69**	−3.49 ± 0.83#
RLEF(kg)	5.91 ± 1.10	5.30 ± 1.06**	−0.61 ± 0.47	5.06 ± 0.75	4.14 ± 0.80**	−0.93 ± 0.32
LLEF(kg)	5.90 ± 1.08	5.27 ± 1.02**	−0.63 ± 0.47	5.00 ± 0.72	4.11 ± 0.76**	−0.89 ± 0.30
MM(kg)	48.83 ± 3.60	44.90 ± 4.11**	−3.93 ± 2.40	49.09 ± 5.36	46.83 ± 3.96*	−2.26 ± 2.11
SM(kg)	28.84 ± 2.18	26.22 ± 2.64**	−2.62 ± 1.45	29.01 ± 3.40	27.36 ± 2.48*	−1.65 ± 1.39
RULSM(kg)	2.93 ± 0.34	2.57 ± 0.37**	−0.36 ± 0.20	2.86 ± 0.37	2.64 ± 0.26**	−0.22 ± 0.14
LULSM(kg)	2.91 ± 0.32	2.57 ± 0.37**	−0.34 ± 0.19	2.84 ± 0.36	2.63 ± 0.27**	−0.21 ± 0.15
TSM(kg)	24.29 ± 2.07	22.22 ± 2.24**	−2.07 ± 0.98	23.68 ± 2.18	22.28 ± 1.65**	−1.40 ± 0.81
RLLSM(kg)	7.90 ± 0.65	7.39 ± 0.63**	−0.51 ± 0.20	7.92 ± 1.04	7.66 ± 0.87	−0.26 ± 0.32

	Control group			Exercise group		
LLLSM(kg)	7.86 ± 0.56	7.35 ± 0.57**	−0.51 ± 0.16	7.88 ± 1.06	7.58 ± 0.94*	−0.30 ± 0.26
BMR(kcal)	1488.11 ± 83.66	1400.33 ± 95.14**	−87.78 ± 57.26	1495.63 ± 122.65	1466.75 ± 188.85*	−28.88 ± 27.42#

TBW(Total body water) after 4 weeks showed a highly significant decrease in the control group ($P < 0.01$) and a significant decrease in the exercise group ($P < 0.05$). P (Protein) weight and IS (inorganic salt) before and after differences in the exercise group were not different from the control group ($P > 0.05$). BF(body fat) weight after 4 weeks showed a highly significant decrease in both groups, exercise and control ($P < 0.01$), and there was no difference in reducing BF weight between the two groups ($P > 0.05$). The decrease in BF% after 4 weeks in the control group was 1.63 ± 2.45%, which was not significant ($P > 0.05$). In contrast, the BF% level decreased extremely significantly ($P < 0.01$) by 4 weeks of exercise, with a decrease of 4.59 ± 1.51%, and the exercise group was greater than the control group in reducing BF%. VFA was highly significant ($P < 0.01$) in both the control and exercise groups on post-test values after 4 weeks. However, the exercise group was superior to the control group in terms of the magnitude of VFA reduction for the 4-week exercise intervention ($P < 0.05$). Both UEF (upper extremity fat) and LEF (lower extremity fat) indicators were highly significantly decreased in both exercise and control groups after 4 weeks ($P < 0.01$), and there was no difference between the exercise and control groups in reducing upper and lower extremity fat in both groups ($P > 0.05$). TF was highly significantly decreased in both groups on the measurement after 4 weeks ($P < 0.01$). However, the exercise group with the 4-week exercise intervention was superior to the control group in terms of TF reduction effect ($P < 0.05$). The control group showed a highly significant decrease ($P < 0.01$) in MM (muscle mass) after 4 weeks, with a decrease of 3.93 ± 2.40 kg. In the case of the exercise intervention, the exercise group showed a significant decrease ($P < 0.05$) after 4 weeks, with a decrease of 2.26 ± 2.11 kg. The exercise group did not differ from the control group in delaying the loss of muscle mass ($P > 0.05$), but slowed the magnitude of muscle mass loss. The amount of SM (skeletal muscle) decreased significantly in both the control and exercise groups after 4 weeks, and the loss of skeletal muscle was also less in the exercise group than in the control group, and the improvement of skeletal muscle in the exercise group was not statistically different from that in the control group ($P > 0.05$). The exercise and control groups showed highly significant decreases in both UESM (upper extremity skeletal muscle) and TSM (trunk skeletal muscle) post-test ($P < 0.01$), and there was no difference in the difference between the changes in upper extremity skeletal muscle and trunk skeletal muscle between the two groups ($P > 0.05$). In the control group, the RLLSM (right lower limb skeletal muscle) decreased significantly after 4 weeks ($P < 0.01$), and the amount of right lower limb skeletal muscle did not change significantly after 4 weeks of exercise ($P > 0.05$), and there was no difference in the magnitude of decrease between the control and exercise groups of 0.51 ± 0.20 kg and 0.26 ± 0.32 kg, respectively ($P > 0.05$). The LLESM (left lower extremity skeletal muscle) decreased very significantly after 4 weeks in the control group ($P < 0.01$) and after exercise ($P < 0.05$), and there was no difference in the change of the magnitude of the decrease between the two groups ($P > 0.05$). The BMR in the control group decreased highly significantly after 4 weeks (P < 0.01), and the BMR values also decreased significantly after 4 weeks of exercise (P < 0.05), and the magnitude of their decreases were 87.78 ± 57.26 kcal and 28.88 ± 27.42 kcal, respectively. analysis of the magnitude of their changes showed that the exercise group was better than the control group in delaying the decrease in BMR.

Table 4
Changes in glucose metabolism before and after the four-week intervention

	Control group			**Exercise group**		
Items	Pre-test	Post-test	Within-group change	Pre-test	Post-test	Within-group change
FBG(mmol/L)	6.21 ± 2.41	3.95 ± 0.81**	-2.26 ± 1.66	5.34 ± 0.65	4.93 ± 0.67	-0.41 ± 0.49##
FINS(uIU/ml)	22.46 ± 12.06	8.20 ± 6.91**	-14.27 ± 10.12	20.33 ± 8.31	7.86 ± 3.00**	-12.47 ± 9.68
CP(ng/ml)	3.63 ± 0.84	1.92 ± 1.15**	-1.71 ± 0.94	3.33 ± 0.64	2.08 ± 0.49**	-1.25 ± 0.93
HbA1c(%)	6.28 ± 1.51	5.42 ± 1.48**	-0.83 ± 0.60	6.30 ± 1.50	5.55 ± 0.56	-0.75 ± 0.97
HOMA-IR	6.39 ± 4.70	1.61 ± 1.62**	-4.81 ± 3.42	4.81 ± 1.89	1.78 ± 0.86**	-3.03 ± 2.18
ISI	0.01 ± 0.01	0.09 ± 0.11*	0.09 ± 0.11	0.01 ± 0.00	0.03 ± 0.02*	0.02 ± 0.02

The control group had a highly significant decrease in FBG after 4 weeks (P < 0.01), and the control group was superior to the exercise intervention in reducing FGB (P < 0.01). Both the control and exercise groups showed a highly significant decrease in FINS and CP after 4 weeks (P < 0.01), and exercise did not outperform the control group in improving FINS and CP (P > 0.05). The decrease in HbA1c levels after 4 weeks in the control group was 0.83 ± 0.60% (P < 0.01), and the decrease in HbA1c in the exercise group was 0.75 ± 0.97% (P > 0.05), and the change in HbA1c did not differ between the exercise group and the control group after 4 weeks of exercise intervention (P > 0.05). after 4 weeks of exercise intervention, HOMA-IR in the exercise group was highly significant decreased (P < 0.01). The HOMA-IR in the control group also decreased significantly after 4 weeks (P < 0.01). The decrease in the control group was 4.81 ± 3.42 and the decrease in the exercise group was 3.03 ± 2.18 (P > 0.05). Meanwhile, the ISI of both the control and exercise groups significantly improved after 4 weeks (P < 0.05), and the exercise group did not differ from the control group in terms of improving ISI (P > 0.05).

Table 5
Changes in lipid metabolism before and after the four-week intervention

	Control group			**Exercise group**		
Items	Pre-test	Post-test	Within-group change	Pre-test	Post-test	Within-group change
TC(mmol/L)	4.87 ± 0.43	3.60 ± 0.51**	-1.27 ± 0.38	5.60 ± 0.80a	4.30 ± 0.74**	-1.30 ± 0.87
TG(mmol/L)	1.58 ± 1.11	0.99 ± 0.37	-0.60 ± 1.12	1.79 ± 0.63	1.12 ± 0.16*	-0.67 ± 0.63
HDL-C (mmol/L)	0.96 ± 0.21	0.64 ± 0.11**	-0.32 ± 0.13	0.98 ± 0.22	1.02 ± 0.25	0.03 ± 0.16##
LDL-C (mmol/L)	3.03 ± 0.43	2.06 ± 0.40**	-0.97 ± 0.20	3.66 ± 0.69a	2.68 ± 0.59**	-0.98 ± 0.72

As can be seen from Table 5, TC after 4 weeks was highly significant ($P < 0.01$) in both the control and exercise groups, and the magnitude of its decline did not vary much between the two groups ($P > 0.05$). The decrease in TG in the control group after 4 weeks was 0.60 ± 1.12 mmol/L ($P > 0.05$), and the decrease in TG in the exercise group after 4 weeks was 0.67 ± 0.63 mmol/L ($P < 0.05$). And the exercise group was not superior to the control group in terms of TG lowering effect ($P > 0.05$). HDL-C decreased in the control group after 4 weeks ($P < 0.01$), while the exercise group showed an increasing trend ($P > 0.05$). In contrast, the exercise group was superior to the control group in terms of improving HDL-C. LDL-C indexes decreased highly significantly in both the control and exercise groups after 4 weeks ($P < 0.01$), and there was no significant change in the magnitude of LDL-C decrease in the two groups ($P > 0.05$).

Discussion

In this study, we compared postoperative exercise by 4 weeks and regular management in the postoperative control group, and both groups were effective in reducing the improvement of weight, BMI, NC, WC, and HC indicators. One study on postoperative weight change found that the initial phase of rapid weight loss usually enters in the first 3 months after bariatric surgery, followed by a slow phase and finally weight stabilization occurs, while the initial rapid weight loss is mainly due to a decrease in energy intake [13] .One of the reasons for the significant weight loss in both groups in this study may be due to the postoperative energy intake problem, which resulted in significant weight loss in both groups due to the intake being less than their own consumption. There was no statistical difference between the pre- and post-group changes in weight, BMI, NC, and WC in the two groups ($P > 0.05$), indicating that there was no statistical difference in the effect of the postoperative exercise intervention at 4 weeks versus the conventional postoperative management in the control group in reducing these indicators. Also, Metcalf

[14] et al. obtained the same conclusion of this study by exercise intervention in postoperative patients, and although there was a significant decrease in weight change in the exercise and control groups, the improvement in the exercise group was also non superior to the control group ($P > 0.05$). In another study, Castello [15] et al. noted that postoperative obese women were randomized to the exercise group (n = 11) versus the control group (n = 10) after 3 months of aerobic training (50–70% HRmax) with 60 minutes of exercise 3 times per week. There was a significant decrease in weight, BMI and circumference after the intervention, and no statistical difference between the exercise and control groups in terms of weight and BMI reduction ($P > 0.05$). Meanwhile, the reduction in HC was significantly greater in the control group compared with the exercise group, and the control group was superior to the exercise group in terms of HC reduction ($P < 0.05$). The present study obtained the same results as this finding in terms of HC reduction, indicating that the control group was superior to the 4-week exercise intervention in terms of HC reduction. The reason for this may be due to the fact that the resistance training in this experiment not only improved the strength quality of the subjects but also may have delayed the decrease in HC, WHR is not only a measure of obesity but also an important way of judging body proportions. In this study, there was no significant change in WHR in the control group after 4 weeks ($P > 0.05$), while the 4-week exercise intervention caused a significant decrease in WHR ($P < 0.05$), and the change in the difference before and after WHR in the exercise group was statistically different from that in the control group ($P < 0.01$), indicating that the effect of exercise in reducing WHR was better than that in the control group. One of the main reasons may be due to the fact that the control group was superior to the 4-week intervention effect of exercise in reducing HC, and there was no statistical difference between the two groups in reducing WC, prompting the ratio of WC to HC in the exercise group to be smaller than that of the control, indicating that the 4-week exercise intervention was superior to the control group in reducing the effect of WHR and better improving body proportions.

The substantial weight loss in the control group at 4 weeks postoperatively was accompanied by a loss of muscle mass and protein catabolism. Although protein loss occurred after 4 weeks of exercise, the strength training in the exercise intervention may have had a better effect in improving strength and skeletal muscle synthesis, and the 4 weeks of exercise in this experiment contributed to the synthesis and relative improvement of skeletal muscle, which in turn alleviated and improved protein loss. The values of VFA measured after 4 weeks in both the exercise and control groups in this study were significantly lower ($P < 0.01$), with the 4-week exercise being greater in reducing VFA than the control group. In Bellicha [16] et al. provided evidence in the meta-analysis of their study that exercise training has an additional benefit on fat loss after bariatric surgery, which is also identical to the results of the present study. In terms of changes in muscle mass and skeletal muscle at 4 weeks postoperatively, the control group in this study showed a decreasing trend in the change in muscle mass before and after the 4-week exercise intervention, and the muscle mass remained on a decreasing trend ($p > 0.05$). However, the exercise group was lower than the control group in terms of the magnitude of the decline. Voican[17] et al. A study by Carnero [18] et al. reported that rehabilitation exercises after bariatric surgery are more important. Exercise exercise especially strength exercise will help to reduce muscle mass loss in postoperative patients after bariatric surgery. Both the exercise and control groups showed significant decreases in

BMR posttest and were superior to the control group in delaying BMR decline ($P < 0.05$).Coen[19] et al. have shown that BMR is determined by total body weight, which is primarily non-total fat. Significant loss of muscle mass after weight loss surgery will decrease BMR levels. Both groups showed significant weight loss, while in terms of the magnitude of muscle loss, the control group showed greater muscle loss than the exercise group, prompting a statistical difference between the two groups, which in turn indicated that the exercise group had a better effect than the control group.

Glucose metabolic indexes improved improved in both control and exercise groups, with no statistical difference in the within-group difference changes in FINS, CP, HbA1c, HOMA-IR and ISI between the two groups ($P > 0.05$), while there was an advantage in improving FBG indexes in the control group ($P < 0.01$). In a study [20], 60 post-bariatric surgery patients were randomly assigned to a control combination exercise group (twice a week) and metrics were collected before surgery and at 6, 12 and 24 months after surgery, and significant decreases in glucose metabolism metrics were found in both the exercise and control groups. The effect of FBG, FINS, HbA1c and HOMA-IR by exercise intervention was not statistically different from the control group ($P > 0.05$).Campos [21] and Lin [22] and other studies have reported that weight loss surgery rapidly improves FBG and ISI in addition to significant weight loss, and that these effects occur in the post-surgical period and are modulated by multiple mechanisms. Within a few weeks after surgery, HOMA-IR also showed a decrease due to caloric restriction improving the ISI of the liver. The effect of FBG decrease was better in the control group than in the exercise group in this study ($p < 0.01$). Although bariatric surgery has a better effect on FBG reduction in patients, one study reported that one-third of patients undergoing laparoscopic gastric bypass and sleeve gastrectomy had symptoms of hypoglycemia [23] The reason for the significant glucose-lowering effect of the control group over the exercise group in lowering blood glucose in this study may be that four of the nine subjects in the control group in this study experienced hypoglycemia in the posttest FBG measurement after 4 weeks. In contrast, of the 8 subjects in the exercise group, only one subject developed a hypoglycemic condition. It also suggests that exercise may have a role in controlling the relative stability of FBG and improving hypoglycemia.

Dyslipidemia also contributes to the increased incidence of cardiovascular disease [24]. The control group in this study had highly significant reductions in TC and LDL-C levels after 4 weeks ($P < 0.01$) and no significant changes in TG levels ($P > 0.05$), and the exercise group also had significant reductions in all three of these indicators after 4 weeks of exercise. However, there was no significant change from the control group in the magnitude of reduction in TC, TG, and LDL-C. Kelley [25] et al. indicated that post-weight loss surgery was very effective in reducing LDL-C levels. However, exercise exercise did not add additional effect on LDL-C improvement. Another study showed [26] that the improvement in LDL-C after bariatric surgery may diminish the benefit of exercise when bariatric patients are in the first postoperative year of an active weight loss phase. For the reasons for the decrease in HDL-C in the control group, it has been shown that HDL-C levels change during weight loss and that weight loss usually increases lipoprotein lipase activity, especially after weight stabilization. However, during acute caloric restriction, the concentration of this enzyme decreases by 50%, contributing to the decline in HDL-C in the postoperative period [27, 28]. A study showed that in subjects with 30 minutes of supervised exercise training per session for 6 months, TC, LDL-C and TG levels decreased, while HDL-C levels tended to increase after exercise [29]. In Barter [30], a study indicated that patients after bariatric surgery experience low HDL-C levels and that exercise training at 6 months postoperatively has a favorable effect on increasing HDL-C levels.

Conclusions

(1) Both groups had an improving effect on body composition, with the control group having a greater effect on WC reduction in subjects, and exercise having a more significant effect on reducing WHR and TF and delaying skeletal muscle loss and BMR reduction.

(2) Both groups had an improving effect on glucolipid metabolism. The control group had a greater effect on the reduction of FBG, but exercise could regulate the relative stability of FBG levels. The effect of exercise to increase HDL-C was significant.

Abbreviations

BMI:Body mass index;NC Neck circumference;WC:Waist circumference;HC:Hip circumference;WHR:Waist hip ratio;TBW:Total Body Water;P:Protein;IS:inorganic salt BF:Body fat;VFA:Visceral fat area;UEF:upper extremity fat;LEF:lower extremity fat; TF:Trunk fat; MM :muscle mass;SM:skeletal muscle;UESM:upper extremity skeletal muscle;TSM:trunk skeletal muscle;RLLSM:right lower limb skeletal muscle;LLESM:left lower extremity skeletal muscle;BMR: Basal metabolic Rate ;FBG:fasting blood-glucose;FINS:Fasting insulin;

Declarations

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Author contributions

YWS participated in the research design and data collection, while YFS, YHS, HM and HZY participated in the research design, data analysis and interpretation, and manuscript drafting. All authors participated in the research design, data collection, manuscript drafting, reading and approving the final manuscript.

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Consent for publication Not applicable

Informed Consent Informed consent was obtained from all individual participants included in the study.

Availability of data and materials Not applicable

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