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# Ameliorated lipid distribution in prediabetes - Effects of 12 weeks traditional Chinese YiJinJing exercise plus TheraBand: A randomized controlled trial

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ABSTRACT

*Background/Objective:* Lipid distribution plays a crucial role in glucose metabolism, and this study aimed to investigate the effects of 12 weeks traditional Chinese YiJinJing exercise on specific lipid distributions in patients with prediabetes.

*Methods:* Sixty participants with prediabetes were randomly allocated to either a control group (Con, n = 30) or an exercise group (Ex, n = 30). The Ex group underwent YiJinJing exercise plus Theraband, engaging in 1-h sessions, 3 times per week, over a total period of 12 weeks. Dual-energy X-ray absorptiometry (DEXA) and magnetic resonance imaging (MRI) were used to measure lipid distribution in different body segments and organs. Additionally, a body composition analyser was employed to measure visceral fat, and laboratory tests were conducted to measure indicators related to glycolipid metabolism.

*Results:* Following a 12-week intervention with Exercise, 37 % of prediabetic patients in the Ex group achieved normal blood glucose levels. Significant reductions were observed in upper limb fat (ULF), trunk fat (TrF) and liver fat (LF) values in the Ex group compared to the Con group. Additionally, within the Ex group, there were notable decreases in triglyceride (TG) levels, body mass index (BMI), waist-hip ratio (WHR), android fat (AF), ULF, thigh fat (ThF), renal sinus fat (RSF), and LF compared to baseline.

*Conclusions:* Traditional Chinese YiJinJing plus TheraBand exercise can significantly reduce blood glucose levels through improved lipid distribution and metabolism in prediabetic patients. Hence, YiJinJing can serve as a crucial intervention for individuals with prediabetes.

## 1. Introduction

Prediabetes, an intermediate state of hyperglycaemia characterized by abnormally elevated blood glucose level that has not reached the diagnostic threshold for diabetes, is a critical stage in the progression of diabetes.[1] Prediabetes is often accompanied by impaired fasting glucose (IFG) or impaired glucose tolerance (IGT), or both.[2] According to the International Diabetes Federation (IDF) report, the 2021 figures for global IFG and IGT were as high as 319 million and 541 million, respectively. These figures were projected to increase to 440 million and 730 million by 2045, accounting for about 18 % of the adult population (22–79 years).[3] In China, the 2018 data suggested that the prevalence of prediabetes had reached 38.1 % of the total population.[4] Excessive intra-abdominal fat combined with insulin resistance (IR) is recognized as a potential precursor to the metabolic syndrome.[5] This condition is linked to significant health risks and therefore necessitates early management.

Prediabetes is a transitional state between normal blood glucose levels and diabetes, and an effective intervention could impede its progression to T2DM, substantially reducing the incidence of diabetes.[6,7] Individuals with prediabetes could reduce the rate of progression to diabetes by approximately 58 % within 3 years through lifestyle changes, such as engaging in weight loss, exercise and making dietary adjustments.[8] Exercise intervention is crucial in reshaping adipose

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tissue, particularly visceral fat (VF) and subcutaneous fat storage. The American Diabetes Association (ADA) recommends that prediabetic individuals participate in 150 min of moderate-intense physical activity per week, since a meta-analysis of a prospective cohort study revealed that this can lower the risk of developing T2DM in prediabetic individuals.[9] However, the type of exercise, especially culturally sensitive exercise, plays an important role in exercise adherence, which directly affects the effect of exercise.[10] In China, a large number, particularly older people, engage in Chinese traditional exercises, such as TaiChi and YiJinJing. Although the effect of TaiChi on glycaemic control has been extensively investigated,[11–13] the effect of YiJinJing has not been explored. YiJinJing exercise, as a moderately intense mind-body practice, emphasizes the coordination of posture, meditation, and breathing, making it easily accessible, with few limitations.[14] The lack of data on the effect of YiJinJing on prediabetes affects the provision of evidence-based exercise prescription in community health promotion.

Accordingly, the current study aimed to examine the effect of 12 weeks traditional Chinese YiJinJing on prediabetes. Specifically, we not only assessed glucose tolerance and insulin resistance, but also monitored lipid distribution, given that an increasing number of studies have found fat distribution is an important factor associated with diabetes.[15] We hypothesized that YiJinJing plus TheraBand exercise can significantly ameliorate glycaemic control in individuals with prediabetes by altering lipid metabolism and distribution.

## 2. Materials and methods

### 2.1. Study design and participants

This was a randomized controlled trial, which was approved by the Ethics Committee of Shanghai University of Sport (Approval number 102772021RT066) and registered in the clinical trial registry (Registration number: ChiCTR2100054684).

The sample size was calculated by using the G*Power software. The main measurement was blood glucose, and to give appropriate power to detect a medium effect size, the total number of with prediabetes needed was at least 60. Accordingly, 60 volunteers were recruited and agreed to provide written informed consent. After baseline assessment, participants were randomly assigned to either the exercise group (Ex, $n = 30$) or the control group (Con, $n = 30$). Participants were blinded to the allocation numbers until the baseline assessment was completed. Throughout the experiment, participants followed their typical lifestyle and dietary patterns; additionally, health education sessions will be conducted. A telephone or WeChat follows up once a week.

The inclusion criteria comprised patients meeting the diagnostic criteria for prediabetes, regardless of gender. In contrast, the exclusion criteria involved patients with cardiovascular, musculoskeletal, or other diseases, as well as those not leading a highly active lifestyle. All participants were instructed to maintain their daily activities without changing their exercise and dietary habits, and their daily physical activities and dietary habits were closely monitored through weekly interviews. All participants underwent standard operating procedure (SOP) training to ensure they understood each trial procedure.

### 2.2. Exercise training protocol

The intervention focuses on the practice of Traditional Chinese YiJinJing exercise, supplemented with TheraBand to provide additional resistance if needed. This approach aligns with ACSM's recommendation for older adults, which are to engage in moderate-intensity aerobic exercises duration for minimum of 150–300 min/wk of moderate activity a week, resistance exercises for 2–3 d/wk. Furthermore, YiJinJing is considered an aerobic exercise due to its stretching and bone extension effects.[16]

The exercise intervention took place in the Workers' and Peasants' Park, adjacent to Shanghai Shidong Hospital. The sessions were conducted three times weekly, with no more than a 2-day interval between sessions, each lasting 1 h, for 12 weeks. During the first week, participants focused on learning the exercises. In the subsequent month, they initially performed YiJinJing twice (13 min each time) alongside resistance exercises with TheraBand twice (5 min each time). As the program progressed, participants transitioned to performing YiJinJing three times per session, followed by a 2–3 min break, then participants continued with three sessions of elastic band exercises but never on consecutive days, with the appropriate resistance value according to the calculated medium strength bullseye rate, or adjust the strength by changing the distance between the two ends of the limb.

Before each session, participants engaged in 5–10 min of warm-up activities, followed by approximately 5 min of stretching, and finally, 3–5 min of muscle relaxation after the exercise (warm-up and relaxation periods were not part of the exercise duration).

Initially, the exercise intensity was moderate, gradually increasing based on individual response. The Polar heart rate telemeter (Finnish version) is used to monitor the heart rate during exercise in real time, and the exercise intensity is evaluated by the measured heart rate [ Moderate intensity HRmax = (220-Age) × (60%–80 %) ]. Subjective feelings also served as an effective way to monitor exercise intensity.

### 2.3. Measurement methods

#### 2.3.1. MRI Inspection equipment

Primary imaging was conducted using the Siemens Magnetom Skyra 3.0T MRI scanner fitted with an 8-channel phased-array coil specifically designed for abdominal imaging. The imaging protocol included abdominal basic sequences and the multi-echo Dixon technique. Before the examination, all participants were instructed to fast for ≥4 h. Trained staff guided the participants through abdominal breathing and breath-holding exercises that required them to hold their breath for ≥13 s. Following that, the examination procedure and precautions were explained, and informed consent was obtained from the participants for undergoing MRI. The MRI employed the water and fat separation imaging technique to produce a fat fraction (FF) map, which was calculated as follows: $FF = [ Mfat/(Mfat + Mwater) ] \times 100\ \%$, where Mwater and Mfat represent the water image and fat image within the region of interest (ROI), respectively. The measurement of the residual sinus fat area extended from the renal hilum to the renal parenchyma area. For the liver, one ROI was selected for each of the left and right liver lobes, as well as the anterior, posterior, internal, and external segments, and the average value was recorded.

#### 2.3.2. Serum laboratory testing

First, participants underwent fasting blood collection in the morning before consuming a glucose solution (75g of anhydrous glucose mixed with 300 mL of warm water). Blood samples were then collected separately using tubes with coagulants for fasting and 2 h after consuming the glucose solution, followed by serum centrifugation at 3500 rpm for 5 min. Indicators, including fasting blood glucose (FBG), oral glucose tolerance test at 2 h (OGTT 2h), HbA1c, fasting insulin (FIns), TC, TG, low-density lipoprotein cholesterol (LDL-C), and high-density lipoprotein cholesterol (HDL-C) were examined at the Shanghai Yangpu District City East Hospital laboratory. HOMA-IR was determined using the following formula: (Fasting Plasma Glucose [mmol/L] x Fasting Serum Insulin [μU/mL])/22.5.

#### 2.3.3. DEXA scanning and Inbody measurement

A DEXA scanner (GE Medical System, Lunar prodigy, version 12.2) was utilized for assessing body fat content, specifically in the Android and Gynoid regions, as well as for determining the overall body fat content and body fat percentage (BF%). A body composition analyser was utilized to measure VF content.

### 2.4. Statistical analysis

Statistical analyses were performed using SPSS 24.0 software, and graphs were generated using R Studio and GraphPad prism software. Data analysis was based on the intention-to-treat principle. An independent samples *t*-test was employed for intergroup comparisons in normally distributed and homoscedastic metric data, and these results were presented as Mean ± Standard Deviation (SD). Intergroup comparisons for non-normally distributed data were performed using the Mann-Whitney non-parametric test, and the results were expressed in quartiles. Paired t-tests were used for pairwise comparisons, while non-normally distributed data were analysed using the Wilcoxon signed-rank test. Pearson's correlation coefficient and the Spearman rank correlation test were used for correlation analysis and analysing normally and non-normally distributed data, respectively. Results or differences with $p < 0.05$ were considered statistically significant.

## 3. Results

### 3.1. Participants and baseline characteristics

After 12 weeks, the overall attrition rate was 18 %. During the intervention, seven participants from the exercise group were lost, resulting in an attrition rate of 23 %. In the control group, four participants were lost, with an attrition rate of 13 %. (Fig. 1).

Table 1 shows the baseline data of the control and exercise groups. There were no significant age or gender differences between the two groups. Furthermore, the two groups exhibited similar FBG, OGTT 2h, FIns, and HOMA-IR, with abnormal glucose tolerance being the primary distinguishing factor. Similarly, various lipid distribution-related indicators, including BMI, WHR, VF, BF, Android fat (AF), Gynoid fat (GF), ULF, ThF, TrF, RSF, and LF, showed no significant differences between the two groups. Additionally, except for free fatty acids (FFA), other lipid metabolism-related biochemical indicators, including TC, TG, HDL,

**Table 1**
Baseline Data of prediabetic patients in the Control and Exercise Groups.

| | Control (n = 30) | Exercise (n = 30) | | |
|---|---|---|---|---|
| | $\bar{X} \pm S$, M ($Q_L$, $Q_U$) | $\bar{X} \pm S$, M ($Q_L$, $Q_U$) | *t* | *p* |
| Age ( y ) | 61.92 ± 4.46 | 62.43 ± 4.83 | 0.385 | 0.702 |
| BMI (kg/m$^2$) | 24.42 (23.24–25.84) | 25.05 ± 2.86 | | 0.733 |
| WHR | 0.89 ± 0.07 | 0.92 ± 0.05 | 1.467 | 0.149 |
| FBG (mmol/L) | 5.97 ± 0.58 | 6.24 ± 0.56 | 1.652 | 0.105 |
| OGTT 2h (mmol/L) | 9.4 ± 1.02 | 9.71 ± 0.96 | 1.098 | 0.278 |
| FIns (μU/mL) | 10.33 ± 5.13 | 10.38 ± 4.15 | 0.039 | 0.969 |
| HOMA-IR | 2.74 ± 1.5 | 2.89 ± 1.23 | 0.402 | 0.69 |
| Visceral fat | 100.21 ± 23.07 | 104.64 ± 22.78 | 0.676 | 0.503 |
| Body fat ( % ) | 33.41 ± 6.5 | 35.66 ± 6.36 | 0.662 | 0.228 |
| Android fat (kg) | 2.1(1.78, 2.55) | 2.43 ± 0.63 | | 0.109 |
| Gynoid fat (kg) | 3.41 ± 0.84 | 3.36 ± 0.68 | −0.232 | 0.824 |
| Upper limb fat (kg) | 2.2(1.63, 2.98) | 2.38 ± 0.72 | | 0.417 |
| Thigh fat (kg) | 5.91 ± 1.64 | 5.76 ± 1.5 | 0.402 | 0.734 |
| Trunk fat (kg) | 11.18(10.46, 15.25) | 13.7(12.06, 14.8) | | 0.253 |
| RSF area (cm$^2$) | 3.81(2.88, 4.85) | 3.74(2.93, 5.64) | | 0.756 |
| Liver fat grey value ( % ) | 4.61(3.58, 7.13) | 8.1 ± 5 | | 0.076 |
| FFA (mmol/L) | 0.5(0.37–0.68) | 0.65 ± 0.2 | | 0.027 |
| TC (mmol/L) | 5.55 ± 1.01 | 5.91 ± 1 | 0.868 | 0.219 |
| TG (mmol/L) | 1.12(0.88, 1.57) | 1.5(0.98, 2.25) | | 0.167 |
| HDL (mmol/L) | 1.42 ± 0.25 | 1.52 ± 0.33 | 0.606 | 0.246 |
| LDL (mmol/L) | 3.53 ± 0.64 | 3.76 ± 0.73 | 0.782 | 0.231 |

Abbreviations: BMI = Body Mass Index, WHR = Waist-Hip Ratio, FBG = Fasting Blood Glucose, OGTT 2h = Oral Glucose Tolerance Test At 2 h, FIns = Fasting Insulin, RSF = Renal Sinus Fat, FFA = Free Fatty Acids, TC = total Cholesterol, TG = Triglyceride, LDL-C = Low-Density Lipoprotein Cholesterol, HDL-C = High-Density Lipoprotein Cholesterol.

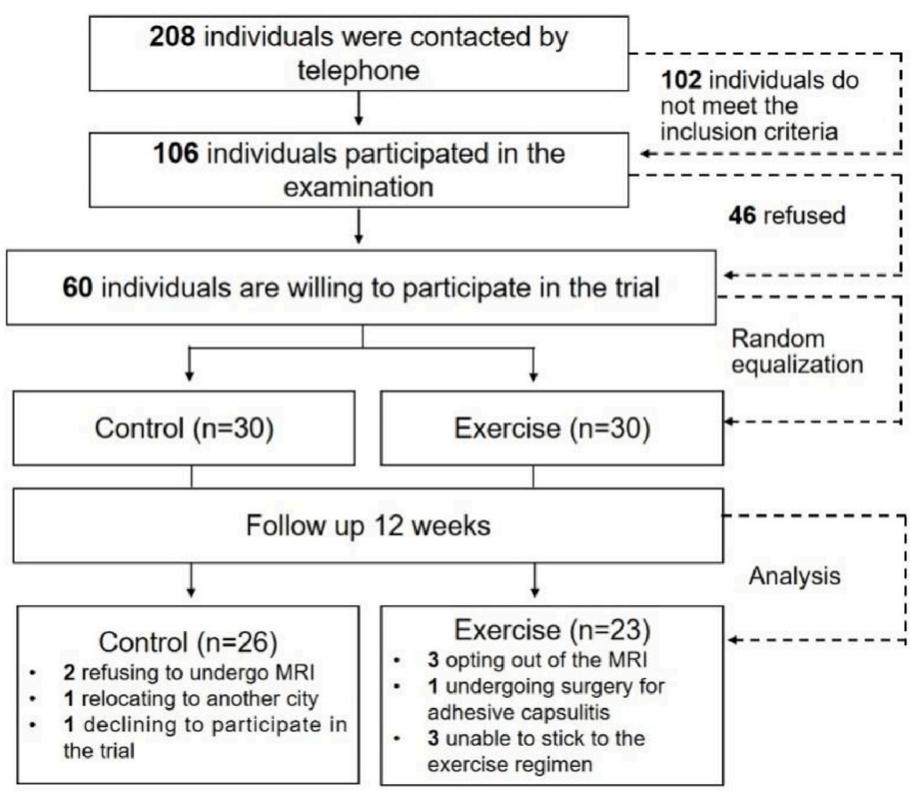


**Fig. 1.** The study profile of the trial participants.

and LDL, displayed no significant differences between the two groups.

### 3.2. Correlation between lipid metabolism and distribution, blood glucose, and insulin

Laboratory tests for glucose and lipid metabolism and MRI tests for lipid distribution revealed that HOMA-IR was significantly positively correlated with; BMI ($r = 0.38$, $p = 0.007$), WHR ($r = 0.41$, $p = 0.004$), VF ($r = 0.42$, $p = 0.003$), AF ($r = 0.35$, $p = 0.013$), ULF ($r = 0.41$, $p = 0.004$), TrF ($r = 0.42$, $p = 0.003$), RSF ($r = 0.3$, $p = 0.04$), LF ($r = 0.54$, $p < 0.000$), and TG ($r = 0.53$, $p < 0.001$), and significantly negatively correlated with HDL ($r = -0.32$, $p = 0.025$) (Fig. 2 A). This finding demonstrates the significance of IR in lipid metabolism and lipid distribution. On the other hand, OGTT 2h was significantly positively correlated with AF ($r = 0.41$, $p = 0.003$), ULF ($r = 0.43$, $p = 0.002$), TrF ($r = 0.46$, $p = 0.001$), and LF grey value ($r = 0.38$, $p = 0.003$) (Fig. 2 B).

### 3.3. Comparison of blood glucose and glucolipid metabolism between the exercise and control groups after 12 weeks

By analysing the correlation between lipid metabolism, lipid distribution, blood glucose, and insulin, significant correlation indexes were obtained. YiJinJang exercise was used for the physical intervention, and analysis conducted to observe changes in the indices before and after the intervention. After 12 weeks intervention with YiJinJing, according the intention-to-treat principle, 37 % of prediabetic patients in the exercise group showed normal blood glucose levels, and none met the diagnostic criteria for diabetes (FBG $\geq$7.8 mmol/L; OGTT 2h $\geq$ 11.1 mmol/L). In the other group, 27 % of the control participants met the diagnostic criteria for diabetes, and none had normal glucose levels (Fig. 3 A). Blood glucose levels were converted into an ordered categorical variable (normal = 1; pre-diabetes = 2; diabetes = 3) for analysis. The Wilcoxon signed-rank test was employed to analyze the ratio differences between the groups, revealing that the prevalence of diabetes in the Ex group was significantly lower than that in the Con group ($p < 0.001$). However, there were no significant differences in HOMA-IR levels. Fig. 3 shows the changes in lipid distribution indicators just associated with OGTT 2h.

Compared with the Con group, the values of changes in the Ex group revealed a significant decrease in LF ($-2.3 \pm 1.17$ vs. $1.16 \pm 1.14$; $p = 0.02$) (Fig. 3 B). Apart from effectively reducing visceral ectopic fat deposition, YiJinJing may also be advantageous for decreasing subcutaneous fat. The values of changes in the ULF[-1.4-(95%CI,-2.5–0.2) vs. 0.09(−0.02-0.21); $p < 0.01$] and Tr[-0.96(95%CI,-1.49–0.43) vs.0.42 (95%CI,0.19–0.64); $p < 0.001$] were significantly changed after YiJinJing intervention (Fig. 3 B). Based on these findings, YiJinJing exercise was effective at stabilizing and normalizing blood glucose levels.

### 3.4. Intra-group comparison of changes in blood glucose and insulin levels after 12 weeks

After 12 weeks of the exercise intervention, the Ex group showed significantly lower FBG [0.09 (95 % CI, 0.04–0.4); $t = 2.503$, $p = 0.012$], FIns [0.55 (95 % CI, 1.11–3.38); $t = 4.092$, $p < 0.001$], and HOMA-IR (0.17 (95 % CI, 0.33–1.05); $t = 3.973$, $p = 0.001$) values compared to baseline (Fig. 4). This finding indicates that the combination of YiJinJing and TheraBand exercise effectively controlled blood glucose in the Ex group. Although the Con group exhibited no significant differences in FIns and HOMA-IR, it showed a significantly higher FBG compared to baseline [0.1 (95%CI, −0.47–0.06); $t = -2.696$, $p = 0.012$], indicating that lack of exercise may increase the risk of high blood glucose in prediabetic patients.

### 3.5. Intra-group comparison of changes in lipid metabolism and lipid distribution after 12 weeks

Body lipid distribution significantly influences blood glucose levels.[17,18] After 12 weeks of the combined exercise intervention, participants in the Ex group exhibited reductions in BMI [0.21 (95 % CI, 0.65–1.52); $t = 5.186$, $p < 0.001$] and WHR [0.01 (95 % CI, 0.02–0.06), $t = 4.176$, $p < 0.001$] (Fig. 5 A). Furthermore, MRI water-fat separation imaging revealed a marked decrease in RSF ($z = -4.152$, $p < 0.001$) and LF ($z = -3.815$, $p < 0.001$) (Fig. 5 B). In addition, DEXA revealed significant reductions in AF ($z = -3.468$, $p = 0.001$), ULF [0.05 (95 % CI, 0.02–0.25), $t = 2.514$, $p = 0.02$], and ThF [0.13 (95 % CI, 0.38–0.9), $t = 5.047$, $p < 0.001$]. The Con group exhibited no significant changes in BMI, RSF, and ThF following 12 weeks of observation compared to baseline. However, the Con group's LF ($z = -3.975$, $p < 0.001$), and ULF ($z = -2.019$, $p = 0.043$) values were significantly higher compared to baseline (Fig. 5C). These findings indicate that while the exercise

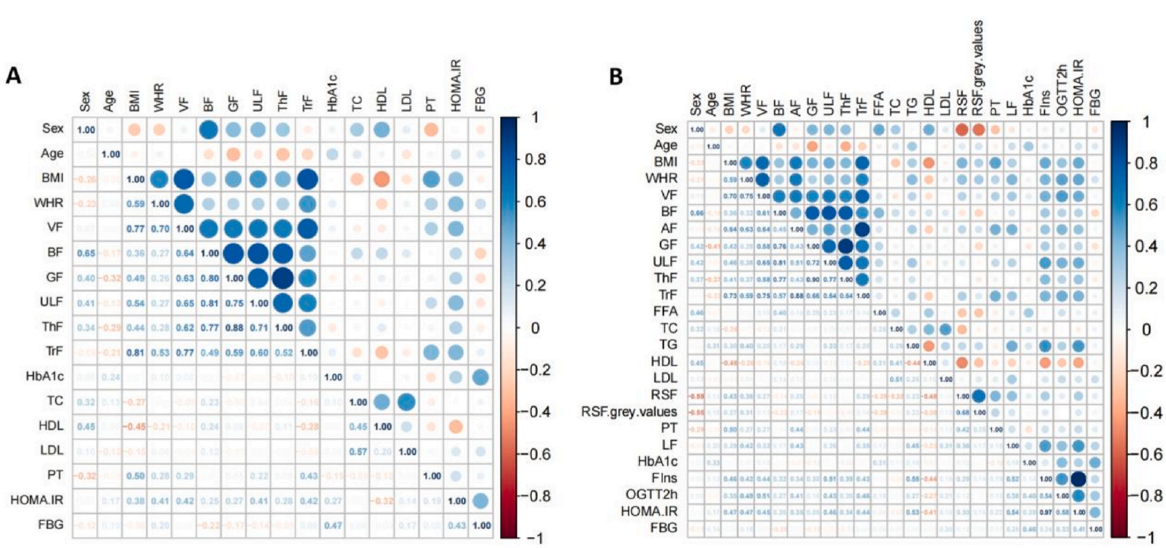


**Fig. 2.** Correlation between blood glucose, insulin, lipid metabolism, and lipid distribution in prediabetic patients. panel (A): Pearson correlation; panel (B): Spearman correlation. Sixty participants are included in the analysis; blue and red denote positive and negative correlations, respectively. Abbreviations: BMI = Body Mass Index, WHR = Waist to Hip Ratio, VF = Visceral Fat, BF = Body Fat, GF = Gynoid Fat, AF = Android Fat, ULF = Upper Limb Fat, ThF = Thigh Fat, TrF = Trunk Fat, RSF = Renal Sinus Fat, TC = Total Cholesterol, TG = Triglyceride, PT = Perirenal Fat.

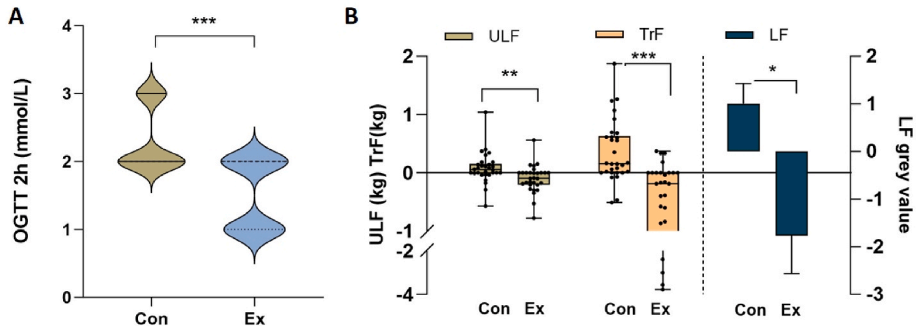


**Fig. 3.** Comparison of glucolipid metabolism between the exercise and control groups after 12 weeks. (A) OGTT 2h changes in the exercise and control groups. (B) Upper limb fat, trunk fat and liver fat grey values change in the exercise and control groups. $*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

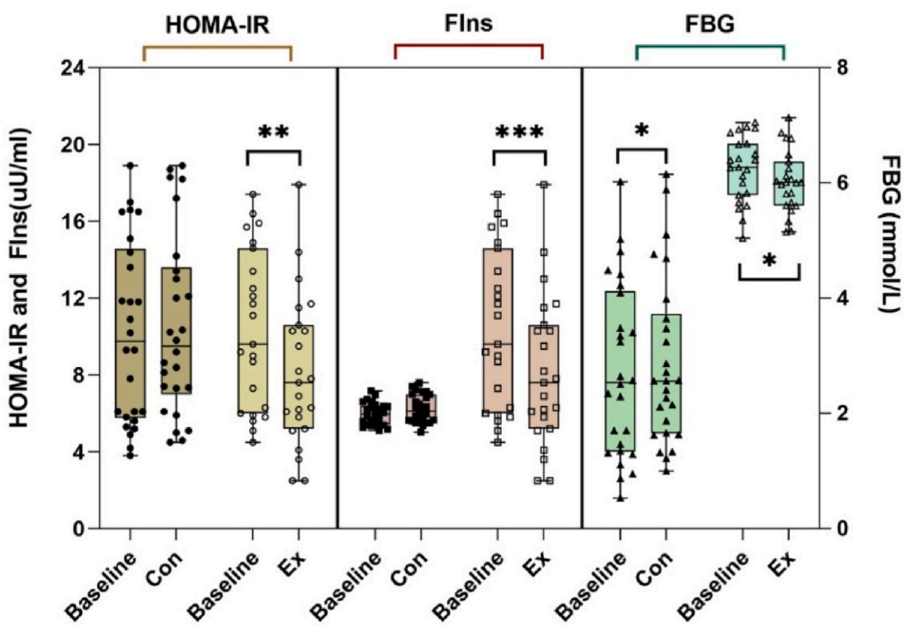


**Fig. 4.** Intra-group comparison for glucose metabolism after 12 weeks. $*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

intervention effectively improves lipid distribution in prediabetic patients, the lack of exercise may increase the risk of unfavourable lipid distribution.

In addition, the Ex group showed a significantly lower TG compared to baseline ($z = -2.816$, $p = 0.005$). However, the Con group without the exercise intervention had a significantly higher TG compared to baseline ($z = -2.019$, $p = 0.04$) (Fig. 5 D).

## 4. Discussion

Prediabetes is a critical stage in the progression of diabetes. Our study found that the 12 weeks exercise can effectively lower blood glucose levels and improve insulin resistance compared to the control group. As a Chinese traditional exercise, YiJinJing, unlike TaiChi, is easily accessible with few limitations, and the data here provide compelling evidence for it reducing the progression of diabetes.

After 12 weeks YiJinJing plus TheraBand intervention, none of the exercise group patients progressed to diabetes, and some exhibited normalized blood glucose levels. However, none of the control group patients experienced a restoration of blood glucose to normal levels. Although the exercise intervention resulted in a statistically significant improvement in the OGTT 2h, its specific benefits for prediabetic patients remain unclear. As shown in the results, exercise effectively improved insulin sensitivity. Individuals with IFG exhibit high hepatic IR, with almost normal values in the skeletal muscles,[19,20] and impaired liver glucose production inhibition, as evidenced by fasting hyperglycemia.[21] In contrast, the primary IR site in IGT is in the muscles, with only moderate changes in hepatic insulin sensitivity.[19] The measure HOMA-IR is derived in a basal state and thus is considered to reflect basal or hepatic insulin sensitivity. As the most sensitive organ, the liver experiences insulin injury more rapidly than other organs; hence, hepatic IR is a major event leading to the subsequent development of peripheral tissue IR.[22] Improved insulin action may enhance bodily functions. Examples include increased insulin-mediated muscle blood flow and muscle protein synthesis (MPS), as well as improved muscle cell quality. Therefore, YiJinJing exercise demonstrates high efficacy in glycaemic control by significantly enhancing lower limb strength and, when combined with TheraBand training, it can boost muscle mass and muscle fibre count,[23] thereby accelerating glucose metabolism.

Fat distribution pattern is closely linked to insulin sensitivity, insulin secretion, and T2DM risk.[24] Patel et al.[25] found that enlarged adipocytes are an independent marker of IR in SF tissue in individuals with T2DM and prediabetes. Our research shows a significant correlation between IR in prediabetic patients and the accumulation of VF, limb fat, and ectopic fat, indicating the impact of lipid distribution on insulin production. This finding is consistent with previous research that found a strong correlation between IR and VF.[26] Interventions based on YiJinJing and supplemented with TheraBand exercises have shown

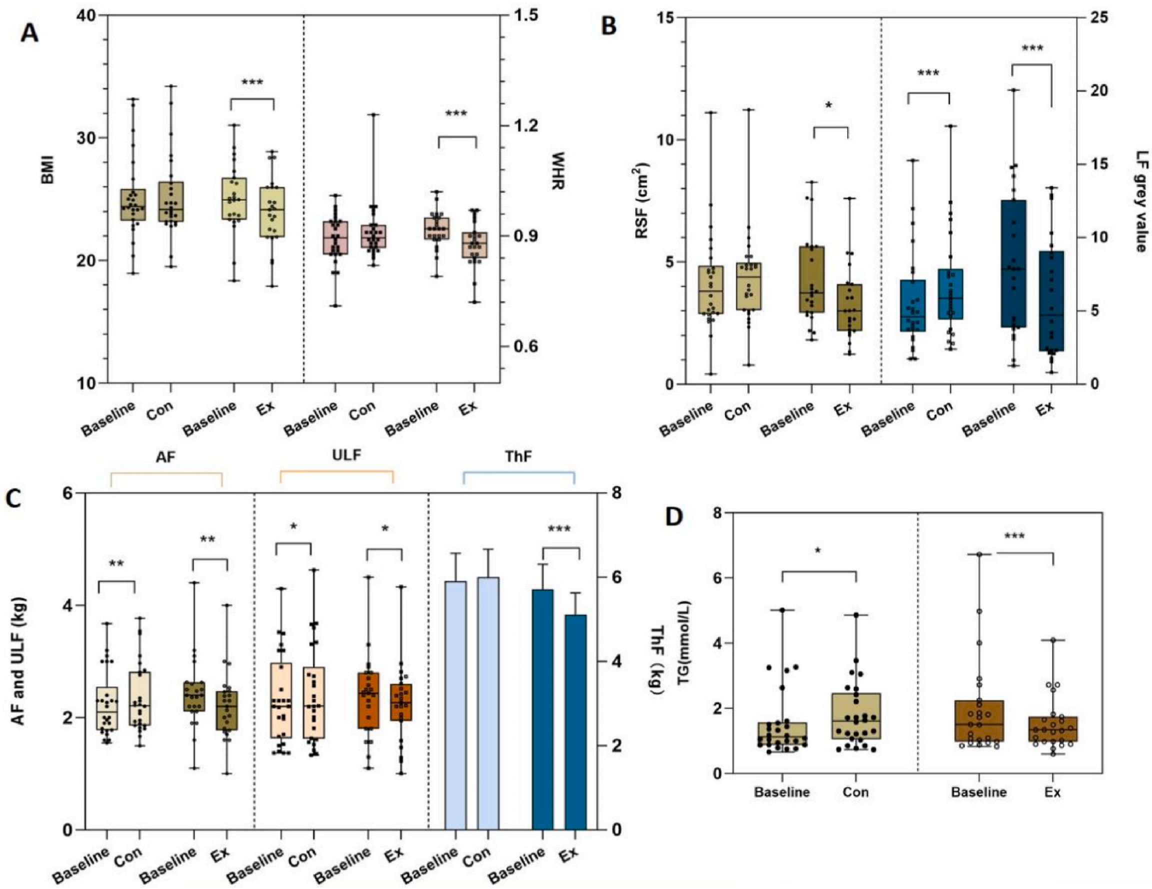


**Fig. 5.** Intra-group comparison of changes in lipid metabolism and lipid distribution after 12 weeks. (A) Intra-group comparison of BMI and WHR. (B) Intra-group comparison of RSF and LF. (C) Intra-group comparison of AF, ULF, and ThF. (D) Intra-group comparison of TG. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

beneficial effects in improving lipid distribution, as well as reducing BMI, WHR, AF, ULF, ThF, RSF, and LF, thereby improving glucose tolerance and IR. A high proportion of upper body (or abdominal) fat, as assessed by the WHR, indicates an elevated risk of IGT, IR, and hypertriglyceridemia.[27] Moreover, WHR-defined central obesity is associated with a higher risk of cardiovascular and microvascular diseases in individuals with prediabetes or diabetes, independent of BMI.[28] Ectopic fat is found in organs such as the liver and kidneys, or accumulates around them as VF.[29] VF content is a crucial indicator of IR, which is the pathological basis of diabetes.[30,31] Regional fat distribution has been suggested to be critically involved in the development of cardiovascular and renal metabolic diseases in non-obese populations.[32] Notably, epicardial adipose tissue in both diabetic and non-diabetic heart failure patients show impaired glucose and lipid metabolism.[33] Similarly, patients with non-alcoholic fatty liver disease may exhibit liver fat IR. Multi-parametric MRI data revealed a marked increase in liver fat and inflammation in T2DM patients with normal liver biochemistry.[34] Consequently, distinct fat distribution patterns exert varying effects on IR.

A meta-analysis has shown that regular aerobic exercises can decrease VF and potentially reduce liver fat in overweight/obese adults and those with T2DM.[35] Yarizadeh et al.[36] found that a combined aerobic and resistance exercise intervention was more effective in reducing subcutaneous abdominal fat tissue than using these exercises individually. Exercise may positively reduce ectopic fat independent of clinically significant weight loss, but this requires further research for verification. Our study has revealed that the YiJinJing plus TheraBand exercise intervention can reduce waist and abdominal fat, including WHR and AF. Nevertheless, DEXA measurements cannot differentiate between abdominal SF and VF. Notably, WHR is often used as a measure of abdominal fat distribution, potentially reflecting VF. A smaller hip circumference or SF may also contribute to a higher WHR. Therefore, YiJinJing paired with resistance exercise may be more effective in reducing abdominal IMAT and VF.

In addition to reducing abdominal fat, our exercise intervention also significantly lowered TrF, ThF, and ULF, which could be attributed mostly to the decrease in IMAT. However, research has demonstrated the beneficial effects of ThF on blood glucose improvement, particularly the protective role of SF compared to IMAT.[37] This study involved both white and black participants, and further research and discussion are needed to determine the benefits of SF in the buttocks and the storage quantity that is advantageous for Asians. GF, which refers to the distribution of fat in the buttocks and legs, did not show a significant association with abnormal blood glucose levels in this study, implying that buttock and leg fat accumulation may positively impact blood glucose and lipids.

In healthy individuals, excessive energy intake results in the storage of excess calories as TGs in white fat. Exercise intervention significantly reduces TG in prediabetic patients, thereby improving ectopic fat deposition in the patients' organs. In healthy, non-obese Asians, increased ectopic fat deposition is associated with decreased insulin sensitivity and increased insulin secretion. According to previous research, aerobic exercise can ameliorate ectopic fat deposition and abnormal glucose homeostasis regulation.[38] In addition, the combination of aerobic and resistance exercise can enhance MPS and muscle cell quality, preserving muscle mass and upregulating the myocyte-enhancing factor 2A.[39] When individually applied, aerobic exercise could lead to an extended increase in growth hormone release over 24 h, whereas resistance exercise may induce an acute increase in growth hormone secretion.

## 5. Limitations

This study is subject to some limitations. Although its objective was to create personalized exercise intervention programs for diabetes prevention and treatment, the small sample size may have underpowered the correlation analysis. Moreover, the analysis of fat distribution only utilized DEXA for measuring whole-body and limb fat, without differentiation between subcutaneous fat and visceral fat. Future research endeavours should consider using larger sample sizes and more accurate imaging techniques.

## 6. Conclusions

Traditional Chinese YiJinJing plus TheraBand exercise effectively enhances glucose tolerance and ameliorated IR in prediabetic patients via markedly reducing the lipid distribution. Additionally, this study underscores the significance of considering the impact of different fat depots on blood glucose and IR, as well as the selection of appropriate exercise modalities during treatment, laying the groundwork for developing more personalized strategies for T2DM prevention and management.

## Author statement

Shasha Wang contributed to the conception and design of the study, acquisition of the data, analysis and draft the article; Mu Cui contributed to acquisition of the data and analysis; Jing-yuan Li contributed to acquisition of the data; Huai-ming Zhang contributed to acquisition of the data; or revising it critically for important intellectual content; Xiang-yun Liu contributed to design of the study; and Jia Han contributed to the final approval of the version to be published.

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