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Effects of Life Style Modifications (Dietary and Exercise) on Insulin Resistance in Egyptian Men with Impaired Glucose Tolerance

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Abstract

Insulin resistance (IR) is considered one of the most serious chronic conditions. Although IR usually starts silently (euglycemic state), it can seriously lead to impaired glucose tolerance and the development of diabetes mellitus (DM) with other debilitating complications. The current study was conducted for four months to test the application of healthy dietary modification and/or regular programmed exercise on 120 Egyptian male subjects with high blood glucose levels, high insulin levels, and high homeostatic model assessment of insulin resistance (HOMA-IR). They were assigned into 4 groups. The first group received no intervention (control). The second group received healthy dietary intervention. The third group received regular exercise program. The fourth group received both healthy dietary intervention and regular exercise program. Along with blood glucose and insulin levels; weight and triglycerides (TG) levels were also assessed. Compared to the control group, the results showed significant reduction ($p<0.05$) in both fasting and postprandial blood glucose and insulin levels as represented by HOMA-IR along with significant reduction ($p<0.05$) in the other metabolic parameters assessed during the study in both dietary intervention alone and exercise intervention alone groups. The reduction was more significant ($p<0.05$) in the group that received both healthy dietary and regular exercise intervention. In conclusion; IR could be avoided if either healthy dietary modification and/or regular programmed exercise are adopted.

Keywords: *Insulin resistance, dietary modification, exercise, HOMA-IR.*

1. Introduction

Fasting hyperinsulinemia is believed to be the first incident to precede the development of other characteristics of the metabolic syndrome such as increased weight hypertension, hyperglycemia, dyslipidemia (Lin et al., 2022). Insulin resistance (IR) is mainly defined as the increased need for secreting more and more insulin to keep the euglycemic state. At this point the blood sugar level is still within normal while insulin level is increased. This by itself is not necessarily dangerous but the real danger ambushes in the time ahead when target cells become less sensitive to insulin (although increased) until they become insensitive and blood glucose levels begin to rise (Mirabelli, 2020). The obesity-related IR increases the prevalence of DM. The globally increased rate of obesity is a direct result of physical inactivity and unhealthy diet (Guo et al., 2020).

Promoting lifestyle changes such as adopting healthy diet and regular physical activity among the at-risk people or even healthy population can reduce IR (Galaviz et al., 2018). Adopting a healthy diet concept that emphasizes enough dietary fiber, less carbohydrates, more proteins and healthy fats can improve IR (Barber et al., 2020).

Aerobic physical activity can greatly improve blood glucose levels and insulin sensitivity in both normal and insulin-resistant individuals. IR is considered the major underpinning link between physical inactivity and the development of impaired glucose tolerance. (Lin et al., 2022). Resistance exercise is the most effective way to increase muscle mass which can promote insulin sensitivity. If it is regularly performed for single set even for a short duration until failure, it remains as effective as prolonged multiple sessions of resistance exercise (Ismail et al., 2019).

2. Materials and Methods

The research protocol was approved by the local ethics committee of the Faculty of Medicine at Cairo University. The study continued for four months and was a randomized controlled exercise and feeding trial that tested the effects of healthy dietary modification and/or regular exercise on IR and some other parameters on subjects with impaired glucose tolerance.

Study population

One hundred and forty adult Egyptian males (aged 25-45 years) were randomly selected from the internal medicine outpatient clinics of Cairo University Hospitals during their regular check-up routine. They were all discovered to have IR based on HOMA-IR with or without family history of type 2 DM. They were all sedentary (they never had exercise routine) and they were all over-weighted or obese. Only 120 subjects were included and they all completed the study.

All included subjects met the inclusion criteria. They had no apparent health conditions and took no anti-hyperglycemic medications. They all had impaired glucose tolerance with elevated two hours post prandial glucose (PPG) (140 – 199 mg/dl) and elevated two hours post prandial insulin (PPI) (>25.7 µU/ml) (Rao et al., 2004). The HOMA-IR values for all participants were high (>5) (Kawada et al., 2010) (Qu et al., 2011). 20 subjects were excluded from the study as they didn't meet the inclusion criteria. They had co-morbid chronic conditions that could affect blood glucose levels (cardio-pulmonary, renal insufficiency, diabetes, or endocrinal diseases) and those who used medications affecting blood glucose levels in addition to alcoholics.

Study groups

The subjects who all passed the inclusion criteria were randomly allocated into four groups each with thirty subjects (n=30) with a total number of one hundred and twenty subjects:

The control group: received no dietary nor exercise intervention. The diet-only group: received healthy dietary intervention. The exercise-only group: received regular exercise intervention. The diet & exercise group: received both healthy dietary and regular exercise program intervention.

Study parameters

The study parameters were measured for all participants before beginning (baseline), during (after two months) and at the end of the study (after four months). They included PPG (mg/dl) (Tietz, 1995), PPI (µU/ml) (Mercodia, 1991), HOMA-IR by the formula (Kawada et al., 2010):

$$HOMA-IR = \frac{Fasting\ glucose\ (mg/dl)\ \times Faasting\ insulin\ (\mu U/ml)}{405}$$

They also included blood triglycerides (TG) (mg/dl) (Fassati and Prencip, 1982) and weight (Kg).

Before conducting the study; all included participants underwent a thorough medical examination that included abdominopelvic ultra-sonography and some laboratory investigations for blood sodium (Na+) and potassium (K+) levels (Albert et al., 2011), thyroid stimulating hormone (TSH) (NHANES, 2002), blood creatinine level (NHANES, 2002), and complete urine analysis (Roxe, 1990) where there were no abnormalities detected for all included participants that could affect or terminate the study.

The laboratory parameters were done at Cairo University Hospital Laboratories. Glucose concentration was measured by using the GOD-PAP enzymatic colorimetric method. Samples were collected from venous blood after 2 hours of the main daily meal which is the mid-day meal. Fluorides were added to each sample used in this test. Serum was separated within 30 minutes when blood was drawn and permitted to clot and to stand uncentrifuged at room temperature. Glucose is determined after enzymatic oxidation in the presence of glucose oxidase. The formed hydrogen peroxide reacts under catalysis of peroxidase with phenol and 4-aminoantipyrine to form a red violet quinoneimine dye as an indicator (Tietz, 1995).

Insulin concentration was measured by using Mercodia insulin enzyme-linked immunosorbent assay (ELISA) which is a two-site enzyme immunoassay utilizing the direct sandwich technique. Samples were collected from venous blood after 2 hours of the main daily meal which is the mid-day meal for. Samples were stored at -20oC or lower if not assayed immediately (within 24 hours). Repeated freezethaw cycles of the sample were avoided. 25 µL of each sample of serum was required to test each specimen singly per assay (Mercodia, 1991).

TG concentration was measured by using the enzymatic colorimetric method. Venous blood samples were collected from all participants after an over-night fasting (12 hours). Serum was separated within 30 minutes when blood was drawn and permitted to clot and to stand uncentrifuged at room temperature. Serum samples were mixed with enzymatic reagents including lipase, glycerokinase, glycerol-3-phosphate oxidase and peroxidase to form colored quinoneimine dye as an indicator (Fassati and Prencip, 1982).

The weight was measured by using the same scale and under the same circumstances throughout the study period. While fasting, the subject stood calmly on the scale bare footed and with the least clothes possible then the weight was taken to the nearest value (Nuttall, 2015).

Intervention

This study was conducted at the Physiology Department, Faculty of Medicine, Cairo University. The control group underwent no intervention, the diet-only group consumed healthy dietary intervention, the exercise-only group performed regular patterns of both aerobic and strength exercise and the diet & exercise group consumed both dietary and exercise interventions.

Dietary intervention

A pattern of low-caloric, low-carbohydrate (< 26% of the planned caloric intake) (Ebbeling et al., 2018) and high-protein dietary intervention at a given number of servings of food of which their total caloric summation constituted 1000 Calories per day was consumed by the subjects of the diet-only group and the diet & exercise group on daily basis for 4 months (Barber et al., 2021). The dietary pattern contained plenty of proteins of animal and plant sources and vegetables, moderate amounts of fruits and nuts, and small amounts of whole grains and sugar-containing foods with no limitation for water drinking (WHO, 2003). The meal plan was divided into two daily meals with 8 hours interval where the 1st meal was delayed until after 2 hours of waking up (Lopez et al., 2019) with periods of intermittent fasting for 16 hours (Collier, 2013). The total daily calories were calculated and incorporated into three different examples of daily intake where the subjects were asked to freely switch among them (HHS, 2016).

Example (1)

Grains: (2 servings) = 1 slice of whole wheat bread + 0.8 cups (200 ml) cooked rice. Vegetables: (3 servings) = 2 cups (473 ml) salad (cucumber, tomatoes, and green pepper) + ½ cups (118 ml) cooked zucchinis. Fruits: (2 servings) = 2 medium oranges or apples, or one cup (8) apricots. Dairy: (2 servings) = 10.7 oz. (300 gm) milk + 1 oz. (28 gm) cheese. Poultry: (3 servings) = 9 oz. (254 gm) cooked chicken. Nuts and beans: (1 serving): one serving = 1½ oz (42 gm) peanuts, or ½ oz. pumpkin seeds, or ½ cups cooked fava beans. Fats: (2 servings) = 2 tsp (10 ml) olive oil. Sweets: (2 servings per week): one serving = 1 Tbsp (15 ml) sugar or jam or jelly.

Example (2)

Grains: (3 servings) = 1 slice of whole wheat bread + 0.8 cups (200 ml) cooked pasta + 1 oz. (28 gm) dry whole grain cereals. Vegetables: (2.5 servings) = 1 cup (237.5 ml) salad (cucumber, tomatoes, and green pepper) + 0.75 cups (177.5 ml) cooked spinach. Fruits: (1 servings) = 1 medium orange or pineapple, or ½ cups (5) strawberries. Dairy: (2 servings) = 5.8 oz. (150 gm) milk + 1.3 cups (314 ml) yogurt. Meats: (2 servings) = 6 oz. (170 gm) cooked beef. Nuts and beans: (1 serving): one serving = ½ cups (118 ml) cooked lentils, or ½ cups kidney beans, or ½ cups dry beans, or ½ cups fava beans. Fats: (2 servings) = 2 tsp (10 ml) corn oil. Sweets: (2 servings per week): one serving = 1 Tbsp (15 ml) sugar or jam or jelly.

Example (3)

Grains: (2 servings) = 1 slice of whole wheat bread + 0.8 oz (23 gm) dry whole grain cereals. Vegetables: (3 servings) = 1.2 cups (285 ml) salad (cucumber, tomatoes, and green pepper) + 0.9 cups (213 ml) cooked green peas. Fruits: (2 servings) = 1 medium orange, or mango, or ½ cups (5 plums). Dairy: (2 servings) = 0.7 cup (158 ml) fat free yogurt + 2 oz. (57 gm) cheese. Meats: (4 servings) = 12 oz. (340 gm) cooked fish. Nuts and beans: (1 serving): one serving = 1½ oz. (42 gm) seeds, or ½ cups (118 ml) lentils, or kidney beans. Fats: (3 servings) = 1 tsp (5 ml) flaxseed oil + 1 tsp (5 ml) olive oil + 1 Tbsp (15 ml) low fat mayonnaise. Sweets: (2 servings per week): one serving = 1 Tbsp (15 ml) sugar or jam or jelly, or 8 oz. (225 gm) lemon juice.

Exercise intervention

Regular exercise program for 5 days a week of moderate to severe intensity was utilized by subjects of the exercise-only group and the diet & exercise group. The program consisted of exercise sessions of 45 minutes each. Every session consisted of an aerobic period for 30 minutes (Hsieh et al., 2019) followed by a resistance (strength) period of short volitional single-set of failure for a maximum of 15 minutes (Ismail et al., 2019). Additional periods of warming up and stretching for 5 minutes and cooling down for another 5 minutes were added to each session throughout the whole study period which lasted for 4 months (ADA, 2002). Extensive monitoring, proper footwear and proper hydration were assured to all subjects during the exercise period (ADA, 2002). Before, during and after each exercise session; every subject's resting and exercising heart rate (HR) were monitored by using a finger pulse oximeter as an indicator for exercise intensity. The predicted maximal HR was calculated for each participant by using the formula: maximal HR = 220 – age (Colberg et al., 2016).

Aerobic exercise

The subjects exercised on a cycle ergometer (Embreex 360, Brusque, Brazil) for a 30 minutes period. Starting at low cycling speed; the subjects progressively increased their speeds until they reached a moderate to severe intensity exercise form. The intensity was assessed by monitoring the subjects' heart rates where they were allowed to increase progressively but they were kept at or below 80% of their maximal (Colberg et al., 2016). The intensity was also assessed by observing the degree of subjects' exertion which was evaluated by using the modified Borg Dyspnea Scale or Category (C) Ratio (R) graded (0-10) scale (CR10). According to the scale, the subjects' perceived exertion was registered in an incremental fashion every 5 minutes based on their ability to stand the increasing cycling speeds. The intensity was maintained at levels between (5-10). The subjects were asked to slow down when limits were exceeded (Soriano et al., 2014).

1 – 10 Borg Rating of Perceived Exertion Scale	
0	Rest
1	Really Easy
2	Easy
3	Moderate
4	Sort of Hard
5 6	Hard
7 8	Really Hard
9	Really, Really Hard
10	Maximal: just like my hardest race

Fig. (1): Borg' exertional (CR10) scale (Soriano et al., 2014).

Resistance (strength) exercise

Following the aerobic session; the subjects utilized resistance exercise for a period of 15 minutes duration to avoid getting deeply into the anaerobic state which works against insulin and can cause an increase in blood glucose (Lukács and Barkai, 2015). Each session consisted of a volitional single-set of failure where every subject practiced a continuous set of resisting loads until feeling of severely exerted and letting go of the load. The time was equally divided between the upper and lower limbs (Ismail et al., 2019). For upper limb resistance set; weights (to the extent at which each subject can bear) were carried by hands doing continuous bench presses and biceps curls until failure. This took some participants less time than targeted (Ismail et al., 2019). For lower limb resistance set; the weights (to the extent at which each subject can bear) were pushed by legs doing leg presses and extensions until failure. This also took some participants less time than targeted (Ismail et al., 2019).

Statistical analysis

Data were revised, coded and calculated using the statistical package for the Social Sciences (SPSS) version 26 (IBM Corp., Armonk, NY, USA). Quantitative data were summarized using mean and standard deviation (SD). Comparisons between groups were done using ANOVA with post hoc test. P-values<0.05 were considered statistically significant (Chan, 2003). For comparison of serial measurements within each group repeated measures ANOVA was used. Frequency and percentage were used for presenting qualitative data. Suitable analysis was done according to the type of data (Chan, 2004).

3. Results and Discussion

The mean values illustrated by table (1) and figure (2) showed significant reduction (P<0.05) in PPG values recorded over the time course after 2 months from the corresponding baseline values, after 4 months from the corresponding baseline values and after 4 months from the corresponding 2 months values as well of the exercise-only group and the diet & exercise group. In the exercise-only group, the reduction from the corresponding baseline value was (-10.9% & -17%) at month 2 & month 4 respectively. However, in the diet & exercise group the reduction from the corresponding baseline value was greater (-15.1% & -20.35%) at month 2 & month 4 respectively. In the diet only group there was an increase from the corresponding baseline value by (+0.6%) after 2 months, and then a significant reduction happened by (-8.82%) after 4 months in comparison to the corresponding baseline value. Anyways the control group showed increase in PPG value by (+0.7% and +1.1%) at month 2 & month 4 respectively from the corresponding baseline value.

Comparing different groups; there was a significant reduction (P<0.05) in PPG values after 2 months and 4 months in the exercise-only group and the diet & exercise group in comparison to the corresponding values in the diet-only group. It also showed significant reduction (P<0.05) in PPG values after 4 months in the exercise-only group and the diet & exercise group in comparison to the corresponding values in the control group.

Table (1): PPG (mean ± SD) of individual groups and comparison among different groups.

	Control group	Diet-only group	Exercise-only group	Diet and exercise group
PPG 0	172.1±15.91 (mg/dL)	180.1±12.69 (mg/dL)	172.2±18.89 (mg/dL)	174.4±14.85 (mg/dL)
PPG 2	173.3±13.25 (mg/dL)	181.2±37.04 (mg/dL)	153.4±15.56@# (mg/dL)	148±10.52@# (mg/dL)
% Month 2	+0.70%	+0.60%	-10.90%	-15.10%
PPG 4	174±13.86 (mg/dL)	164.2±10.98@ (mg/dL)	142.9±14.91@&*# (mg/dL)	138.9±10.71@&*# (mg/dL)
% Month 4	+1.10%	-8.82%	-17%	-20.35%

PPG 0: at the beginning (baseline). PPG 2: after 2 months. PPG 4: after 4 months. @- statistically significant compared to corresponding value measured at baseline (P<0.05). &- statistically significant compared to corresponding value measured after 2 months (P<0.05). *- statistically significant compared to corresponding value in Control group (P<0.05). #- statistically significant compared to corresponding value in diet group (P<0.05).

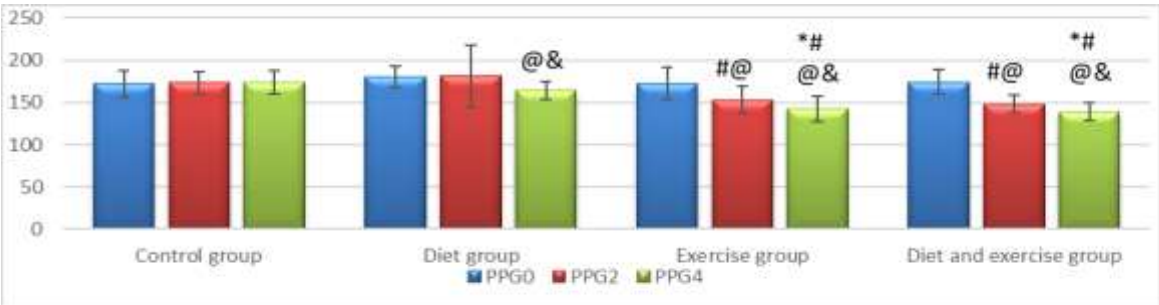

Fig. (2): PPG (mg/dL) (mean ± SD). PPG 0: at the beginning (baseline). PPG 2: after 2 months. PPG 4: after 4 months. *- statistically significant compared to corresponding value in control group (P<0.05). #- statistically significant compared to corresponding value in diet group (P<0.05). @- statistically significant compared to corresponding value measured at baseline (P<0.05). &- statistically significant compared to corresponding value measured after 2 months (P<0.05).

The mean values illustrated by table (2) and figure (3) showed significant reduction (P<0.05) in PPI values recorded over the time course after 2 months from the corresponding baseline values, after 4 months from the corresponding baseline values and after 4 months from the corresponding 2 months values as well of the diet-only group, the exercise-only group and the diet & exercise group. A more prominent significant reduction from corresponding baseline values was observed in both the exercise-only group and the diet & exercise group than other groups. In the exercise-only group the reduction was (-18.57% & -28.34%) at month 2 & month 4, respectively. However, in the diet & exercise group the reduction was greater (-19.57% & -29.25%) at month 2 & month 4 respectively. The reduction in the diet-only group from the corresponding baseline value was (-11.3% & -19.83%) at month 2 & month 4 respectively. Anyways the control group showed increase in PPI value from the corresponding baseline value by (+2.90% and +2.53%) at month 2 & month 4 respectively.

Comparing different groups; there were no significant differences of PPI values recorded among different groups for their corresponding values after 2 months of the study, while after 4 months there was a significant reduction (P<0.05) of PPI values in the exercise-only group and the diet & exercise group in comparison to the corresponding values in the control group.

Table (2): PPI (mean ± SD) of individual groups and comparison among different groups.

	Control group	Diet-only group	Exercise-only group	Diet and exercise group
PPI 0	38.31±8.15 (µU/mL)	43.4±6.53 (µU/mL)	39.79±8.42 (µU/mL)	42.04±9.5 (µU/mL)
PPI 2	39.42±5.88 (µU/mL)	38.5±5.61@ (µU/mL)	32.4±6.49@ (µU/mL)	33.81±8.65@ (µU/mL)
% Month 2	+2.90%	-11.30%	-18.57%	-19.57%
PPI 4	39.28±6.22 (µU/mL)	34.79±5.25@& (µU/mL)	28.51±5.62@&* (µU/mL)	29.74±6.96@&* (µU/mL)
% Month 4	+2.53%	-19.83%	-28.34%	-29.25%

PPI 0: at the beginning (baseline). PPI 2: after 2 months. PPI 4: after 4 months. @- statistically significant compared to corresponding value measured at baseline (P<0.05). &- statistically significant compared to corresponding value measured after 2 months (P<0.05). *- statistically significant compared to corresponding value in Control group (P<0.05).

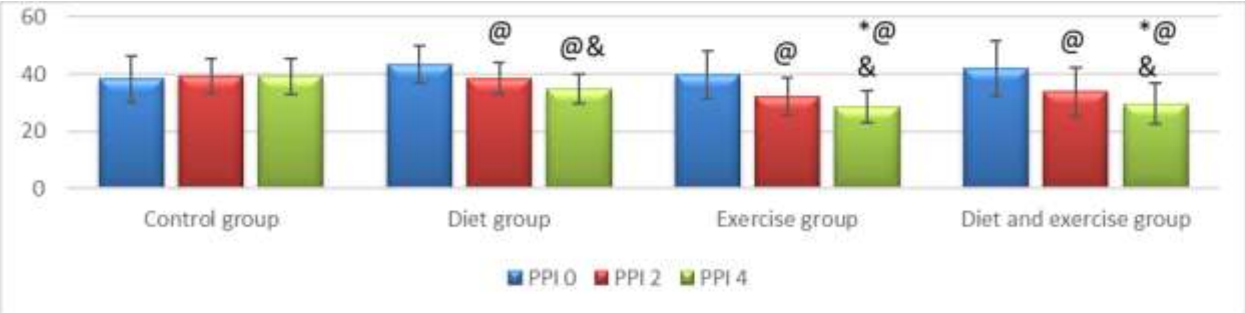

Fig. (3): PPI (µU/mL) (mean ± SD). PPI 0: at the beginning (baseline). PPI 2: after 2 months. PPI 4: after 4 months. *- statistically significant compared to corresponding value in Control group (P<0.05). @- statistically significant compared to corresponding value measured at baseline (P<0.05). &- statistically significant compared to corresponding value measured after 2 months (P<0.05).

The mean values illustrated by table (3) and figure (4) showed significant reduction (P<0.05) in HOMA-IR values recorded over the time course after 2 months from the corresponding baseline values, after 4 months from the corresponding baseline values and after 4 months from the corresponding 2 months values as well of the diet-only group, the exercise-only group and the diet & exercise group. A more prominent significant reduction from corresponding baseline values was observed in both the exercise-only group and the diet & exercise group than other groups. In the exercise-only group, the reduction was (-9.56% & -20%) at month 2 & month 4 respectively. However, in the diet & exercise group the reduction was greater (-14.9% & -33.56%) at month 2 & month 4 respectively. The reduction in the diet-only group from the corresponding baseline value was (-8% & -17.9%) at month 2 & month 4, respectively. Anyways the control group showed increase in HOMA-IR value from the corresponding baseline value by (+1.60% and +2.86%) at month 2 & month 4 respectively.

Comparing different groups; there were no significant differences of HOMA-IR values recorded among different groups for their corresponding values after 2 months of the study, while after 4 months there was a significant reduction (P<0.05) of HOMA-IR value in the diet & exercise group in comparison to the corresponding value in the control group.

Table (3): HOMA-IR (mean ± SD) of individual groups and comparison among different groups.

	Control group	Diet-only group	Exercise-only group	Diet and exercise group
HOMA-IR 0	6.28±1.64	6.76±1.44	6.59±1.49	7.24±1.81
HOMA-IR 2	6.38±1.67	6.22±1.17@	5.96±1.11@	6.16±1.22@
% Month 2	+1.60%	-8%	-9.56%	-14.90%
HOMA-IR 4	6.46±1.6	5.55±1.1@&	5.27±1.08@&	4.81±0.9@&*
% Month 4	+2.86%	-17.90%	-20%	-33.56%

HOMA-IR 0: at the beginning (baseline). HOMA-IR 2: after 2 months. HOMA-IR 4: after 4 months. @- statistically significant compared to corresponding value measured at baseline (P<0.05). &- statistically significant compared to corresponding value measured after 2 months (P<0.05). *- statistically significant compared to corresponding value in Control group (P<0.05).

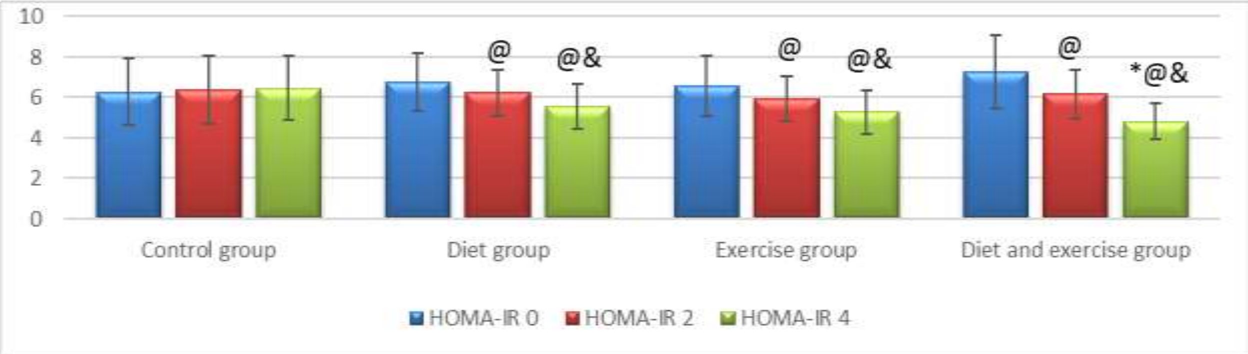

Fig. (4): HOMA-IR (mean ± SD). HOMA-IR 0: at the beginning (baseline). HOMA-IR 2: after 2 months. HOMA-IR 4: after 4 months. *- statistically significant compared to corresponding value in Control group (P<0.05). @- statistically significant compared to corresponding value measured at baseline (P<0.05). &- statistically significant compared to corresponding value measured after 2 months (P<0.05).

The mean values illustrated by the table (4) and figure (5) showed significant reduction (P<0.05) in TG values recorded over the time course after 2 months from the corresponding baseline values, after 4 months from the corresponding baseline values and after 4 months from the corresponding 2 months values as well of the diet-only group, the exercise-only group and the diet & exercise group. A more prominent significant reduction from the corresponding baseline values was observed in both the diet-only group and the diet & exercise group than other groups. In the diet-only group, the TG reduction was (-6.86% & - 11.77%) at month 2 & month 4, respectively. However, in the diet & exercise group the reduction was greater (-12.9% & -18.5%) at month 2 & month 4 respectively. The reduction in the exercise-only group from the corresponding baseline value was (-6.25% & -9.6%) at month 2 & month 4 respectively. Anyways the control group showed an increase in TG value from the corresponding baseline value by (+0.46% and +2.1%) at month 2 & month 4 respectively.

Comparing different groups; there were no significant differences in TG values recorded among different groups for the corresponding values throughout the study periods (after 2 months and after 4 months).

Table (4): TG (mean ± SD) of individual groups and comparison among different groups.

	Control group	Diet-only group	Exercise-only group	Diet and exercise group
TG 0	173.5±27.05 (mg/dL)	174.9±31.21 (mg/dL)	179±51.53 (mg/dL)	178.9±38.2 (mg/dL)
TG 2	174.3±28.3 (mg/dL)	162.9±24.41@ (mg/dL)	167.8±38.54@ (mg/dL)	155.8±25.42@ (mg/dL)
% Month 2	+0.46%	-6.86%	-6.25%	-12.90%
TG 4	177.2±28.35 (mg/dL)	154.3±22@& (mg/dL)	161.8±37.08@& (mg/dL)	145.8±18.6@& (mg/dL)
% Month 4	+2.10%	-11.77%	-9.60%	-18.50%

TG 0: at the beginning (baseline). TG 2: after 2 months. TG 4: after 4 months. @- statistically significant compared to corresponding value measured at baseline (P<0.05). &- statistically significant compared to corresponding value measured after 2 months (P<0.05).

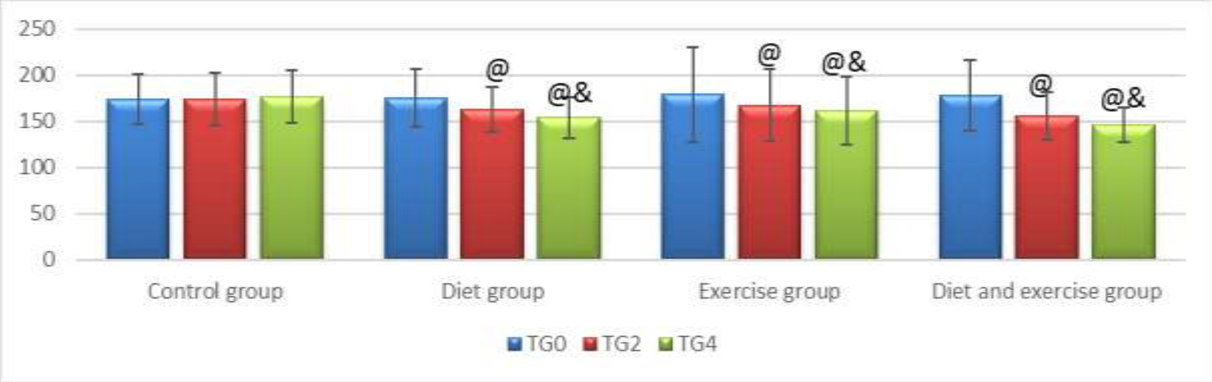

Fig. (5): TG (mg/dL) (mean ± SD). TG 0: at the beginning (baseline). TG 2: after 2 months. TG 4: after 4 months. @- statistically significant compared to corresponding value measured at baseline (P<0.05). &- statistically significant compared to corresponding value measured after 2 months (P<0.05).

The mean values illustrated by table (5) and figure (6) showed significant reduction (P<0.05) in weight recorded after 2 months from the corresponding baseline values, after 4 months from the corresponding baseline values and after 4 months from the corresponding 2 months values of the diet-only group, the exercise-only group and the diet & exercise group with more prominent significant reduction in both the diet-only group and the diet & exercise group. In the diet-only group; the percentage reduction was (-5.2% & -9.42%) at month 2 & month 4 respectively. However, in the diet & exercise group there was more reduction (-6.8% & -11.8%) at month 2 & month 4 respectively. The reduction in the exercise-only group was (-2.76% & -6%) at month 2 & month 4 respectively. The control group showed increase in weight values from the corresponding baseline values by (+1% and +1.65%) at month 2 & month 4 respectively. Comparing different groups; there were no significant differences in weight values recorded among different groups for the corresponding values throughout the study period.

Table (5): weight (mean ± SD) of individual groups and comparison among different groups.

	Control group	Diet-only group	Exercise-only group	Diet & exercise group
WT0	95.3±7.17 (Kg)	101.9±10.41 (Kg)	97.7±13.48 (Kg)	106.9±9.65 (Kg)
WT2	96.3±5.76 (Kg)	96.6±10.22@ (Kg)	95±12.57@ (Kg)	99.6±9.22@ (Kg)
% Month 4	+1%	-5.2%	-2.76%	-6.80%
WT4	96.9±6.62 (Kg)	92.3±9.55@& (Kg)	91.8±11.23@& (Kg)	94.2±8.63@& (Kg)
% Month 4	+1.65%	-9.42%	-6%	-11.80%

WT0: weight at baseline. WT2: weight after 2 months. WT4: weight after 4 months. @- statistically significant compared to corresponding value measured at baseline (P<0.05). &- statistically significant compared to corresponding value measured after 2 months (P<0.05).

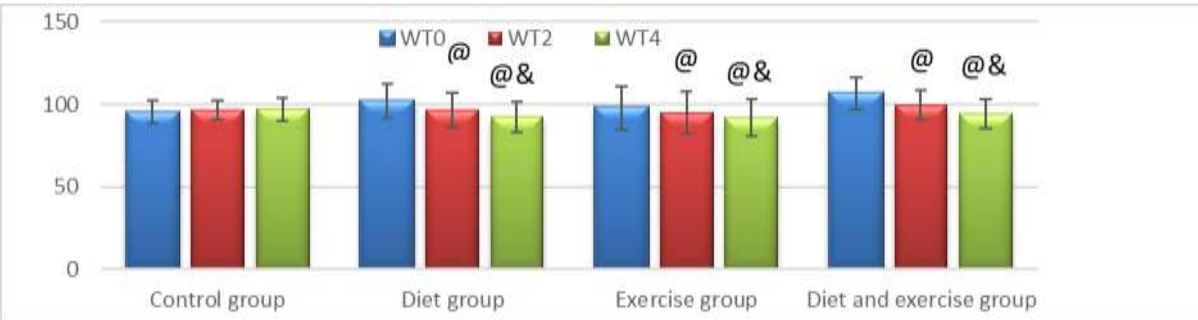

Fig. (5): Weight (Kg) (mean ± SD). WT0: weight at baseline. WT2: weight after 2 months. WT4: weight after 4 months. @- statistically significant compared to corresponding value measured at baseline

($P<0.05$). &- statistically significant compared to corresponding value measured after 2 months ($P<0.05$).

Discussion: Lifestyle changes such as regular exercise and dietary intervention may help improve insulin sensitivity and decrease IR which can develop at any tissue level including the most sensitive organs like brain (Kullmann et al., 2020). Type 2 DM, IR, and metabolic syndrome are clearly reversible diseases that could be handled with such lifestyle changes where it was proved clinically that restricting energy intake (specially restricting carbohydrates) can reduce central obesity and improve IR (van Ommen et. al., 2018). The low carbohydrates content of the intervention diet of the present study had played an important role in reducing some of the parameters of the study especially weight (Barber et. al., 2021). Intermittent fasting can also lead to clinically significant weight loss as well as improving other metabolic parameters in individuals with obesity (Gu et al., 2022).

In the current study, significant reductions ($P<0.05$) of mean values of all parameters were observed. The changes happened after 2 months of the beginning of the study (mid-study), and it were more prominent at the end of the study period. The reductions of the mean values of TG levels and weight were more pronounced with the dietary intervention subjects than with the exercise intervention subjects while both interventions combined had the most reductions.

Keeping in mind the control group which showed increases of TG values; in the diet-only group the reduction was -6.86% & - 11.77% at month 2 & month 4 respectively compared to the exercise-only group where it was -6.25% & -9.6% at month 2 & month 4 respectively with more apparent reduction in the diet & exercise group (-12.9% & -18.5% at month 2 & month 4 respectively). Compared to the control group which showed increases of weight values; in the diet-only group the weight reduction was -5.2% & - 9.42% at month 2 & month 4 respectively compared to the exercise-only group which was -2.76% & -6% at month 2 & month 4 respectively with more apparent reduction in the diet & exercise group (-6.8% & -11.8% at month 2 & month 4 respectively).

Adopting a regular exercise program dramatically reduces insulin levels and improves HOMA-IR values (Lin et al., 2022). Physical activity decreases insulin resistance directly by promoting the oxidation of free fatty acids and reducing lipotoxicity occurring in skeletal muscles and liver (Galaviz et al., 2018). Aerobic physical activity has a beneficial impact on blood glucose levels, where the higher the intensity, the duration, and maneuverability (repeated muscle contraction and relaxation), the higher the reduction of blood glucose concentrations (Li et al., 2021). Multiple improvements in glucose and insulin levels were prominent with exercise intervention that also included the resistance type (Wang et al., 2021).

Exploring the exercise intervention impact of the current study; it was noted that regular combined exercise had positive (reducing) effects on all study parameters ($P<0.05$). It had more prominent reductions in the mean values of PPG, PPI, and HOMA-IR than the dietary intervention, meanwhile both interventions combined had the most reductions.

Compared to the control group which showed increases of PPG levels; in the exercise-only group PPG levels were reduced dramatically. The reduction in the exercise-only group was -10.9% & -17% at month 2 & month 4 respectively compared to the diet-only group which was +0.6% & -8.82% at month 2 & month 4 respectively with more apparent reduction in the diet & exercise group (-15.1 & -20.35 at month 2 & month 4 respectively).

In contrast to the control group which showed increases of PPI values; in the exercise-only group PPI levels were reduced dramatically. The reduction in the exercise-only group was -18.57% & -28.34% at month 2 & month 4 respectively compared to the diet-only group where it was -11.3% & -19.83% at month 2 & month 4 respectively with more apparent reduction in the diet & exercise group (-19.57% & -29.25% at month 2 & month 4 respectively).

Compared to the control group which showed increases of HOMA-IR values; in the exercise-only group, the HOMA-IR reduction was more pronounced than the diet-only group -9.56% & -20% at month 2 & month 4 respectively where in the diet-only group it was -8% & -17.9% at month 2 & month 4 respectively with more apparent reduction in the diet & exercise group (-14.9% & -33.56% at month 2 & month 4 respectively).

4. Conclusion:

Either healthy diet or regular exercise or both combined, proved to have powerful impacts on reducing HOMA-IR as they showed reductions in blood glucose and insulin levels as well as other metabolic parameters including weight and TG levels. Both approaches should be considered as essential life style changes that should be adopted not only by insulin resistant population but healthy individuals as well.

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