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Efektivitas latihan aerobik pada metabolisme glukosa darah remaja dengan obesitas: meta-analisis

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Abstrak
Remaja dengan kelebihan berat badan dan obesitas akan mengalami resistensi insulin yang berkaitan dengan kurangnya aktivitas fisik. Resistensi insulin pada remaja dapat menyebabkan sindrom metabolik dan penyakit kardiovaskular di masa dewasa. Aktivitas fisik pada remaja dengan obesitas belum banyak dikaji efek terapeutiknya pada gangguan metabolisme glukosa darah akibat resistensi insulin. Penelitian ini bertujuan untuk mengetahui efektivitas latihan aerobik dalam meningkatkan sensitivitas insulin dalam metabolisme glukosa darah pada remaja obesitas. Penelitian ini merupakan meta-analisis dari artikel *Randomized Controlled Trials* pada basis data elektronik DOAJ, PEDro, PubMed, OVID, dan ScienceDirect. Pencarian artikel menggunakan kata kunci *"glucose metabolism" OR "insulin resistance" AND "obese adolescents" OR "adolescents with obesity" OR "adolescents with overweight" AND exercise*. Analisis data dilakukan menggunakan program RevMan 5.3 dengan ukuran efek menggunakan *Cohen's d*. Terdapat 6 artikel yang diikutsertakan dalam meta-analisis. Hasil analisis artikel menunjukkan bahwa latihan aerobik efektif dalam memperbaiki skor *Homeostasis Model Assessment of Insulin Resistance* (HOMA-IR) dengan ukuran efek yang besar (d = -0,69; CI = -1,38 hingga -0,00; P <0,001) dibandingkan dengan kelompok kontrol. Latihan aerobik efektif memperbaiki skor HOMA-IR. Perbaikan skor HOMA-IR menjadi indikator pemulihan resistensi insulin pada remaja obesitas.

Kata Kunci: glukosa darah; latihan aerobik; metabolisme

Effectiveness of aerobic exercise on blood glucose metabolism of obese adolescents: a meta-analysis

Abstract
Adolescents with overweight and obesity will experience insulin resistance associated with physical inactivity. Adolescents' insulin resistance can cause metabolic syndrome and cardiovascular disease in adulthood. Physical activity in adolescents with obesity has not been widely studied for its therapeutic effects on blood glucose metabolism disorders due to insulin resistance. This research aims to determine the effectiveness of aerobic exercise in improving insulin sensitivity in the blood glucose metabolism in obese adolescents. This study is a meta-analysis of the Randomized Controlled Trials article on the electronic databases DOAJ, PEDro, PubMed, OVID, and ScienceDirect. The article search uses keywords "glucose metabolism" OR "insulin resistance" AND "obese adolescents" OR "adolescents with obesity" OR "adolescents with overweight" AND exercise. Data analysis was performed using the RevMan 5.3 program with effect size using Cohen's d. There were 6 articles included in the meta-analysis. The analysis results of articles showed that aerobic exercise is effective in repairing the Homeostasis Model Assessment of Insulin Resistance (HOMA-IR) score with a large effect size (d = -0,69; CI= -1,38 to -0,00; P <0,001) compared to the control group. Aerobic exercise effectively improves HOMA-IR scores. Improvement in HOMA-IR scores is an indicator of recovery from insulin resistance in obese adolescents.

Keywords: *aerobic exercises; blood glucose; metabolism.*

1. Introduction

Adolescence is a transition period between childhood and adulthood, between the ages of 10 and 19, which is important for forming healthy living behaviors (WHO, 2025). Obesity in adolescents continues to increase in prevalence above 16% worldwide (Vasconcellos et al., 2021). Obesity in adolescents increased prevalence of from 16.2% in 1980 to 22.6% in 2013 in developing countries

(Meng et al., 2022). Obesity adolescents have an increased 21% risk of cardiovascular disease mortality and diabetes mellitus in the U.S.A. (Kelly et al., 2024).

Adolescents' obesity has excess adipose tissue characterized by chronic pro-inflammatory dysfunctional tissue, causing insulin resistance (Ahmed, Sultana, & Greene, 2021). Adolescents with obesity will cause resistance to insulin and beta cell dysfunction in blood glucose metabolism, which causes diabetes mellitus (McCormack et al., 2014). Insulin resistance in adolescents can be analyzed by the parameter of an increase in the Homeostasis Model Assessment of Insulin Resistance (HOMA-IR) score (Tahapary et al., 2022).

Adolescents obesity are associated with physical inactivity and the risk of cardiovascular disease (Davis et al., 2022). Obese adolescents will be impacted in physical fitness and glucose metabolic disorders due to insulin resistance (McCormack et al., 2014). Physical exercise can improve metabolic syndrome, the risk of reduced cardiovascular disease, and premature death (Zehsaz, Farhangi, & Ghahramani, 2016). Adolescence will be a critical period for the increase of obesity and cardiovascular morbidity in the future (Martin-Moraleda et al., 2022).

Adolescents' obesity needs intensive physical exercise to prevent metabolic and cardiovascular diseases (Vasconcellos et al., 2021). Aerobic exercise can repair insulin resistance in blood glucose metabolism in obese adolescents (Ahmed, Sultana, & Greene, 2021). Aerobic exercise does not provide repair sensitivity to insulin in obese adolescents (de Lira et al., 2017). However, the literature review on the therapeutic effects of aerobic exercise on insulin resistance in obese adolescents remains limited. Based on the description above, the author would like to conduct a literature review on the effectiveness of aerobic exercise in improving insulin sensitivity in the blood glucose metabolism in obese adolescents.

2. Research Methods

The research study uses a systematic review and meta-analysis framework with the PRISMA 2020. The PICOS framework using namely adolescents with overweight and obesity (population/problem), aerobic exercise program (intervention), usual care with health education or nutritional advice without an exercise program (comparison), decrease in HOMA-IR score (outcome), articles with Randomized Control Trial research method (study design).

The author searched for article publications from 2014 to 2025 in 5 databases: DOAJ, PEDro, PubMed, OVID, and ScienceDirect. The article search was conducted from 9 June 2025 until 6 July 2025. The search keywords are a combination of "glucose metabolism" OR "insulin resistance" AND "obese adolescents" OR "adolescents with obesity" OR "adolescents with overweight" AND exercise. Researcher 1 worked simultaneously with Researcher 2 to select and extract research data. If there were differences of opinion between Researchers 1 and 2 regarding the selection and extraction of article data, Researcher 3's opinion was the final decision.

The inclusion criteria were: (1) full text articles with a Randomized Control Trial (RCT) design, (2) Research subjects were adolescents aged 10-19 years with Body Mass Index (BMI) criteria ≥ 23 and HOMA-IR score ≥ 2.0, (3) experimental group research subjects received an aerobic exercise program (intervention), While the control group received daily care as usual without an exercise program, with or without nutritional advice. The exclusion criteria for this article were: (1) full text articles other use non English, (2) articles text available abstract only, (3) all subject researche get nutritional diet intensive interventions combined with exercise so that the effects of aerobic exercise could not be isolated, (4) articles without indicator data of the Homeostasis Model Assessment of Insulin Resistance (HOMA-IR) score.

Researchers use a critical appraisal tool Joanna Briggs Institute (JBI). JBI tools critique the research articles analyzed and assess whether the study has addressed potential bias. The 13 JBI

instrument items are assessed using the assessment indicators "yes with the symbol (+), no (-), unclear (UC), and not applicable (NA)". The RevMan 5.3 program is used to analyze with effect size using Cohen's d. If the p value ≥ 0.05 or the I2 value <50%, then the fixed effect was used, but if the p value <0.05 or the I2 value >50%, then the random effect was used.

3. Results and Discussion

3.1.Results

PICO inclusion criteria excluded 618 articles, 4 articles could not be accessed, and 1 article outcome study only of fasting glucose. After reviewing the eligibility of 14 full-text articles, 8 articles were excluded, and 6 articles were included in the qualitative synthesis and meta-analysis in Figure 1.

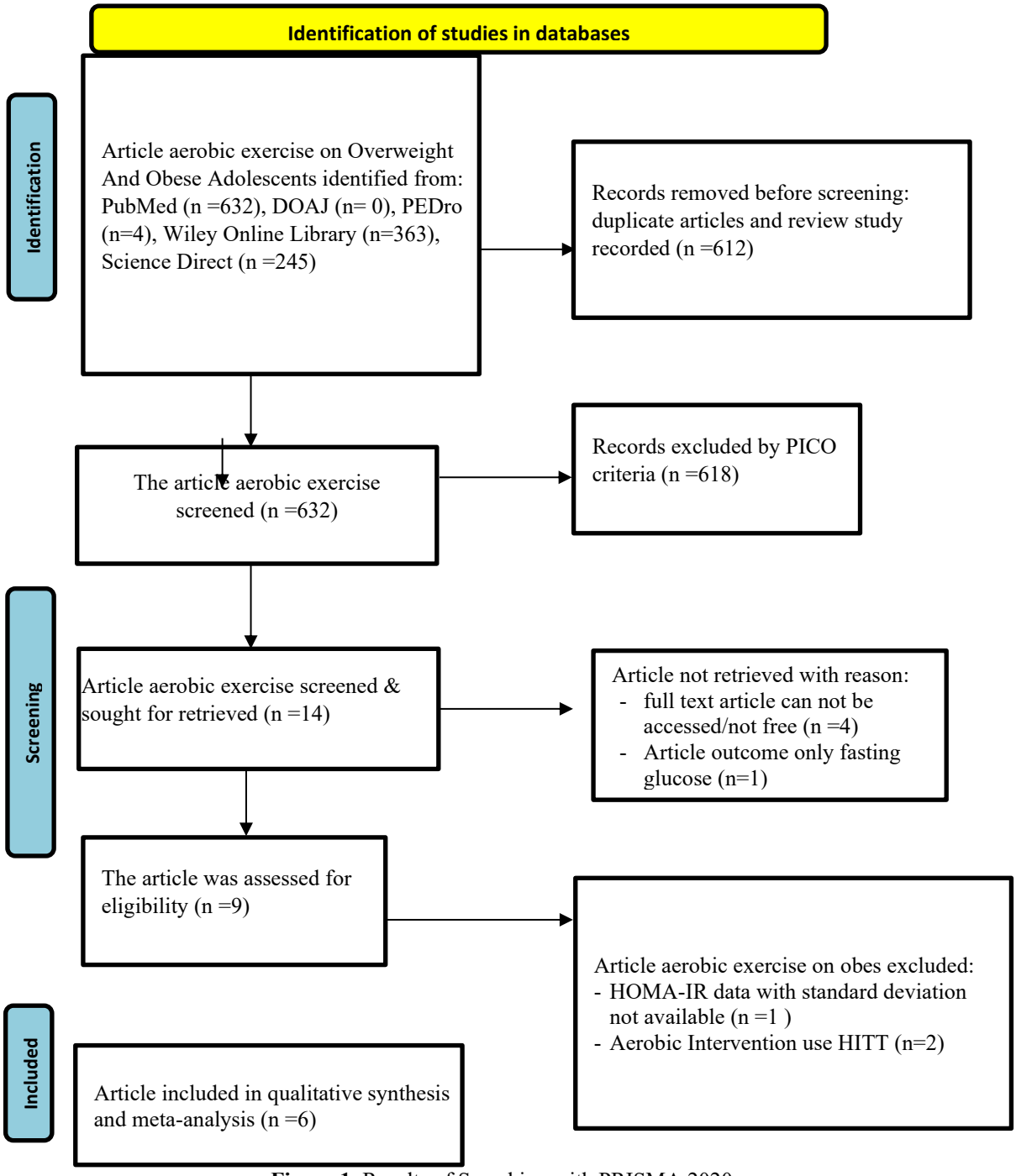

Figure 1. Results of Searching with PRISMA 2020

The results of the critical appraisal used JBI items to be included in this study are ≥ 10/13. The results of the 6 articles analyzed are ≥ 10/13 in Table 1.

Table 1. Results of Critical Appraisal Use The Joanna Briggs Institute (JBI)

Study	Critical assessment items use JBI													Result
	1	2	3	4	5	6	7	8	9	10	11	12	13	
De Lira et al., 2017	+	+	+	+	-	+	+	+	+	-	+	+	+	11/13
Dias et al., 2018.	+	+	+	+	-	+	+	+	+	-	+	+	+	11/13
Kim et al., 2020	+	+	+	+	-	+	+	+	+	-	-	+	+	10/13
Vasconcellos et al., 2015.	+	+	+	+	-	+	+	+	+	-	-	+	+	10/13
Meng et al., 2022	+	+	+	+	-	+	+	+	+	+	+	+	+	12/13
Savoye et al., 2014	+	+	+	+	-	+	+	+	+	+	+	+	+	11/13

The study included 6 articles in the qualitative analysis in Table 2. The subjects of research were from Brazil (1 article), China (1 article), Australia (1 article), Portugal (1 article), the United States of America (1 article), and the Republic of Korea (1 article). From a total of 297 subjects with an average age of 11,2–14,77 years, Randomization was carried out with 144 subjects in the group of aerobic exercise intervention, and 153 subjects in the control group with usual care. Subjects of study had self-efficacy to complete the program is 262 subjects (88,22 %), and 35 subjects (11,78%) did not complete the program.

The subject study in the 2 articles included in the meta-analysis had fasting insulin mean values > 25 μU/ml, which indicates insulin resistance leading to prediabetic mellitus conditions. In addition, 5 of the 6 articles analyzed used study subjects in adolescents with a Body Mass Index (BMI) of more than 25. 3 articles described intervention aerobic exercise in the community, 2 articles described personal aerobic exercise, and 1 article described a personal exercise program combined with group therapy.

Table 2. Effectiveness of Aerobic Exercise for Blood Glucose Metabolism

Author & Country	Study design	Subjects Characteristics & Total (n)	Intervention Group (IG)	Control Group (CG)	Result of Study
De Lira et al., 2017. Brasil	RCT	n= 76 subjects (25 IG, 33 CG). 41 % is male. mean age: 14,77 (IG) 14,72 (CG). BMI (Kg/m2): 34,07 (IG), 35,09 (CG). Mean score of HOMA-IR: 4,84 (IG), 5,53 (CG). dropout rate of intervention : 0%.	Personal low-intensity aerobic exercise with a treadmill 3x/week for 12 weeks	Usual care	Personal low-intensity aerobic exercise with a treadmill does not improve insulin sensitivity in blood glucose metabolism in obese adolescents compared to usual care.
Dias et al., 2018. Australia	RCT	n = 66 subjects (32 IG, 34 CG). 53,5 % is female. mean age:12,0. BMI (Kg/m2): 30,4 (IG), 29,6 (CG). Mean score of HOMA-IR: 2,05 (IG), 2,06 (CG). dropout rate of intervention: 15 subjects (22%).	Personal aerobic exercises use continuous moderate intensity 3 times/week for 12 weeks	Usual care	Personal aerobic exercises does not improve insulin sensitivity in blood glucose metabolism in obese adolescents than usual care.

Author & Country	Study design	Subjects Characteristics & Total (n)	Intervention Group (IG)	Control Group (CG)	Result of Study
Kim et al., 2020. Republic of Korea	RCT	n= 48 subjects (24 IG, 24 CG). 100 % are girls. mean age: 15,1 (IG) 15,1 (CG). BMI (Kg/m2): 28 (IG), 29 (CG). Mean score of HOMA-IR: 3,2 (IG), 2,8 (CG). dropout rate of intervention : 0%.	exercise group program jump rope 5x/week for 12 week	Usual care	An exercise group program jump rope is effective in repairing insulin sensitivity in blood glucose metabolism in obese adolescents compared to usual care.
Vasconcellos et al., 2015. Portugal.	RCT	n= 20 subjects (10 IG, 10 CG). 30 % are girls. mean age: 14,1 (IG) 14,8 (CG). BMI (Kg/m2): 31,1 (IG), 32,2 (CG). Mean score of HOMA-IR: 8,2 (IG), 8 (CG). dropout rate of intervention : 0%.	a soccer program for recreation 3x/week for 12 week	Usual care	a soccer program for recreation effective in repairing insulin sensitivity in blood glucose metabolism in obese adolescents than usual care.
Meng et al., 2022. China	RCT	n= 30 subjects (15 IG, 15 CG). 100 % are boys. mean age: 11,2 (IG) 11 (CG). BMI (Kg/m2): 24,4 (IG), 23,8 (CG). Mean score of HOMA-IR: 2,1 (IG), 2,4 (CG). dropout rate of intervention :6 subjects (20%)	Running group school-based use moderate intensity, 30 min 3x/week for 12 weeks.	Usual care	Run uses moderate intensity effective in repairing insulin sensitivity in blood glucose metabolism in obese adolescents compared to usual care.
Savoye et al., 2014. USA	RCT	n= 75 subjects (38 IG, 37 CG). 64 % is female. Mean age: 11,2 (IG) 11 (CG). BMI (Kg/m2): 32,1 (IG), 34,6 (CG). Mean score of HOMA-IR: 8,7 (IG), 9,3 (CG). dropout rate of intervention :17 subject (23%)	Personal aerobic exercise 50-min 3x/week for 6 months, with 1x/month, got children to play activity-specific in the community.	Usual care	Personal aerobic exercise is effective in repairing insulin sensitivity in blood glucose metabolism in obese adolescents than usual care.

Five of the six articles reviewed in this meta-analysis used a three-month aerobic exercise program. Only one article conducted a six-month aerobic exercise program. Most of the articles analyzed showed that the beneficial effects of exercise improve insulin sensitivity in blood glucose metabolism in obese adolescents in Table 3.

Table 3. The results of the meta-analysis article on aerobic exercise in blood glucose metabolism

Author	Country	SMD	95 % CI	P
De Lira et al., 2017	Brasil	0,04	(-0,48 s/d 0,56)	<0.001
Dias et al., 2018.	Australia	0,46	(-0,03 s/d 0,95)	<0.001
Kim et al., 2020	Republic of Korea	-0,94	(-1,54 s/d -0,34)	<0.05
Vasconcellos et al., 2015.	Portugal	-1,61	(-2,65 s/d -0,57)	0.003
Meng et al., 2022	China	-2,27	(-3,21 s/d -1,33)	0.001
Savoye et al., 2014	USA	-0,37	(-0.83 s/d 0.09)	0.03

The forest plots show the effectiveness of aerobic exercise in repairing the Homeostasis Model Assessment of Insulin Resistance (HOMA-IR) score for 297 adolescents in Figure 2. The forest plot shows that the effect size of the aerobic exercise in repairing HOMA-IR score compared to the control

group is large (d = -0,69; CI= -1,38 to -0,00). Statistical analysis shows very significant results (P <0,001), Heterogeneity (I2) = 87% indicates heterogeneous data distribution (random effect model).

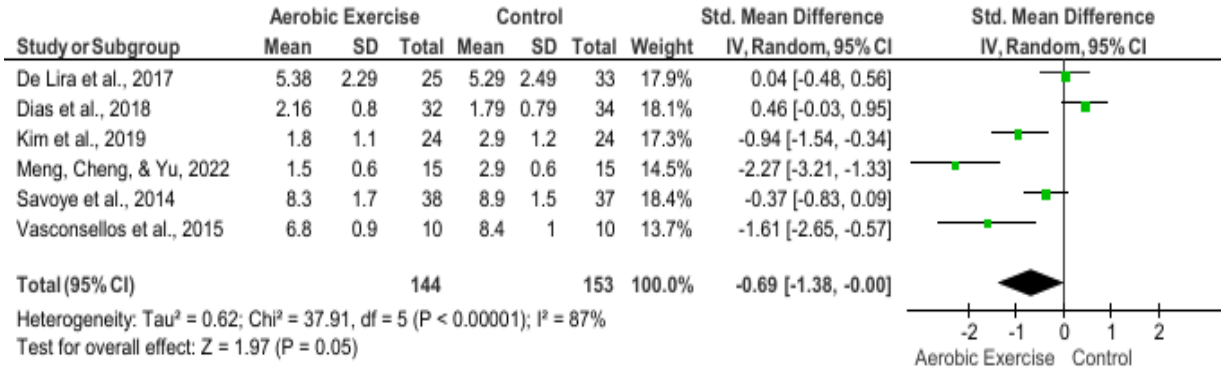

Figure 2. Forest plots the effectiveness of aerobic exercise on the decrease in HOMA-IR score

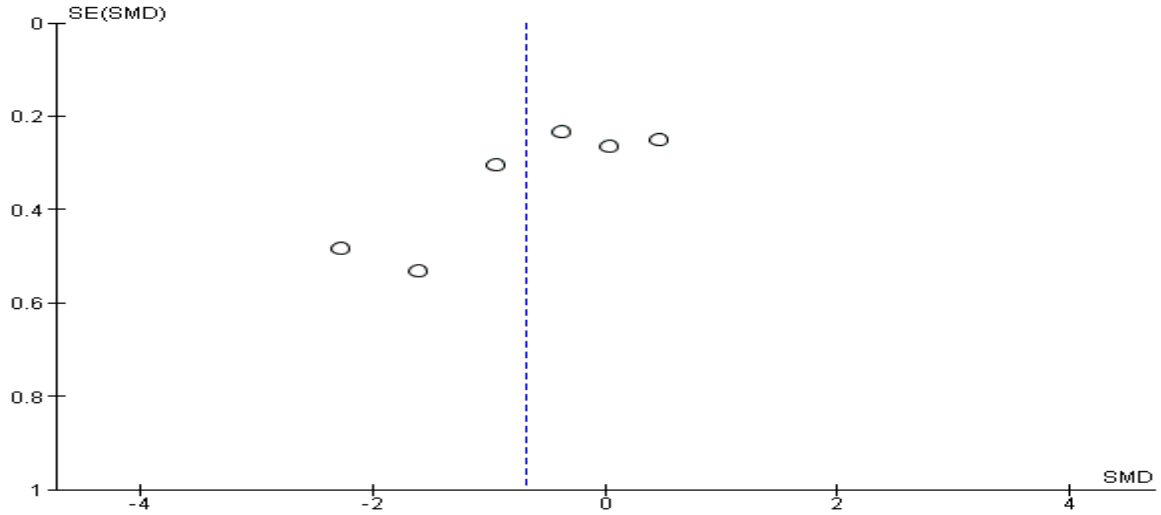

Figure 3. Funnel plots the effectiveness of aerobic exercise on the decrease in HOMA-IR score

Researcher analysis in shows indicated publication bias with an asymmetric axis shown by the distribution of 3 funnel plots on the left and 3 funnel plots on the right in Figure 3. The standard error of the funnel plot on the left is 0,31 – 0,54 and the standard error of the funnel plot on the right is 0,23 – 0,27.

Based on the results of the meta-analysis in forest plot 2 above, aerobic exercise effectively improves HOMA-IR scores with a large effect size (d = -0,69; CI= -1,38 to -0,00; P<0,001). The effectiveness of aerobic exercise in improving HOMA-IR scores is supported by the heterogeneity of the data from the articles included in this meta-analysis.

3.2.Discussion

The effectiveness of an aerobic exercise program in repairing insulin sensitivity in blood glucose metabolism in obese adolescents was measured by the HOMA-IR score. The HOMA-IR score has become a relatively simple and reliable non-invasive method for examining insulin resistance (Schrank et al., 2024). The normal HOMA-IR score is determined by age, gender, and BMI category (Shashaj et al., 2016). However, the cut-off point of the HOMA-IR value to identify resistance to insulin is influenced by the pubertal maturity stage (Da Silva et al., 2023).

Aerobic exercise is effective in repairing the HOMA-IR score with a large effect size (d = -0,69; CI= -1,38 to -0,00; P <0,001) compared then the control group. Adolescents with obesity will enter the peak of puberty with high HOMA-IR score levels at Tanner stages 1 and 2 (Gobato et al., 2012). High HOMA-IR scores are a biomarker for the incidence of diabetes mellitus disease and a predictor of chronic kidney disease (Lee et al., 2023). Obese adolescents who receive aerobic exercise will have reduced HOMA-IR scores, with an impact on repairing insulin resistance and reducing the risk of type 2 diabetes mellitus in adulthood (Kim et al., 2020).

Exercises can improve the relief of insulin resistance by 34% in HOMA-IR scores (McCormack et al., 2014). Obese adolescents who received a 12-week aerobic exercise program showed an effective reduction in HOMA-IR scores (Kimt al., 2020; Meng et al., 2022). Aerobic exercise can stimulate insulin metabolism in skeletal muscles by 80% of whole-body glucose metabolism (Belanger, Rao, & Robbins, 2019). The number and size of mitochondria can increase by aerobic exercise, in addition to its impact on increasing the sensitivity of glucose metabolism to insulin and the availability of lipids for oxidation in skeletal muscles during exercise (McCormack et al., 2014).

Physical exercise can improve insulin response in body glucose metabolism, which varies depending on the duration and intensity of exercise intervention (Belanger, Rao, & Robbins, 2019). Obese adolescents doing aerobic exercise for 12 weeks without dietary changes can increase omentin-1 levels to improve insulin sensitivity and weight loss (Zehsaz, Farhangi, & Ghahramani, 2016). However, with weight loss still varying, regular aerobic exercise in the long term will improve insulin sensitivity by reducing adipose tissue mass (Belanger, Rao, & Robbins, 2019). Obese adolescents who do an exercise program for 6 months can repair the pattern of eating and appetite (Alberga et al., 2023). Adolescents with eating disorders will cause obesity (Jebeile et al., 2021). Physical activity with aerobic exercise programs aimed at producing adolescents who can manage their weight (Martin et al., 2014).

Aerobic exercise combined with health education will improve knowledge, attitudes, and practices of physical activity compliance, which will impact the treatment of eating disorders in adolescents with obesity (Al-Haroni et al., 2024). Anthropometric measurements with BMI have become the most effective measurement to identify insulin resistance (Gobato et al., 2012). Adolescent obesity has become a result of excessive and irregular eating behavior accompanied by a sedentary lifestyle (Alberga et al., 2023). Eating disorders have received little attention with approaches other than dietary approaches in adolescents with obesity (Jebeile et al., 2021). Aerobic exercise programs can be a solution for managing the weight of adolescents with obesity.

The effectiveness of aerobic exercise in improving the HOMA-IR score is caused by self-efficacy in adolescents to finish the aerobic program. The effect size of the aerobic exercise intervention on all study subjects, with the effect size on study subjects with good self-efficacy in completing the exercise program, did not differ significantly. Implementation of an aerobic exercise program in obese adolescents requires strict monitoring in its implementation (McCormack et al., 2014). Parental monitoring of diet, physical activity, and recreational activities is key to prevention in obese adolescents (Ash et al., 2017).

Obese adolescents who participate in a group aerobic exercise program in the community will have a much greater effect on reducing HOMA-IR scores compared to personal aerobic exercise therapy (Kim et al., 2022). Aerobic exercise carried out in groups in the community will increase participant interaction with exercise instructors and other participants. Implementation of an exercise program in a group can provide social support that strengthens the results of exercise (Golaszewski et al., 2022).

Subjects of study had self-efficacy to complete the program, 262 subjects (88,22 %), and 35 subjects (11,78%) did not complete the program However, none of the articles we analyzed in this study explained the monitoring model for the intervention program. Attrition bias will increase with

lack of monitoring in the implementation of intervention activities. Selection bias in this study was caused by the limited number of articles included in the systematic review. Limited access to paid articles and article inclusion criteria have narrowed the results of this systematic review. The limitations of this study's results can be improved by further literature review research without limited access to existing secondary data sources.

4. Conclusion

Aerobic exercise effectively repairs HOMA-IR scores. Repaired HOMA-IR scores can be an early indicator of improved insulin resistance in obese adolescents. A group aerobic exercise program of 50 minutes, 3x/week for 12 weeks can be recommended for adolescents with obesity.

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