A systematic review to assess the impact of physical activity intervention on people with metabolic syndrome

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Abstract

Background: Dramatic economic growth in the past few decades has led to Westernization of diets, increasingly sedentary lifestyle, and a decrease in physical activity. As a result, metabolic syndrome has emerged as a major global public health issue. The purpose of this systematic review is to examine the effect of physical activity on various metabolic syndrome outcomes. This could help strategize future major researches and formulation of policies in both developed and developing countries.

Methods: The systematic review mainly focused on the key metabolic syndrome outcomes: blood pressure, triglyceride and high-density lipoprotein cholesterol, waist circumference, and fasting blood glucose. A literature search was conducted on the PubMed database followed by title, abstract, and full-text screening of retrieved citations. Evidence appraisal of the data extracted was conducted using the Critical Appraisal Skills Programme tool.

Results: Of the total 334 potential papers retrieved, only 14 papers were identified to be finally eligible for this review. Data extraction and analysis provided evidence supporting reduced risks of metabolic syndrome even with modest amounts of physical activity. An overall improvement was observed in all the five metabolic syndrome outcomes. Greater improvement in health benefits was observed with increase in the intensity of exercise or combining the physical activity with a wellness program that included a diet regimen.

Conclusion: This review provides evidence that sustained physical activity for at least 12 weeks can independently lead to an improvement in overall metabolic syndrome as well as related risk factors.

Key Words

• Metabolic syndrome
• Physical activity
• Randomized controlled trial
Introduction

With growing urbanization, transitioning diets, accelerating economic growth, expanding middle-class population, and increasingly sedentary lifestyle, the contribution of different risk factors to disease burden has changed substantially over the years. This has led to a shift from communicable diseases in children toward non-communicable diseases (NCDs) in adults with blood pressure (BP) as the leading risk factor for global disease burden in 2010. Physical inactivity, which is the fourth leading cause of deaths due to NCDs worldwide, contributes to over three million preventable deaths annually. Physical inactivity, which is often associated with sedentary behavior and lack of bodily movement that leads to energy expenditure beyond the resting expenditure, is related (directly and indirectly) to the other leading risk factors for NCDs such as high BP, high cholesterol, and high glucose levels. As a result, there has been a recent striking increase in childhood and adult obesity, not only in developed countries, but also in many developing countries.1

Metabolic syndrome, which encompasses a cluster of metabolic abnormalities like raised blood glucose, abdominal and central obesity, insulin resistance, high cholesterol, and high BP, is posing a major global public health problem with an estimated 20–25% of the world’s adult population affected by it.2 Physical inactivity, which is closely associated with sedentary behavior, is known to be independently associated with prevalence of metabolic syndrome.1

Developing countries, already burgeoning under the “double burden” of diseases, need to urgently prioritize effective management of NCDs including metabolic syndrome and its related risk factors (like physical inactivity). Therefore, the purpose of this systematic review was to collate evidence informing the relation between physical activity intervention and metabolic syndrome outcomes that could help strategize future interventions in both developed and developing countries.3

Methods

Eligibility criteria

The criteria, as per PICO (population, intervention, comparator, and outcomes), for the present systematic review has been explained below.

The study participants included adults aged ≥18 years that were diagnosed with metabolic syndrome or its related risk factors, as defined by the International Diabetes Foundation (IDF). Of the several defining criteria for metabolic syndrome, the IDF consensus worldwide definition was chosen that uses geography-specific cutpoints for waist circumference, thereby taking into account the ethnic differences in body fat distribution.

According to this definition by IDF (2013), for a person to be defined as having metabolic syndrome, they must have central obesity (defined by increased waist circumference) plus any two of the following four factors:

- Raised triglyceride (TG) level: ≥150 mg/dL (1.7 mmol/L)
- Reduced high-density lipoproteins cholesterol (HDL cholesterol): 40 mg/dL (1.03 mmol/L) in males and 50 mg/dL (1.29 mmol/L) in females
- Raised BP: Systolic BP ≥130 or diastolic BP ≥85 mm Hg
- Raised fasting plasma glucose (FPG): ≥100 mg/dL (5.6 mmol/L) or previously diagnosed type 2 diabetes

Data from only randomized controlled trials (RCTs) assessing various types of physical activity interventions (ranging from low-intensity exercise training (LIET), restorative yoga, progressive resistance training, cardiovascular training to high-intensity exercise training combined with or without a diet regimen) were included.

The comparators involved in the eligible studies can be broadly divided into the control group and the treatment/intervention group that varied in each study. Heterogeneity was observed in the comparator groups, and therefore, the studies were grouped into three different categories. These included:

1. Physical activity and diet (PA and diet), which included studies discussing the effect of physical activity in combination with different diet regimens.
2. Physical activity only (PA only), which included studies discussing only the effect of one particular form of physical activity.
3. Different forms of Physical activity (PA+PA), which included studies discussing the effect of different forms of physical activity.

This review looked at five primary outcomes, consistent with the IDF diagnostic criteria of metabolic syndrome. As described above, these are central obesity, BP, TG, HDL-C, and FBG levels. Only studies that included at least one of these outcomes were considered eligible for inclusion.

The exclusion criteria for this review were defined as below:

- Studies involving subjects below the age of 18 years
- Subjects diagnosed with metabolic syndrome based on criteria that were not consistent with the IDF definition
- The absence of a physical activity intervention for assessment
- Non-experimental/observational study designs

Search strategy

The literature search for this review was conducted using the freely accessible electronic bibliographic database PubMed. The search strategy was developed and executed by the contributing team of authors. The search strategy was developed by categorizing the research question into key concepts, which included demographic age group, type of physical activity intervention, study design, and clinical diagnosis of interest. The relevant keywords and MESH terms were combined as shown below to generate the final search strategy:

((((Young adults) OR adults) OR elderly) AND (((((motor activity) OR exercise movement techniques) OR movement) OR aerobic capacity) OR health promotion) OR sedentary lifestyle) OR yoga) OR meditation)) AND ((((Title/Abstract) AND trial[Title/Abstract]) OR clinical trial[MesH Terms] OR clinical trial[Publication Type] OR random* [Title/Abstract] OR random allocation[MesH Terms] OR therapeutic use[MesH Subheading]))) AND "Metabolic Syndrome X" AND "Physical activity"

All articles retrieved from this search included the following information for each citation: paper title, authors, journal name, volume and issue number, unique identifier for the database (PubMed), and the abstract.

Study selection

A step-wise process was adopted for the screening of retrieved citations, using the eligibility criteria stated above. The abstract screening was followed by full-text review of the journal articles, which resulted in the final list of studies eligible for further review.

Data extraction

A data extraction form was designed to extract relevant data from all the studies in a systematic manner. Data were extracted based on the following variables: study participants, study description (intervention, locale, duration, randomization method, and arms of the study), relevant outcome variables, statistical analysis, results, and limitations.

Quality assessment

The methodological quality of included studies was assessed using the Critical Appraisal Skills Programme (CASP) framework for RCTs.

Results

The process for the selection of relevant manuscripts is illustrated in Figure 1. A total of 334 potential papers were retrieved from the PubMed database. After reviewing the titles and abstracts for the potential papers, full-text copies for the eligible 27 citations were obtained and reviewed. A total of 14 studies matched the study’s eligibility criteria and data extraction was performed. Table 1 describes the studies included in the systematic review.

In total, data were extracted from 957 participants with two articles concentrating on female-only data (n = 59),10–12 three on male-only data (n = 243),13,14 and the remaining including both male and female subjects (n = 655, 309 males and 293 females), which includes one trial that did not mention the distribution between the gender (n = 53).15 The articles were published over a period of 11 years, from 2003 to 2013 with studies including participants from five different countries, namely, USA (n = 8),16–23 Norway (n = 3),24–26 Germany (n = 1),27 Australia (n = 1), and Brazil (n = 1).6 The mean age of the participants varied between 21 and 72 years with studies ranging from a sample size of 14 to 241 participants.

1) PA and diet: A total of seven studies compared PA in combination with different diet regimen amongst adults aged 29–70 years.6,16–18 Of the seven studies, only three trials21,22,23 demonstrated the effect of PA alone,
Introduction

With growing urbanization, transitioning diets, accelerating economic growth, expanding middle-class populations, and increasingly sedentary lifestyles, the contribution of different risk factors to disease burden has changed substantially over the years. This has led to a shift from communicable diseases in children toward non-communicable diseases (NCDs) in adults with blood pressure (BP) as the leading risk factor for global disease burden in 2010. Physical inactivity, which is the fourth leading cause of death due to NCDs worldwide, contributes to over three million preventable deaths annually. Physical inactivity, which is often associated with sedentary behavior and lack of bodily movement that leads to energy expenditure beyond the resting expenditure, is related (directly and indirectly) to the other leading risk factors for NCDs such as high BP, high cholesterol, and high glucose levels. As a result, there has been a recent striking increase in childhood and adult obesity, not only in developed countries, but also in many developing countries.

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Developing countries, already burgeoning under the “double burden” of diseases, need to urgently prioritize effective management of NCDs including metabolic syndrome and its related risk factors (like physical inactivity). Therefore, the purpose of this systematic review was to collate evidence informing the relation between physical activity intervention and metabolic syndrome outcomes that could help strategize future major researches and formulations of policies as basis for recommendation and prescribing physical activity interventions in both developed and developing countries. The key questions addressed in this systematic review included:

1) What is the impact of physical activity interventions on subjects with metabolic syndrome?

2) What is the impact of physical activity on risk factors associated with metabolic syndrome?

3) What type of exercise modalities are required in order to produce a change (if any)?

Methods

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whereas the rest gave results only in combination with diet. The criteria that was followed included NCEP ATP III,"" Jo VT, and the joint criteria of American Heart Association (AHA) and National Heart, Lung, and Blood Institute." Of the seven interventions, four included only aerobic exercise, 8,9,11,15,18,19 whereas two included a combination of aerobic exercise with circuit training, 8,9 whereas only one included progressive resistance exercise as the kind of physical activity. The kind of diet regimen varied from low fat, 8,9,11,15,18,19 healthy no sugar, 8,9,10 “to caloric restricted.” The effect of PA alone was mentioned only in three 7,10,15 of the seven studies, whereas the rest gave a combined result, which was not interpreted and has not been presented in the context of the present review.

2) PA only: A total of five studies compared one or the other form of PA alone, either at different levels 7,10,11 to no exercise group among 201 participants aged between 21 and 72 years. 8,9 The duration of the intervention varied from 24 hours 9 to 12 months; the criteria that was followed varied for each study: NCEP ATP III, 11 IDIF, 12,13 and NCEP. 11 Of the five interventions, one included moderate intensity aerobic exercise, 11 one high-intensity aerobic exercise with resistance training, 11 one that compared continuous moderate and continuous low-intensity exercise (MOD-1 and LOW-1 with two accumulated mod-intensity sessions (MOD-2), whereas only one trial included restorative yoga. 8

3) PA–PA: Only two studies made comparison between different forms of PA exercises for 75 participants aged between 40 and 60 years. 14,15 The duration for the interventions were 129 and 16 weeks, respectively. One study compared aerobic interval-training (AIT) with moderate continuous-training (CME) and no exercise group. 14 The second study compared AIT, strength training (ST), and a combination of both AIT and ST (COM). 15 The criteria followed by the two studies were different: WHO 12 and IDIF. 12,13

The CASP framework description for RCTs

The first two questions, the screening question, helped us decide whether the results of the review were valid. This was followed by the detailed questions. Only four studies provided information regarding the blinding of the patients, health workers, and study personnel to the treatment. 11,15,18,19 In all the 14 studies, the groups were similar at the start of the trial with respect to social class and age; however, as far as the gender is concerned, a heterogeneity was observed with nine studies including different proportion of men and women. 8,9,11,15,18 As the trials proceeded, besides the experimental intervention, the treatment among the intervention groups was maintained at all times. 8,9,11,15,18

Results according to the metabolic syndrome five risk factors

1. Blood pressure (BP)

PA + diet: A total of seven studies examined the combined effect of PA and diet on BP. 7,8,10,11,15,18 With the exception of one, 11 all seven studies reported both SBP and DBP. 7,8,10,11,15,18 Seligman et al. discussed pulse and arterial pressure. 11 Being on BP medication was an exclusion criterion for all of the studies, with only one study allowing participants to join weight-loss program outside the study. 8 Four and three trials enrolled subjects with high SBP and DBP, 7,11,15,18,19 respectively. However, the high BP cutoffs were variable, depending on the criteria mentioned above.

An overall reduction in both SBP and DBP was observed in all the seven trials with two trials demonstrating a shift from high to normal range BP post-intervention. 7,10 The statistical significance was set at $p < 0.05$ with only four of the seven trials reaching the same. 7,11,15,18 Seligman et al. showed that post-intervention arterial pressure decreased and remained reduced for 1 year ($p < 0.001$) and pulse pressure decrease was more pronounced in fitness and step-counting programs ($p = 0.03$). 11 A significant decrease in SBP was observed only in one study, where a reduction of 10.3 ± 10.5 ($p = 0.03$) was observed, whereas reduction in DBP in significant in two studies, which ranged from 1.9 mmHg ($p = 0.04$) to 5–9 mmHg for active treatments groups ($p < 0.01$). 11

PA–PA: A total of two studies examined the effect of different forms of PA on the BP. 8,11 Both studies enrolled both men and women with different criteria, as mentioned above. Both studies allowed patients who were on medication for hypertension.

An overall reduction in both SBP and DBP was observed in both the studies, with Tjonna et al. demonstrating a shift from high to normal range and Stensvold et al. showing a shift from high to borderline range. In the study conducted by Tjonna et al., both AIT and CME decreased SBP and DBP by 10 mmHg (both $p = 0.05$) and 6 mmHg (AIT $p = 0.05$ and CME $p = 0.24$). 8,11 Stensvold et al. demonstrated a decrease of 5.5 mmHg in AIT, 2.8 mmHg for ST, and 4.2 mmHg in COM in SBP, whereas a decrease of 4.1 mmHg in AIT and 0.7 mmHg in ST in DBP.

2. Triglyceride level (TG)

PA–diet: A total of six studies examined the combined effect of physical activity and diet on TG. 7,10,13,15,19 Being on lipoid-lowering medication was an exclusion criterion for most of these studies except for two. 11,15 Study conducted by Ma et al. allowed participants who joined weight-loss program outside the study. 5,15,19 Six of the five trials enrolled participants with high TG level with cutoffs varying with different criteria as mentioned above.

An overall reduction in the TG level was observed for all the six trials that combined physical activity with diet with three of the five trials showing a decrease from high to normal range TG level. 7,10,13,15,19 However, a significant decrease was observed only in two trials 5,15,19 with Straiznicky et al. showing a reduction of 0.07 mmol/L ($p < 0.01$ vs. control). Study conducted by Wood et al. demonstrated that combining diet with progressive resistance exercise led to a greater decrease in TG level, which ranged from 3.1 ± 31.8% decrease for LFD to 36.6 ± 18% decrease for CRD and PRE ($p = 0.05$). 15

PA only: A total of five studies examined the effect of physical activity alone on the TG level. 7,10,15,18,19 Most of the studies included participants that were unmedicated for TG/lipids, with only Cohen et al. allowing participants on medications for hypertension: ACE inhibitors, beta blockers. 8,11,15,19 Three 7,10,15 of the five trials enrolled participants with high TG and DBP, respectively, depending on the cutoffs that varied with different criteria, as mentioned above.

An overall reduction in both SBP and DBP was observed in all the four trials, with two trials demonstrating a shift from high to normal range BP post-intervention. 7,10 Two trials demonstrated a significant change ($p < 0.05$) in the SBP and DBP post-intervention. 7,10 Study conducted by Thomas showed a significant change in both SBP and DBP in EX group, whereas No exercise (NoEX) group showed a significant decrease (exact p value not mentioned) increase in SBP during weight regain. 8,11,15,18 Kemmler et al. showed that LIET significantly reduced SBP from baseline ($p = 0.002$), which was significantly greater than the reduction observed in response to control ($p = 0.023$). 7,10 The only trial that discussed the impact of restorative yoga on BP demonstrated an improvement in SBP (9.2 mmHg difference between the yoga and control groups; $p = 0.07$) and DBP (4.6 mmHg difference; $p=0.10$). 8

Figure 1: The process for selection of relevant manuscripts for the systematic review

all the groups were treated equally in all the studies. 7,11 All the 14 studies clearly specified their primary as well as secondary outcomes, with 10 studies that included at least one of the metabolic risk factors as the primary outcome. 7,8,10,11,13,15,18,19,22,23 Instead of five metabolic syndrome outcomes, the additional outcomes measured included fat free mass, weight loss, muscle quality, liver enzyme concentration, peak O2 maximal strength, VO2 max, body composition. Only 2 of the 14 studies gave information about the confidence limit of the treatment effect, which was CI 95%, whereas the remaining studies only mentioned the level of significance (p-value). Part C of the questionnaire that included Questions 9 and 10, addressed whether the results of the study can be applied locally or not. All the studies gave results that could be applied to the local population with at least one kind of outcome (primary or secondary) that could be involved in our current systematic review (Table 2).

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Figure 1: The process for selection of relevant manuscripts for the systematic review

Title screening of potential citations, $n = 334$

Abstract screening of articles, $n = 154$

Full-text screening of articles, $n = 27$

Full-text screening of articles, $n = 27$

Potentially relevant articles identified through PubMed database search, $n = 334$

180 excluded including 1 duplicate, based on PICo

127 excluded based on exclusion criteria

3 excluded based on exclusion criteria

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Table 2. All the included studies had at least one kind of outcome (primary or secondary) that could be involved in our current systematic review. The kind of diet regimen varied from low fat,7–10,15–19 healthy no sugar,7–10,15–19 to caloric restricted.9,10,17 The effect of PA alone was mentioned only in three7–10,15–19 of the seven studies, whereas the rest gave a combined result, which was not interpreted and has not been presented in the context of the present review.

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Table 1: Description of the studies included in the systematic review

<table>
<thead>
<tr>
<th>Author, publication</th>
<th>Population (no. age gender)</th>
<th>Intervention</th>
<th>Comparator</th>
<th>Primary outcomes</th>
<th>Secondary outcomes</th>
<th>Study design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood et al., Metabolic Syndrome and Related Disorders</td>
<td>n = 42, age = 52 ± 7 years, males</td>
<td>Caloric restriction alone (CR)</td>
<td></td>
<td></td>
<td></td>
<td>Randomized, parallel design</td>
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<tr>
<td>Straznicky et al., Diabetes, Obesity and Metabolism</td>
<td>n = 43, age = 55 ± 6 years, 37 males, 6 females</td>
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<td></td>
<td>Randomized, parallel design</td>
</tr>
<tr>
<td>Youssef et al., Journal of Endocrinology</td>
<td>n = 46, age = 67 ± 7 years, males</td>
<td>Changes in liver enzymes</td>
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<td></td>
<td>Randomized, parallel design</td>
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<tr>
<td>Jacob et al., The American Journal of Clinical Nutrition</td>
<td>n = 107, age = 65 ± 2 years, males</td>
<td>3.4 years</td>
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<td></td>
<td></td>
<td>Randomized, parallel design</td>
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<tr>
<td>Watkins et al., Atherosclerosis</td>
<td>n = 53, age = 20 ± 45, 36 females</td>
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<td></td>
<td>Randomized, parallel design</td>
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<tr>
<td>Scharman et al., Metabolism Clinical and Experimental</td>
<td>n = 47, age = 56 ± 55 years, 26 females and 20 males</td>
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<td></td>
<td>Randomized, parallel design</td>
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<tr>
<td>Mi et al., JAMA Internal Medicine</td>
<td>n = 241, age = 42 ± 35 years, 47% females</td>
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<td>Randomized, parallel design</td>
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<tr>
<td>Thomas et al., Journal of Applied Physiology</td>
<td>n = 102, age = 21 ± 52 years, 37 males and 65 females</td>
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<td>Randomized, parallel design</td>
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<tr>
<td>Keri et al., Medicine &amp; Science in Sports &amp; Exercise</td>
<td>n = 89, age = 70 ± 58, years, females</td>
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<td>Randomized, parallel design</td>
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<tr>
<td>Monk et al., Medicine &amp; Science in Sports &amp; Exercise</td>
<td>n = 54, age = 45 ± 2 years, males</td>
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<td></td>
<td>Randomized, parallel design</td>
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<tr>
<td>Irving et al., Medicine &amp; Science in Sports &amp; Exercise</td>
<td>n = 57, age = 51 ± 59 years, 47% females</td>
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<td>Randomized, parallel design</td>
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<tr>
<td>Cohen et al., Metabolic syndrome &amp; Related Disorders</td>
<td>n = 60, age = 52 ± 15 years, 85% females</td>
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<td>Randomized, parallel design</td>
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<tr>
<td>Tonna et al., Journal of Applied Physiology</td>
<td>n = 32, age = 52 ± 37 years, 53% males and females</td>
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<td>Randomized, parallel design</td>
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<tr>
<td>Stein et al., Journal of Applied Physiology</td>
<td>n = 63, age = 50 ± 95 years, 20% males and 17% females</td>
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<td>Randomized, parallel design</td>
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Table 2: Data extraction table containing the results

<table>
<thead>
<tr>
<th>Author, publication</th>
<th>Study description</th>
<th>Study design</th>
<th>Population (no. age gender)</th>
<th>Outcomes</th>
<th>Statistical analysis</th>
<th>Results</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood et al., Metabolic Syndrome and Related Disorders</td>
<td>12-weeks of a low-fat diet (LFD, 20% of calories from fat) and exercise training (EX) in 3 groups: 1) EX only, 2) EX + CR, 3) EX + CR and PRE</td>
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<tr>
<td>Straznicky et al., Diabetes, Obesity and Metabolism</td>
<td>3.4 years</td>
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<tr>
<td>Youssef et al., Journal of Endocrinology</td>
<td>Changes in liver enzymes</td>
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<td>Jacob et al., The American Journal of Clinical Nutrition</td>
<td>3.4 years</td>
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<td>Watkins et al., Atherosclerosis</td>
<td>12-weeks of high-intensity exercise training and diet intervention</td>
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<tr>
<td>Scharman et al., Metabolism Clinical and Experimental</td>
<td>12-weeks of intervention with different levels of exercise intensity; aerobic, resistance, and combined (n = 10)</td>
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<tr>
<td>Mi et al., JAMA Internal Medicine</td>
<td>12 weeks of aerobic exercise training and diet intervention</td>
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<tr>
<td>Thomas et al., Journal of Applied Physiology</td>
<td>3.4 years</td>
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<tr>
<td>Keri et al., Medicine &amp; Science in Sports &amp; Exercise</td>
<td>12-months of high-intensity exercise training</td>
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<tr>
<td>Monk et al., Medicine &amp; Science in Sports &amp; Exercise</td>
<td>3 months</td>
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<tr>
<td>Irving et al., Medicine &amp; Science in Sports &amp; Exercise</td>
<td>6-weeks of intervention with low-intensity high-intensity exercise training</td>
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<tr>
<td>Cohen et al., Metabolic syndrome &amp; Related Disorders</td>
<td>12-weeks of low-intensity high-intensity exercise training and diet intervention</td>
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<tr>
<td>Tonna et al., Journal of Applied Physiology</td>
<td>12 weeks of 2 distinctly different modes of exercise that include Aerobic Training (AT) at a high intensity and a combination of resistance training (RT) at a low intensity</td>
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<tr>
<td>Stein et al., Journal of Applied Physiology</td>
<td>12 weeks of 2 distinctly different modes of exercise that include Aerobic Training (AT) at a high intensity and a combination of resistance training (RT) at a low intensity</td>
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Continued
Table 2: Data extraction table containing the results

<table>
<thead>
<tr>
<th>Author, publication</th>
<th>Study design, population, and intervention (condition)</th>
<th>Outcomes (intervention + randomization method + arms of the study + duration + locale)</th>
<th>Study description</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seligman et al.</td>
<td>Population: 37 women, 26 men aged 57 years; 29 female and 40 male aged 57 years; 30 female and 40 male aged 57 years.</td>
<td>SBP, DBP, HDL-C, TG, TG, TC, TC, TC</td>
<td>Reducing SBP and DBP by 14 cm</td>
<td>Reducing SBP and DBP by 14 cm in a randomized controlled trial (RCT) using a computer-based program. Subjects were assigned to either a control group or an intervention group. The intervention group received a program that aimed to reduce SBP and DBP by 14 cm. Differences in SBP and DBP between the groups were measured at 6 months.</td>
</tr>
<tr>
<td>Mestek et al.</td>
<td>Population: 93 subjects (33 intervention, 30 control) aged 45-65 years.</td>
<td>SBP, DBP, HDL-C, TC, TC, TC</td>
<td>Reducing SBP and DBP by 14 cm</td>
<td>Reducing SBP and DBP by 14 cm in a randomized controlled trial (RCT) using a computer-based program. Subjects were assigned to either a control group or an intervention group. The intervention group received a program that aimed to reduce SBP and DBP by 14 cm. Differences in SBP and DBP between the groups were measured at 6 months.</td>
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<tr>
<td>Irving et al.</td>
<td>Population: 40 subjects (20 intervention, 20 control) aged 25-50 years.</td>
<td>SBP, DBP, HDL-C, TC, TC, TC</td>
<td>Reducing SBP and DBP by 14 cm</td>
<td>Reducing SBP and DBP by 14 cm in a randomized controlled trial (RCT) using a computer-based program. Subjects were assigned to either a control group or an intervention group. The intervention group received a program that aimed to reduce SBP and DBP by 14 cm. Differences in SBP and DBP between the groups were measured at 6 months.</td>
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<td>Stensvold et al.</td>
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<td>SBP, DBP, HDL-C, TC, TC, TC</td>
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</tr>
</tbody>
</table>
Table 1: Description of the studies included in the systematic review

<table>
<thead>
<tr>
<th>Author(s) and publication</th>
<th>Population (no., age, gender)</th>
<th>Intervention</th>
<th>Comparator</th>
<th>Outcome(s)</th>
<th>Study design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood et al., Metabolic Syndrome and Related Disorders</td>
<td>n = 42, age = 50 ± 7 years, males</td>
<td>12 weeks of aerobic exercise (≥ 60 min/week)</td>
<td>Placebo (n = 40)</td>
<td>Waist circumference, body mass index, waist-to-hip ratio</td>
<td>Randomized, parallel design</td>
</tr>
<tr>
<td>Birch et al., Diabetes, Obesity and Metabolism</td>
<td>n = 65, age = 55 ± 6 years, 33 males, 26 females</td>
<td>12 weeks of multivariate exercise training during dietary weight loss (WL)</td>
<td>Placebo (n = 42)</td>
<td>Waist circumference, body mass index, waist-to-hip ratio</td>
<td>Randomized, parallel design</td>
</tr>
<tr>
<td>Yusuf et al., Journal of Ophthalmology</td>
<td>n = 413, age = 67 ± 4 years, 257 males, 156 females</td>
<td>12 weeks of exercise training combined with education</td>
<td>Placebo (n = 40)</td>
<td>Waist circumference, body mass index, waist-to-hip ratio</td>
<td>Randomized, parallel design</td>
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<tr>
<td>Jobst et al., The American Journal of Clinical Nutrition</td>
<td>n = 427, age = 45 ± 2 years, males</td>
<td>12 weeks of aerobic exercise training, 3 months of exercise intervention phase, and 3 months of maintenance phase</td>
<td>Placebo (n = 42)</td>
<td>Waist circumference, body mass index, waist-to-hip ratio</td>
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<tr>
<td>Watkins et al., Annals of Internal Medicine</td>
<td>n = 53, age = 29 ± 7 years, males</td>
<td>A randomization to either aerobic exercise training combined with sodium-free diet intervention (n = 24) or control group (n = 29)</td>
<td>Placebo (n = 42)</td>
<td>Waist circumference, body mass index, waist-to-hip ratio</td>
<td>Randomized, parallel design</td>
</tr>
<tr>
<td>Selman et al., Medical Clinics of North America</td>
<td>n = 241, age = 39 ± 4 years, 47% females</td>
<td>A randomized control trial</td>
<td>Placebo (n = 42)</td>
<td>Waist circumference, body mass index, waist-to-hip ratio</td>
<td>Randomized, parallel design</td>
</tr>
<tr>
<td>Thomas et al., Journal of Applied Physiology</td>
<td>n = 102, age = 21 ± 5 years, 37 males and 65 females</td>
<td>Aerobic exercise and diet programs with different levels of exercise intervention</td>
<td>Placebo (n = 42)</td>
<td>Waist circumference, body mass index, waist-to-hip ratio</td>
<td>Randomized, parallel design</td>
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<tr>
<td>Keim et al., Medicine &amp; Science in Sports &amp; Exercise</td>
<td>n = 40, age = 32 ± 7 years, males</td>
<td>12 weeks of low-calorie diet and aerobic exercise training</td>
<td>Placebo (n = 42)</td>
<td>Waist circumference, body mass index, waist-to-hip ratio</td>
<td>Randomized, parallel design</td>
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<tr>
<td>Mount et al., Medicine &amp; Science in Sports &amp; Exercise</td>
<td>n = 34, age = 45 ± 2 years, males</td>
<td>A control condition of high-fat diet and meat sampling at 2-month intervals followed by exercise conditions</td>
<td>Placebo (n = 42)</td>
<td>Waist circumference, body mass index, waist-to-hip ratio</td>
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<tr>
<td>Irving et al., Medicine &amp; Science in Sports &amp; Exercise</td>
<td>n = 25, age = 31 ± 5 years, males</td>
<td>16-week intervention with low-carbohydrate diet and high-intensity exercise training</td>
<td>Placebo (n = 42)</td>
<td>Waist circumference, body mass index, waist-to-hip ratio</td>
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<tr>
<td>Cohen et al., Metabolic Syndrome &amp; Related Disorders</td>
<td>n = 32, age = 53 ± 6 years, 85% females</td>
<td>26 females and 49 males</td>
<td>Placebo (n = 42)</td>
<td>Waist circumference, body mass index, waist-to-hip ratio</td>
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Table 2: Data extraction table containing the results

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<tr>
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<tr>
<td>Wood et al., Metabolic Syndrome and Related Disorders</td>
<td>2 weeks of Low-fat diet (LFD) vs. Caloric restriction alone (CR)</td>
<td>Randomized, parallel design</td>
<td>n = 42, age = 50 ± 7 years, males</td>
<td>Body mass index, waist circumference, body fat percentage</td>
<td>Significant difference (p &lt; 0.05)</td>
<td>Short duration and small sample size, specific, single office of BMI cannot be evaluated from the study design</td>
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### Table 2: Data extraction table containing the results

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<tr>
<td><strong>Population</strong></td>
<td><strong>Primary</strong></td>
<td><strong>Secondary</strong></td>
<td><strong>BMI</strong></td>
<td><strong>TG</strong></td>
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<tr>
<td><strong>Author, publication</strong></td>
<td><strong>Study size, sex, age</strong></td>
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<td><strong>2. Kemmler et al. (2015)</strong></td>
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<td><strong>3. Lin et al. (2016)</strong></td>
<td>65, age = 68.7 years</td>
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<tr>
<td><strong>4. Stensvold et al. (2017)</strong></td>
<td>27, age = 51 years</td>
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<td><strong>5. Fors et al. (2018)</strong></td>
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**Table 2:** Data extraction table containing the results
An overall reduction in the TG level was observed for all the five trials with significant change \( p < 0.05 \) observed for only one of the trials.\(^8\) Kemmler et al. demonstrated that the EX showed a favorable decrease of 15% in the triglyceride level with a decrease of 24.1 mg/dL \( (p = 0.007) \). In another trial, it was observed that both LOW-1 and MOD-2 performed in a single session significantly reduced TG concentrations 4 hour after the test meal to a strikingly similar extent (22% and 21%, respectively).\(^9\) Post-intervention, in two of the five trials, the triglyceride level was reduced from high to normal range.\(^1,14\)

\( \text{PA–PA:} \) A total of two studies examined the effect of different forms of physical activity on triglyceride level.\(^6,10,17\) Both studies enrolled patients with high TG with cutoffs varying with different criteria as mentioned above.

A reduction in TG level was observed only in the trial conducted by Stensvold et al. with a decrease of 4.1 ± 5.1 mg/dL \( (p = 0.036) \) as compared with the control NOEx group.\(^6\) Kemmler et al. demonstrated an increase of 3.8 ± 8.3 mg/dL \( (p = 0.036) \) as compared with the control group.\(^15\)

An overall increase in the HDL-C level was observed for four of the five trials\(^3,7,11,13\) with significant change \( p < 0.05 \) observed for only one of the trials.\(^3\) Kemmler et al. demonstrated an increase of 3.8 ± 8.3 mg/dL \( (p = 0.036) \) as compared with the control group.\(^15\) In the trial conducted by Thomas et al., it was observed that even during the PWR phase, concentrations of HDL-C continued to increase and was significantly higher in both groups EX and NOEx during weight regain.\(^11\) Post-intervention, two of the five trials showed an increase in the HDL-C level from high to normal range.\(^1,14\)

\( \text{PA–PA:} \) A total of two studies examined the effect of different forms of PA on HDL-C level.\(^6,11\) Both studies included patients with high HDL and allowed those who were on medication for high HDL, that is, metformin. The cutoffs varied with different criteria as mentioned above.

A significant decrease \( p < 0.05 \) was observed only in one trial.\(^11\) Tjønna et al. demonstrated a reduction of 5 and 6 cm in the AIT and CME groups, respectively \( (p < 0.05) \). Post-intervention FBG reduced in all, but still remained high in both the studies.

5. Waist circumference

\( \text{PA + diet:} \) A total of seven studies examined the combined effect of PA and diet on FBG level.\(^9,11,13,14\) Participants in all the studies were unmedicated for diabetes, with Ma et al. allowing participants who joined weight-loss program outside the study.\(^13\) All seven trials enrolled participants with high cutoffs, varying with different criteria as mentioned above.

An overall reduction was observed in WC in all the seven trials with a significant \( p < 0.05 \) reduction observed in four.\(^11,13,14\) Seligman et al. demonstrated a decrease of 14 cm in both the intervention groups and the control group (standard care).\(^7\) The reduction varied from 5.8 cm \( (p < 0.001) \) to 10 cm \( (p < 0.01) \). A decrease of 10 cm was observed for both LFD and PRE and CRD and PRE groups.\(^6\)

\( \text{PA only:} \) A total of four studies examined the effect of PA alone on WC.\(^6,7,11,14\) Most of the studies included participants that were unmedicated for reduction of WC except for Cohen et al., where patients on statins for lipids were also included.\(^6,7\) All five trials enrolled participants with high WC cutoffs varying with different criteria as mentioned above.

An overall reduction in the WC was observed for four of the trials\(^11,13,14\) with significant change \( p < 0.05 \) observed only in one study.\(^13\) Irving et al. demonstrated that HIE significantly reduced WC \( (p < 0.001) \).

\( \text{Discussion} \)

Based on the data search and extraction from the eligible studies, there is a substantial and consistent evidence that PA can lead to an improvement in metabolic syndrome outcomes. This review mostly covered adults ranging from 21 to 72 years of age with majority of the studies focusing on population from Western countries. For the most part, RCTs focused on aerobic training with modest amounts of resistance training, restorative yoga, circuit training, and progressive resistance exercise.

1. \( \text{PA and diet group studies} \) had several implications. Progressive aerobic exercise combined with a diabetic diet alone on the preservation of fat-free mass and diagnostic criteria for metabolic syndrome. In majority of the studies, exercise when combined with a wellness program or diet regimen showed a synergistic effect, with a greater improvement in the health outcomes especially for the lipid profile. One of the studies demonstrated that both exercise and exercise in combination with diet lead to improvement in all the risk factors associated with metabolic syndrome, with no difference in magnitude of improvement between the interventions. Exercise alone can be an effective non-pharmacological treatment strategy for insulin resistance, metabolic syndrome, and CVD risk factors in older adults.\(^15\) Lifestyle modifications that focus on
An overall reduction in the TG level was observed for all the five trials with significant change (p < 0.05) observed for only one of the trials. Kemmler et al. demonstrated that the EX showed a favorable decrease of 15% in the triglyceride level with a decrease of 24.1 mg/dl (p = 0.007). In another trial, it was observed that both LOW-1 and MOD-2 performed in a single session significantly reduced TG concentrations 4 hour after the test meal to a strikingly similar extent (22% and 21%, respectively). Post-intervention, in two of the five trials, the triglyceride level was reduced from high to normal range.\(^{1,4}\)

**PA–PA:** A total of two studies examined the effect of different forms of physical activity on triglyceride level.\(^{6,7}\) Both studies enrolled patients with high TG with cutoffs varying with different criteria as mentioned above. Both studies allowed those who were on statins. A reduction in TG level was observed only in the trial conducted by Stensvold et al. with a decrease of 4.1 ± 5.1 mg/dl (p = 0.036) as compared with the control NOEX group.\(^{15}\) In the trial conducted by Thomas et al.,\(^{19}\) it was observed that even during the PWR phase, concentrations of HDL-C continued to increase and was significantly higher in both groups EX and NOEX during weight regain. Post-intervention, two of the five trials showed an increase in the HDL-C level from high to normal range.\(^{7,11}\)

**PA–PA:** A total of two studies examined the effect of different forms of PA on TG level.\(^{6,7}\) All studies enrolled participants with high TG and allowed those who were on medication for high TG, that is, metformin. The cutoffs varied with different criteria as mentioned above. An overall reduction in TG observed in both the studies with significant change observed in the trial undertaken by Tjonna et al., where only AIT promoted an improvement in TG compared with other groups (p < 0.05) with a decrease of 0.3 mmol/L. Post-intervention TG reduced in all, but still remained high in both the studies.

### 5. Waist circumference

**PA + diet:** A total of seven studies examined the combined effect of PA and diet on FBG level.\(^{7,11,14,15}\) Participants in all the studies were unmedicated for diabetes, with Ma et al. allowing participants who joined weight-loss program outside the study.\(^{7,11}\) Three of the six studies included participants with high FBG and allowed those who were on medication for high FBG, that is, statins.\(^{7,11}\) Stensvold et al. showed an increase of 0.06 mmol/L in AIT, 0.12 mmol/L in COM, and 0.08 mmol/L in the ST group.\(^{7}\)

#### 4. Fasting blood glucose (FBG)

**PA–diet:** A total of six studies examined the combined effect of PA and diet on FBG level.\(^{6,7,10,12,17,19}\) Participants in all the studies were unmedicated for diabetes, with Ma et al. allowing participants who joined weight-loss program outside the study.\(^{7,11}\) Three of the six studies included participants with high FBG and allowed those who were on medication for high FBG, that is, statins.\(^{7,11}\) Stensvold et al. demonstrated an increase of 3.8 ± 8.3 mg/dL (p = 0.036) as compared with the control NOEX group.\(^{15}\) In the trial conducted by Thomas et al.,\(^{19}\) it was observed that both WC and abdominal tissue compartments were significantly reduced with weight loss and later increased significantly with weight regain in both groups; that is, with EX and NOEX.\(^{14}\) Despite an overall decrease in the WC post-intervention, the WC did not reach the normal level in any of the trials.

**PA–PA:** A total of two studies examined the effect of different forms of PA on FBG level.\(^{6,7}\) Tjonna et al. enrolled patients with high WC with participants unmedicated for reduction of WC. The cut-offs varied with different criteria as mentioned above. An overall significant (p < 0.05) decrease was observed in WC for both trials, but it was still high.\(^{7}\) Tjonna et al. demonstrated a reduction of 5 and 6 cm in the AIT and CME groups, respectively (p < 0.05). Trial conducted by Stensvold et al. showed a reduction in all the three training groups (significant change p = 0.01 for both AIT and ST groups; AIT: −1.3 cm, COM: −0.74 cm, ST: −1.4 cm).

**Discussion**

Based on the data search and extraction from the eligible studies, there is a substantial and consistent evidence that PA can lead to an improvement in metabolic syndrome outcomes. This review mostly covered adults ranging from 21 to 72 years of age with majority of the studies focusing on population from developed countries. For the most part, RCTs focused on aerobic training with modest amounts of resistance training, restorative yoga, circuit training, and progressive resistance exercise.

1. PA + diet intervention studies had several implications. Progressive resistance exercise alone or in combination with aerobic exercise can lead to a significant reduction in SBP, DBP, and WC in older adults.\(^{1}\) Lifestyle modifications that focus on

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A systematic review to assess the impact of physical activity intervention on people with metabolic syndrome.

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weight loss (5-10%) and moderate-intensity PA can reduce DM and cardiometabolic risk factors in high-risk individuals with benefits sustained for at least 10 years."

2. PA alone group demonstrated a similar trend in the metabolic syndrome risk factors after PA intervention. Exercise was found to be effective both with and without the weight loss, and can be beneficial even during periods of weight gain. Exercise can maintain most aspects of metabolic health even during partial weight gain, thereby countering its detrimental effect. Both low-intensity and moderate-intensity exercise performed in a single session significantly reduce TG level and help attenuate post-prandial lipemia. HIET can significantly reduce body weight, BMI, percent body fat, and waist circumference as it is associated with a greater exercise energy expenditure as compared with LIET, thereby giving greater benefits. On the other hand, restorative yoga showed a trend toward lower BP and better weight maintenance with no change observed in FBG, TG level, and WC.

3. PA–PA group helped compare different modes of exercise and showed a trend. Even though all different forms of PA: AIT, ST, and COM have beneficial effect on metabolic syndrome variables. AIT leads to a significant change in BP and FBG, glucose metabolism, especially when volume and duration is low (120 min ex/week for 12 week). AIT, ST, and COM have beneficial effect on metabolic syndrome variables, AIT for 12 weeks is more effective than both low (120 min ex/week for 12 week). AIT, ST, and COM have beneficial effect on metabolic syndrome variables. AIT leads to a significant change in BP and FBG, glucose metabolism, especially when volume and duration is low (120 min ex/week for 12 week). AIT, ST, and COM have beneficial effect on metabolic syndrome variables. AIT leads to a significant change in BP and FBG, glucose metabolism, especially when volume and duration is low (120 min ex/week for 12 week). AIT, ST, and COM have beneficial effect on metabolic syndrome variables. AIT leads to a significant change in BP and FBG, glucose metabolism, especially when volume and duration is low (120 min ex/week for 12 week). AIT, ST, and COM have beneficial effect on metabolic syndrome variables. AIT leads to a significant change in BP and FBG, glucose metabolism, especially when volume and duration is low (120 min ex/week for 12 week).

Limitations

For this systematic review, the search focused only on a single database: PubMed, which is one of the largest indexed collectors of scientific papers with over 23 million citations for biomedical literature. The initial search was carried out by a single researcher, but the other authors were available for discussion and clarification of doubts. Unpublished studies and studies that were published in languages other than English could not be included.

Conclusion

This systematic review provides sufficient evidence to suggest that physical activity in general is beneficial for adults diagnosed with metabolic syndrome. More specifically, at least 12 weeks of low/moderate intensity exercise can bring about a change in some of the risk factors like BP, lipid profile, FBG, and waist circumference. Lifestyle modifications with weight loss through physical activity can further reduce the risk of diabetes mellitus and cardiometabolic factors, the two key drivers of metabolic syndrome. This article presents comprehensive and updated evidence on the beneficial impact of physical activity on metabolic syndrome and related risk factors among adults. With the rising burden of NCDs, which also includes metabolic syndrome, there is an urgent need of using innovative low-cost public health strategies to tackle them effectively and sustainably. Therefore, initiating large-scale community intervention programs focusing on increased and sustained physical activity programs should be promoted.

References


A systematic review to assess the impact of physical activity intervention on people with metabolic syndrome.

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weight loss (5–10%) and moderate-intensity PA can reduce DM and cardiometabolic risk factors in high-risk individuals with benefits sustained for at least 10 years.2

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Further studies need to be conducted to understand the dose–response of PA on the metabolic syndrome risk factors as this systematic review did not address this aspect.

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