Talebi Anaraki *et al. BMC Pediatrics* (2025) 25:431
https://doi.org/10.1186/s12887-025-05759-6

BMC Pediatrics

RESEARCH

Open Access

Managing pediatric metabolic syndrome: a systematic review of current approaches

Kasra Talebi Anaraki[1], Motahar Heidari-Beni[1], Mehrnoosh Arefian[2] and Roya Kelishadi[1*]

Abstract

Background There are various pharmacological and non-pharmacological approaches in the management and treatment of metabolic syndrome (MetS). We aimed to systematically review the effect of different approaches in the management of pediatric MetS.

Methods A systematic search was conducted in Medline, Scopus, Embase, Web of Science, and Google Scholar up to April 15, 2025. All interventional that had assessed the effects of lifestyle modifications in terms of changes in dietary habits, increased physical activity, and pharmacological interventions in the management of pediatrics MetS were included.

Results Among 1701 records found in the databases, 31 articles were included. Lifestyle modification, physical exercise, and dietary habits alteration were the commonest effective approaches in modulating MetS. The Mediterranean and DASH (Dietary Approaches to Stop Hypertension) diets improved the metabolic profile of MetS and reduced its prevalence. Metformin was the most frequently prescribed medication that was prescribed for pediatric MetS. However, its efficacy alone in comparison to lifestyle modifications remains to be determined. The effect of omega-3 supplements on the metabolic profile of MetS cases was inconsistent, but vitamin D supplementation was shown to have some favorable effects. Natural products such as fermented camel milk, grape juice, and pomegranate juice did not show any significant improvement in pediatric MetS.

Conclusion Multidisciplinary lifestyle modification is considered the first recommendation for the prevention and management of MetS in childhood. Metformin can be an effective adjuvant therapy to lifestyle modifications in some cases of MetS, especially in children with other comorbidities.

Trial code CRD42024502835.

Keywords Metabolic syndrome, Child, Adolescent, Life style, Systematic review

*Correspondence:
Roya Kelishadi
roya.kelishadi@gmail.com
[1]Child Growth and Development Research Center, Research Institute for Primordial Prevention of Non-communicable Disease, Isfahan University of Medical Sciences, Isfahan, Iran
[2]Department of Natural Sciences, School of Science and Technology, University of Georgia, Tbilisi 0171, Georgia

Introduction

Affecting approximately a quarter of the population, metabolic syndrome (MetS) has spread all around the world in recent years due to the considerable changes in dietary habits and lifestyle. According to the latest meta-analysis on more than 550,000 youths, the prevalence of MetS among children and adolescents was reported to be 3% and 5%, respectively [1]. As a cluster of various medical issues that can lead to complications such as diabetes mellitus (DM), cardiovascular disease (CVD), metabolic-associated fatty liver disease (MAFLD), and renal disease, the MetS has attracted increased attention through the last two decades [2, 3]. MetS is characterized by a set of cardio-metabolic risk factors including the presence of hypertension, abdominal obesity, high blood sugar levels, hypertriglyceridemia, and reduced serum high-density-lipoprotein cholesterol (HDL-C) [4]. Although yet, the complex pathogenesis of MetS is not fully understood [5]. Studies have suggested a strong interaction between environmental factors and genetic predispositions in the development of MetS [6].

It is important to notice that the criteria used to define MetS in adults could not apply to children and adolescents [7]. Although discrepancies exist in various definitions of the pediatric metabolic syndrome, but the components are similar to adults, with variations in the cutoff points [8]. Given the increasing prevalence of MetS in the pediatric population and the potential long-term health risks, understanding its development and management is crucial.

A growing body of evidence demonstrated that pediatric MetS tracks to adulthood and increases the risk of serious health complications and chronic diseases [9]. Early intervention and effective management in childhood could significantly reduce the burden of these conditions later in life [10]. However, much of the research has focused on adults, with limited data available for pediatric populations.

To date, various clinical trials have evaluated the efficacy of different approaches for managing MetS in adults, which mainly included weight loss by lifestyle modification, pharmacotherapy, and even surgical approaches [11–13]. However, this evidence is still scarce in the pediatric age group. Moreover, some controversies exist regarding the efficacy of some of these approaches. For instance, Raub and Goldberg demonstrated that metformin when added to lifestyle modifications, did not show any clinically important efficacy compared to lifestyle modification alone in a pediatric population with MetS [14], whereas Stagi et al. [15] and Fu et al. [16] showed the efficacy of it in modulating the metabolic profiles of children with MetS. Rabbani et al. indicated no significant change in MetS prevalence among elementary schoolchildren after 2 years of lifestyle modification [17]. In the case of supplement therapy, Ahmadi et al. did not find any significant improvement in pediatric MetS components after 8 weeks of consuming Omega-3 (2.4 gr/day) [18]. However, García-López et al. reported significant improvement in lipid and glycemic profile as well as blood pressure following 1 month of the same intervention [19].

Given the importance of MetS from childhood and the controversies regarding its management, we aimed to conduct a comprehensive review of different pharmacological and non-pharmacological approaches in the prevention and management of MetS among children and adolescents. This review seeks to summarize the current evidence, highlight gaps in the existing literature, and provide recommendations for future research and clinical practice.

Methods

Protocol registration

The protocol for this review was developed according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) 2020 guidelines [20] and registered on the International Prospective Register of Systematic Reviews (PROSPERO) with the CRD42024502835 registration code.

Search strategy

A comprehensive literature review was conducted through Medline (PubMed), Embase, Web of Science, Google Scholar, and Scopus up to April 15, 2025 using various combinations of related keywords such as "Pediatrics", "Child", "Adolescents", "Metabolic Syndrome", "Life Style", "Diet", "Exercise", "medication*", "pharmac*", "drug*", and "behave*". The details of the search string for each dataset are mentioned in Appendix 1. There is no restriction for language, date, or publication status. Furthermore, the reference lists of the retrieved articles and the relevant reviews were examined to identify eligible studies.

Inclusion and exclusion criteria

All interventional studies assessing different approaches including increasing physical activity, reducing sedentary behavior, promoting healthy eating habits, and using pharmacological interventions to prevent and manage MetS occurrence among children and adolescents were included. There is no restriction for MetS definition. In vitro studies, animal investigations, conference abstracts, editorials, book chapters, and studies in languages other than English were excluded. Studies on both adults and pediatrics and studies with insufficient data or poor quality were also excluded. After retrieving the search results and excluding duplicates, two researchers independently screened the titles, abstracts, and full texts according to the prespecified criteria and it was re-checked by another reviewer. According to the PICOS framework, the population (P) consisted of pediatric patients with MetS. The intervention (I) included various approaches, such as lifestyle modifications, dietary interventions, pharmacological treatments, and supplement consumption. The comparison (C) involved evaluating the differences between these approaches. The outcome (O) focused on changes in the metabolic profile of the patients, and the study design (S) encompassed interventional investigations.

Data extraction

The data extraction process was conducted independently by two reviewers, and their results were compared. Any disagreements were resolved through discussion, and if consensus could not be reached, a third reviewer was consulted to make the final decision. First author's name, publication date, country of research, the exact design of the study (blindness and arms of the trial), characteristics of enrolled participants, number of participants, criteria for MetS diagnosis, type and duration of intervention, and the main outcome were extracted.

Quality assessment

The quality of the included articles was evaluated using the National Institute of Health (NIH) quality assessment tool for controlled intervention studies and before-after (pre-post) studies without control group [21]. This scale consists of 14 questions for controlled interventional studies and 12 items for before-after investigations and qualifies studies as poor, fair, or good. Two independent reviewers assessed the quality of the studies, and controversies were reconciled via consensus with the third reviewer.

Results

Study selection

The study selection process is summarized in Fig. 1. The primary search identified 1701 records. After duplicate removal, 1225 studies remained for assessment based on the title and abstract. After the screening, 44 studies were eligible for further evaluation through the full text. Two articles have been found in the reference checking of the relevant studies and reviews. Finally, 31 studies were included in the systematic review.

Study characteristics

The details of the 31 included studies are summarized in Table 1. Fourteen studies assessed the efficacy of different approaches in the prevalence of MetS [17, 22–34], while others evaluated different approaches to change the metabolic parameters among cases with MetS [14–16, 18, 19, 35–46]. Five studies assessed the efficacy of diet modification [22, 23, 35–37], four studies physical activity training [24, 25, 27, 38], three studies pharmacological interventions [14–16], nine studies different supplements and natural products consumption [18, 19, 33, 41–46], and ten studies assessed lifestyle management [17, 26, 29–32, 34, 39, 40, 47]. Ten research was conducted in a before-after manner without control group [16, 24, 26, 29–32, 34, 36, 40] and others were performed in a controlled intervention design. Included investigations have utilized different diagnostic criteria for MetS including International Diabetes Federation (IDF) criteria [15, 18, 23, 25, 27, 29, 32, 34, 35, 39–43, 45, 47], modified National Cholesterol Education Program Adult Treatment Panel III (ATP III) [17, 22, 24, 26, 31, 37, 38, 46], and adopted World Health Organization (WHO) criteria [19, 30]. A few articles used a mixture of different criteria [16, 47]. Included surveys were conducted between 2006 and 2023 in 12 different countries including eleven in Iran [17, 18, 22, 35, 37, 39, 41, 43–46], five in Brazil [24, 25, 27, 30, 40], four in the USA [14, 31, 34, 36], three in Mexico [19, 23, 26], two in Germany [32, 47], and one in Spain [29], Italy [15], Poland [42], China [16], Egypt [38], and Saudi Arabia [33]. According to the NIH quality assessment tool, 20 out of 31 included articles in this study qualified as good [15, 17, 19, 22–25, 27, 29, 30, 33, 35, 37–43, 46], and the rest as fair. Details of the quality assessment process are shown in Appendix 2.

According to the available literature, the low number of studies on each intervention, the great heterogeneity of included studies due to different study designs, MetS criteria, and characteristics of participants persuade us not to conduct a meta-analysis.

Diet modification for pediatric MetS

Two studies have assessed the efficacy of the Mediterranean diet for a duration of 12 [35] and 16 [23] weeks. Their results demonstrated a significant improvement in both the metabolic profile of MetS and a reduction in its prevalence among obese children and adolescents. Two investigations by the same research group on 6 weeks of Dietary Approaches to Stop Hypertension (DASH) diet intervention among post-pubescent adolescent girls demonstrated a significant reduction in the prevalence of MetS compared to usual dietary advice (UDA) [22, 37]. However, no significant change was observed compared to the baseline levels [22]. They also showed a reduction in circulating levels of hs-CRP, but not other inflammatory markers among cases with MetS following the DASH diet [37]. A before-after trial among obese children with MetS suggested a significant improvement in lipid profile following 9 days of an isocaloric fructose restriction diet [36].

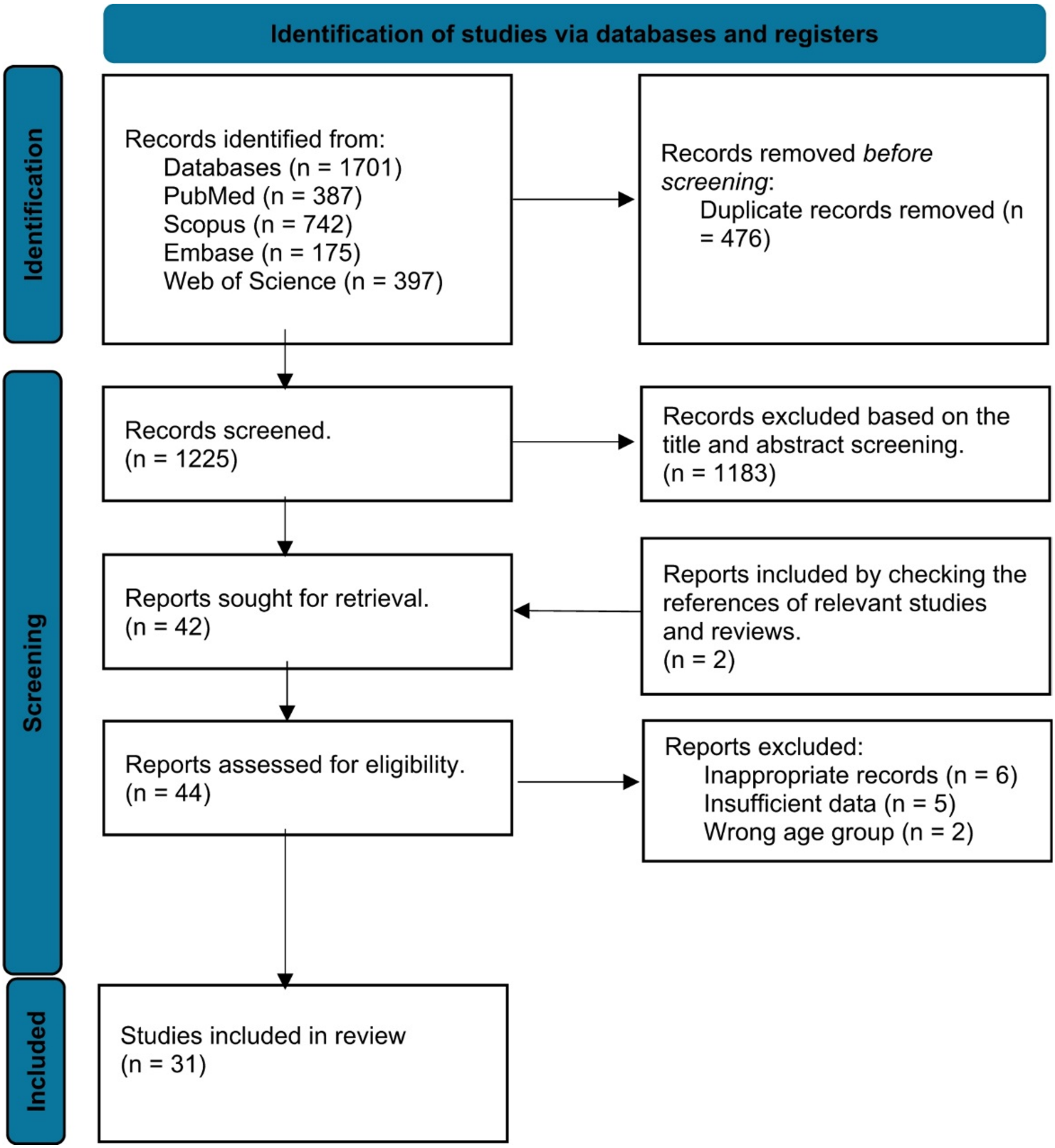

Fig. 1 PRISMA flow diagram

Physical activity for pediatric MetS

Kamal and Ragy [38] showed that a set of exercises three times per week, for twelve weeks by a trained physiologist, decreased the prevalence of MetS from 12.9 to 7.5%, and also significantly improved the metabolic profile and inflammatory biomarkers of MetS patients. A study by Vasconcellos et al. [27] suggested that a 12-week recreational soccer training (3 times per week), effectively reverses the status of MetS among obese adolescents with MetS. de Mello et al. [25] showed a significant reduction in MetS prevalence and improvement in its components following both aerobic training and aerobic plus resistance training. Leite et al. [24] also demonstrated the same results after 12 weeks of indoor cycling or outdoor walking or running.

Table 1 Characteristics of included studies

Approach	Author	Year	Country	Study Design	Participants	MetS diagnostic criteria	Sample size (male %)		Age (men ± SD or range)		Intervention	Duration	Outcome
							Con	Int	Con	Int			
Dietary habit interventions	Asoudeh [35]	2023	Iran	Two arms, open-label RCT	Adolescent girls with MetS	IDF criteria	35 (0)	35 (0)	14 ± 1	14 ± 1	Mediterranean diet	12 weeks	Significant improvement in anthropometrics, MetS components, and inflammatory markers
	Gugliucci [36]	2016	USA	Before-after trial	Obese children with MetS	NR	37 (NR)		13.3 ± 2.7		Isocaloric fructose restriction	9 days	Significant reduction in lipoprotein markers
	Saneei [22]	2013	Iran	Two arms, randomized cross-over trial	Post-pubescent adolescent girls with MetS	Modified ATP III criteria	60 (0)		14.2 ± 1.7		DASH diet	6 weeks	Significant reduction in the prevalence of MetS compared to UDA, but no significant change compared to the baseline levels
	Saneei [37]	2014	Iran	Two arms, randomized cross-over trial	Post-pubescent adolescent girls with MetS	Modified ATP III criteria	60 (0)		14.2 ± 1.7		DASH diet	6 weeks	Reduction in circulating levels of hs-CRP, but not other inflammatory markers
	Velázquez-López [23]	2014	Mexico	Two arms, open-label RCT	Obese children and adolescents	IDF criteria	25 (40)	24 (54)	11.4 ± 2.9	11.2 ± 2.7	Mediterranean diet	16 weeks	Significant reduction in the prevalence of MetS
Physical exercise	Leite [24]	2009	Brazil	Before-after trial	Obese adolescents with and without MetS	Modified ATP III criteria	30 (NR)	25 (NR)	(10–16)		Indoor cycling or outdoor walking or running in addition to nutritional consultation	12 weeks	Significant decrease in MetS prevalence and improvement in its components
	de Mello [25]	2011	Brazil	Two arms, open-label RCT	Obese adolescents with MetS undergoing AT (Con) or AT + RT (Int)	IDF criteria	15 (NR)	15 (NR)	(15–19)		Treadmill running	6 and 12 months	Significant decrease in MetS prevalence and improvement in its components in both groups
	Kamal and Ragy [38]	2012	Egypt	Three arms, open-label RCT	MetS and non-MetS children	Modified ATP III criteria	49 (50)	12 (66)	10.1 ± 1.2	11 ± 1.1	Exercise 3 times per week	12 weeks	Significant improvement in anthropometrics, MetS components, and inflammatory markers
	Vasconcellos [27]	2020	Brazil	Two arms, single-blind RCT	Obese adolescents with MetS	IDF criteria	7 (71)	6 (66)	14.7 ± 2.3	13.9 ± 1.6	Recreational soccer training 3 times per week	12 weeks	The intervention was effective in reversing MetS's status
Lifestyle modification	Elizondo-Montemayor [26]	2013	Mexico	Before-after trial	Overweight or obese children	Modified ATP III criteria	96 (54)		9 ± 1.4		Lifestyle modification by trained RD	10 months	Significant reduction in the prevalence of MetS
	Reinehr [47]	2009	Germany	Two arms, open-label RCT	Obese children	IDF criteria, and Weiss's definition	186 (42)	288 (45)	12.8	12.5	Obeldicks lifestyle intervention	12 months	Significant reduction in the prevalence of MetS based on both definitions

Table 1 (continued)

Approach	Author	Year	Country	Study Design	Participants	MetS diagnostic criteria	Sample size (male %)		Age (men ± SD or range)		Intervention	Duration	Outcome
							Con	Int	Con	Int			
	Marti [29]	2021	Spain	Before-after trial	Children with abdominal obesity	IDF criteria	29 (48)		(7–16)		Lifestyle modification	2 and 12 months	Significant reduction in the prevalence of MetS
	Caranti [30]	2007	Brazil	Before-after trial	Post-puberty obese adolescents	Adopted WHO criteria	62 (NR) 37 (40)		(15–19)		Lifestyle modification (nutritional, exercise, clinical, and psychological therapy)	6 months 12 months	Significant reduction in the prevalence of MetS based on both short-term and long-term therapy
	Chen [31]	2006	USA	Before-after trial	Overweight children	Modified ATP III criteria	16 (62)		(10–17)		Diet and exercise intervention	2 weeks	Significant reduction in the prevalence of MetS
	Hakim [39]	2022	Iran	Four arms, open-label RCT	Children with MetS	IDF criteria	12 (50)	10 (50)	8.5 ± 1.7	8.3 ± 1.7	Diet modification	4 months	Significant improvement in MetS components in all interventions
								12 (50)		9.2 ± 1.7	Physical activity training		
								13 (53)		8.7 ± 1.6	Diet modification and physical activity training		
	Lass [32]	2011	Germany	Before-after trial	Adolescent girls with PCOS that have gone through Obeldicks lifestyle intervention, with or without successful weight loss	IDF criteria	33 (0)	26 (0)	15.1 ± 0.7	14.9 ± 0.8	Obeldicks lifestyle intervention	12 months	Significant decrease in MetS prevalence among cases that have loosened weight successfully
	Masquio [40]	2016	Brazil	Before-After trial	Post-puberty obese adolescents with MetS	IDF criteria	32 (NR)		16.8 ± 1.5		Interdisciplinary therapy (nutrition, psychology, physical activity, and clinical support)	12 months	Significant improvement in MetS components
	Rabbani [17]	2022	Iran	Two arms, open-label RCT	Elementary school children	Modified ATP III criteria	803 (42)	589 (42)	NR	NR	Educating students, teachers, and parents; changes in food services and physical activity	24 months	No significant change in MetS prevalence, but significant improvement in blood pressure and abdominal obesity
	Abrams [34]	2013	USA	Before-after trial	Obese adolescents	IDF criteria	113 (29)		15 ± 1.3		Weight loss by lifestyle modification program	4 months	Significant decrease in MetS prevalence after weight loss

Table 1 (continued)

Approach	Author	Year	Country	Study Design	Participants	MetS diagnostic criteria	Sample size (male %)		Age (men ± SD or range)		Intervention	Duration	Outcome
							Con	Int	Con	Int			
Pharmacological intervention	Fu [16]	2006	China	Before-after trial	Adolescents with MetS with age over 10 years	Chinese diabetes association definition	20 (NR)		(7–16)		500 mg metformin twice per day and lifestyle modification	3 months	Significant improvement in MetS components
	Raub and Goldberg [14]	2012	USA	Two arms, open-label RCT	Adolescents with MetS undergoing lifestyle modification alone or in combination with metformin therapy	NR	30 (53)	30 (53)	13.2	13.2	500 mg metformin twice per day	303 days for Int and 469 days for Con	No significant changes were observed
	Stagi [15]	2017	Italy	Three arms, open-label RCT	Children and adolescents with MetS	IDF criteria	51 (47)	129 (48)	12.4	12.6	500 mg metformin three times per day	12 months	Metformin alone shows short-term efficacy in modulating metabolic profiles, while combination with PGR potentiates its long-term effects
					Children and adolescents with MetS that have consumed metformin for 12 months			58 (NR)		13.8	500 mg metformin three times per day	12 months	
								71 (NR)		13.7	500 mg metformin and 725 mg PGR three times per day	12 months	
Supplements consumption	Ahmadi [18]	2014	Iran	Three arms, double-blind RCT	Adolescents with MetS	IDF criteria	27 (74)	30 (46)	16.6 ± 2.3	16.1 ± 1.8	Vitamin E 400 IU/day	8 weeks	Omega-3 effectively improved endothelial function (assessed by measuring VEGF value), while this was not confirmed following Vitamin E consumption. No significant improvement in the MetS component was observed following these interventions
								26 (66)		17.1 ± 2.8	Omega-3 2.4 gr/day		
	Al-Daghri [33]	2019	Saudi Arabia	Three arms, open-label RCT	Apparently healthy adolescents	NR	166 (48)	180 (38)	16.1 ± 1.9	14.3 ± 1.6	vitamin D tablet (1000IU/day)	6 months	Oral vitamin D supplementation significantly reduced the prevalence of MetS, but fortified milk consumption did not show a significant change
								189 (49)		14.4 ± 1.5	vitamin D fortified milk (200 ml/day, 40IU/100 ml)		
	Alizadeh [41]	2021	Iran	Two arms, double-blind RCT	Adolescents with MetS	IDF criteria	21 (23)	21 (66)	15.6 ± 1.8	14.8 ± 1.9	Grape seed extract 100 mg/day	8 weeks	Grape seed extract improves insulin resistance and its concentrations
	Duchnowicz [42]	2018	Poland	Two arms, open-label RCT	Adolescents with MetS	IDF criteria	11 (45)	66 (NR)	(13–19)		300 mg/day of extract from Aronia melanocarpa	2 months	Significant modulation of lipid profile

Table 1 (continued)

Approach	Author	Year	Country	Study Design	Participants	MetS diagnostic criteria	Sample size (male %)		Age (men ± SD or range)		Intervention	Duration	Outcome
							Con	Int	Con	Int			
	Fallah [43]	2018	Iran	Two arms, double-blind cross-over RCT	Adolescents with MetS consuming FCM or DCY	IDF criteria	24 (42)	24 (42)	13.7 ± 1.8	13.7 ± 1.8	250 mL of FCM for Int and 250 mL of DCY for Con	8 weeks	No significant improvement was observed
	García-López [19]	2016	Mexico	Two arms, open-label RCT	Schoolchildren with MetS	Adopted WHO criteria	30 (50)	39 (51)	(11–12)		2.4 gr Omega-3 per day (1440 mg EPA and 960 mg DHA)	1 month	Significant improvement in lipid and glycemic profile and blood pressure was observed
	Kelishadi [44]	2010	Iran	Two arms, triple-blind cross-over RCT	Prepubescent children with MetS	NR	60 (59)		9.1 ± 1.1		20 mg/day elemental zinc	8 weeks	Significant improvement in MetS components
	Kelishadi [45]	2011	Iran	Two arms, open-label RCT	Adolescents with MetS consuming grape or pomegranate juice	IDF criteria	15 (NR) 15 (NR)		13.4 ± 1.1		18 ml/kg/day of grape juice 240 ml/day of pomegranate juice	1 month	No significant change in lipid profile and CRP was observed
	Kelishadi [46]	2014	Iran	Two arms, triple-blind RCT	Children with MetS	Modified ATP III criteria	22 (NR)	21 (NR)	(10–16)		300,000 IU vitamin D per week	12 weeks	Significant reduction in insulin resistance and c-MetS was observed

Abbreviations: Int: intervention, Con: control, RCT: randomized clinical trial, MetS: metabolic syndrome, IDF: International Diabetes Federation, NR: not reported, ATP III: National Cholesterol Education Program Adult Treatment Panel III, DASH: Dietary Approaches to Stop Hypertension, UDA: Usual dietary advice, AT: aerobic training, RT: resistance training, RD: registered dietitians, PCOS: polycystic ovarian syndrome, PGR: Policaptil Gel Retard, VEGF: Vascular endothelial growth factor, FCM: fermented camel milk, DCY: diluted cow's yogurt, EPA: eicosapentaenoic acid, DHA: docosahexaenoic acid, c-MetS: continuous metabolic syndrome

Lifestyle modifications for pediatric MetS

Six studies [26, 29–32, 47] demonstrated a significant reduction in MetS prevalence following different types of lifestyle modifications (including a mixture of dietary modifications, physical activity changes, and loosening weight) following different durations ranging from 2 weeks to 12 months. Abrams et al. [34] showed a significant reduction in MetS prevalence (1.9 after 4 months) after loosening weight through lifestyle modification. On the other hand, a study conducted by Rabbani et al. [17] did not show a significant change in MetS prevalence after 2 years of lifestyle modification (educating students, teachers, and parents; changes in food services and physical activity), compared to its baseline level and even the control group. Two of the included records utilized the "Obeldicks" lifestyle intervention (a combination of physical activity, nutrition education, and behavior therapy) [32, 47]. Two other investigations indicated the beneficial effects of lifestyle changes in modulating the metabolic parameters of children with MetS [39, 40]. Of note, Hakim et al. [39] showed the beneficial effects of diet modification and physical activity training both in combination (as a lifestyle modification) and separately.

Pharmacological interventions for pediatric MetS

A before-after trial among adolescents with MetS aged over 10 years indicated a significant improvement in MetS components following administration of metformin (1000 mg per day) for 3 months [16]. Stagi et al. [15] also found the same results following the consumption of 1500 mg metformin per day for 12 months. Moreover, they suggested that adding 2175 mg of Policaptil Gel Retard (PGR) to the mentioned treatment potentiates the metformin's long-term effects for the following 12 months. Another study by Raub and Goldberg [14] found that metformin when added to lifestyle modifications, did not show any clinically obvious efficacy compared to lifestyle modification alone.

Supplements and natural products for pediatric MetS

Two articles have assessed the efficacy of vitamin D supplements [33, 46]. Al-Daghri et al. [33] showed consumption of vitamin D tablets significantly reduced the prevalence of MetS, but vitamin D-fortified milk consumption did not show a significant change. Kelishadi et al. [46] found a significant reduction in insulin resistance and c-MetS following 12 weeks of vitamin D (300000 IU per week). Two studies evaluated the effect of Omega-3 consumption on the metabolic profile of children with MetS [18, 19]. Ahmadi et al. [18] showed no significant improvement in MetS components after 8 weeks of consuming either vitamin E (400 IU/day) or Omega-3 (2.4 gr/day). However, García-López et al. [19] demonstrated a significant improvement in lipid and glycemic profile and blood pressure of children with MetS following 1 month of Omega-3 (2.4 gr/day). Zinc supplementation also demonstrated a significant improvement in the metabolic profile of prepubescent children with MetS [44]. Extracts from Aronia melanocarpa and grape seed were found to be effective for children with MetS [42].

Fermented camel milk (FCM) [43], grape juice, and pomegranate juice consumption [45] showed no significant improvement in the metabolic parameters of MetS.

Discussion

The current study aims to systematically review different approaches in the prevention and management of MetS among children and adolescents. The efficacy of different methods such as diet modification, physical activity changes, lifestyle modification and multidisciplinary therapy, pharmacological interventions, and consuming different supplements and natural products has been assessed in different settings (Fig. 2). A large number of included studies have focused on lifestyle modifications and utilizing different supplements and natural products. In most studies, lifestyle modifications were found to be effective in reducing the prevalence of MetS or modulating the metabolic profile of MetS cases.

According to the included studies, the Mediterranean diet was found to be an effective dietary plan for MetS management [23, 35]. To date, different observational studies have shown the relationship between adherence to the Mediterranean diet and lower risk of MetS incidence among children [48–50]. Martino et al. [49] showed that children with poor adherence to this habit and lower physical activity levels accompanied by 7 times increased possibility of MetS incidence. Mohammadi et al. [48] also demonstrated lower odds of being metabolically unhealthy among obese adolescents with higher adherence to the Mediterranean diet. The DASH diet was also found to be more effective than usual dietary advice in lowering MetS prevalence [22]. Higher adherence to the DASH diet among children correlates with lower odds of developing MetS and modulates different metabolic abnormalities [51].

Different types of physical exercise were found to be impressive in lowering MetS prevalence and modulating its components among children [24, 25, 27, 38]. A systematic review conducted by Cao et al. [52] showed that aerobic exercise has beneficial effects on lipid profile, blood pressure, and anthropometrics among children with MetS, but cannot completely reverse the MetS status. According to the WHO guidelines, children and adolescents are recommended to do moderate to vigorous-intensity physical exercise for at least 1 h per day [53]. After the COVID-19 pandemic era, sedentary behaviors increased among children and adolescents [54, 55]. A systematic review regarding this issue demonstrated

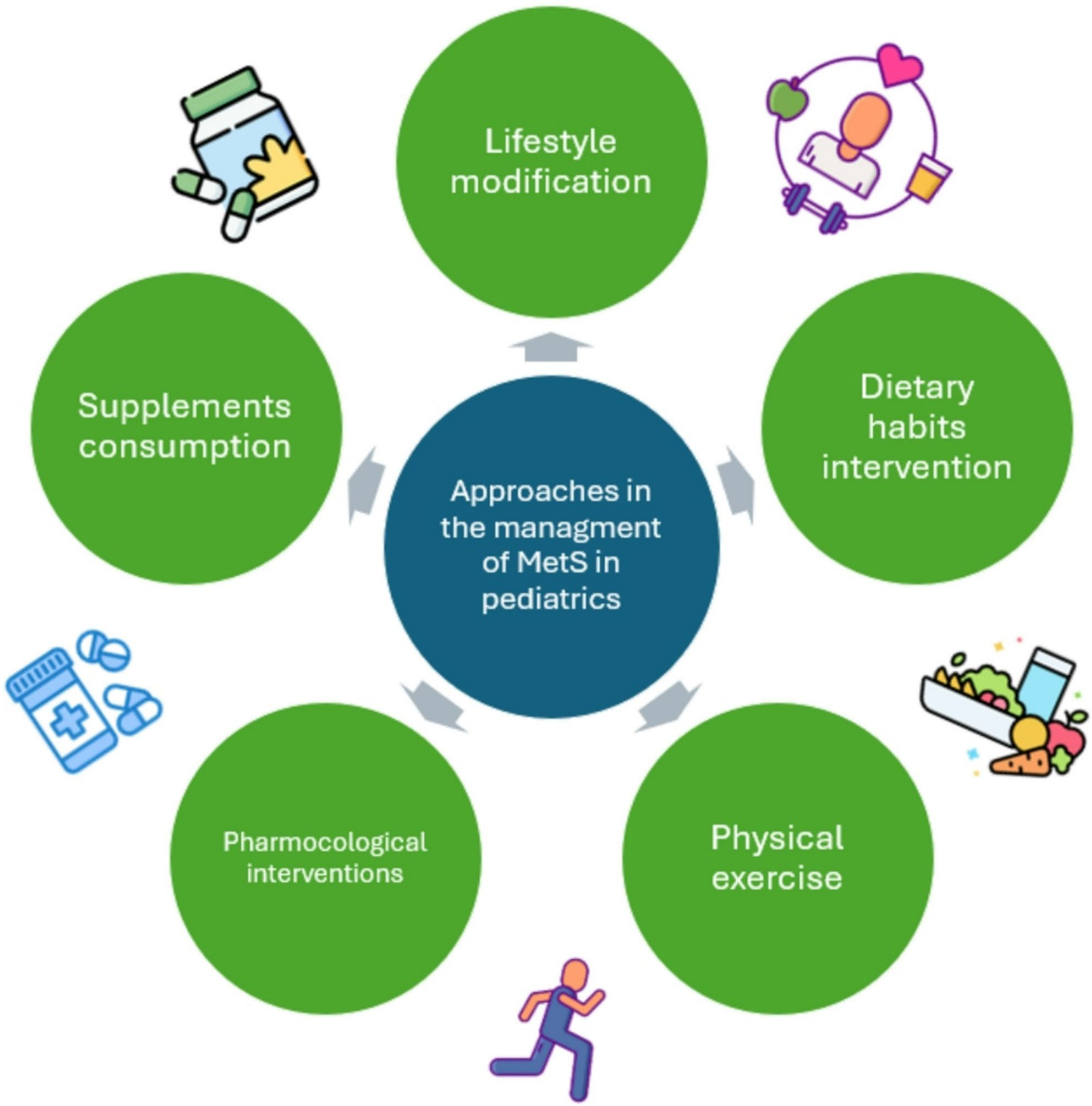

Fig. 2 Approaches in the management of MetS in pediatrics

a significant association between lower physical activity, increased sedentary time due to COVID-19, and MetS among adolescents [56].

Lifestyle modification through different multidisciplinary approaches (a combination of dietary habit changes, physical exercise recommendations, and psychological and clinical consultations) was found to be the most important intervention for modulating MetS in childhood [57]. However, its efficacy varies between different research. To the point that even Rabbani et al. [17] show no significant changes in MetS prevalence following 2 years of lifestyle modification. This variation might be due to the methods of lifestyle modification, healthcare providers, duration of intervention, and the adherence of children and their families to the recommendations. Obeldicks lifestyle intervention is a combination of physical exercise, behavioral and psychological therapy of both children and their parents, and nutritional education. Studies showed its efficacy in loosening weight [28], and thus modulating MetS among obese children [32, 47].

Metformin is the most frequent medication that has been prescribed for the management of MetS in childhood. Fu et al. [16] showed the effectiveness of metformin in the management of metabolic profiles of MetS when combined with lifestyle modifications. However, its efficacy alone in comparison to lifestyle modifications is questionable [14]. With all these explanations, it appears that metformin could act as an adjuvant alongside lifestyle modifications in treating MetS, especially in children with additional risk factors such as type 2 DM [15]. According to the American Diabetes Association (ADA), metformin can be started at a dose of 500–1000 mg per day for the first one or two weeks. Then titration of the dose can be done weekly over three to four weeks, depending on patient tolerance, to a maximal dose of 1000 mg twice per day [58].

The results surrounding the effect of omega-3 supplement on the metabolic profile of MetS cases are inconsistent [18, 19]. Our results go along with a systematic review conducted by Tureck et al. [59] on observational and interventional studies regarding this issue. Further well-designed randomized clinical trials and cohort studies are needed to better clarify the exact association. Vitamin D supplementation has been shown to have favorable effects in modulating cardiometabolic factors of children with MetS [46] and even reducing its prevalence [33]. A systematic review by Rouhani et al. [60] indicated that higher levels of serum vitamin D is associated with lower odds of MetS in children.

Metabolic and Bariatric Surgery is approximately the final step in combating metabolic disorders. The American Society for Metabolic and Bariatric Surgery (ASMBS) guideline for pediatrics recommended to consider surgery for adolescents between 10 and 19 years old with a body mass index (BMI) greater than 35 kg/m^2 in the presence of severe comorbidities such as type 2 DM, obstructive sleep apnea syndrome, nonalcoholic steatohepatitis, or benign intracranial hypertension. Besides, adolescents with a BMI higher than 40 kg/m^2 and less severe complications may also be considered for surgery [61].

Strengths and limitations

According to the available literature, actually there is only one systematic review [62] that aimed to assess different interventions for pediatric MetS; it includes just 9 RCTs that were conducted up to 2017. Moreover, they excluded before-after investigations and did not include a few relevant studies. This persuaded us to conduct a comprehensive updated review surrounding this issue in different databases and fill this gap. In addition to addressing the limitations of the previous review, all of the included studies in our review were assessed for quality, and we ensured that only those with acceptable methodological rigor were included. This adds strength to our findings and ensures that the conclusions drawn are based on reliable evidence. However, as previously mentioned, due to the limited number of high-quality studies available, we were unable to conduct a meta-analysis. We recognize that the absence of this analysis is a limitation in our study, but we believe our approach offers valuable insights into the existing interventions and lays the groundwork for future research in this area. Another limitation of our review is the inability to separate the data based on pubertal status or age groups (pre-pubertal children vs. adolescents) due to the lack of detailed information on pubertal status in the included studies. Additionally, most studies included both children and adolescents, which may have impacted the ability to evaluate age-related differences in metabolic outcomes.

Conclusion

Multidisciplinary lifestyle modification through different methods was found to be the first recommendation for preventing and managing MetS in childhood. A combination of physical activity, dietary changes, and behavioral interventions has been shown to be particularly effective. Mediterranean and DASH diets are effective dietary habits in modulating MetS. Metformin was found to be an effective adjuvant therapy to lifestyle modifications in modulating MetS, especially in children with other comorbidities such as type 2 DM. Results surrounding the efficacy of omega-3 supplements in MetS management are controversial. Vitamin D supplements have been shown to possess favorable effects in pediatrics MetS. Future clinical trials with long-term follow-ups are essential for the evaluation of different management methods for pediatric MetS. Additionally, exploring the underlying mechanisms of how these interventions influence MetS will be crucial in developing personalized treatment strategies for affected children.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12887-025-05759-6.

Supplementary Material 1: Appendix 1. Details of search string for each database

Supplementary Material 2: Appendix 2. Details of quality assessment process

Acknowledgements

None.

Author contributions

KTA, MHB, and RK contributed to the conception and design of the research. KTA, MHB, MA, and RK reviewed the literature and drafted the manuscript. KTA, MHB, RK, and MA contributed to the interpretation of the data and revision. All authors read and approved the final manuscript and accepted its content.

Funding

This study was supported by Isfahan University of Medical Sciences (Research Ethics code: IR.ARI.MUI.REC.1402.215).

Data availability
The data is available at the corresponding author and may be provided upon request.

Declarations

Ethical approval
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 18 August 2024 / Accepted: 12 May 2025
Published online: 28 May 2025

References

1. Noubiap JJ, Nansseu JR, Lontchi-Yimagou E, Nkeck JR, Nyaga UF, Ngouo AT, et al. Global, regional, and country estimates of metabolic syndrome burden in children and adolescents in 2020: a systematic review and modelling analysis. Lancet Child Adolesc Health. 2022;6:158–70.
2. Saklayen MG. The global epidemic of the metabolic syndrome. Curr Hypertens Rep. 2018;20:12.
3. Fahed G, Aoun L, Bou Zerdan M, Allam S, Bou Zerdan M, Bouferraa Y, et al. Metabolic syndrome: updates on pathophysiology and management in 2021. Int J Mol Sci. 2022;23:786.
4. Bovolini A, Garcia J, Andrade MA, Duarte JA. Metabolic syndrome pathophysiology and predisposing factors. Int J Sports Med. 2021;42:199–214.
5. Wang HH, Lee DK, Liu M, Portincasa P, Wang DQ-H. Novel insights into the pathogenesis and management of the metabolic syndrome. Pediatr Gastroenterol Hepatol Nutr. 2020;23:189–230.
6. Arefian M, Mazaheri-Tehrani S, Yazdi M, Kelishadi R. Caveolin gene, a possible risk factor for metabolic syndrome in humans: a systematic review and meta-analysis. Int J Prev Med. 2025;16:7.
7. Weihe P, Weihrauch-Blüher S. Metabolic syndrome in children and adolescents: diagnostic criteria, therapeutic options and perspectives. Curr Obes Rep. 2019;8:472–9.
8. Reisinger C, Nkeh-Chungag BN, Fredriksen PM, Goswami N. The prevalence of pediatric metabolic syndrome-a critical look on the discrepancies between definitions and its clinical importance. Int J Obes (Lond). 2021;45:12–24.
9. Mameli C, Zuccotti GV, Carnovale C, Galli E, Nannini P, Cervia D, et al. An update on the assessment and management of metabolic syndrome, a growing medical emergency in paediatric populations. Pharmacol Res. 2017;119:99–117.
10. Magge SN, Goodman E, Armstrong SC, COMMITTEE ON NUTRITION, SECTION ON ENDOCRINOLOGY, SECTION ON OBESITY. The metabolic syndrome in children and adolescents: shifting the focus to cardiometabolic risk factor clustering. Pediatrics. 2017;140:e20171603.
11. Peiris CL, van Namen M, O'Donoghue G. Education-based, lifestyle intervention programs with unsupervised exercise improve outcomes in adults with metabolic syndrome. A systematic review and meta-analysis. Rev Endocr Metab Disord. 2021;22:877–90.
12. Guzmán A, Navarro E, Obando L, Pacheco J, Quirós K, Vásquez L, et al. Effectiveness of interventions for the reversal of a metabolic syndrome diagnosis: an update of a meta-analysis of mixed treatment comparison studies. Biomedica. 2019;39:647–62.
13. Sequi-Dominguez I, Alvarez-Bueno C, Martinez-Vizcaino V, Fernandez-Rodriguez R, Del Saz Lara A, Cavero-Redondo I. Effectiveness of mobile health interventions promoting physical activity and lifestyle interventions to reduce cardiovascular risk among individuals with metabolic syndrome: systematic review and meta-analysis. J Med Internet Res. 2020;22:e17790.
14. Raub RM, Goldberg SJ. Assessment of metformin as an additional treatment to therapeutic lifestyle changes in pediatric patients with metabolic syndrome. Cholesterol. 2012;2012:961410.
15. Stagi S, Ricci F, Bianconi M, Sammarco MA, Municchi G, Toni S, et al. Retrospective evaluation of metformin and/or metformin plus a new polysaccharide complex in treating severe hyperinsulinism and insulin resistance in obese children and adolescents with metabolic syndrome. Nutrients. 2017;9:524.
16. Fu J-F, Liang L, Zou C-C, Hong F, Wang C-L, Wang X-M, et al. Prevalence of the metabolic syndrome in Zhejiang Chinese obese children and adolescents and the effect of metformin combined with lifestyle intervention. Int J Obes (Lond). 2007;31:15–22.
17. Rabbani B, Chiti H, Sharifi F, Mazloomzadeh S. Effect of lifestyle modification for two years on obesity and metabolic syndrome components in elementary students: a community- based trial. Casp J Intern Med. 2022;13:555–66.
18. Ahmadi A, Gharipour M, Arabzadeh G, Moin P, Hashemipour M, Kelishadi R. The effects of vitamin E and omega-3 PUFAs on endothelial function among adolescents with metabolic syndrome. Biomed Res Int. 2014;2014:906019.
19. García-López S, Villanueva Arriaga RE, Nájera Medina O, Rodríguez López CP, Figueroa-Valverde L, Cervera EG, et al. One month of omega-3 fatty acid supplementation improves lipid profiles, glucose levels and blood pressure in overweight schoolchildren with metabolic syndrome. J Pediatr Endocrinol Metab. 2016;29:1143–50.
20. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71.
21. Study Quality Assessment Tools| NHLBI, NIH. https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools. Accessed 24 Sep 2021.
22. Saneei P, Hashemipour M, Kelishadi R, Rajaei S, Esmaillzadeh A. Effects of recommendations to follow the dietary approaches to stop hypertension (DASH) diet V. usual dietary advice on childhood metabolic syndrome: a randomised cross-over clinical trial. Br J Nutr. 2013;110:2250–9.
23. Velázquez-López L, Santiago-Díaz G, Nava-Hernández J, Muñoz-Torres AV, Medina-Bravo P, Torres-Tamayo M. Mediterranean-style diet reduces metabolic syndrome components in obese children and adolescents with obesity. BMC Pediatr. 2014;14:175.
24. Leite N, Milano GE, Cieslak F, Lopes WA, Rodacki A, Radominski RB. Effects of physical exercise and nutritional guidance on metabolic syndrome in obese adolescents. Braz J Phys Ther. 2009;13:73–81.
25. de Mello MT, de Piano A, Carnier J, Sanches P, de L, Corrêa FA, Tock L, et al. Long-term effects of aerobic plus resistance training on the metabolic syndrome and adiponectinemia in obese adolescents. J Clin Hypertens (Greenwich). 2011;13:343–50.
26. Elizondo-Montemayor L, Castillo EC, Rodríguez-López C, Villarreal-Calderón JR, Gómez-Carmona M, Tenorio-Martínez S, et al. Seasonal variation in vitamin D in association with age, inflammatory cytokines, anthropometric parameters, and lifestyle factors in older adults. Mediators Inflamm. 2017;2017:5719461.
27. Vasconcellos F, Cunha FA, Gonet DT, Farinatti PTV. Does recreational soccer change metabolic syndrome status in obese adolescents?? A pilot study. Res Q Exerc Sport. 2021;92:91–9.
28. Reinehr T, Temmesfeld M, Kersting M, de Sousa G, Toschke AM. Four-year follow-up of children and adolescents participating in an obesity intervention program. Int J Obes (Lond). 2007;31:1074–7.
29. Marti A, Martínez I, Ojeda-Rodríguez A, Azcona-Sanjulian MC. Higher lipopolysaccharide binding protein and chemerin concentrations were associated with metabolic syndrome features in pediatric subjects with abdominal obesity during a lifestyle intervention. Nutrients. 2021;13:289.
30. Caranti DA, de Mello MT, Prado WL, Tock L, Siqueira KO, de Piano A, et al. Short- and long-term beneficial effects of a multidisciplinary therapy for the control of metabolic syndrome in obese adolescents. Metabolism. 2007;56:1293–300.
31. Chen AK, Roberts CK, Barnard RJ. Effect of a short-term diet and exercise intervention on metabolic syndrome in overweight children. Metabolism. 2006;55:871–8.
32. Lass N, Kleber M, Winkel K, Wunsch R, Reinehr T. Effect of lifestyle intervention on features of polycystic ovarian syndrome, metabolic syndrome, and intima-media thickness in obese adolescent girls. J Clin Endocrinol Metab. 2011;96:3533–40.
33. Al-Daghri NM, Amer OE, Khattak MNK, Sabico S, Ghouse Ahmed Ansari M, Al-Saleh Y, et al. Effects of different vitamin D supplementation strategies in reversing metabolic syndrome and its component risk factors in adolescents. J Steroid Biochem Mol Biol. 2019;191:105378.
34. Abrams P, Levitt Katz LE, Moore RH, Xanthopoulos MS, Bishop-Gilyard CT, Wadden TA, et al. Threshold for improvement in insulin sensitivity with adolescent weight loss. J Pediatr. 2013;163:785–90.
35. Asoudeh F, Fallah M, Aminianfar A, Djafarian K, Shirzad N, Clark CCT, et al. The effect of mediterranean diet on inflammatory biomarkers and

components of metabolic syndrome in adolescent girls. J Endocrinol Invest. 2023;46:1995–2004.
36. Gugliucci A, Lustig RH, Caccavello R, Erkin-Cakmak A, Noworolski SM, Tai VW, et al. Short-term isocaloric fructose restriction lowers apoC-III levels and yields less atherogenic lipoprotein profiles in children with obesity and metabolic syndrome. Atherosclerosis. 2016;253:171–7.
37. Saneei P, Hashemipour M, Kelishadi R, Esmaillzadeh A. The dietary approaches to stop hypertension (DASH) diet affects inflammation in childhood metabolic syndrome: a randomized cross-over clinical trial. Ann Nutr Metab. 2014;64:20–7.
38. Kamal NN, Ragy MM. The effects of exercise on C-reactive protein, insulin, leptin and some cardiometabolic risk factors in Egyptian children with or without metabolic syndrome. Diabetol Metab Syndr. 2012;4:27.
39. Hakim A, Bagheri R, Ahmadi Angali K. The effect of diet counseling and physical activity on the components of metabolic syndrome in children: a randomized clinical trial. SAGE Open Med. 2022;10:20503121221100335.
40. Masquio DCL, de Piano-Ganen A, Oyama LM, Campos RM, da Santamarina S, de Souza AB, de MH GI, et al. The role of free fatty acids in the inflammatory and cardiometabolic profile in adolescents with metabolic syndrome engaged in interdisciplinary therapy. J Nutr Biochem. 2016;33:136–44.
41. Mohammad A, Shahnaz T, Sorayya K. Effect of 8 weeks' supplementation grape seed extract on insulin resistance in Iranian adolescents with metabolic syndrome: a randomized controlled trial. Diabetes Metab Syndr. 2021;15:197–203.
42. Duchnowicz P, Ziobro A, Rapacka E, Koter-Michalak M, Bukowska B. Changes in cholinesterase activity in blood of adolescent with metabolic syndrome after supplementation with extract from Aronia melanocarpa. Biomed Res Int. 2018;2018:5670145.
43. Fallah Z, Feizi A, Hashemipour M, Kelishadi R. Effect of fermented camel milk on glucose metabolism, insulin resistance, and inflammatory biomarkers of adolescents with metabolic syndrome: a double-blind, randomized, crossover trial. J Res Med Sci. 2018;23:32.
44. Kelishadi R, Hashemipour M, Adeli K, Tavakoli N, Movahedian-Attar A, Shapouri J, et al. Effect of zinc supplementation on markers of insulin resistance, oxidative stress, and inflammation among prepubescent children with metabolic syndrome. Metab Syndr Relat Disord. 2010;8:505–10.
45. Kelishadi R, Gidding SS, Hashemi M, Hashemipour M, Zakerameli A, Poursafa P. Acute and long term effects of grape and pomegranate juice consumption on endothelial dysfunction in pediatric metabolic syndrome. J Res Med Sci. 2011;16:245–53.
46. Kelishadi R, Salek S, Salek M, Hashemipour M, Movahedian M. Effects of vitamin D supplementation on insulin resistance and cardiometabolic risk factors in children with metabolic syndrome: a triple-masked controlled trial. J Pediatr (Rio J). 2014;90:28–34.
47. Reinehr T, Kleber M, Toschke AM. Lifestyle intervention in obese children is associated with a decrease of the metabolic syndrome prevalence. Atherosclerosis. 2009;207:174–80.
48. Mohammadi S, Lotfi K, Mirzaei S, Asadi A, Akhlaghi M, Saneei P. Adherence to mediterranean diet and its association with metabolic health status in overweight and obese adolescents. Int J Clin Pract. 2022;2022:9925267.
49. Martino F, Puddu PE, Lamacchia F, Colantoni C, Zanoni C, Barillà F, et al. Mediterranean diet and physical activity impact on metabolic syndrome among children and adolescents from Southern Italy: contribution from the Calabrian Sierras community study (CSCS). Int J Cardiol. 2016;225:284–8.
50. George ES, Gavrili S, Itsiopoulos C, Manios Y, Moschonis G. Poor adherence to the mediterranean diet is associated with increased likelihood of metabolic syndrome components in children: the healthy growth study. Public Health Nutr. 2021;24:2823–33.
51. Asghari G, Yuzbashian E, Mirmiran P, Hooshmand F, Najafi R, Azizi F. Dietary approaches to stop hypertension (DASH) dietary pattern is associated with reduced incidence of metabolic syndrome in children and adolescents. J Pediatr. 2016;174:178–e1841.
52. Cao Y, Zhu L, Liu J. Effects of aerobic exercise on obese children with metabolic syndrome: a systematic review and meta-analysis. J Pediatr Endocrinol Metab. 2021;34:1069–79.
53. Chaput J-P, Willumsen J, Bull F, Chou R, Ekelund U, Firth J, et al. 2020 WHO guidelines on physical activity and sedentary behaviour for children and adolescents aged 5–17 years: summary of the evidence. Int J Behav Nutr Phys Act. 2020;17:141.
54. Mazaheri-Tehrani S, Kelishadi R. COVID-19 and the prevalence of physical inactivity. In: Selk-Ghaffari M, Memari A, Mahdaviani B, Kordi R, editors. Physical activity and pandemics: lessons learned from COVID-19. Singapore: Springer Nature; 2023. pp. 1–8.
55. Mahdavi SB, Mazaheri-Tehrani S, Riahi R, Vahdatpour B, Kelishadi R. Sedentary behavior and neck pain in children and adolescents; a systematic review and meta-analysis. Health Promot Perspect. 2022;12:240–8. https://doi.org/10.34172/hpp.2022.31
56. Musa S, Elyamani R, Dergaa I. COVID-19 and screen-based sedentary behaviour: systematic review of digital screen time and metabolic syndrome in adolescents. PLoS ONE. 2022;17:e0265560.
57. Tagi VM, Samvelyan S, Chiarelli F. Treatment of metabolic syndrome in children. Horm Res Paediatr. 2020;93:215–25.
58. Soliman A, De Sanctis V, Alaaraj N, Hamed N. The clinical application of metformin in children and adolescents: a short update. Acta Biomed. 2020;91:e2020086.
59. Tureck C, Barboza BP, Bricarello LP, Retondario A, Alves M, de Moura Souza A. Scientific evidence of the association between oral intake of OMEGA-3 and OMEGA-6 fatty acids and the metabolic syndrome in adolescents: a systematic review. Nutr Metab Cardiovasc Dis. 2022;32:2689–704.
60. Rouhani P, Hajhashemy Z, Saneei P. Circulating serum vitamin D levels in relation to metabolic syndrome in children: a systematic review and dose-response meta-analysis of epidemiologic studies. Obes Rev. 2021;22:e13314.
61. Pratt JSA, Browne A, Browne NT, Bruzoni M, Cohen M, Desai A, et al. ASMBS pediatric metabolic and bariatric surgery guidelines, 2018. Surg Obes Relat Dis. 2018;14:882–901.
62. Albert Pérez E, Mateu Olivares V, Martínez-Espinosa RM, Molina Vila MD, Reig García-Galbis M. New insights about how to make an intervention in children and adolescents with metabolic syndrome: diet, exercise vs. Changes in body composition. A systematic review of RCT. Nutrients. 2018;10:878.

Publisher's note