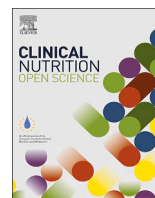




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Review

The effect of zinc supplementation on serum concentration of lipid profile among children and adolescents: A systematic review on randomized controlled trials

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ABSTRACT

Background: New evidence suggests that zinc supplementation may significantly influence serum lipid profile levels and vascular health in children and adolescents. Therefore, this systematic review aims to investigate and summarize published data regarding the effects of zinc supplementation on lipid profiles in children and adolescents.

Methods: A systematic search was conducted across multiple databases, including the Cochrane Library, ClinicalTrials.gov, ISI Web of Science, Scopus, and PubMed, up to May 2025. Search terms related to zinc, low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), total cholesterol (TC), triglycerides (TG), children, adolescents, and clinical trials were identified using both Medical Subject Headings (MeSH) and non-MeSH terms. The search strategy employed asterisks, parentheses, quotation marks, and Boolean operators (AND/OR) to optimize retrieval of relevant studies.

Results: A total of five studies were included in this systematic review. Serum TG, LDL-C, and HDL-C levels were assessed in four studies, and TC levels in five studies. TC decreased in one study. TG and LDL-C levels showed significant reductions compared with placebo in two studies. A significant increase in HDL-C levels was observed in one study.

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Conclusion: Zinc supplementation may be effective in improving lipid profiles among children and adolescents. However, further well-designed randomized clinical trials involving children and adolescents with varying health conditions, larger sample sizes, different zinc dosages, and longer follow-up periods are strongly recommended to confirm the effectiveness of zinc supplementation in this population.

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Introduction

Dyslipidemia is defined as abnormal levels of lipids and/or lipoproteins [1] and is recognized as a major risk factor for cardiovascular diseases (CVDs), which are among the leading causes of mortality worldwide [2]. In addition to CVDs, dyslipidemia is associated with several comorbid conditions, including coronary, cerebrovascular, and peripheral vascular diseases [3]. Although the majority of the clinical burden of CVD manifests during adulthood, evidence indicates that the development of atherosclerotic cardiovascular disease begins early in life and progressively advances throughout the lifespan [4].

Studies have shown that approximately 40–50 % of children with dyslipidemia continue to exhibit hyperlipidemia in adulthood and develop subclinical atherosclerotic changes originating in childhood, which may ultimately lead to overt CVD [5]. Moreover, dyslipidemia is a central component of metabolic syndrome in pediatric populations and is closely associated with conditions such as nonalcoholic fatty liver disease [6], nephrolithiasis [7], pancreatitis [8], and other metabolic disorders [9].

In recent years, increasing attention has been directed toward the role of dietary factors and micronutrients in the development and management of dyslipidemia [10]. Zinc is an essential trace element involved in numerous biological functions [11], including structural protein integrity [12], enzymatic activity [13], transcription factor regulation [14], and cellular growth, development, and differentiation [15]. Zinc deficiency in children is associated with anorexia [16], growth retardation [17], and recurrent infections [18], while in adolescents it may lead to delayed sexual maturation and skeletal abnormalities [19]. In adults, inadequate zinc status has been linked to impaired glycemic control, diabetes mellitus [20], and cardiovascular diseases [21].

Zinc deficiency has been shown to adversely affect aortic cell structure [22], fatty acid and carbohydrate metabolism, and overall vascular health [23], while also increasing susceptibility to oxidative stress in endothelial cells [24]. Zinc deficiency renders vascular endothelial cells more susceptible to the effects of oxidative stress [25,26]. Furthermore, in low-density lipoprotein cholesterol (LDL-C) receptor knock-out mice acute zinc deficiency elicits changes in key transcription factors and adhesion molecules that are pro-atherogenic [27]. Observational studies in humans have demonstrated that low dietary zinc intake is associated with an increased risk of diabetes and cardiovascular diseases, suggesting a protective role of zinc against atherogenesis [28]. Several clinical studies have investigated the effects of zinc supplementation on serum lipid profiles, yielding inconsistent results [29–32].

A meta-analysis of 20 studies reported that zinc supplementation significantly reduced total cholesterol (TC), very-low-density lipoprotein cholesterol (VLDL-C), and triglyceride (TG) levels in adults [33]. However, the role of zinc supplementation in the management of dyslipidemia among children and adolescents remains insufficiently explored. Therefore, the present systematic review aims to evaluate and summarize the existing evidence regarding the effects of zinc supplementation on lipid profiles in pediatric and adolescent populations.

Methods

This systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and was registered in PROSPERO (ID: CRD420251127753).

A systematic search was conducted across multiple databases, including the Cochrane Library, [ClinicalTrials.gov](https://www.clinicaltrials.gov), ISI Web of Science, Scopus, and PubMed, covering all records up to May 2025. Search terms related to zinc, LDL-C, high-density lipoprotein cholesterol (HDL-C), TG, TC, children, adolescents, and clinical trials were identified using both Medical Subject Headings (MeSH) and non-MeSH terms. The search strategy incorporated asterisks, parentheses, quotation marks, and Boolean operators (AND, OR) to optimize retrieval. Detailed search strategies for each database are provided in [Supplementary Table 1](#).

The study selection process involved several steps. First, all retrieved records were exported to EndNote X21, and titles and abstracts were independently screened by two reviewers (MH and AGh). Subsequently, the full texts of potentially eligible articles were independently assessed based on the predefined inclusion and exclusion criteria. To identify any additional relevant studies, the reference lists of included articles were manually searched. Any uncertainties were resolved by contacting the corresponding authors via email.

Study eligibility criteria

All stages of the systematic review were performed independently by two reviewers (MH and AGh), including study screening and selection, methodological quality assessment, application of inclusion and exclusion criteria, and data extraction. Discrepancies were resolved through discussion until consensus was reached.

The inclusion criteria were defined according to the PICOS (Population, Intervention, Comparison, Outcomes, Study design) framework. Eligible studies were randomized controlled trials (RCTs) involving participants aged 18 years or younger who received zinc supplementation as the intervention, with reported changes in LDL-C, HDL-C, TG, and TC. Both parallel and cross-over RCT designs were considered.

Exclusion criteria

Studies were excluded if they met any of the following criteria: (I) RCTs in which participants received additional nutrients alongside zinc; (II) RCTs in which zinc was obtained from dietary sources rather than supplements or fortified foods; (III) RCTs lacking a placebo or comparison group; (IV) RCTs that did not report serum lipid profile data before and/or after the intervention for both groups; (V) RCTs that did not specify the zinc dosage; (VI) Trials published in languages other than English.

Data extraction

Data were extracted using a standardized data collection form. Two independent reviewers (MH and FA) recorded the following information: mean changes in lipid profile parameters and their corresponding standard deviations (SDs); study title; first author's name; year of publication; sample size; trial design; intervention duration; geographical location; participants' age and sex; health status; body mass index (BMI); and zinc dosage. In RCTs with multiple intervention or comparison groups, each group was considered a separate study for the purposes of the systematic review. Any unclear or missing data were clarified by contacting the corresponding authors. Discrepancies between reviewers were resolved through discussion until consensus was reached.

Quality assessment

The methodological quality of the included RCTs was assessed using a modified version of the Cochrane Risk of Bias 2 (RoB 2) tool. Each RCT was evaluated across six domains: [1] randomization process; [2] deviations from intended interventions; [3] bias arising from period and carryover effects

(applicable only to cross-over trials); [4] missing outcome data; [5] outcome measurement; and [6] selection of the reported results. Based on these criteria, studies were classified as low risk, some concerns, or high risk. Two reviewers (MH and FA) independently assessed each RCT, and any disagreements were resolved through discussion with a third reviewer (AGh).

Results

Figure 1 illustrates the study selection process. The database search identified 423 articles. After the removal of duplicate records, 330 articles were screened based on their titles and abstracts, and irrelevant studies were excluded. Full-text versions of 10 articles were subsequently retrieved and assessed for eligibility. Of these, five studies were excluded for the following reasons: co-administration of zinc with other nutrients (n = 3), absence of a placebo group (n = 1), and zinc intake derived from foods naturally high in zinc rather than from supplements or fortified foods (n = 1). Ultimately, five studies were included in the systematic review [34–38].

Based on the findings of our systematic review, serum TG levels were evaluated in four studies [34–36,38], TC in five studies [34–38], and LDL-C and HDL-C cholesterol in four studies [34–36,38]. Zinc doses ranged from 2.57 mg/day to 50 mg/day, with intervention durations varying from 9 months to several years. All studies, were randomized controlled trials. Study populations included healthy children [37,38], children with obesity [35,36], and children with non-alcoholic steatohepatitis

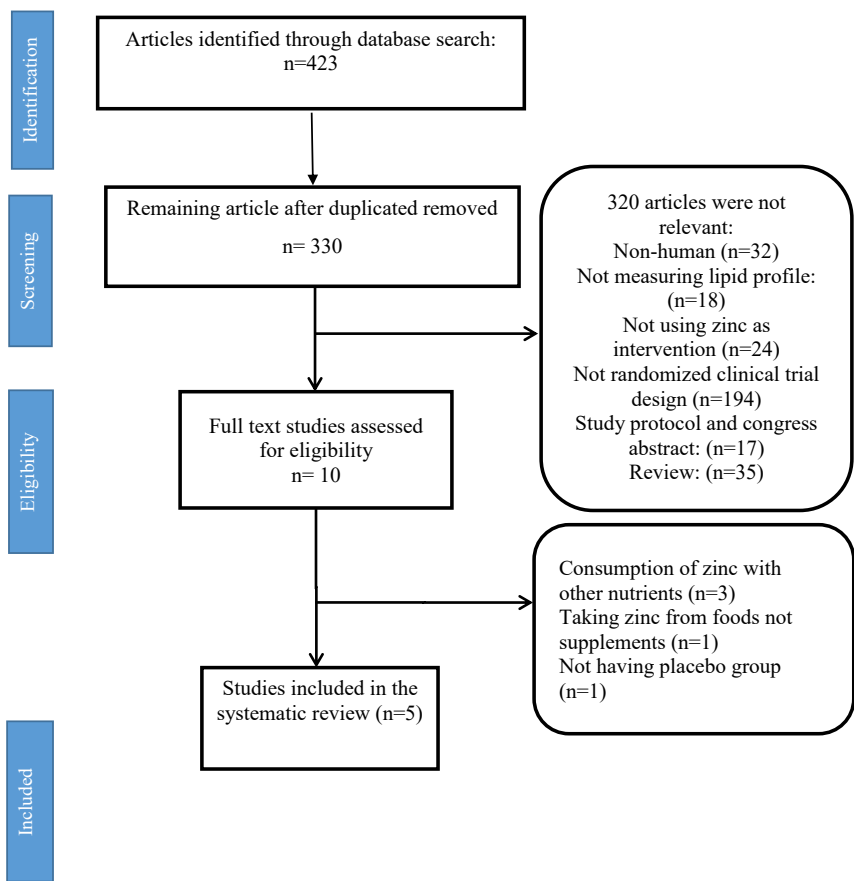


Figure 1. Flowchart of study selection process.

(NASH) [34], with participants aged between 1 and 18 years. TC decreased in one study [35]. TG and LDL-C levels showed significant decreases compared to placebo in two studies [35,36]. HDL-C levels increased significantly in one study [34] [Table 1].

In a double-blind, placebo-controlled trial, Bertinato *et al.* [38] evaluated the effects of zinc supplementation on TG, TC, LDL-C, and HDL-C in healthy boys aged 6–8 years. Participants received either a placebo or zinc at doses of 5, 10, or 15 mg/day. Serum lipid profiles were assessed after two and four months of intervention. The findings indicated that zinc supplementation, regardless of dose or duration, had no significant effect on lipid profile. Similarly, Hambidge *et al.* [37] found that long-term consumption of zinc-fortified breakfast cereals providing approximately 2.6 mg/day of additional zinc over nine months had no measurable impact on lipid profiles in healthy preschool children.

In contrast, studies conducted in obese or metabolically compromised children consistently demonstrated beneficial effects of higher-dose zinc supplementation, even when administered for shorter periods. In a triple-masked randomized crossover trial, supplementation with 20 mg/day of elemental zinc for eight weeks significantly reduced TG and LDL-C levels in obese children [36], although no significant effects were observed for TC or HDL-C. These findings were corroborated by Kelishadi *et al.*, [35] who reported significant reductions in TC and LDL-C following zinc supplementation at the same dose and duration, whereas the placebo caused the neutral lipid changes.

Moreover, evidence suggests that higher doses combined with longer intervention durations may selectively improve lipid profiles. Ostadmohammadi *et al.* [34] demonstrated that zinc supplementation at 30 mg/day for 16 weeks significantly increased HDL-C levels in overweight or obese children with nonalcoholic steatohepatitis (NASH), further supporting the notion that both dose intensity and metabolic context might modulate the effect of zinc supplementation on serum lipid profiles.

Quality assessment

Figure 2 presents each study quality assessment. According to these results, one study had poor quality [37] due to randomization process, deviations from intended interventions, and selection of reported results. Three studies had fair quality [35,36,38] due to selection of the reported result [35,36,38], measurement of the outcome [35], and missing outcome data [35] and one study had good quality [34]. We presented more details regarding quality assessment in Figure 2.

Discussion

According to the results of our systematic review, this study represents the first evidence concerning the effects of zinc supplementation on lipid profiles in children and adolescents. Five articles met the inclusion criteria and were included in the review. Overall, the evidence supporting zinc supplementation in this population is limited. Most studies, except the study by Kelishadi *et al.*, reported no significant effect of zinc supplementation on serum TC levels. However, our results indicated that zinc supplementation at a dose of 20 mg/day for 16 weeks can significantly reduce serum levels of LDL-C and TG. Regarding HDL-C, higher doses of zinc supplementation appear necessary to achieve significant increases in serum levels.

Meta-analytic evidence in adults suggests that zinc supplementation can increase HDL-C and reduce TC, LDL-C, and TG levels [39]; however, another meta-analysis reported that zinc doses ≥ 140 mg/day are required to improve serum lipid profiles, whereas lower doses may be ineffective [40]. Although the limited number of studies in children and adolescents precluded identification of a clearly effective dose in this population, it is possible that the use of low-dose zinc supplementation in some studies [37,38] contributed to the lack of observed effects. For example, Bertinato *et al.* [38] demonstrated that zinc supplementation at doses corresponding to daily requirements (5 or 10 mg/day) or slightly above (15 mg/day) for 8–16 weeks did not significantly alter lipid profiles. In contrast, other studies reported that zinc supplementation at 20 mg/day and 30 mg/day could reduce LDL-C and TG [35,36] and increase HDL-C [34], respectively. These findings suggest that zinc dose may have a greater impact on lipid profiles in this population than intervention duration.

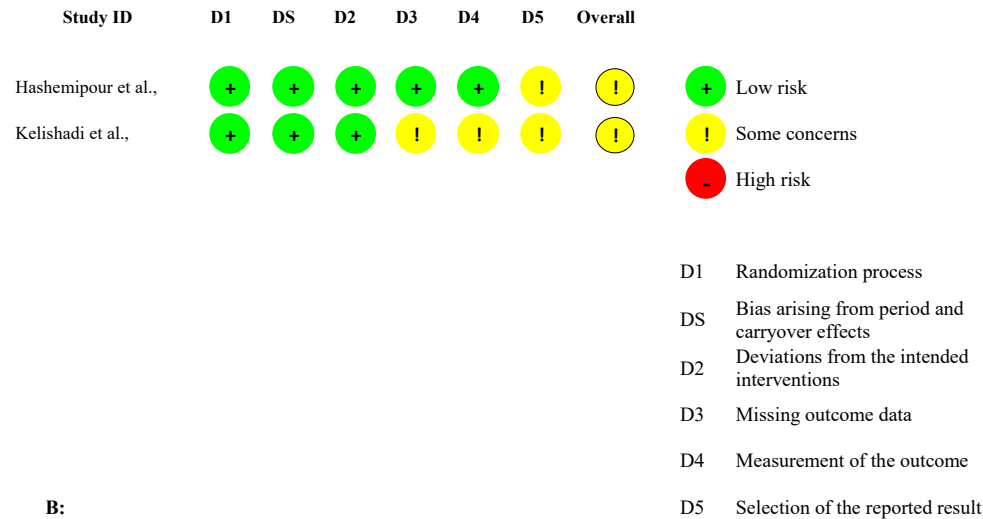
Table 1
Randomized controlled trial studies included in the systematic review and meta-analysis.

Code Author (year) (Country)	Study population (sample size)	Age (years) (mean±SD or range) and sex	Study design	Intervention duration (week)	Zinc dose (g)	Placebo	Outcome	Results
1.1 Bertinato <i>et al.</i> (2013) Canada	Healthy Boys N = 20	92.7 ± 3.4 (months)	Double-blinded, placebo-controlled, randomized trial	8	5 mg/d zinc gluconate + microcrystalline cellulose	Containing microcrystalline cellulose, dicalcium phosphate dihydrate, croscarmellose sodium	TG, TC, LDL-C, and HDL-C	TG, TC, LDL-C, and HDL-C did not change significantly between groups
1.2 Bertinato <i>et al.</i> (2013) Canada	Healthy Boys N = 20	92.7 ± 3.4 (months)	Double-blinded, placebo-controlled, randomized trial	16	5 mg/d zinc gluconate + microcrystalline cellulose	Containing microcrystalline cellulose, dicalcium phosphate dihydrate, croscarmellose sodium	TG, TC, LDL-C, and HDL-C	TG, TC, LDL-C, and HDL-C did not change significantly between groups
1.3 Bertinato <i>et al.</i> (2013) Canada	Healthy Boys N = 19	96.7 ± 2.5 (months)	Double-blinded, placebo-controlled, randomized trial	8	10 mg/d zinc gluconate + microcrystalline cellulose	Containing microcrystalline cellulose, dicalcium phosphate dihydrate, croscarmellose sodium	TG, TC, LDL-C, and HDL-C	TG, TC, LDL-C, and HDL-C did not change significantly between groups
1.4 Bertinato <i>et al.</i> (2013) Canada	Healthy Boys N = 19	96.7 ± 2.5 (months)	Double-blinded, placebo-controlled, randomized trial	16	10 mg/d zinc gluconate + microcrystalline cellulose	Containing microcrystalline cellulose, dicalcium phosphate dihydrate, croscarmellose sodium	TG, TC, LDL-C, and HDL-C	TG, TC, LDL-C, and HDL-C did not change significantly between groups
1.5 Bertinato <i>et al.</i> (2013) Canada	Healthy Boys N = 18	94, 8± 3.2 (months)	Double-blinded, placebo-controlled, randomized trial	8	15 mg/d zinc gluconate + microcrystalline cellulose	Containing microcrystalline cellulose, dicalcium phosphate dihydrate, croscarmellose sodium	TG, TC, LDL-C, and HDL-C	TG, TC, LDL-C, and HDL-C did not change significantly between groups
1.6 Bertinato <i>et al.</i> (2013) Canada	Healthy Boys N = 18	94.8 ± 3.2 (months)	Double-blinded, placebo-controlled, randomized trial	16	15 mg/d zinc gluconate + microcrystalline cellulose	Containing microcrystalline cellulose, dicalcium phosphate dihydrate, croscarmellose sodium	TG, TC, LDL-C, and HDL-C	TG, TC, LDL-C, and HDL-C did not change significantly between groups
2 Hambidge <i>et al.</i> (1979) USA	Healthy young children N = 96	2.5–7.5 F = 40 M = 56	Double-blinded, placebo-controlled, randomized trial	36	2.57 mg/ d (fortified cereal)	Non zinc-fortified ready-to-eat breakfast cereals	TC	TC did not change significantly between groups
3 Hashemipour <i>et al.</i> (2009) Iran	Obese prepubertal children N = 60	9.1 ± 1.1 y F = 35 M = 25	Triple-blinded, placebo-controlled, randomized cross- over trial	16	20 mg/ d elemental zinc as zinc sulfate	Yes (not mention formulation)	TG, TC, LDL-C, and HDL-C	TG and LDL-C decreased significantly in comparison to placebo, but TC and HDL-C did not change significantly
4 Kelishadi <i>et al.</i> (2010) Iran	Obese children N = 60	6–10 F = 36 M = 24	Triple-blinded, placebo-controlled, randomized cross- over trial	16	20 mg/ d elemental zinc as zinc sulfate	Yes (not mention formulation)	TG, TC, LDL-C, and HDL-C	TG and LDL-C decreased significantly in comparison to placebo, but TC only decreased in zinc group and HDL-C did not change significantly

5 Ostadmohammadi <i>et al.</i> (2024) Iran	Children with NASH N = 52	14.2 ± 2.6 F = 23 M = 29	Double-blinded, placebo-controlled, randomized trial	16	30 mg/d zinc sulfate	Edible starch	TG, TC, LDL-C, and HDL-C	HDL-C increased significantly in comparison to placebo
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Zn = Zinc, Mo = months, W = weeks, NASH = Nonalcoholic Steatohepatitis, TG = Triglyceride, TC = Total cholesterol, LDL-C = low-density lipoprotein cholesterol, HDL-C = High -density lipoprotein cholesterol.

A:



B:

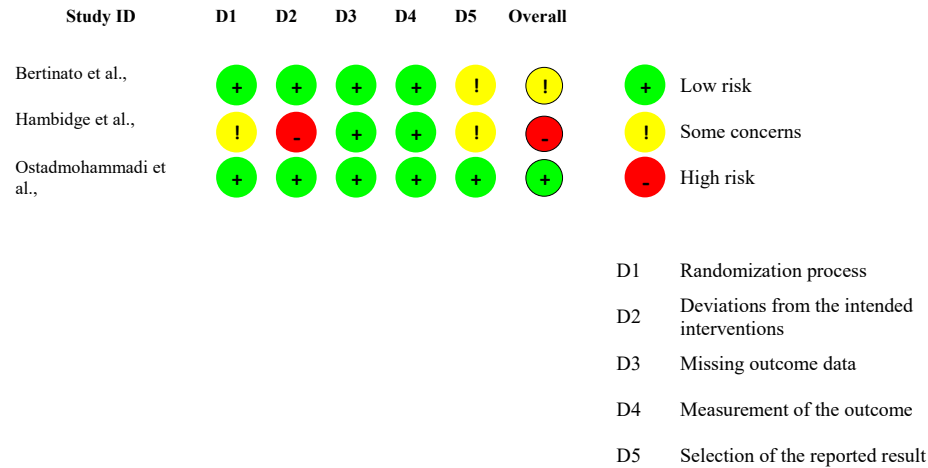


Figure 2. Quality assessment. A: crossover studies; B: parallel studies.

However, to prevent interactions that may interfere with the absorption of other nutrients and minerals, the upper tolerable intake level for zinc among adolescents and children should be determined at different age intervals [41].

In addition, the type of zinc may be another factor influencing the results due to possible differences in bioavailability. Our results showed that studies using zinc sulfate [34–36] reported more favorable effects on lipid profiles compared with studies using zinc gluconate [38]. Similarly, one meta-analysis suggested that zinc sulfate had a greater effect on decreasing serum levels of LDL-C, TC, and TG, as well as increasing serum levels of HDL-C, compared with zinc gluconate in the adult population [42].

It should be noted that baseline serum zinc levels are very important and may influence these results [43]. In two studies conducted among adult populations, the findings highlighted an association between zinc deficiency and metabolic disorders related to obesity, such as dyslipidemia and thyroid hormonal dysfunction [44,45]. In a meta-analysis by Khajeh *et al.*, subgroup analyses were performed based on baseline serum zinc levels to assess whether these levels could modify the outcomes [42]. Their findings indicated that baseline serum zinc levels had a significant impact on the overall results related to lipid profiles.

The study by Al-Maroofof *et al.* [46] demonstrated that serum zinc levels were reduced in diabetic patients due to their disease, and the effects of zinc supplementation were significantly different compared with those observed in healthy individuals. In our study, children with chronic diseases benefited more from zinc supplementation than healthy children [34]. This may be because serum zinc levels are lower in these children compared with healthy peers, making zinc supplementation more effective. Unfortunately, none of the studies included in our systematic review reported baseline serum zinc levels in the studied populations.

The potential mechanisms through which zinc affects lipid profiles are still unclear. In rats with zinc deficiency, decreased serum levels of HDL-C and apoproteins A1, A2, C, and E, along with increased TC levels, have been observed [47,48]. Moreover, zinc supplementation has been shown to inhibit the development of atherosclerosis in rabbits fed a high-cholesterol diet [49]. New evidence indicates that zinc plays an important role in insulin secretion and storage in the pancreas [49]. Furthermore, pancreatic beta cells utilize a highly efficient transporter known as ZnT8 to accumulate zinc within the cells [50]. As a result, zinc deficiency or alterations in ZnT8 expression may reduce insulin secretion. Scientists also believe that zinc deficiency leads to insulin resistance and increased flux of free fatty acids to the liver, resulting in hypertriglyceridemia [51–53].

Therefore, zinc supplementation, by decreasing insulin resistance, may prevent lipolysis in adipose tissue, reduce the release of free fatty acids into the circulation, and decrease lipoprotein synthesis in liver cells. In addition, zinc directly affects lipid metabolism [54]. Animal studies have shown that zinc deficiency, by altering the gene expression of enzymes responsible for hepatic lipid homeostasis, decreases fatty acid utilization in peroxisomes and mitochondria, increases lipid synthesis in the liver, and leads to abnormalities in lipid profiles [55,56]. Zinc may also improve lipid metabolism through inhibition of hormone-sensitive lipase via the PI3K–Akt/PKB signaling pathway, as well as through its involvement in lipoprotein lipase and lecithin–cholesterol ester transferase pathways [57]. Recent evidence also suggests that zinc plays an important role in the synthesis of an adipokine called zinc- α 2-glycoprotein, which has multiple functions, including lipid metabolism and glucose regulation [58].

Several strengths of our study should be noted. To our knowledge, this study is the first systematic review to assess the effects of zinc supplementation on lipid profiles among children and adolescents. Our systematic search had no time limitations. Moreover, we followed PRISMA guidelines to conduct this systematic review and report the findings.

However, some limitations should also be acknowledged. Due to the small number of available studies, we were unable to perform a meta-analysis. The age range of participants was very wide, preventing us from identifying the age group that may benefit most from zinc supplementation. Additionally, firm conclusions regarding the most effective intervention duration, supplementation dose, and form of zinc could not be drawn due to limited evidence. Most of the included studies did not measure serum zinc levels at baseline or after the intervention; therefore, the effect of baseline serum zinc levels on the final results could not be evaluated. Despite contacting the corresponding author to obtain information about the form of zinc used in one study, no response was received.

In conclusion, zinc supplementation may be effective in improving lipid profiles among children and adolescents. Further well-designed randomized controlled trials involving children and adolescents with different health statuses, larger sample sizes, varying doses, and longer follow-up periods are strongly recommended to confirm the effectiveness of zinc supplementation in this population.

Author contributions

AGh designed search strategy. **MH** and **AGh** searched data bases and found relevant RCTs. They also read articles full text, excluded irrelevant RCTs. **MH** and **FA** conducted data extraction and quality assessment. **All authors** wrote the manuscript. Discrepancies in every part of work were resolved through group discussions.

Ethics approval

Ethical approval of this study was granted by the Ethics Committee of Neyshabur University of Medical Sciences (Ethical code: IR.NUMS.REC.1404.023).

Availability of data and materials

Data sets generated during the current study are available from the corresponding author on reasonable request.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.nutos.2026.100629>.

References

- [1] Peterson AL, McBride PE. A review of guidelines for dyslipidemia in children and adolescents. *Wmj* 2012;111(6):274–81. quiz 82.
- [2] Nelson RH. Hyperlipidemia as a risk factor for cardiovascular disease. *Prim Care* 2013;40(1):195–211.
- [3] Vaseghi G, Javanmard SH, Heshmat-Ghahdarjani K, Sarrafzadegan N, Amerizadeh A. Comorbidities with Familial Hypercholesterolemia (FH): a systematic review. *Curr Probl Cardiol* 2023;48(5):101109.
- [4] Newman 3rd WP, Freedman DS, Voors AW, Gard PD, Srinivasan SR, Cresanta JL, et al. Relation of serum lipoprotein levels and systolic blood pressure to early atherosclerosis. The Bogalusa Heart Study. *N Engl J Med* 1986;314(3):138–44.
- [5] Marateb HR, Mohebian MR, Javanmard SH, Tavallaei AA, Tajadini MH, Heidari-Beni M, et al. Prediction of dyslipidemia using gene mutations, family history of diseases and anthropometric indicators in children and adolescents: the CASPIAN-III study. *Comput Struct Biotechnol J* 2018;16:121–30.
- [6] Dowla S, Aslibekyan S, Goss A, Fontaine K, Ashraf AP. Dyslipidemia is associated with pediatric nonalcoholic fatty liver disease. *J Clin Lipidol* 2018;12(4):981–7.
- [7] DiBianco JM, Jarrett TW, Mufarrij P. Metabolic syndrome and nephrolithiasis risk: should the medical management of nephrolithiasis include the treatment of metabolic syndrome? *Rev Urol* 2015;17(3):117–28.
- [8] Chung YL, Rhie Y-J. Metabolic syndrome in children and adolescents. *Ewha Med J* 2022;45(4):e13.

- [9] Liao Y, Liu Y, Mi J, Tang C, Du J. Risk factors for dyslipidemia in Chinese children. *Acta Paediatr* 2008;97(10):1449–53.
- [10] Berisha H, Hattab R, Comi L, Giglione C, Migliaccio S, Magni P. Nutrition and lifestyle interventions in managing dyslipidemia and cardiometabolic risk. *Nutrients* 2025;17(5):776.
- [11] Kiouri DP, Tsoupra E, Peana M, Perlepes SP, Stefanidou ME, Chasapis CT. Multifunctional role of zinc in human health: an update. *Excli J* 2023;22:809–27.
- [12] Yao G, Wang Z, Xie R, Zhanghuang C, Yan B. Trace element zinc metabolism and its relation to tumors. *Front Endocrinol* 2024;15:2024.
- [13] Costa MI, Sarmiento-Ribeiro AB, Gonçalves AC. Zinc: from biological functions to therapeutic potential. *Int J Mol Sci* 2023;24(5).
- [14] Liu L-L, Song C-C, Abu-Elala N, Tan X-Y, Zhao T, Zheng H, et al. Transcriptional regulation of Znt family members znt4, znt5 and znt10 and their function in zinc transport in yellow catfish (*Pelteobagrus fulvidraco*). *Biochim Biophys Acta (BBA) - Gene Regul Mech* 2024;1867(3):195041.
- [15] Beyersmann D, Haase H. Functions of zinc in signaling, proliferation and differentiation of mammalian cells. *Biometals* 2001;14(3–4):331–41.
- [16] Lask B, Fosson A, Rolfe U, Thomas S. Zinc deficiency and childhood-onset anorexia nervosa. *J Clin Psychiatry* 1993;54(2):63–6.
- [17] Abdollahi M, Ajami M, Abdollahi Z, Kalantari N, Houshiarrad A, Fozouni F, et al. Zinc supplementation is an effective and feasible strategy to prevent growth retardation in 6 to 24 month children: A pragmatic double blind, randomized trial. *Heliyon* 2019;5(11):e02581.
- [18] Gwardys M, Stepien E, Jerzyńska J, Mospinek E, Pawłowska-Iwanicka K, Stelmach I. Serum levels of zinc in children with recurrent infections from Lodz Province. *Pediatrics I Medycyna Rodzinna* 2020;16:83–6.
- [19] Salgueiro M, Weill R, Zubillaga M, Lysionek A, Caro R, Goldman C, et al. Zinc deficiency and growth: current concepts in relationship to two important points: intellectual and sexual development. *Biol Trace Element Research* 2004;99:49–69.
- [20] Capdor J, Foster M, Petocz P, Samman S. Zinc and glycemic control: a meta-analysis of randomised placebo controlled supplementation trials in humans. *J Trace Elem Med Biol* 2013;27(2):137–42.
- [21] Chu A, Foster M, Samman S. Zinc status and risk of cardiovascular diseases and type 2 diabetes mellitus—A systematic review of prospective cohort studies. *Nutrients* 2016;8(11).
- [22] Nakatani S, Mori K, Shoji T, Emoto M. Association of zinc deficiency with development of CVD events in patients with CKD. *Nutrients* 2021;13(5).
- [23] Beattie JH, Gordon MJ, Rucklidge GJ, Reid MD, Duncan GJ, Horgan GW, et al. Aorta protein networks in marginal and acute zinc deficiency. *Proteomics* 2008;8(10):2126–35.
- [24] Marreiro DD, Cruz KJ, Moraes JB, Beserra JB, Severo JS, de Oliveira AR. Zinc and oxidative stress: current mechanisms. *Antioxidants (Basel)* 2017;6(2).
- [25] Beattie JH, Kwun IS. Is zinc deficiency a risk factor for atherosclerosis? *Br J Nutr* 2004;91(2):177–81.
- [26] Meerarani P, Ramadass P, Toborek M, Bauer HC, Bauer H, Hennig B. Zinc protects against apoptosis of endothelial cells induced by linoleic acid and tumor necrosis factor alpha. *Am J Clin Nutr* 2000;71(1):81–7.
- [27] Reiterer G, MacDonald R, Browning JD, Morrow J, Matveev SV, Daugherty A, et al. Zinc deficiency increases plasma lipids and atherosclerotic markers in LDL-receptor-deficient mice. *J Nutr* 2005;135(9):2114–8.
- [28] Shen T, Zhao Q, Luo Y, Wang T. Investigating the role of zinc in atherosclerosis: a review. *Biomolecules* 2022;12(10).
- [29] Fathi M, Alavinejad P, Haidari Z, Amani R. The effects of zinc supplementation on metabolic profile and oxidative stress in overweight/obese patients with non-alcoholic fatty liver disease: a randomized, double-blind, placebo-controlled trial. *J Trace Elem Med Biol* 2020;62:126635.
- [30] Foroozanfar F, Jamilian M, Jafari Z, Khassaf A, Hosseini A, Khorammian H, et al. Effects of zinc supplementation on markers of insulin resistance and lipid profiles in women with polycystic ovary syndrome: a randomized, double-blind, placebo-controlled trial. *Exp Clin Endocrinol Diabetes* 2015;123(4):215–20.
- [31] Partida-Hernández G, Arreola F, Fenton B, Cabeza M, Román-Ramos R, Revilla-Monsalve MC. Effect of zinc replacement on lipids and lipoproteins in type 2-diabetic patients. *Biomed Pharmacother* 2006;60(4):161–8.
- [32] Khan S, Akhter QS, Rana MSA. Effect of supplementation of oral zinc on serum lipid profile status in patients with type 2 diabetes mellitus: a prospective study. *Mymensingh Med J* 2024;33(2):561–7.
- [33] Khazdouz M, Djalalinia S, Sarrafi Zadeh S, Hasani M, Shidfar F, Ataie-Jafari A, et al. Effects of zinc supplementation on cardiometabolic risk factors: a systematic review and meta-analysis of randomized controlled trials. *Biol Trace Elem Res* 2020;195(2):373–98.
- [34] Ostadmohammadi V, Namazi MJ, Rezasoltani M, Kheirkhah D, Rajabi M, Sharif A, et al. Effects of zinc supplementation on inflammatory status and nonalcoholic steatohepatitis in overweight or obese children: a randomized clinical trial. *Biol Trace Element Res* 2024;202(8):3496–503.
- [35] 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(6):505–10.
- [36] Hashemipour M, Kelishadi R, Shapouri J, Sarrafzadegan N, Amini M, Tavakoli N, et al. Effect of zinc supplementation on insulin resistance and components of the metabolic syndrome in prepubertal obese children. *Hormones (Athens)* 2009;8(4):279–85.
- [37] Hambidge KM, Chavez MN, Brown RM, Walravens PA. Zinc nutritional status of young middle-income children and effects of consuming zinc-fortified breakfast cereals. *Am J Clin Nutr* 1979;32(12):2532–9.
- [38] Bertinato J, Simpson JR, Sherrard L, Taylor J, Plouffe LJ, Van Dyke D, et al. Zinc Supplementation Does Not Alter Sensitive Biomarkers of Copper Status in Healthy Boys. *J Nutr* 2013;143(3):284–9.
- [39] Ranasinghe P, Wathurapatha WS, Ishara MH, Jayawardana R, Galappaththy P, Katulanda P, et al. Effects of Zinc supplementation on serum lipids: a systematic review and meta-analysis. *Nutr Metab (Lond)* 2015;12:26.
- [40] Heidari Seyedmahalleh M, Montazer M, Ebrahimpour-Koujan S, Azadbakht L. The effect of zinc supplementation on lipid profiles in patients with type 2 diabetes mellitus: a systematic review and dose-response meta-analysis of randomized clinical trials. *Adv Nutr* 2023;14(6):1374–88.

- [41] Lopes M, Coimbra MA, Costa MDC, Ramos F. Food supplement vitamins, minerals, amino-acids, fatty acids, phenolic and alkaloid-based substances: an overview of their interaction with drugs. *Crit Rev Food Sci Nutr* 2023;63(19):4106–40.
- [42] Khajeh M, Hassanizadeh S, Pourteymour Fard Tabrizi F, Hassanizadeh R, Vajdi M, Askari G. Effect of zinc supplementation on lipid profile and body composition in patients with type 2 Diabetes mellitus: a GRADE-assessed systematic review and dose-response meta-analysis. *Biol Trace Elem Res* 2024;202(11):4877–92.
- [43] Li J, Cao D, Huang Y, Chen B, Chen Z, Wang R, et al. Zinc intakes and health outcomes: an umbrella review. *Front Nutr* 2022;9:798078.
- [44] Cruz JAA. Dietary habits and nutritional status in adolescents over Europe—Southern Europe. *Eur J Clin Nutr* 2000;54:S29–35.
- [45] Cruz JA. Dietary habits and nutritional status in adolescents over Europe—Southern Europe. *Eur J Clin Nutr* 2000;54(Suppl 1):S29–35.
- [46] Al-Maroof RA, Al-Sharbatti SS. Serum zinc levels in diabetic patients and effect of zinc supplementation on glycemic control of type 2 diabetics. *Saudi Med J* 2006;27(3):344–50.
- [47] Khoja SM, Marzouki ZM, Ashry KM, Hamdi SA. Effect of dietary zinc deficiency on rat lipid concentrations. *Saudi Med J* 2002;23(1):82–6.
- [48] Koo SI, Lee CC. Cholesterol and apolipoprotein distribution in plasma high-density-lipoprotein subclasses from zinc-deficient rats. *Am J Clin Nutr* 1989;50(1):73–9.
- [49] Jenner A, Ren M, Rajendran R, Ning P, Huat BT, Watt F, et al. Zinc supplementation inhibits lipid peroxidation and the development of atherosclerosis in rabbits fed a high cholesterol diet. *Free Radic Biol Med* 2007;42(4):559–66.
- [50] Mocchegiani E, Giacconi R, Malavolta M. Zinc signalling and subcellular distribution: emerging targets in type 2 diabetes. *Trends Mol Med* 2008;14(10):419–28.
- [51] Lynch CJ, Patson BJ, Goodman SA, Trapolsi D, Kimball SR. Zinc stimulates the activity of the insulin- and nutrient-regulated protein kinase mTOR. *Am J Physiol Endocrinol Metab* 2001;281(1):E25–34.
- [52] Tang X, Shay NF. Zinc has an insulin-like effect on glucose transport mediated by phosphoinositol-3-kinase and Akt in 3T3-L1 fibroblasts and adipocytes. *J Nutr* 2001;131(5):1414–20.
- [53] Ginsberg HN. Insulin resistance and cardiovascular disease. *J Clin Invest* 2000;106(4):453–8.
- [54] tom Dieck H, Döring F, Fuchs D, Roth HP, Daniel H. Transcriptome and proteome analysis identifies the pathways that increase hepatic lipid accumulation in zinc-deficient rats. *J Nutr* 2005;135(2):199–205.
- [55] Li XB, Guan Y, Shi X, Ding H, Song Y, Li C, et al. Effects of High Zinc Levels on the Lipid Synthesis in Rat Hepatocytes. *Biol Trace Element Research* 2013;154.
- [56] Sun JY, Wang JF, Zi NT, Jing MY, Weng XY. Gene expression profiles analysis of the growing rat liver in response to different zinc status by cDNA microarray analysis. *Biol Trace Elem Res* 2007;115(2):169–85.
- [57] Wagner S, Hess MA, Ormonde-Hanson P, Malandro J, Hu H, Chen M, et al. A broad role for the zinc finger protein ZNF202 in human lipid metabolism. *J Biol Chem* 2000;275(21):15685–90.
- [58] Banaszak M, Górna I, Przysławski J. Zinc and the innovative zinc- α 2-glycoprotein adipokine Play an important role in lipid metabolism: a critical review. *Nutrients* 2021;13(6).