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REVIEW

The effect of healthy Nordic diet on cardio-metabolic markers: a systematic review and meta-analysis of randomized controlled clinical trials

Nahid Ramezani-Jolfaie[1,2] · Mohammad Mohammadi[1,2] · Amin Salehi-Abargouei[1,2]

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Abstract

Background and aims The Nordic diet (ND), is supposed to be associated with a reduced cardiovascular risk; however, clinical trials have led to inconsistent results regarding the effect of this diet on cardio-metabolic markers. Using systematic review and meta-analysis of randomized controlled trials (RCTs), this study aimed to investigate the effect of the ND on circulating levels of total, low-density lipoprotein (LDL), and high-density lipoprotein (HDL) cholesterol, and triglyceride (TG), as well as blood pressure in human adults.

Methods PubMed, Scopus, ISI Web of Science, and Google Scholar were searched up to February 2018 for relevant articles. Random effects model was used to estimate the overall effects.

Results Five RCTs consisting of 513 participants were included in the present review. The meta-analysis of five eligible studies showed that ND significantly reduces the total [weighted mean difference (WMD) = −0.38 mmol/l, 95% confidence interval (CI) −0.76, −0.01, $P=0.044$] and LDL cholesterol (WMD = −0.30 mmol/l, 95% CI −0.54, −0.06, $P=0.013$) levels compared with the control groups; however, none was seen for HDL cholesterol and TG levels. The meta-analysis of four eligible RCTs revealed that the ND significantly reduces the systolic (WMD = −3.97 mmHg, 95% CI −6.40, −1.54, $P=0.001$) and diastolic blood pressure (WMD = −2.08 mmHg, 95% CI −3.43, −0.72, $P=0.003$).

Conclusion The Nordic dietary pattern improves blood pressure and also some of blood lipid markers and it should be considered as a healthy dietary pattern.

Keywords Nordic diet · Baltic Sea diet · Lipid profile · Blood pressure · Systematic review · Meta-analysis

Introduction

The Nordic diet (ND) also known as the Baltic Sea diet, is developed in the Nordic or Northern European regions [1] and emphasizes on the consumption of different healthy foods such as whole grains, fruits (such as berries, apples, and pears), vegetables, legumes (such as oats, barley, and almonds), rapeseed oil, fatty fish (such as salmon, herring and mackerel), shellfish, seaweed, low-fat choices of meat (such as poultry and game), low-fat dairy, and salt restriction and also discourages the intake of sugar-sweetened products [2, 3].

The ND as well as the dietary approaches to stop hypertension (DASH) diet which is high in fruits, vegetables, whole grains, fish, poultry, nuts and low in sodium, and the Mediterranean diet which is known with high amounts of fruits, vegetables, legumes, nuts, fish, olive oil and low amount of red meat, and sweets have been considered as healthy dietary patterns. Several meta-analyses of clinical studies have shown that the adherence to the DASH and the Mediterranean dietary patterns is associated with improvements in lipid profile and blood pressure, and cardiovascular diseases (CVDs) risk [4–7]. Hypertension and dyslipidemia both contribute to a significant proportion of mortality; because they are well-known risk factors for CVDs as the worldwide leading causes of death [8–10]. Furthermore, hypertension and dyslipidemia are associated with other

✉ Amin Salehi-Abargouei
abargouei@ssu.ac.ir; abargouei@gmail.com

1 Nutrition and Food Security Research Center, Shahid Sadoughi University of Medical Sciences, Yazd, Iran

2 Department of Nutrition, School of Public Health, Shahid Sadoughi University of Medical Sciences, Yazd, Iran

diseases including kidney diseases, and type 2 diabetes mellitus [8, 9].

The ND is also supposed to be effective in improving cardiovascular risk factors including blood pressure and blood lipid profile [11]. A number of observational studies have proposed an inverse association between adherence to the Nordic dietary pattern and risk of stroke, type 2 diabetes, and all-cause mortality [12–14]; however, the other investigations could not reveal the same results [15, 16]. Several randomized controlled clinical trials have been also conducted regarding the effect of the ND on blood pressure and lipid profile; this is while they have led to inconsistent findings. Although, a number of trials could not reveal the significant effect of the ND on some blood lipid concentrations and blood pressure [2, 17], the others represented the favorable effect of this dietary pattern on these outcomes [3, 18]. Randomized clinical trials are considered as the best methodological approaches to evaluate the causal association between diet and metabolic conditions. We are not aware of any study trying to summarize the effect of ND on cardiovascular risk factors. Therefore, the present systematic review and meta-analysis of randomized controlled trials (RCTs) was designed to assess the overall effect of the ND on cardio-metabolic markers including blood pressure and lipid profile among the adult population.

Materials and methods

The study protocol was registered in the PROSPERO database in January 2017 (http://www.crd.york.ac.uk/PROSPERO; CRD42017054096) [19]. The current report is also designed in accordance with the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guideline [20].

Search strategy

Potentially eligible studies were identified through searching PubMed (http://www.pubmed.com; National Library of Medicine), Scopus (http://www.scopus.com/), ISI Web of Science (http://www.thomsonreuters.com), and Google Scholar (http://www.scholar.google.com) from inception up to February 2018. The search was performed without any restrictions, and the title and abstracts were searched with the use of the following search query: (Nordic AND diet*) OR (nordiet) OR ("baltic sea" AND diet*).

The initial screening of titles and abstracts of all potentially eligible articles, as well as further assessment of the full texts was done independently by two investigators (NRJ, MM) and any discrepancy was resolved by consulting the third author (ASA). In addition, the reference list of included papers and related review articles was manually scanned to identify any other potentially relevant trials.

Eligibility criteria

The following inclusion criteria were considered for selecting the relevant investigations: (1) RCTs which reported the effect of the ND or Nordic nutrition recommendations (which is similar to the Nordic diet [21]) on adult humans; (2) reporting circulating blood lipids [total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), and triglyceride (TG)], apolipoproteins (apolipoprotein A1, and apolipoprotein B), and blood pressure (systolic and/or diastolic blood pressure) as the primary or secondary outcome variable.

Trials were excluded if (1) they were performed in children or adolescents aged younger than 18 years; (2) reported duplicate data of bigger studies (we included those with the longest follow-up and more sample size); (3) they were used the concomitant intervention in the ND arm/period (i.e., difference between the intervention and the control groups/periods was more than ND; such as pharmacological treatments or exercise); (4) evaluated the effect of replacing individual food component(s) rather than the whole dietary pattern.

Data extraction

Two authors (NRJ, MM) extracted data from the selected trials. This process was verified by another investigator (ASA). The following data were extracted: first author's last name, publication year, country in which the study was performed, study design (parallel/crossover), sample size, age (mean or median), sex (female/male/both genders), intervention duration (day), participants' health status, the food/nutrient composition of the dietary patterns advised to the intervention and control groups, the method used to check the dietary adherence, and the outcome variables. To obtain the data that were not presented in the original articles, we sent two e-mails 1 week apart to the corresponding authors.

Risk of bias assessment

The individual publications included in the present systematic review were checked using the Cochrane collaboration's risk of bias assessment tool considering seven domains: (1) random sequence generation (selection bias), (2) allocation concealment (selection bias), (3) blinding of participants and personnel (performance bias), (4) blinding of outcome assessment (detection bias), (5) incomplete outcome data (attrition bias), (6) selective reporting (reporting bias), and (7) evaluation of the dietary compliance as another possible source of bias. Because blinding is not possible in dietary interventions, we graded the RCTs regarding the other six domains (random sequence generation, allocation concealment, blinding of outcome assessment, incomplete outcome data, selective reporting, and evaluation of dietary compliance). Each domain was judged as low risk of bias, high risk of bias, or unclear risk of bias [22]. Eventually, the overall quality of studies was classified as good (low risk for more than two domains), fair (low risk for two domains), and weak (low risk for less than two domains).

Statistical analysis

The mean change values from baseline to after follow-up for each intervention and control group/period and their standard deviations (SDs) were extracted to calculate the mean difference and its standard error (SE) between the Nordic and control diets, which was used as the effect size for meta-analysis. If the change values were not reported, we calculated SD for the change values by selecting 0.5 as the correlation coefficient ($r = 0.5$) and to make sure that the meta-analysis was not sensitive to the selected correlation coefficient, all analyses were repeated using correlation coefficients of 0.2 and 0.8.

The weighted mean difference (WMD) and its corresponding 95% confidence intervals (CIs) were calculated using the random effects model which takes the between-study heterogeneity into account [23]. The between-study heterogeneity was assessed using the Cochrane Q test and I-squared statistic (I^2 is an estimate ranging from 0 to 100%, with its lower values indicate lower levels of heterogeneity) [24]. To examine the potential sources of between-study heterogeneity, several subgroup analyses were performed according to follow-up time (≤ 3 months/> 3 months), the health status of the participants (with/without metabolic syndrome), and type of control diet (typical diets/average Danish diet). Sensitivity analysis was used to assess the robustness of the meta-analyses results by sequentially removing individual included studies [25]. The presence of the publication bias was checked for each outcome through statistical asymmetry tests (Egger's regression asymmetry test and Begg's adjusted rank correlation test), and also by visually inspecting Begg's funnel plot [26]. All statistical analyses were performed using STATA, version 11.2 (Stata Corp, College Station, TX) and two-sided P values less than 0.05 were considered as statistically significant.

Results

Study selection

The electronic search resulted in 2719 potentially relevant studies. The screening of the titles/abstracts led to 44 papers in which their full texts were checked for their eligibility. Of these, 39 articles were excluded because (1) 10 studies were conducted in participants aged younger than 18 years [27–36], (2) 18 studies evaluated the effect of the ND on other outcomes and had no data on selected outcome variable [37–54], (3) 5 papers [50, 55–58] reported data from studies which were already included in the current review [2, 18, 59], (4) 4 studies examined the effect of individual food components rather than the whole Nordic dietary pattern [60–63]. One study compared the effect of the Nordic diet with the Paleolithic diet which was different from the control diets in other included studies [64], and (5) 1 study had no control group [65]. In total, five eligible RCTs were reviewed in the present systematic review and meta-analysis [2, 3, 17, 18, 59]. Five trials ($n = 513$) reported the effect of the ND on lipid profile and four trials ($n = 492$) reported the effect on blood pressure. The detailed steps of the study selection process are shown in Fig. 1.

Description of the intervention and the control diets

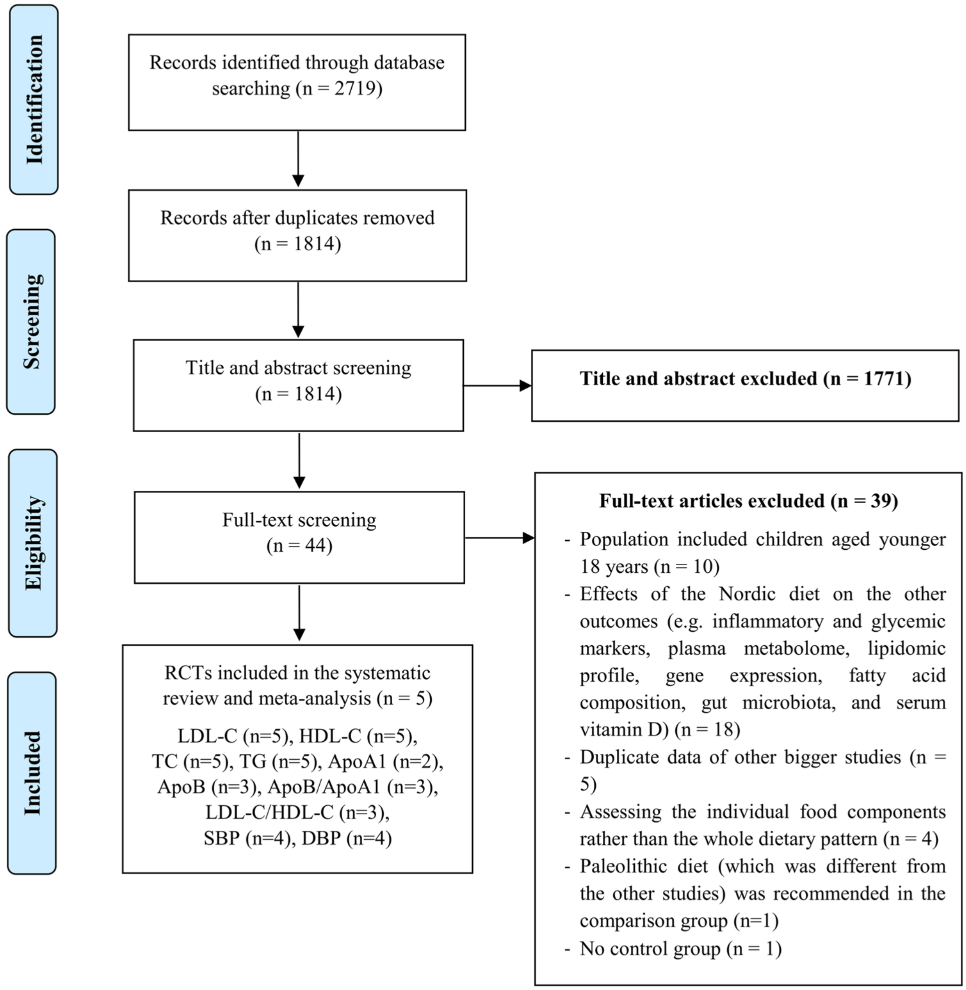
The intervention diets were as follows: Nordic diet [including whole grains, fruits (such as berries, apples, and pears), vegetables, legumes (such as oats, barley, and almonds), rapeseed oil, fatty fish (such as salmon, herring and mackerel), shellfish, seaweed, low-fat choices of meat (such as poultry and game), low-fat dairy and low-salt products and also no intake of sugar-sweetened products] [2, 3, 17, 18] or Nordic nutrition recommendation [including a low-fat (28% of energy) and high-fiber diet] which is similar to the Nordic diet [59].

The control diets were as follows: typical diets [the usual diets that subjects already consumed] or average Danish diet [including refined grains (e.g., rice and pasta), dairy and cheese, meat, convenience foods, sugary products and a lower content of low-fiber vegetables and imported fruit (e.g., citrus, bananas, and melons)] (Table 1). In overall, the main differences between the intervention and control diets were in the intake of whole grains, fatty fish, bilberries and salt.

Study characteristics

Four studies had a parallel design [2, 3, 17, 18] and one study used a crossover design [59]. The included investigations were performed between 1994 and 2014 in European countries, and enrolled 513 participants. The average intervention duration varied between 2 weeks and 6 months. The study population in all trials consisted of both gender, with the age ranging from 39 to 60 years. Moreover, studies had participants with different health status. One study included mildly hypercholesterolemic individuals [3], three studies were done in patients with MetS [2, 17, 18], and one study

Fig. 1 The study selection flow diagram



included healthy participants [59]. The characteristics of the included studies are abstracted in Table 1.

Risk of bias assessment

With regard to the specific domains of the risk of bias assessment tool developed by the Cochrane Collaboration, the overall quality of all included studies was rated as "good" (low risk of bias) [2, 3, 17, 18], except one that was "fair" in quality [59]. None of these dietary intervention trials could blind their participants or personnel. All of the studies stated that the participants were randomized; however a number of them did not mention the randomization method [2, 59]. There was no report of allocation concealment and blinding of outcome assessment in the majority of the trials. No indication of bias due to selective reporting or attrition was observed in all of the included studies. The majority of included studies were low risk regarding the method used for the assessment of the dietary compliance because they described a method to ensure this point and the food items were provided for the participants (Table 1). The included studies used several approaches to check the dietary compliance such as organizing regular meetings with dietitian for general advice on healthy eating and how to comply with the diet [18], using a short questionnaire regarding dietary compliance of participants and their satisfaction with the diet [18], providing daily study checklists including menus for up to 4 days [3], asking participants to comment and describe any deviation from the menu [3], assessing the dietary intake by 3- or 4-day dietary records several times during the study [2, 17, 18], and in two studies participants kept consumption records regarding the intake of main foods like cereal products, fish, vegetables and berries throughout the study period to ensure compliance in addition to the food records [2, 17]. There was only one study which did not report the method for assessing the adherence [59]. The methods used to assess the adherence in each eligible study is provided in Table 1. The results of the methodological quality assessment are summarized in Table 2.

Table 1 Characteristics of randomized controlled clinical trials that were included in the systematic review

References	Number and gender (F/M)	Mean age (year)	RCT design	Feeding trial[a]	Duration (days)	Intervention diet	Control diet	Reported data	Participants	Assessment of dietary adherence
Lankinen et al. [17]	36F/35M	Intervention 59 Control 59	Parallel	Yes	84	Healthy Nordic food pattern CHO: 48.1% Fat: 30.5% Pro: 18.5%	Typical diet CHO: 47.3% Fat: 31.9% Pro: 18.3%	LDL, HDL TC, TG apoB apoB/apoA1 SBP, DBP	Subjects with impaired glucose metabolism and features of the MetS (BMI = 26–39 kg/m^2)	Assessing the dietary intake by 4-day dietary records keeping consumption records regarding the intake of fish, grain products and berries throughout the study period
Poulsen et al. [18]	146 F/M	Intervention 42.7 Control 41	Parallel	Yes	182	Nordic diet (percent changes of ND vs. ADD) CHO: 3.2% Fat: − 5.1% Pro: 2.1%	Average Danish Diet (ADD)	LDL, HDL TC, TG LDL/HDL SBP, DBP	Subjects with one or more IDF's criteria for MetS, centrally obese (BMI ~ 30.2 kg/m^2, 22.6–47.3)	Organizing regular meetings with dietitian for general advice on healthy eating and how to comply with the diet, using a short questionnaire regarding dietary compliance of participants and their satisfaction with the diet, assessing the dietary intake by 3-day dietary records
Uusitupa et al. [2]	126F/63M	Intervention 54 Control 54.9	Parallel	Yes	168	Healthy Nordic diet CHO: 46.8% Fat: 31.7% Pro: 17.5%	Typical diet CHO: 44.6% Fat: 35.2% Pro: 16.2%	LDL, HDL TC, TG LDL/HDL apoA1, apoB apoB/apoA1 SBP, DBP	Subjects with two IDF's criteria for MetS (BMI = 27–38 kg/m^2)	Assessing the dietary intake by 4-day dietary records, keeping consumption records regarding the intake of cereal products, berry products, vegetables and fish throughout the study period

Table 1 (continued)

References	Number and gender (F/M)	Mean age (year)	RCT design	Feeding trial[a]	Duration (days)	Intervention diet	Control diet	Reported data	Participants	Assessment of dietary adherence
Adamsson et al. [3]	54F/32M	Intervention 52.6 Control 53.4	Parallel	Yes	42	Nordic diet CHO: 52% Fat: 27% Pro: 19%	Typical diet CHO: 46% Fat: 34% Pro: 17%	LDL, HDL TC, TG LDL/HDL apoA1, apoB apoB/apoA SBP, DBP	Mildly hypercholesterolemic individuals (BMI ≥ 20 and ≤ 31 kg/m^2)	Providing daily study check-lists including menus for up to 4 days ask participants to comment and describe any deviation from the menu
Marckmann et al. [59]	11F/10M	53	Cross-over	No	14	Nordic nutrition recommendations CHO: 57% Fat: 28% Pro: 14%	Average Danish Diet CHO: 47% Fat: 39% Pro: 13%	LDL, HDL TC, TG	Healthy middle-aged individuals	Not reported

NR not reported, *F* female, *M* male, *LDL* low-density lipoprotein, *HDL* high-density lipoprotein, *TC* total cholesterol, *TG* triglyceride, *apoA-1* apolipoprotein A-1, *Apo B* apolipoprotein B, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *CHO* carbohydrate, *Pro* protein, *IDF* International Diabetes Federation, *MetS* metabolic syndrome

[a]In feeding trials, the components of the studied diet were provided for participants free of charge during the study period

Table 2 Study quality and risk of bias assessment using Cochrane Collaboration's tool

	Poulsen et al. [18]	Lankinen et al. [17]	Uusitupa et al. [2]	Adamsson et al. [3]	Marckmann et al. [59]
Random sequence generation (selection bias)	+	+	?	+	?
Allocation concealment (selection bias)	+	?	?	?	?
Blinding of participants and personnel (performance bias)	–	–	–	–	–
Blinding of outcome assessment (detection bias)	?	?	+	?	?
Incomplete outcome data (attrition bias)	+	+	+	+	+
Selective reporting (reporting bias)	+	+	+	+	+
Other sources of bias (evaluating the dietary compliance)	+	+	+	+	?
Total score	5	4	4	4	2
Quality	Good	Good	Good	Good	Fair

Meta-analysis

Total cholesterol (TC)

The pooled mean difference derived from five trials with 513 subjects [2, 3, 17, 18, 59] was −0.38 mmol/l (95% CI −0.76, −0.01, $P=0.044$; Fig. 2a), with high between-study heterogeneity (Q statistic = 48.43, Cochrane Q test, $P<0.001$, $I^2=91.7\%$). The subgroup analysis showed that adherence to the ND led to a significant reduction in TC concentrations compared with the average Danish diet (WMD = −0.30 mmol/l, 95% CI −0.48, −0.13, $P<0.001$; $I^2=24.8\%$, Cochrane Q test, $P=0.249$), but when compared with typical diets, the effect was not significant. Moreover, significant change of TC following the ND was observed in studies with more than 3 months of follow-up (WMD = −0.18 mmol/l, 95% CI −0.31, −0.05, $P=0.005$; $I^2=0\%$, Cochrane Q test, $P=0.359$), while there was no considerable difference in studies with less than 3 months of duration. The overall effect of ND on serum TC as well as the results of the subgroup analyses are provided in Table 3.

Low-density lipoprotein cholesterol (LDL-C)

Five clinical trials evaluated the effect of adherence to the Nordic dietary pattern on LDL-C levels [2, 3, 17, 18, 59]. The analysis showed that the ND intake was associated with a significant reducing effect on LDL-C levels (WMD = −0.30 mmol/l, 95% CI −0.54, −0.06, $P=0.013$; Fig. 2b). The heterogeneity between studies was also considerable (Cochran's Q test, Q statistic = 32.73, $P<0.001$, $I^2=87.8\%$). A remarkable reduction in LDL-C concentrations was observed following the ND in studies which conducted among patients with MetS (WMD = −0.13 mmol/l, 95% CI −0.23, −0.02, $P=0.016$; $I^2=0\%$, Cochrane Q test, $P=0.738$), in studies with more than 3 months of follow-up (WMD = −0.14 mmol/l, 95% CI −0.25, −0.03, $P=0.011$; $I^2=0\%$, Cochrane Q test, $P=0.930$), and also in studies in which the Nordic dietary pattern was compared to the average Danish diet (WMD = −0.22 mmol/l, 95% CI −0.37, −0.07, $P=0.003$; $I^2=55.6\%$, Cochrane Q test, $P=0.133$) (Table 2).

High-density lipoprotein cholesterol (HDL-C)

Meta-analysis of data from five studies [2, 3, 17, 18, 59] evaluating the effect of adherence to the ND on HDL-C levels could not show a significant effect (WMD = −0.06 mmol/l, 95% CI −0.15, 0.02, $P=0.150$; Fig. 2c). There was a significant between-study heterogeneity (Cochran's Q test, Q statistic = 29.46, $P<0.001$, $I^2=86.4\%$). The subgroup analysis revealed a significant reduction in HDL-C levels in studies with less than 3 months of intervention period (WMD = −0.13 mmol/l, 95% CI −0.22, −0.03, $P=0.006$; $I^2=62.5\%$, Cochrane Q test, $P=0.07$), and also in studies conducted among subjects without MetS (WMD = −0.17 mmol/l, 95% CI −0.23, −0.11, $P<0.001$; $I^2=0\%$, Cochrane Q test, $P=0.684$). The conciderable changes of HDL-C values were not observed in other subgroups (Table 3).

Triglyceride (TG)

The analysis of five studies [2, 3, 17, 18, 59] represented that the changes in TG levels following the ND were not statistically different from the control diets (WMD = −0.007 mmol/l, 95% CI −0.13, 0.11, $P=0.917$; Fig. 2d). Moreover, a significant heterogeneity across the studies was observed (Q statistic = 9.92, Cochrane Q test, $P=0.042$, $I^2=59.7\%$); however, it was explained by study duration, and the health status of the study participants (with/without MetS). No beneficial effect of the Nordic pattern on serum TG levels was observed in any of subgroups (Table 3).

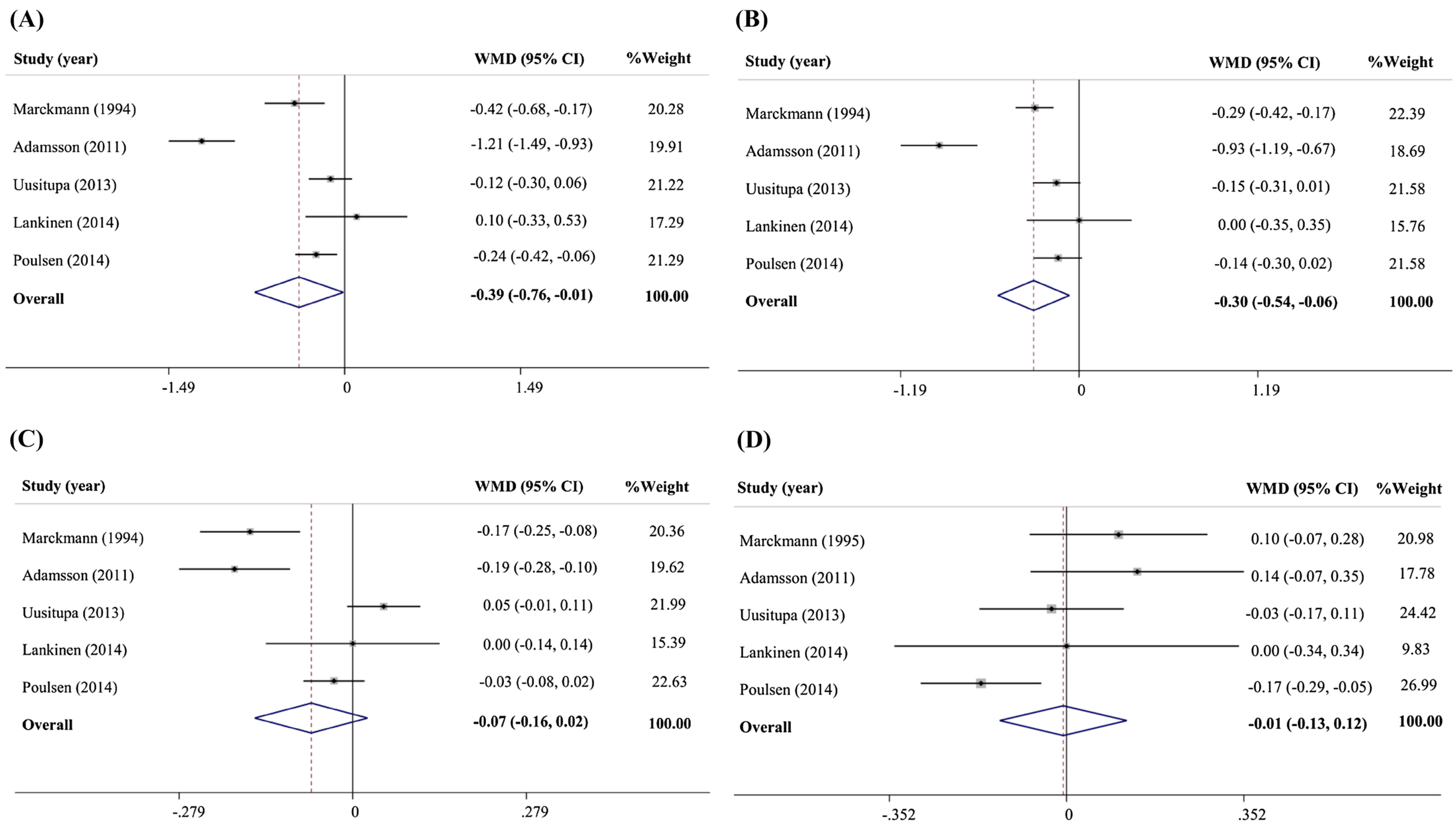


Fig. 2 Forest plots of randomized controlled trials examining the pooled effects of the Nordic diet on circulating levels of total cholesterol (**a**), low-density lipoprotein cholesterol (**b**), high-density lipoprotein cholesterol (**c**), and triglyceride (**d**)

Table 3 Meta-analysis showing the effect of the Nordic diet on blood lipids based on several subgroups as well as all studies (all analyses were conducted using random effects model)

	No. of studies	No. of subjects	Meta-analysis		Heterogeneity			
			WMD[1] (95% CI)	*P* effect	*Q* statistic	*P* within group	I^2 (%)	*P* between group
TC (mmol/l)								
Duration								
≤3 months	3	178	−0.52 (−1.22, 0.17)	0.140	30.16	<0.001	93.4	<0.001
>3 months	2	335	−0.18 (−0.31, −0.05)	0.005	0.84	0.359	0	
With MetS								
Yes	3	406	−0.15 (−0.29, −0.01)	0.029	2.35	0.308	15	<0.001
No	2	107	−0.81 (−1.58, −0.04)	0.038	16.66	<0.001	94	
Control diet								
Typical diets	3	346	−0.41 (−1.20, 0.36)	0.297	46.39	<0.001	95.7	0.400
Average Danish diet	2	167	−0.30 (−0.48, −0.13)	<0.001	1.33	0.249	24.8	
Overall	5	513	−0.38 (−0.76, −0.01)	0.044	48.43	<0.001	91.7	–
LDL-C (mmol/l)								
Duration								
≤3 months	3	178	−0.41 (−0.88, 0.05)	0.082	24.03	<0.001	91.7	0.003
>3 months	2	335	−0.14 (−0.25, −0.03)	0.011	0.01	0.930	0	
With MetS								
Yes	3	406	−0.13 (−0.23, −0.02)	0.016	0.61	0.738	0	<0.001
No	2	107	−0.60 (−1.22, 0.02)	0.058	19.05	<0.001	94.7	
Control diet								
Typical diets	3	346	−0.36 (−0.90, 0.18)	0.190	29.43	<0.001	93.2	0.306
Average Danish diet	2	167	−0.22 (−0.37, −0.07)	0.003	2.25	0.133	55.6	
Overall	5	513	−0.30 (−0.54, −0.06)	0.013	32.73	<0.001	87.8	–
HDL-C (mmol/l)								
Duration								
≤3 months	3	178	−0.13 (−0.22, −0.03)	0.006	5.33	0.07	62.5	<0.001
>3 months	2	335	0.00 (−0.07, 0.08)	0.836	4.20	0.04	76.2	
With MetS								
Yes	3	406	0.00 (−0.05, 0.06)	0.833	4.20	0.123	52.4	<0.001
No	2	107	−0.17 (−0.23, −0.11)	<0.001	0.17	0.684	0	
Control diet								
Typical diets	3	346	−0.04 (−0.21, 0.11)	0.576	19.42	<0.001	89.7	0.144
Average Danish diet	2	167	−0.09 (−0.22, 0.03)	0.165	7.90	0.005	87.3	
Overall	5	513	−0.06 (−0.15, 0.02)	0.150	29.46	<0.001	86.4	–
TG (mmol/l)								
Duration								
≤3 months	3	178	0.10 (−0.02, 0.22)	0.112	0.47	0.792	0	0.007
>3 months	2	335	−0.10 (−0.24, 0.03)	0.130	2.17	0.141	53.8	
With MetS								
Yes	3	406	−0.09 (−0.20, 0.00)	0.069	2.55	0.279	21.7	0.007
No	2	107	0.11 (−0.01, 0.25)	0.087	0.07	0.792	0	
Control diet								
Typical diets	3	346	0.02 (−0.09, 0.13)	0.715	1.72	0.424	0	0.169
Average Danish diet	2	167	−0.04 (−0.3, 0.22)	0.761	6.30	0.012	84.1	
Overall	5	513	−0.00 (−0.13, 0.11)	0.917	9.92	0.042	59.7	–

TC total cholesterol, *LDL-C* low-density lipoprotein cholesterol, *HDL-C* high-density lipoprotein cholesterol, *TG* triglyceride, *WMD* weighted mean difference, *MetS* metabolic syndrome

Other lipid profile parameters

The results of our meta-analysis indicated that the ND considerably decreased the LDL-C/HDL-C ratio (WMD = − 0.15, 95% CI − 0.29, − 0.01, $P = 0.029$; data were available from three studies [2, 3, 18]) and the apoB/apoA1 ratio (WMD = − 0.04, 95% CI − 0.06, − 0.01, $P = 0.002$; data were available from three studies [2, 3, 17]); however, this dietary pattern did not significantly affect apoA1 (WMD = − 0.09 g/l, 95% CI − 0.33, 0.15, $P = 0.456$; data were available from two studies [2, 3]) and apoB (WMD = − 0.10 g/l, 95% CI − 0.25, 0.05, $P = 0.212$; data were available from three studies [2, 3, 17]). Although heterogeneity was evident between studies evaluating the effect on apoA1 ($I^2 = 97\%$, Cochrane Q test, $P < 0.001$) and apoB ($I^2 = 94.8\%$, Cochrane Q test, $P < 0.001$) levels, the subgroup analyses were not performed due to fewer number of studies.

Systolic and diastolic blood pressure (SBP and DBP)

The pooled estimate of four trials [2, 3, 17, 18] revealed a statistically significant reduction in SBP by 3.97 mmHg (95% CI − 6.40, − 1.54, $P = 0.001$; Fig. 3a) and DBP by 2.08 mmHg (95% CI − 3.43, − 0.72, $P = 0.003$; Fig. 3b) favoring the Nordic dietary pattern over the control diets. There was no significant between-study heterogeneity for SBP ($I^2 = 26.1\%$, Cochrane Q test, $P = 0.255$) and DBP ($I^2 = 0\%$, Cochrane Q tets, $P = 0.486$). The subgroup analysis revealed that the lowering effect of the Nordic dietary pattern on both systolic and diastolic blood pressure was significant in long-term interventions (> 3 months). The overall effects as well as subgroup analyses are summarized in Table 4.

Sensitivity analysis and publication bias

The results of the sensitivity analysis showed that removing the studies done by Uusitupa et al. [2], Poulsen et al. [18], and Marckmann et al. [59] changed the overall effect of the Nordic dietary pattern on TC levels to a non-significant value. It was

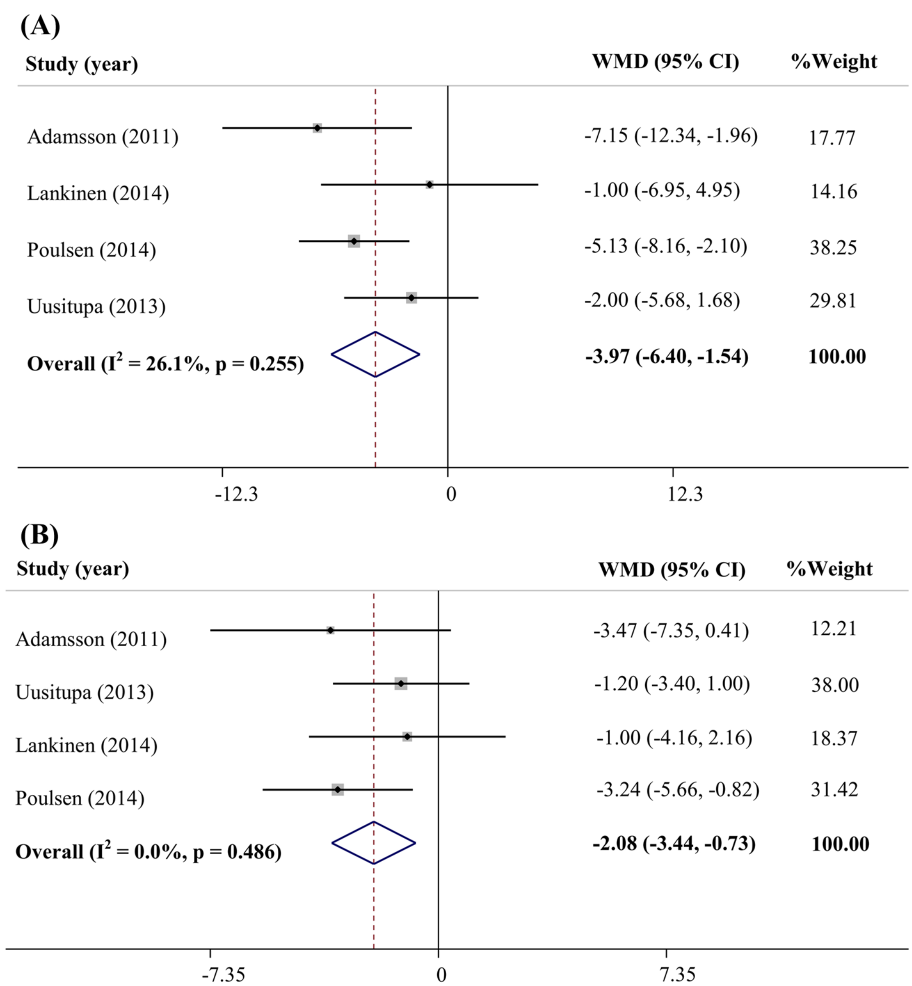


Fig. 3 Forest plots of randomized controlled trials examining the pooled effects of the Nordic diet on systolic blood pressure (**a**), and diastolic blood pressure (**b**)

Table 4 Meta-analysis showing the effect of the Nordic diet on blood pressure based on several subgroups as well as all studies (all analyses were conducted using random effects model)

	No. of studies	No. of subjects	Meta-analysis		Heterogeneity			
			WMD (95% CI)	*P* effect	*Q* statistic	*P* within group	I^2 (%)	*P* between group
SBP (mmHg)								
Duration								
≤3 months	2	157	−4.25 (−10.27, 1.76)	0.166	2.33	0.127	57.1	0.024
>3 months	2	335	−3.74 (−6.79, −0.70)	0.016	1.66	0.198	39.7	
With MetS								
Yes	3	406	−3.35 (−5.82, −0.88)	0.008	2.43	0.297	17.7	0.202
No	1	86	−7.15 (−12.34, −1.96)	0.007	0	–	–	
Control diet								
Typical diets	3	346	−3.30 (−6.80, 0.19)	0.064	3.16	0.206	36.7	0.342
Average Danish diet	1	146	−5.13 (−8.15, −2.10)	0.001	0	–	–	
Overall	4	492	−3.97 (−6.40, −1.54)	0.001	4.06	0.255	26.1	
DBP (mmHg)								
Duration								
≤3 months	2	157	−1.98 (−4.43, 0.46)	0.112	0.94	0.334	0	0.927
>3 months	2	335	−2.15 (−3.43, −0.72)	0.034	1.50	0.221	33.2	
With MetS								
Yes	3	406	−1.88 (−3.33, −0.44)	0.011	1.88	0.391	0	0.454
No	1	86	−3.47 (−7.35, 0.41)	0.080	0	–	–	
Control diet								
Typical diets	3	346	−1.55 (−3.18, 0.08)	0.063	1.15	0.562	0	0.257
Average Danish diet	1	146	−3.24 (−5.65, −0.82)	0.009	0	–	–	
Overall	4	492	−2.08 (−3.43, −0.72)	0.003	2.44	0.486	0	–

SBP systolic blood pressure, *DBP* diastolic blood pressure, *WMD* weighted mean difference, *MetS* metabolic syndrome

also observed that removal of the study done by Marckmann et al. [59] also altered the pooled estimate of LDL-C levels to statistically non-significant result. The summary effect of the ND was sensitive to the study by Uusitupa et al. [2] for HDL values and the study by Poulsen et al. [18] for DBP values. None of the other pooled estimates were sensitive to individual studies.

Although slight asymmetries were seen in the funnel plots depicting the effect sizes (MD) against their corresponding standard errors, statistical asymmetry tests provided no evidence of publication bias for the meta-analysis of TC (Begg's test, $P=0.806$; Egger's test, $P=0.680$), LDL-C (Begg's test, $P=1.00$; Egger's test, $P=0.692$), HDL-C (Begg's test, $P=0.462$; Egger's test, $P=0.486$), TG (Begg's test, $P=0.221$; Egger's test, $P=0.250$), SBP (Begg's test, $P=1.00$; Egger's test, $P=0.817$), and DBP (Begg's test, $P=0.734$; Egger's test, $P=0.719$).

Discussion

In the present systematic review and meta-analysis, we assessed the effectiveness of the Nordic dietary pattern in improving cardio-metabolic markers including blood pressure and lipids by reviewing available published randomized controlled intervention trials. The synthesis of the data from five RCTs with 513 participants showed that adherence to the Nordic dietary pattern results in a significant reduction in systolic and diastolic blood pressure. Our results also showed that the ND significantly affects total and LDL cholesterol levels compared with the control diets. The Nordic dietary pattern failed to generate significant changes in HDL-C and TG values. Moreover, the LDL-C/HDL-C ratio and the apoB/apoA1 ratio which proposed to be better predictors of increased cardiovascular risk [66, 67], significantly decreased following the ND.

In addition, the beneficial effects of this dietary pattern appear to be greater among patients with MetS who had abnormal blood pressure and blood lipid levels, in longer intervention periods, and also when compared with the average Danish diet as a control diet. This result may be due to the food groups characteristics of the average Danish diet which consists of refined grains (e.g., rice and pasta), dairy and cheese, meat, convenience foods, sugary products and a lower content of low-fiber vegetables and imported fruit (e.g., citrus, bananas, and melons) [18]. Several fundamental differences are derived from the comparison of the ND components with this dietary pattern: (1) more calories from plant-based foods and fewer from meat; (2) more sea foods (e.g., fatty fish, shellfish, and seaweed); (3) more local foods collected in the wild; (4) avoidance of sugar-sweetened products [68]. Indeed, the ND provides healthy and effective recommendations for improving the health, compared with the average Danish diet which is highly similar to the Western diet.

Our results regarding the effect of the ND on blood pressure are consistent with a meta-analysis by Ndanuko et al. [9] which evaluated the effects of various healthy diets such as DASH diet, Nordic diet, and Mediterranean diet and found a significant benefit in terms of systolic and diastolic blood pressure reduction in all these dietary patterns. However, the mentioned meta-analysis could include three studies which evaluated the effects of the Nordic pattern on blood pressure. On the other hand, another meta-analysis of three Finnish cross-sectional studies [69] that examined the associations between the Nordic pattern and cardio-metabolic risk factors showed no difference in the TC and TG levels between the quintiles of the Nordic diet score. Moreover, the risk of lowered HDL-C levels was higher in women with the highest quintile compared to the lowest quintile of the ND adherence score. However, no association was observed between the Nordic diet score and hypertension [69].

Several possible mechanisms for the advantageous effect of the ND on lipid profile and blood pressure have been proposed. Some studies have shown that adherence to the Nordic dietary pattern led to lower energy intake compared to those with the control diets [3, 18]. A previously published meta-analysis demonstrated that every 1 kg of weight loss might decrease the systolic and diastolic blood pressure by 1 mmHg [70]. Therefore, the reduction in blood pressure might be the result of reduced energy intake, and consequently weight reduction in the ND recipients. On the other hand, a higher intake of fruits, vegetables, dietary fiber, and nuts as well as a lower intake of sodium could be associated with significant improvements in blood pressure following the ND [71, 72]. The results of two systematic review and meta-analysis also showed that the increased protein intake, as observed in the ND, is associated with improvement in blood pressure [73, 74].

According to the results of pervious meta-analyses, adherence to the DASH diet was favorably associated with SBP (−6.74 mmHg, 95% CI −8.25, −5.2) and DBP (−3.54 mmHg, 95% CI −4.29, −2.79) [5], and also the Mediterranean diet lowered SBP by 1.44 mmHg and DBP by 0.7 mmHg [75]. Although no study has directly compared the effect of the ND on blood pressure with the DASH and the Mediterranean diet, when the results of present meta-analysis are compared with other healthy dietary patterns such as the DASH and Mediterranean diets, the effect of the ND on blood pressure seems to be greater than the Mediterranean diet; however, it was not as effective as the DASH diet in reducing blood pressure. It should be mentioned that the reduced blood pressure following adherence to these dietary patterns could be of great importance at the population level because even a modest reduction of blood pressure in a long-term period might reduce the mortality from CVDs [71].

We also found that the ND beneficially affects some blood lipid markers such as total and LDL cholesterol, LDL-C/HDL-C ratio and the apoB/apoA1 ratio. The lowering effect of the ND on total and LDL cholesterol levels might be associated with its high content of dietary fiber and rapeseed oil [76, 77]. It has been reported that dietary fiber and rapeseed oil have a significant impact on LDL-C and TC values, but no beneficial effects have been observed on TG and HDL levels which are similar to our finding regarding the effects of the ND on lipid profile. Indeed, the high concentrations of alpha-linolenic acid in the rapeseed oil seem to be responsible for its favorable effect on some lipid profile parameters as well as blood pressure [78, 79]. The non-significant effect of the ND on serum HDL levels might be explained by the restricted fat intake in this diet [2]. On the other hand, it has been suggested that the TG concentrations will not increase if the diet is low in sucrose and high in fiber [80] as observed in the Nordic dietary pattern.

The present systematic review and meta-analysis was conducted based on comprehensive and systematic search to identify all relevant published studies and no evidence for publication bias was observed. Moreover, the meta-analysis was restricted to RCTs that met predetermined methodological criteria to minimize the bias. However, it should be considered that all reviewed trials were conducted in the European countries, and there are no data regarding the efficacy of the Nordic dietary pattern in other populations.

The present systematic review and meta-analysis, provides the evidence for beneficial effects of this diet in reducing blood pressure and some lipid profile parameters. Moreover, the ND can be more effective among patients with MetS probably because of more variability among them. Further studies with adequate duration and sample sizes are recommended to investigate the efficacy of the Nordic dietary pattern in the improvement of cardiovascular risk factors.

Author contributions ASA, NRJ and MM developed the study concept and designed the research; NRJ and MM wrote the protocol and conducted the electronic searches and study selection; NRJ and MM conducted data extraction and tabulated data; ASA and NRJ conducted the data analysis and interpretation of results; NRJ and ASA wrote the first draft of the manuscript; and all authors read and approved the final version.

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Compliance with ethical standards

Conflict of interest There is no conflict of interest to report for this study.

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