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Association between espresso coffee and serum total cholesterol: the Tromsø Study 2015–2016

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ABSTRACT

Background Coffee raises serum cholesterol because of its diterpenes, cafestol and kahweol, and the effect varies by brewing method. Population-based research on espresso coffee's impact on serum cholesterol is scarce. Our aim was to examine how various brewing methods, in particular espresso, were associated with serum total cholesterol (S-TC).

Methods We used cross-sectional population data from the seventh survey of the Tromsø Study in Northern Norway (N=21 083, age ≥40 years). Multivariable linear regression was used to assess the association between S-TC as the dependent variable and each level of coffee consumption using 0 cups as the reference level, adjusting for relevant covariates and testing for sex differences.

Results Consumption of 3–5 cups of espresso daily was significantly associated with increased S-TC (0.09 mmol/L, 95% CI 0.01 to 0.17 for women and 0.16 mmol/L, 95% CI 0.07 to 0.24 for men), compared with participants drinking 0 cups of espresso per day. Consumption of ≥6 cups of boiled/plunger coffee daily was also associated with increased S-TC (0.30 mmol/L, 95% CI 0.13 to 0.48 for women and 0.23 mmol/L, 95% CI 0.08 to 0.38 for men), compared with participants drinking 0 cups of boiled/plunger coffee. Consumption of ≥6 cups of filtered coffee daily was associated with 0.11 mmol/L (95% CI 0.03 to 0.19) higher S-TC levels for women but not for men. Instant coffee consumption had a significant linear trend but showed no dose–response relationship when excluding participants not drinking instant coffee. There were significant sex differences for all coffee types except boiled/plunger coffee.

Conclusion Espresso coffee consumption was associated with increased S-TC with significantly stronger association for men compared with women. Boiled/plunger coffee was associated with increased S-TC in both sexes and with similar magnitude as shown in previous research. Filtered coffee was associated with a small increase in S-TC in women. Further research on espresso and S-TC is warranted.

Key questions

What is already known about this subject?

► Coffee raises serum cholesterol because of its diterpenes, cafestol and kahweol. Brewing method is the most important factor affecting the diterpene content. Boiled and plunger coffee contain higher contents of cafestol and kahweol than, for example, filtered coffee. Espresso coffee has an intermediate cafestol and kahweol content, but less is known about its contribution to increased serum cholesterol levels. Previous research regarding espresso is scarce, varies in results and has to some extent suboptimal study designs.

What does this study add?

► The present population-based cross-sectional study explores the association between espresso coffee consumption and serum total cholesterol (S-TC) in an adult and elderly population (age: ≥40 years, mean age: 56.4 years) in Northern Norway. We also assessed other brewing methods: boiled/plunger coffee, filtered coffee and instant coffee. The most important finding was that espresso coffee consumption was significantly associated with increased S-TC.

How might this impact on clinical practice?

► Coffee is the most frequently consumed central stimulant worldwide. Because of the high consumption of coffee, even small health effects can have considerable health consequences. Coffee was included for the first time in the 2021 ESC Guidelines on cardiovascular disease prevention in clinical practice. Increased knowledge on espresso coffee's association with serum cholesterol will improve the recommendations regarding coffee consumption.

INTRODUCTION

Coffee is the most frequently consumed central stimulant worldwide,[1] and Norway has the second-highest coffee consumption in the world.[2] Because of the high consumption of coffee, even small health effects from this popular beverage could have considerable public health consequences and is, therefore, an important topic for research.

Based on cross-sectional population data from Tromsø, Norway, Thelle *et al* were the first to present a positive association between coffee consumption and elevated serum total cholesterol (S-TC).[3] Further studies in Tromsø

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and in the Netherlands concluded that the magnitude of the increase depends on the brewing method.[4–7] The traditional boiled coffee, made by boiling water together with coarsely ground coffee in a pot, significantly increased S-TC. Filtered coffee did not, to the same extent. Dutch researchers found that coffee beans contain the diterpenes cafestol and kahweol which raise S-TC.[8] The brewing method is the most important factor affecting the diterpene content.[9] The more unfiltered the brewing method is, the higher will diterpene contents be in the finished brew.

Although boiled/plunger coffee raises S-TC and serum low density lipoprotein (S-LDL) cholesterol,[10] prospective epidemiological studies have observed J-shaped and U-shaped relationships between habitual coffee consumption and cardiovascular disease (CVD) incidence. Moderate coffee consumption has been associated with the lowest risk of CVD (1–5 cups daily).[11–13] This paradox leads us back to the question of the brewing method and the subsequent rise in S-TC levels. Tverdal *et al* showed that filtered coffee is associated with lower mortality than no coffee or unfiltered coffee only.[14]

Non-filtered coffee, including espresso coffee, contains the LDL cholesterol—raising diterpenes cafestol and kahweol and may be associated with an up to 25% increased risk of CVD mortality by 9 or more drinks a day.[14] According to the 2021 ESC Guidelines on CVD prevention in clinical practice,[15] moderate coffee consumption (3–4 cups per day) is probably not harmful, perhaps even moderately beneficial. However, for espresso coffee, there is no succinct recommendation, although it has been shown that there may be a positive association between espresso and serum cholesterol.[9 16]

We had material from a large population-based cross-sectional study that could answer the question regarding the association between espresso coffee consumption and serum cholesterol. The main aim of this study was to quantify the association between consumption of espresso coffee and S-TC in both men and women, using data from the Tromsø Study. Additionally, we aimed to examine the relationship between consumption of other brewing methods for coffee and S-TC.

METHODS

Study population

The Tromsø Study is one of Norway's most comprehensive population studies through the last 48 years. The study has been repeated every 6th–7th year in the time frame 1974–2016. The present population-based cross-sectional study used data from the 7th survey of the Tromsø Study (Tromsø7, 2015–2016). All inhabitants 40 years and older living in Tromsø (N=32 591) were invited, of which 65% attended (N=21 083, 11 074 women and 10 009 men).[17] Tromsø is the largest municipality in Northern Norway with a population of about 77 000.

Measurements

Following a standardised protocol, data were collected via questionnaires, physical examinations and simultaneous non-fasting venous blood samples collected with standard methods by trained personnel. The dependent variable, S-TC was analysed with enzymatic colorimetric methods with commercial kits on a Cobas8000 c702 (Roche diagnostics, Mannheim, Germany), and measured in mmol/L. The analysis was done by the Department of Laboratory Medicine, University Hospital of North Norway (Tromsø).

The questionnaire included four questions regarding coffee consumption, asking, 'How many cups of coffee or tea do you usually drink daily? Put 0 for the types you do not drink daily' (online supplemental file). The four types of coffee were defined as filtered coffee, boiled coffee/French plunger coffee (coarsely ground coffee for brewing), instant coffee and espresso-based coffee (from coffee machines, capsules, etc). For each coffee type, we categorised consumption into four groups: 0 cups, 1–2 cups, 3–5 cups and ≥6 cups daily. There was no standardised cup size in the questionnaire.

Height and weight measurements were performed in light clothing and without footwear. Age was measured in years. Body mass index (BMI) was calculated by using the formula $BMI = \frac{m}{h^2}$, where m is the mass in kilogrammes and h is the height in metres. Information regarding daily smoking (yes/no/previously), diabetes mellitus (yes/no/previously), education (primary or partly secondary education/upper secondary education/college or university less than 4 years/college or university 4 years or more), self-reported leisure-time physical activity (Saltin-Grimby Physical Activity Level Scale)[18]: sedentary (reading, watching TV or other sedentary activities) or active (walking, cycling or other forms of exercise ≥4 hours/week; recreational sports, heavy gardening ≥4 hours/ week; hard exercise or competitive sports several times per week) and frequency of alcohol consumption (never/monthly or less frequently/2–4 times a month/2–3 times a week/4 or more times a week) was collected from the questionnaire.

Statistical analyses

Three thousand three hundred and seventy three women and 2914 men had missing values for at least one of the coffee variables. One hundred and ninety four women and 94 men had missing values for all coffee variables. Additionally, 534 women and 373 men had missing values on other baseline covariates. Models were run using both complete case analysis (excluding participates with missing answers) and missing indicator method.

Baseline characteristics of participants, according to categories of total coffee intake, were summarised as means and standard deviations (continuous variables) or per cent (categorical variables) using complete case analysis.

The analyses were done separately for each coffee brew, and for men and women. Multivariable linear regression models were used to assess the association between S-TC as the dependent variable and each level of coffee consumption using 0 cups of coffee per day as the reference level.

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The missing indicator method was modelled by including an extra dummy variable (1=participants with missing, 0=participants with non-missing) for each coffee type. Tests for linear trend were performed by including levels of coffee consumption as an ordinal variable in separate models. We adjusted for age, BMI, daily smoking, physical activity, level of education, alcohol consumption, diabetes and combined coffee habits; that is, the other coffee brews were mutually adjusted for. The included covariates were selected by assessing direct acyclic graphs. Tests of sex differences were performed in separate models by adding two-way cross-product terms between sex and each variable of coffee type.

The subset of participants with complete set of values for all variables was compared with the group of participants with missing data. Differences between groups were tested by using χ^2 tests for categorical variables and linear regression for continuous variables.

Assumptions of normality were ensured by visual inspection of distribution of residuals using histograms. Scatter plots of predicted standardised values versus standardised residuals were visually inspected, and no pattern of heteroscedasticity was observed. No collinearity between predictor variables was observed (all variance inflation factors <1.2).

A p value of <0.05 was considered statistically significant. The data were analysed with the programme IBM SPSS Statistics V.28.0 for Macintosh.[17]

RESULTS

Baseline characteristics according to total consumption of coffee are presented in table 1. Using complete case analysis, women drank a mean of 3.8 cups (SD=2.9, n=7167) while men drank a mean of 4.9 cups (SD=3.2, n=6722) of coffee per day. Mean age was 56.4 years. Non-coffee drinkers (11.8% of women and 8.1% of men) were younger than coffee drinkers. Participants who drank ≥7 cups of coffee per day had lower education and were more often daily smokers (37.0% of women and 27.5% of men, compared with 5.6% among women and 6.6% among men drinking 1–2 cups daily) (table 1). The missing group was older and had lower education than the complete data group.

Linear regression analyses found that the association between coffee and S-TC varied between brews (tables 2–5). There were significant sex differences (p≤0.009) for all brews except for boiled/plunger coffee (p=0.55). Results are reported from missing indicator method unless stated otherwise.

Espresso consumption was associated with increased S-TC in men with a significant linear trend (p<0.001, table 2). Men drinking 3–5 cups of espresso per day had 0.16 mmol/L (95% CI 0.07 to 0.24) higher S-TC level than men drinking 0 cups of espresso per day. The difference for men who drank ≥6 cups was 0.14 mmol/L (95% CI 0.00 to 0.28). Women drinking 3–5 cups of espresso per day had 0.09 mmol/L (95% CI 0.01 to 0.17) higher S-TC level than women drinking 0 cups of espresso per day, but test for linear trend was borderline significant (p=0.052). In complete case analysis, however, there was a significant linear trend (p=0.023) and consumption of 3–5 cups of espresso per day was associated with an increased S-TC of 0.13 mmol/L (95% CI 0.04 to 0.23).

Boiled/plunger coffee consumption was associated with increased S-TC in both women and men (table 3). From the lowest (0 cups) to the highest (≥6 cups) consumption category, mean S-TC concentrations increased by 0.30 mmol/L (95% CI 0.13 to 0.48) in women and 0.23 mmol/L (95% CI 0.08 to 0.38) in men compared with participants drinking 0 cups of boiled/plunger coffee per day.

For the association between consumption of filtered coffee and S-TC, there was a significant linear trend over levels of consumption for women (p=0.003) but not for men (p=0.065) (table 4). S-TC concentrations in women who drank ≥6 cups of filtered coffee per day were 0.11 mmol/L higher (95% CI 0.03 to 0.19) than for women who drank 0 cups of filtered coffee per day.

For instant coffee, there was a significant linear trend in both women (p=0.044) and men (p=0.006) (table 5). However, within the group of participants drinking instant coffee, there was no significant linear trend or dose–response relationship, either for women or men.

DISCUSSION

Analyses of data from Tromsø7 confirm recent findings with a significant association between espresso coffee consumption and elevated S-TC. The association was significantly stronger for men than for women. This population-based cross-sectional study adds important information regarding the association between brewing methods and S-TC in men and women.

Previous studies regarding the association between espresso and serum cholesterol have shown varying results.

The randomised controlled trials (RCTs) of D'Amicis *et al*[19] and Martini *et al*,[20] and the cross-sectional study of Grioni *et al*[21] found no significant association between consumption of espresso coffee and increased S-TC. However, the RCTs had a modest level of intake, with three cups of espresso daily in the intervention groups. Also, Martini *et al* had a small sample size divided into three groups (n=7 per group). On the other hand, Cornelis and van Dam used cross-sectional data from the UK Biobank, finding that espresso was associated with increased S-LDL cholesterol in both sexes.[16] Although having a large sample size, results could be affected by a 'healthy volunteer' selection bias, not necessarily making results generalisable. Furthermore, Weusten-Van der Wouw *et al*[22] estimated that every 10 mg of cafestol plus a similar amount of kahweol raised S-TC by 0.13 mmol/L. The following prediction of Urgert *et al*[9] was that five cups of espresso daily would raise S-TC by 0.10 mmol/L.

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Table 1 Baseline characteristics according to total coffee consumption, by sex. The Tromsø Study 2015–2016

	Cups of coffee per day				
Variables	**0**	**1–2**	**3–4**	**5–6**	**≥7**
Women					
n	849	1308	2615	1621	774
Age, years	50.4 (9.4)	56.1 (12.9)	57.38 (11.0)	56.8 (10.5)	56.1 (9.5)
Total cholesterol, mmol/L	5.2 (1.0)	5.5 (1.1)	5.6 (1.0)	5.6 (1.1)	5.7 (1.0)
BMI, kg/m^2	27.5 (5.9)	26.8 (5.1)	26.6 (4.7)	26.9 (4.8)	27.6 (5.2)
Daily smoking, %					
Yes, now	7.4	5.6	9.3	17.9	37.0
Yes, previously	26.4	36.6	46.0	49.5	44.1
Never	66.2	57.8	44.7	32.6	19.0
Physical activity, %					
Low	16.8	13.6	13.0	12.5	15.5
Moderate	58.9	65.4	65.8	66.3	65.2
High	21.4	18.2	18.7	18.8	17.7
Very high	2.8	2.8	2.5	2.5	1.6
Highest level of education, %					
Primary/secondary ≤10 years	13.0	19.3	20.7	24.6	29.6
Upper secondary: 13 years	24.6	20.4	24.6	27.1	28.8
College/university <4 years	20.3	18.9	18.9	17.5	15.9
College/university ≥4 years	42.2	35.8	35.8	30.8	25.7
Diabetes mellitus, %					
No	93.5	94.3	95.6	96.3	94.4
Yes, now	5.2	5.1	3.9	3.0	4.9
Yes, previously	1.3	0.5	0.5	0.7	0.6
Alcohol frequency, %					
Never	18.7	9.3	6.6	8.2	5.2
Monthly or less frequently	39.7	29.9	24.2	24.3	34.0
2–4 times per month	27.6	34.2	37.9	40.1	37.9
2–3 times per week	11.0	21.5	24.8	22.9	19.9
≥4 times per week	3.1	5.2	6.5	4.4	3.1
Men					
n	544	759	1998	1983	1438
Age, years	52.2 (10.2)	58.9 (12.4)	58.4 (11.8)	56.7 (10.7)	55.7 (10.1)
Total cholesterol, mmol/L	5.2 (1.0)	5.3 (1.1)	5.4 (1.1)	5.4 (1.1)	5.5 (1.1)
BMI, kg/m^2	28.4 (4.8)	27.6 (3.8)	27.5 (3.7)	27.8 (4.0)	28.1 (3.9)
Daily smoking, %					
Yes, now	8.6	6.6	6.4	11.4	27.5
Yes, previously	23.7	39.3	44.4	48.1	44.8
Never	67.6	54.2	49.2	40.5	27.7
Physical activity, %					
Low	18.6	15.2	12.9	13.9	17.5
Moderate	49.9	54.7	50.7	50.8	51.0
High	27.2	26.2	32.3	31.7	28.9
Very high	4.8	4.0	4.1	3.6	2.6
Highest level of education, %					
Primary/secondary ≤10 years	18.2	17.4	19.1	19.8	27.6
Upper secondary: 13 years	26.7	29.2	28.6	29.7	34.4

Continued

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Table 1 Continued

Variables	Cups of coffee per day 0	1–2	3–4	5–6	≥7
College/university <4 years	21.1	20.4	23.4	22.2	19.7
College/university ≥4 years	34.0	32.9	28.9	28.3	18.3
Diabetes mellitus, %					
No	91.5	93.0	93.6	94.2	94.7
Yes, now	8.3	6.3	6.0	5.5	5.1
Yes, previously	0.2	0.7	0.5	0.4	0.2
Alcohol frequency, %					
Never	18.0	7.4	5.5	3.0	4.2
Monthly or less frequently	34.4	24.5	18.6	16.2	21.1
2–4 times per month	29.0	33.2	38.5	42.7	43.3
2–3 times per week	13.4	25.4	29.6	30.3	24.4
≥4 times per week	5.1	9.5	7.8	7.8	7.0

Values are means with SD in parenthesis (continuous variables) or percentage (categorical variables).
BMI, body mass index.

There are several possible explanations for the results in our study. Combined intake of other coffee brews together with espresso may have caused the rise in S-TC. However, when running the analysis both with and without adjusting for combined coffee habits, the association was strengthened when adjusting for other coffee types. This suggests that espresso itself rises S-TC. The questionnaire regarding coffee in Tromsø7 had a wide definition of espresso, including coffee machines, capsules and mocha pots. Moeenfard *et al* investigated the variability of diterpenes in different types of espresso, finding that cafestol concentrations were 36 mg/L for mocha and 54 mg/L for espresso machines.[23] For capsules, pods and vending machines, cafestol concentrations varied between 10 mg/L and 43 mg/L. Wuerges *et al* found similar results when testing different commercial capsule coffee in Brazil.[24] This shows that diterpene levels vary within different types of espresso. In comparison, boiled coffee and filtered coffee contained 232 mg/L and 5 mg/L of cafestol, respectively, suggesting that espresso brews may have an intermediate contribution to the intake of cafestol and kahweol compared with other types of coffee. To this

Table 2 Linear regression coefficients for the association between S-TC and consumption of espresso, by sex and according to complete case or missing indicator method. The Tromsø study 2015–2016

Cups of coffee per day	N	Complete case β (95% CI)	N	Missing indicator method β (95% CI)
Women				
0	5409	0 (reference)	5479	0 (reference)
1–2	1193	0.01 (–0.06 to 0.07)	1615	0.02 (–0.04 to 0.08)
3–5	499	0.13 (0.04 to 0.23)	775	0.09 (0.01 to 0.17)
≥6	66	0.09 (–0.15 to 0.34)	100	0.08 (–0.13 to 0.28)
P linear trend		0.023		0.052
Men				
0	4900	0 (reference)	4964	0 (reference)
1–2	1050	0.06 (–0.01 to 0.13)	1396	0.06 (0.00 to 0.13)
3–5	623	0.16 (0.06 to 0.25)	942	0.16 (0.07 to 0.24)
≥6	149	0.11 (–0.07 to 0.28)	246	0.14 (0.00 to 0.28)
P linear trend		0.001		<0.001
P interaction*		<0.001		<0.001

Adjusted for age, BMI, daily smoking, physical activity, education, alcohol consumption, diabetes and combined coffee habits.
β, regression coefficient, difference in total cholesterol (mmol/L) compared with the reference group of 0 cups per day.
*Test for interaction between sex and coffee consumption (as an ordinal variable).
BMI, body mass index; S-TC, serum total cholesterol.

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Table 3 Linear regression coefficients for the association between S-TC and consumption of boiled/plunger coffee, by sex and according to complete case or missing indicator method. The Tromsø Study 2015–2016

Cups of coffee per day	N	Complete case β (95% CI)	N	Missing indicator method β (95% CI)
Women				
0	5988	0 (reference)	6083	0 (reference)
1–2	729	0.10 (0.02 to 0.17)	1066	0.08 (0.01 to 0.15)
3–5	361	0.18 (0.07 to 0.29)	566	0.18 (0.08 to 0.27)
≥6	89	0.37 (0.16 to 0.58)	145	0.30 (0.13 to 0.48)
P linear trend		<0.001		<0.001
Men				
0	5570	0 (reference)	5516	0 (reference)
1–2	656	0.09 (0.01 to 0.18)	1076	0.11 (0.03 to 0.18)
3–5	339	0.22 (0.10 to 0.34)	562	0.25 (0.15 to 0.35)
≥6	157	0.31 (0.14 to 0.48)	162	0.23 (0.08 to 0.38)
P linear trend		<0.001		<0.001
P interaction*		0.52		0.55

Adjusted for age, BMI, daily smoking, physical activity, education, alcohol consumption, diabetes and combined coffee habits.
β, regression coefficient, difference in total cholesterol (mmol/L) compared to the reference group of 0 cups per day.
*Test for interaction between sex and coffee consumption (as an ordinal variable).
BMI, body mass index; S-TC, serum total cholesterol.

can be added variations in the size of coffee cups. Italians drink small cups of espresso, and one cup is defined as a 30 mL serving.[21] There was no standardised cup size in the questionnaire for Tromsø7, and, therefore, up to each subject to define. Norwegians are used to large cups of filtered coffee, and this habit could lead to large cups of espresso as well. If one cup of 'Norwegian' espresso is four times the size of a cup of Italian espresso, more diterpenes will be ingested per cup of coffee.

Several additional factors influence diterpene contents, which affect all coffee brews. First, the variability of cafestol and kahweol contents in commercially roasted and ground coffee is high; they are actually blends of the two species *Coffea arabica* (arabica) and *Coffea canephora*

Table 4 Linear regression coefficients for the association between S-TC and consumption of filtered coffee, by sex and according to complete case or missing indicator method. The Tromsø Study 2015–2016

Cups of coffee per day	N	Complete case β (95% CI)	N	Missing indicator method β (95% CI)
Women				
0	2537	0 (reference)	2585	0 (reference)
1–2	1537	0.04 (–0.03 to 0.10)	2156	0.03 (–0.03 to 0.09)
3–5	2410	0.08 (0.02 to 0.14)	3256	0.07 (0.01 to 0.13)
≥6	683	0.15 (0.5 to 0.24)	913	0.11 (0.03 to 0.19)
P linear trend		0.001		0.003
Men				
0	1943	0 (reference)	1980	0 (reference)
1–2	1189	–0.1 (–0.09 to 0.06)	1625	0.01 (–0.06 to 0.08)
3–5	2424	0.04 (–0.03 to 0.11)	3265	0.04 (–0.02 to 0.11)
≥6	1166	0.07 (–0.02 to 0.15)	1605	0.06 (–0.01 to 0.14)
P linear trend		0.081		0.065
P interaction*		0.001		<0.001

Adjusted for age, BMI, daily smoking, physical activity, education, alcohol consumption, diabetes and combined coffee habits.
β, regression coefficient, difference in total cholesterol (mmol/L) compared to the reference group of 0 cups per day.
*Test for interaction between sex and coffee consumption (as an ordinal variable).
BMI, body mass index; S-TC, serum total cholesterol.

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Table 5 Linear regression coefficients for the association between S-TC and consumption of instant coffee, by sex and according to complete case or missing indicator method. The Tromsø Study 2015–2016

Cups of coffee per day	N	Complete case β (95% CI)	N	Missing indicator method β (95% CI)
Women				
0	5739	0 (reference)	5818	0 (reference)
1–2	990	0.05 (–0.02 to 0.12)	1404	0.04 (–0.2 to 0.10)
3–5	362	0.12 (0.01 to 0.23)	611	0.10 (0.01 to 0.20)
≥6	76	0.09 (–0.15 to 0.34)	123	0.04 (–0.15 to 0.22)
P linear trend		0.25		0.044
Men				
0	5448	0 (reference)	5516	0 (reference)
1–2	796	0.14 (0.06 to 0.21)	1076	0.12 (0.04 to 0.19)
3–5	371	0.02 (–0.10 to 0.13)	562	0.08 (–0.02 to 0.18)
≥6	107	0.10 (–0.10 to 0.31)	162	0.12 (–0.05 to 0.29)
P linear trend		0.031		0.006
P interaction*		0.004		0.009

Adjusted for age, BMI, daily smoking, physical activity, education, alcohol consumption, diabetes and combined coffee habits.
β, regression coefficient, difference in total cholesterol (mmol/L) compared to the reference group of 0 cups per day.
*Test for interaction between sex and coffee consumption (as an ordinal variable).
BMI, body mass index; S-TC, serum total cholesterol.

(robusta).[25] Moeenfard *et al* performed a literary review where arabica coffee was found to have kahweol contents between 182 mg/100 g and 1265 mg/100 g and cafestol contents between 182 mg/100 g and 1308 mg/100 g. Robusta coffee concentrations, on the other hand, were 151–363 mg/100 g and 0–20 mg/100 g, respectively.[26] This shows that arabica coffee contains the highest concentrations of cholesterol-raising diterpenes. Second, an inverse relationship was found between roasting degree and the cafestol concentration in brews prepared without using a paper filter.[27] Third, an inverse relationship between particle size of ground coffee beans and diterpene concentrations in espresso has been demonstrated.[23] Taken together, these findings may explain why studies yield differing results.

Results regarding filtered coffee's association with serum cholesterol vary in the literature, although it is consistently found to be less S-TC-raising than boiled/plunger coffee.[6 28 29] Strandhagen and Thelle found in a controlled study that filtered coffee did raise serum cholesterol and warranted a study on the paper filter quality and physical properties of the filters.[29] Two recent studies tested various types of commercially available filters, to assess whether the filter's diterpene-retaining function varied.[30 31] Cafestol and kahweol concentrations in the brews varied from 1.62 mg/L to 2.98 mg/L and 0.73 to 1.95 mg/L, respectively, and the highest concentrations were obtained using filters with micro perforations. The filters showed high fat permeability. The porosity of the paper filter and the particle size of the ground roasted coffee were determinant factors in obtaining filter coffee brews with lower diterpene contents. The variation in diterpene concentrations passing through the paper filter may be what leads to the variance in results.

The association between espresso and S-TC was stronger for men than for women. Non-physiological explanations for this could hypothetically be (1) a smaller number of women drinking larger quantities of coffee yielding non-significant results, (2) smaller cups of espresso for women than for men, (3) other brewing methods of espresso dominating (capsule, espresso machine or mocha pot) in women compared with men and (4) sex differences regarding subjective views on coffee intake may lead to different reporting in the questionnaire. Furthermore, Weggermans *et al* found a discrepancy between men and women in serum cholesterol response when given concentrates of cafestol and kahweol.[32] The adjusted response of both S-TC and S-LDL cholesterol to cafestol was 0.22 mmol/L higher in men than in women, after adjusting for potential confounders. Lack of compliance, the menstrual cycle, contraceptives and a smaller total intake of energy could not explain the sex discrepancy, suggesting that there could be other unknown physiological sex differences explaining why men's cholesterol metabolism responds more strongly to diterpene intake.

Previous studies regarding instant coffee found no association with increased S-TC.[28] This makes sense, as instant coffee contains negligible amounts of diterpenes.[33] Although there was a significant association between instant coffee and S-TC in our study, there was no linear trend within the group drinking instant coffee, and no dose–response curve.

Results regarding boiled/plunger coffee coincide with previous studies and with the same magnitude

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of effect,[5 28 34] with a positive association and dose–response relationship between consumption and S-TC concentrations.

Interestingly, coffee contains more than a thousand diverse phytochemicals.[35] The intake of each compound also depends on the variety of coffee species, roasting degree, type of brewing method and serving size. Experimental studies show that cafestol and kahweol, in addition to raising S-TC, exert multiple potential pharmacological actions such as anti-inflammatory, hepatoprotective, anticancerogenic, anti-diabetic and anti-osteoclastogenesic activities.[36] This demonstrates how coffee contains compounds that may lead to multiple mechanisms operating simultaneously.

Strengths and limitations

The present study has several strengths, including that all inhabitants ≥40 years of age in the municipality were invited, the high attendance proportion and the broad diversity of health variables allowing to adjust for potential confounding factors. Furthermore, it captures the heterogeneous coffee habits in Northern Norway, making it possible to compare different habits in the same population. The questionnaire, clinical examinations and blood samples are executed with standardised methods and with experienced personnel. Well-known potential confounders are registered and controlled for in the statistical analysis.

However, there are study limitations that require further comments. First, some variables were self-reported, which could lead to overestimation or underestimation of the prevalence of risk factors. Second, although we adjusted for a broad variety of well-known potential confounders related to socioeconomic status and lifestyle, there could be confounding factors like diet, adding milk or sugar to the coffee, or unknown socioeconomic factors not accounted for in the analysis. Third, because of participants with missing values (n=7194), most regarding coffee consumption (n=6287), we used missing indicator methods when analysing data. Comparing the group with complete data sets and the missing group showed that the latter were older, had higher S-TC, smoked less, had fewer years of education and had a larger proportion of women. Furthermore, for women, the association between espresso consumption and S-TC was slightly stronger in complete case analysis than in the missing indicator analysis. Fourth, the cross-sectional design limits causal inference. Last, the external validity refers to Caucasian middle-aged and elderly adults and is not necessarily generalisable to other groups.

Implications

The main finding in the present study was that espresso coffee was associated with increased S-TC. Further research regarding espresso would be beneficial to review these new findings. The preferable study design would be by conducting an RCT, including standardised brewing methods, coffee beans, roasting degree, coffee particle and cup sizes. The goal should be to explore whether there is a reliable dose–response curve to diterpene intake and raise in S-TC, and whether there are sex differences.

Our findings regarding boiled/plunger coffee are the same as in the 1980s,[3 4 6] pointing toward results being generalisable. This supports previous health recommendations[15 37] to reduce intake of boiled/plunger coffee because of its capabilities to increase S-TC.

CONCLUSION

This study assessed the association between S-TC and consumption of variously brewed coffee in men and women in Tromsø7. The observed associations varied with brewing method. Espresso was significantly associated with raised S-TC, with a stronger association for men than for women. Boiled/plunger coffee consumption was significantly associated with raised S-TC in both women and men. Filtered coffee was significantly associated with increased S-TC in women. There was no dose–response relationship between increasing consumption of instant coffee and S-TC. Further research on espresso should be conducted.

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