BMJ Open Sport & Exercise Medicine

Association of LEAF-Q and EDE-QS scores with cholesterol levels in Finnish female athletes

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To cite: Silvennoinen JIK, Ihalainen JK, Valtonen M, *et al*. Association of LEAF-Q and EDE-QS scores with cholesterol levels in Finnish female athletes. *BMJ Open Sport & Exercise Medicine* 2024;**10**:e002050. doi:10.1136/bmjsem-2024-002050

► Additional supplemental material is published online only. To view, please visit the journal online (https://doi.org/10.1136/bmjsem-2024-002050).

Accepted 20 August 2024

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ABSTRACT

Objective Low energy availability (LEA) is common in athletes. Disturbances in sex hormone levels due to insufficient energy availability have been suggested to influence cholesterol metabolism and impact the overall risk for cardiovascular disease. We assessed the relationship between Low Energy Availability in Females Questionnaire (LEAF-Q) and Eating Disorder Examination Questionnaire Short (EDE-QS) scores with cholesterol levels in a cross-sectional study of female athletes.

Method Finnish national- to international-level female athletes self-reported physiological symptoms of LEA, including menstrual disturbances, using the LEAF-Q (n=176) and eating disorder symptoms using the EDE-QS (n=294). Serum cholesterol concentrations (mmol/L) were determined from venous blood samples. We analysed the relationship between the different variables using Pearson's r and linear regression. We also studied separately participants representing lean sports, that is, sports that emphasise leanness (LEAF-Q, n=60; EDE-QS, n=80).

Results LEA symptoms were common; 72 (41%) of 176 participants scored ≥8 points in the LEAF-Q, which is indicative of a high risk of problematic LEA. A one-point increase in LEAF-Q score was associated with a small, non-significant increase in low-density lipoprotein (LDL) cholesterol level (beta=0.024, 95% CI −0.0011 to 0.049, p=0.061). Higher EDE-QS scores were associated with higher LDL cholesterol levels (beta=0.028, 95% CI 0.0098 to 0.046, p=0.0029). These associations were somewhat stronger among athletes representing lean sports (LEAF-Q and LDL: beta=0.043, 95% CI 0.0041 to 0.08, p=0.031; EDE-QS and LDL: beta=0.036, 95% CI 0.0041 to 0.068, p=0.028).

Conclusion In this study, LEAF-Q and EDE-QS were associated with higher LDL cholesterol levels among athletes representing lean sports.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Problematic low energy availability (LEA) and menstrual disturbances have been suggested to be associated with unfavourable lipid profiles.

WHAT THIS STUDY ADDS

⇒ Higher Low Energy Availability in Females Questionnaire (LEAF-Q) and Eating Disorder Examination Questionnaire Short (EDE-QS) scores were associated with elevated low-density lipoprotein cholesterol levels among athletes representing lean sports.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Using the LEAF-Q and EDE-QS questionnaires together could help identify athletes at an increased risk of insufficient energy intake and concomitant disturbances in cholesterol metabolism.
⇒ Further studies should assess the long-term effects of problematic LEA, menstrual disturbances and eating disorder symptoms on the cardiovascular health of athletes.

INTRODUCTION

Sufficient energy intake is crucial for athletes' performance and health. Low energy availability (LEA) is a condition in which the athlete's energy intake does not match the exercise energy expenditure and the energy required to support physiological functions.[1 2] LEA can be caused by an intentional restriction of energy intake (eg, disordered eating patterns or intended weight loss) or by unintentional behaviour (eg, failure to meet energy needs as training volumes increase).[3] The prevalence of indicators of LEA among athletes has been estimated to range from 15% to 80%, depending on the study population, gender and sport.[2] It has been reported that 6%–45% of female athletes suffer from clinical eating disorders or their symptoms[4] and athletes representing lean sports, that is, sports that emphasise leanness, are reported to be at greater risk of disordered eating behaviour.[5]

In the 2023 International Olympic Committee (IOC) Consensus Statement, problematic LEA refers to LEA that is sufficiently severe or long-lasting to negatively affect the physiological functioning of various body systems.[2] Relative energy deficiency in sports (REDs) is defined as impaired physiological and/or psychological functioning caused by problematic LEA.[2] Disturbed hormonal and cardiovascular health are among the important characteristics of REDs.[2] Restriction of calories leads to the inhibition of the hypothalamic-pituitary-ovarian axis, which in turn may result in hypoestrogenism and the cessation of the menstrual cycle (functional hypothalamic amenorrhoea).[6] Oestrogen has many protective properties in the cardiovascular system, such as protecting the blood vessels from atherosclerotic lesion formation and lowering low-density lipoprotein cholesterol (LDL-C) and lipoprotein A levels.[7] The hypoestrogenism seen in problematic LEA could affect the cardiovascular health of young female athletes and predispose them to early pathological changes in the cardiovascular system, as seen in a study by Okoth *et al* where menstrual dysfunction in premenopausal women was associated with a higher risk for future cardiovascular disease.[8] In female athletes, the prevalence of hypothalamic amenorrhoea can be as high as 69%.[9]

Similarly to the changes observed in menopause,[10] higher levels of LDL-C and total cholesterol (TC) have been reported among amenorrhoeic athletes compared with eumenorrhoeic athletes.[6] However, higher levels of high-density lipoprotein cholesterol (HDL-C) (suggesting better rather than worse cardiovascular health) have also been observed among amenorrhoeic athletes compared with eumenorrhoeic athletes,[11] as well as in endurance female athletes compared with sedentary women regardless of the menstrual status.[12] When using the Low Energy Availability in Female athletes Questionnaire (LEAF-Q) as an indicator for high and low risk of LEA in athletes, no differences were found in LDL-C or TC levels between the groups, which might be due to the limited sample size of the study.[13] Elevated non-HDL-C, HDL-C and TC levels have been reported in adolescent girls suffering from amenorrhoea due to disordered eating and weight loss,[14] and patients with anorexia nervosa have also been reported to have elevated LDL-C and TC both before and after weight restoration treatment.[15–17] However, despite the high prevalence of LEA and eating disorder symptoms among athletes and the suggested pathological changes in cholesterol metabolism caused by problematic LEA, to our knowledge, no studies have assessed associations between eating disorder symptoms and cholesterol levels specifically among athletes.

Accordingly, we investigated the relationships of LEAF-Q and Eating Disorder Examination Questionnaire Short (EDE-QS) with cholesterol levels among Finnish national- to international-level female athletes. Our hypothesis was that higher scores of LEAF-Q and EDE-QS would be associated with higher levels of LDL-C and TC.

METHODS

Study design and recruitment of participants

This study was based on data from two studies—Monitoring Illness and Injury in Athletes (MIIA) and Athletic Performance and Nutrition (NoREDS)—both conducted at the University of Jyväskylä, Finland. MIIA was a cross-sectional study of the health of 167 Finnish national- to international-level female athletes, aged 16–35 years, at data collection from 2019 to 2022. NoREDS was a 3-year follow-up study where athletes' body composition and intake of energy and nutrients were examined in different phases of the athletic season. A total of 388 Finnish national- to international-level male and female athletes, aged 16–35 years at baseline, were included in the study and were followed up from 2021 to 2024. In both MIIA and NoREDS, the participants represented ball sports, gymnastics, endurance sports and track and field. Both studies followed the Declaration of Helsinki and were approved by the Ethics Committee of the Central Finland Healthcare District (MIIA 5U/2019) and the Ethics Committee of the University of Jyväskylä (NoREDS 514/13.00.04.00/2021). Participants gave written informed consent before enrolment in the study.

For this study, the first measurements of female athletes from both studies, MIIA and NoREDS, were used for a cross-sectional design. Participants with missing data on key variables (cholesterol values, LEAF-Q, EDE-QS, body mass index, body fat percentage and use of hormonal contraception) were excluded. Thus, the final study sample consisted of 294 female athletes (figure 1). The

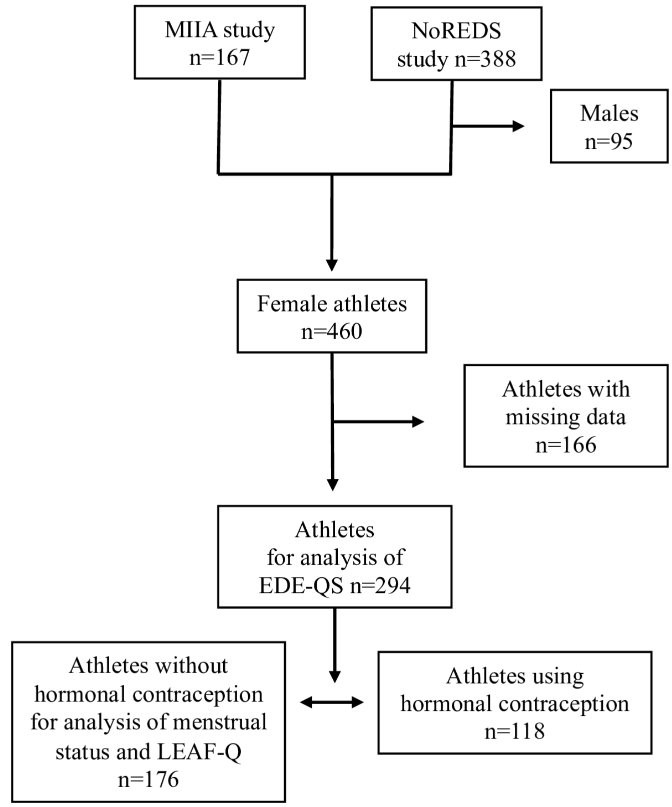

Figure 1 Flow chart describing study participants' selection. EDE-QS, Eating Disorder Examination Questionnaire Short; LEAF-Q, Low Energy Availability in Female athletes Questionnaire; MIIA, Monitoring Illness and Injury in Athletes; NoREDS, Athletic Performance and Nutrition

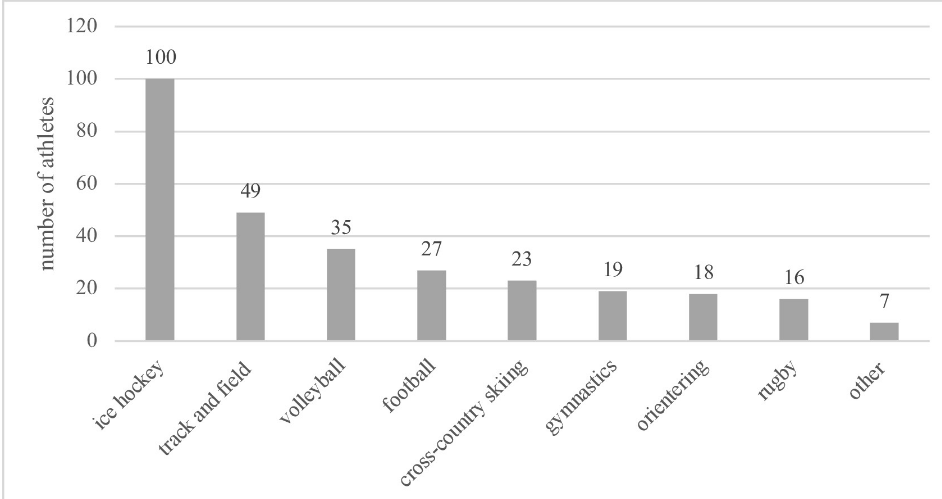

Figure 2 Distribution of participants within different sports. 'Other' includes triathlon and ski jumping.

most common sports were ice hockey, track and field, volleyball, football and cross-country skiing (figure 2). We also analysed separately lean sports (n=80), that is, endurance, aesthetic and weight-dependent sports, which emphasise leanness (long-distance running, triathlon, race walking, cross-country skiing, orienteering, team gymnastics, aesthetic group gymnastics, cheerleading and ski-jumping).

Measures

Symptoms of LEA

The LEAF-Q was used to assess the physiological symptoms of LEA. The LEAF-Q is a screening tool to identify individuals potentially at risk for problematic LEA, comprising 25 questions about menstrual function, history of injuries and gastrointestinal symptoms, with a total score ranging from 0 to 25.[18 19] The questionnaire has been validated in athletes representing endurance sports and dance; a score ≥8 indicates a high risk for LEA in female athletes, with a sensitivity of 78% and specificity of 90%.[18] From the LEAF-Q analysis, we excluded athletes who used any form of hormonal contraception because their menstrual function, which is a major component of the questionnaire, could not be interpreted reliably.

Eating disorder symptoms

Eating disorder symptoms were assessed using the EDE-QS. The EDE-QS is a 12-item version of the original 28-item EDE-Q,[20] assessing the severity, frequency and range of eating disorder symptoms during the past 7 days on a four-point scale.[21] This yields total scores ranging from 0 to 36, with higher scores indicating more unhealthy attitudes toward eating and body image. The EDE-Q has previously been validated on an athlete population,[22] and the EDE-QS has demonstrated high internal consistency (Cronbach's alpha=0.91) and convergent validity with the EDE-Q both among those with (r=0.91) and without (r=0.82) an eating disorder.[23] High EDE-QS scores are a potential major risk factor for problematic LEA.[19 24] A score of 15 has been recommended as a cut-off to screen for individuals at risk for a clinical eating disorder.[21]

Menstrual function

As a part of the LEAF-Q, participants reported their menstrual function. Two interrelated questions were used: (1) whether the menstrual cycle was regular (regular; not regular) and (2) whether the participant had disturbances with their menstrual cycle (amenorrhoea=no natural onset of menstrual cycle by the age of 15 or last menstrual bleeding ≥3 months ago; oligomenorrhoea=last menstrual bleeding 1–2 months ago; eumenorrhoea=normal menstruation, last menstrual bleeding 1–4 weeks ago). These two groups were combined into one group of normally menstruating athletes (eumenorrhoea+regular) and one group of athletes with menstrual disturbances (oligomenorrhoea+amenorrhoea+not regular). Participants who reported using hormonal contraception were excluded from the analysis of menstrual function.

Cholesterol

Fasting venous blood samples were drawn from the antecubital vein in a supine position between 7:00 and 10:00. For serum separation, whole blood was left to clot for 30 min at room temperature and centrifuged at 2200 *g* before aliquoting and storing the sera at −80°C until analysis. Serum HDL-C, LDL-C and TC were measured using a KONELAB 20 XTi or Indico analyser (Thermo Fischer Scientific, Finland) according to the manufacturer's instructions.

Equity, diversity and inclusion statement

The authors are all based in Nordic countries but comprise both women and men and include both junior and senior researchers. The authors have backgrounds as medical doctors or exercise physiologists. Our study population included athletes of different ages. Only female athletes were included in the study.

Patient involvement

Patients or the public were not involved in the design or conduct of the study. Participants received feedback from their own measurements interpreted and explained by a healthcare professional.

Statistical analysis

Differences in descriptive statistics were assessed using the Student's t-test for continuous variables and Pearson's χ^2 test for categorical variables. Cross-sectional relationships between variables were assessed using Pearson's correlation coefficient and linear regression. All linear and logistic regression models were adjusted for age and sport. The significance level was set to 0.05. The assumptions of linear regression were examined using residuals. All CIs are reported at the 95% confidence level. Data analysis was conducted in R (V.2023. R 4.3.0 GUI 1.79). The statistical analysis was reviewed to be consistent with the CHecklist for statistical Assessment of Medical Papers statement.[25] We used the Strengthening the Reporting of Observational Studies in Epidemiology cross-sectional checklist when writing our report.[26]

RESULTS

Participant's characteristics

A total of 460 female athletes were recruited into the study. After excluding 166 athletes with missing data, our analytic sample comprised 294 female participants, who were included in the analyses of EDE-QS scores (figure 1). The LEAF-Q scores and menstrual function could be accurately analysed in 176 participants who were not using hormonal contraception; these participants were included in the analyses of LEAF-Q scores and menstrual function. A total of 72 (41%) of the 176 participants scored ≥8 points in LEAF-Q, potentially indicating a problematic LEA. Menstrual disturbances were reported by 44 (25%) of the 176 participants not using hormonal contraception. In the EDE-QS, 21 (7%) of the 294 participants scored ≥15 points, which indicates a high risk for eating disorders. A total of 57 (19%) of the 294 participants had an LDL-C value over the reference (≥3 mmol/L). Further characteristics of the participants are described in table 1. Correlations between the exposure variables and anthropometrics are shown in online supplemental table S1.

LEAF-Q score and cholesterol

LEAF-Q score and LDL-C had a positive association in the linear regression analysis, but this association was not statistically significant (table 2). Of those scoring below the cut-off (<8 points) in LEAF-Q, 15% had LDL-C over the clinical reference value of ≥3 mmol/L; of those scoring above the cut-off (≥8 points) in LEAF-Q, 17% had elevated LDL-C (adjusted OR 1.17, 95% CI 0.64 to 2.15, p=0.62, table 3).

Menstrual function and cholesterol

Menstrual disturbances were not associated with changes in HDL-C, LDL-C or TC (tables 2–4).

Eating disorder symptoms and cholesterol

EDE-QS scores correlated positively with LDL-C and TC levels (table 2). After adjusting the linear regression model for LEAF-Q score in addition to age and sport, the association between EDE-QS and LDL-C was strengthened (beta 0.049, 95% CI 0.030 to 0.069, p<0.001). Of those scoring below the cut-off (<15 points) in EDE-QS, 18% had LDL-C over the clinical reference value of ≥3 mmol/L; of those scoring above the cut-off (≥15 points) in EDE-QS, 38% had elevated LDL-C (adjusted OR 2.82, 95% CI 1.06 to 7.05, p=0.030, table 3).

Analysis restricted to lean sports

There were 80 athletes representing lean sports in the analysis of EDE-QS and 60 in the analysis of LEAF-Q and menstrual function. Among them, 7 (9%) of 80 athletes scored ≥15 points in EDE-QS, 28 (47%) of 60 athletes scored ≥8 points in LEAF-Q, and 23 (38%) of 60 athletes had menstrual dysfunction. The point estimates for associations between LEAF-Q and EDE-QS with LDL-C were higher than in the whole sample (table 4). Descriptive statistics and correlations between exposure variables and anthropometrics among those representing lean sports are shown in online supplemental tables S2 and S3.

DISCUSSION

In this cross-sectional study of Finnish national- to international-level female athletes, we investigated associations of the LEAF-Q and the EDE-QS scores with cholesterol levels. In the whole study sample, higher EDE-QS scores were associated with higher LDL-C levels. Among athletes representing lean sports, both LEAF-Q and EDE-QS scores were associated with elevated LDL-C levels with point estimates that were higher than those in the whole sample.

The prevalence of high LEAF-Q scores (≥8), potentially indicating a high risk of problematic LEA, was 41% in our whole study sample comprising athletes representing several different sports and 47% among athletes representing lean sports. This high prevalence is in line with previous studies, in which prevalence rates of indicators of problematic LEA in female athletes have ranged from 23% to 80%.[2] Menstrual dysfunction was reported by 25% of the athletes in our whole study sample and 38% of the lean sport participants. Similar results have been previously published; the prevalence of menstrual dysfunction, including oligomenorrhoea and primary/secondary amenorrhoea, in athlete populations has ranged from 0% to 69%, depending on the sport.[9,27]

Similar to previous studies, in which LEAF-Q scores in female athletes have not been associated with changes in LDL-C or TC,[14,15] we found no statistically significant associations between LEAF-Q and LDL-C in linear models in our full sample. Nevertheless, participants

Table 1 Characteristics of study participants

Characteristic	By LEA symptoms (LEAF-Q score)					By eating disorder symptoms (EDE-QS score)					Total	
	Low LEAF-Q-score (<8)		High LEAF-Q-score (≥8)			Low EDE-QS-score (<15)		High EDE-QS-score (≥15)				
	N	Mean (SD)/n (%)	N	Mean (SD)/n (%)	P value	N	Mean (SD)/n (%)	N	Mean (SD)/n (%)	P value	N	Mean (SD)/n (%)
Age	104	21.6 (5.0)	72	21.2 (4.3)	0.61	273	22.0 (4.7)	21	22.2 (4.5)	0.87	294	22.0 (4.7)
BMI (kg/m^2)	104	23.3 (3.4)	72	22.4 (2.7)	0.072	273	23.0 (2.7)	21	25.8 (4.7)	**<0.001**	294	23.1 (3.0)
Body fat %	104	25.0 (8.0)	72	22.6 (8.0)	0.051	273	24.3 (7.5)	21	28.1 (10.2)	**0.031**	294	24.5 (7.8)
LEAF-Q	104	4.1 (1.8)	72	11.0 (2.8)	**<0.001**	164	6.9 (4.0)	12	7.1 (6.0)	0.90	176	6.9 (4.1)
EDE-QS	104	4.8 (5.1)	72	6.0 (4.7)	0.10	273	4.4 (3.5)	21	18.7 (2.7)	**<0.001**	294	5.4 (5.0)
HDL-C (mmol/L)	104	1.6 (0.5)	72	1.7 (0.5)	0.33	273	1.8 (0.7)	21	1.6 (0.6)	0.37	294	2.0 (0.7)
LDL-C (mmol/L)	104	2.4 (0.8)	72	2.6 (0.5)	**0.024**	273	2.5 (0.8)	21	2.7 (1.0)	0.13	294	2.5 (1.0)
TC (mmol/L)	104	4.2 (1.0)	72	4.6 (0.7)	**0.020**	273	4.4 (1.0)	21	4.7 (1.0)	0.16	294	4.4 (1.0)
Menstrual disturbances	104	11 (11%)	72	33 (45%)	**<0.001**	164	38 (23%)	12	6 (50%)	0.084	176	44 (25%)
Use of hormonal contraception	–	–	–	–	–	273	109 (40%)	21	9 (42%)	0.90	294	118 (40%)

Characteristics	Low LDL-C (<3 mmol/L)		High LDL-C (≥3 mmol/L)			Normal menstrual cycle		Disturbed menstrual cycle		
	N	Mean (SD)/n (%)	N	Mean (SD)/n (%)	P value	N	Mean (SD)	N	Mean (SD)	P value
Age	237	21.8 (4.6)	57	22.9 (5.0)	0.20	132	21.7 (5.0)	44	20.5 (3.9)	0.16
BMI (kg/m^2)	237	23.0 (2.8)	57	23.9 (3.6)	**0.022**	132	23.3 (3.3)	44	21.7 (2.4)	**0.0052**
Body fat %	237	24.3 (7.4)	57	25.7 (9.1)	0.21	132	25.0 (8.2)	44	21.0 (6.7)	**0.0036**
LEAF-Q	148	6.8 (3.9)	28	7.9 (5.0)	0.19	132	6.0 (3.5)	44	9.8 (4.4)	**<0.001**
EDE-QS	237	5.0 (4.6)	57	7.1 (6.2)	**0.004**	132	4.9 (4.7)	44	6.5 (5.6)	0.055
HDL-C (mmol/L)	237	1.7 (0.7)	57	1.8 (0.4)	0.91	132	1.6 (0.4)	44	1.7 (0.5)	0.86
LDL-C (mmol/L)	237	2.2 (0.5)	57	3.6 (0.9)	**<0.001**	132	2.4 (0.7)	44	2.5 (0.7)	0.38
TC (mmol/L)	237	4.1 (0.7)	57	5.7 (0.9)	**<0.001**	132	4.3 (0.9)	44	4.5 (1.0)	0.40
Menstrual disturbances	148	34 (23%)	28	10 (36%)	0.23	–	–	–	–	–
Use of hormonal contraception	237	89 (38%)	57	29 (51%)	0.16	–	–	–	–	–

The p values are for difference between low versus high LEAF-Q and EDE-QS scores and LDL-C levels and menstrual status groups, respectively. Bolded p values are below the set statistical significance level of 0.05.

BMI, body mass index; EDE-QS, Eating Disorder Examination Questionnaire Short; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; LEAF-Q, Low Energy Availability in Females Questionnaire; TC, total cholesterol.

Table 2 Associations and correlations LEAF-Q, EDE-QS and menstrual disturbances with cholesterol levels among Finnish national- to international-level female athletes

Outcome	β	CI	P value	R	CI	P value
HDL cholesterol						
EDE-QS	−0.0077	−0.024 to 0.0085	0.35	−0.006	−0.13 to 0.12	0.93
LEAF-Q	0.0087	−0.0069 to 0.024	0.27	0.11	−0.04 to 0.25	0.15
Menstrual disturbances	−0.040	−0.19 to 0.11	0.60	0.01	−0.13 to 0.16	0.86
LDL cholesterol						
EDE-QS	0.028	0.0098 to 0.046	**0.0029**	0.15	0.04 to 0.26	**0.010**
LEAF-Q	0.024	−0.0011 to 0.049	0.061	0.13	0.10 to 0.28	0.076
Menstrual disturbances	0.028	−0.22 to 0.27	0.82	0.07	−0.08 to 0.21	0.38
Total cholesterol						
EDE-QS	0.036	0.013 to 0.058	**0.0023**	0.17	0.05 to 0.28	**0.0041**
LEAF-Q	0.023	−0.0089 to 0.056	0.15	0.12	−0.03 to 0.27	0.10
Menstrual disturbances	0.0097	−0.31 to 0.33	0.95	−0.06	−0.08 to 0.21	0.40

Betas are reported per unit change in exposure variable and adjusted for age and sport. Bolded p values are below the set statistical significance level of 0.05.
EDE-QS, Eating Disorder Examination Questionnaire Short; HDL, high-density lipoprotein; LDL, low-density lipoprotein; LEAF-Q, Low Energy Availability in Females Questionnaire; R, Pearson's correlation coefficient.

whose LEAF-Q score was at or above the cut-off of eight points, potentially indicating a higher risk of problematic LEA, tended to have slightly higher LDL-C and TC levels than those below the cut-off. The difference was 0.2 mmol/L for LDL-C and 0.4 mmol/L for TC. While this difference is small, it may not be meaningless, as each 1 mmol/L reduction in LDL-C in patients treated with statins has been associated with a 22% relative risk reduction in cardiovascular events over a period of 5 years.[28] In a meta-analysis,[29] diet and other nonstatin therapies had a similar effect on the risk of cardiovascular events with statins when the same change in LDL-C was achieved.

The lack of a strong association between LEAF-Q and LDL-C could be due to the reduced specificity of the LEAF-Q questionnaire in our study population. As LEAF-Q has only been validated in endurance sports and dance, which emphasise leanness, the validity of the questionnaire in our mixed sports study sample is questionable.[30 31] One particular problem with LEAF-Q is that the questionnaire screens for injuries without specifying the aetiology of them. Overuse injuries are common in endurance sports. Athletes with problematic LEA are thought to be predisposed to them due to poor bone health,[18] but not all injuries are caused by poor bone health and overuse. For example, in ball sports, tackling and contact with other athletes are common and may cause injuries that are not related to problematic LEA.[30] To address this, we conducted an analysis restricted to participants representing endurance and other lean sports, finding an association between LEAF-Q and LDL-C that was stronger than in the whole sample. This finding supports the current understanding that LEAF-Q is a better indicator of problematic LEA in athletes representing lean sports than among athletes in general.

Table 3 Associations between elevated LEAF-Q and EDE-QS scores and menstrual disturbances with elevated LDL-C

		LDL-C		
		<3 mmol/L n (%)	≥3 mmol/L n (%)	OR (95% CI) (p value)
LEAF-Q score	<8	88 (85%)	16 (15%)	1.17 (0.64 to 2.15) (0.62)
	≥8	60 (83%)	12 (17%)	
EDE-QS score	<15	224 (82%)	49 (18%)	2.94 (1.06 to 7.78) (**0.031**)
	≥15	13 (62%)	8 (38%)	
Menstrual function	Normal	114 (86%)	18 (14%)	1.57 (0.59 to 4.07) (0.36)
	Disturbed	34 (77%)	10 (23%)	

ORs were adjusted for age and sport. Bolded p values are below the set statistical significance level of 0.05.
EDE-QS, Eating Disorder Examination Questionnaire Short; LDL-C, low-density lipoprotein cholesterol; LEAF-Q, Low Energy Availability in Females Questionnaire.

Table 4 Associations and correlations of LEAF-Q, EDE-QS and menstrual disturbances with cholesterol levels among Finnish national- to international-level female athletes representing lean sports

Outcome	β	CI	P value	R	CI	P value
HDL cholesterol						
EDE-QS	−0.0039	−0.027 to 0.019	0.74	−0.11	−0.32 to 0.11	0.32
LEAF-Q	0.012	−0.017 to 0.042	0.41	0.11	−0.14 to 0.36	0.39
Menstrual disturbances	−0.076	−0.36 to 0.21	0.59	0.023	−0.23 to 0.27	0.86
LDL cholesterol						
EDE-QS	0.036	0.0041 to 0.068	**0.028**	0.17	−0.05 to 0.38	0.13
LEAF-Q	0.043	0.0041 to 0.08	**0.031**	0.23	−0.03 to 0.46	0.079
Menstrual disturbances	0.074	−0.30 to 0.45	0.70	0.12	−0.14 to 0.36	0.36
Total cholesterol						
EDE-QS	0.036	−0.0066 to 0.079	0.096	0.10	−0.12 to 0.31	0.37
LEAF-Q	0.035	−0.017 to 0.086	0.19	0.16	−0.099 to 0.40	0.23
Menstrual disturbances	0.014	−0.48 to 0.51	0.96	0.076	−0.18 to 0.32	0.56

Betas are reported per unit change in exposure variable and adjusted for age and sport. Bolded p values are below the set statistical significance level of 0.05.
EDE-QS, Eating Disorder Examination Questionnaire Short; HDL, high-density lipoprotein; LDL, low-density lipoprotein; LEAF-Q, Low Energy Availability in Females Questionnaire; R, Pearson's correlation coefficient.

We found no associations between menstrual disturbances and HDL-C, LDL-C and TC levels, neither in the whole study sample nor in the lean sports subgroup. Evidence from earlier studies is mixed. Amenorrhoea has been associated with elevated LDL-C and TC levels in some[6 11 32] but not all studies.[33 34] In addition, athletes have been reported to have higher HDL-C regardless of menstrual status compared with sedentary women.[12 35] The lack of association between menstrual status and cholesterol values in many studies might reflect false negative findings due to small sample sizes; the sample sizes of previous studies on this topic have ranged from 14 to 51. Although our study with 294 participants was considerably larger, we too had to study menstrual status in a subsample of only 176 participants, who did not use hormonal contraception that masks the natural menstrual function or lack thereof.

To our knowledge, this is the first study to report an association between eating disorder symptoms and increased levels of LDL-C and TC in an athlete population. Those scoring above the screening threshold of ≥15 points on the EDE-QS had an increased risk of having clinically elevated LDL-C levels (≥3 mmol/L). The difference in LDL-C between athletes who scored above versus below the screening threshold on the EDE-QS was on average 0.2 mmol/L. This difference was the same as that between athletes with high versus low LEAF-Q scores, although not statistically significant due to the small number (n=21) of athletes with high EDE-QS scores.

Previous evidence for an association between LEAF-Q and EDE-QS is mixed. One study found an association,[36] whereas another did not.[37] Nevertheless, in our study, the association between EDE-QS and LDL-C was independent of LEAF-Q. This suggests that the EDE-QS could be used to complement the LEAF-Q in the screening of athletes at an increased risk of problematic LEA and related disturbances in cholesterol metabolism. One of the benefits of the EDE-QS is that compulsive exercise, which is a significant risk factor for developing problematic LEA, is inquired about but is not in the LEAF-Q.[19] At present, the longer 28-item EDE-Q is part of the screening tools listed in the International Olympic Committee Relative Energy Deficiency in Sport Clinical Assessment Tool version 2 (IOC REDs CAT 2[38]), but the more concise 12-item EDE-QS could be a more practical alternative.

Strengths and limitations

The principal strength of our study is the sample size, which is large compared with many previous studies in the field. However, there was also a substantial amount of missing data, which may have affected our findings.

Our study has some important limitations. Causality cannot be inferred because this was a cross-sectional study. We also cannot exclude the possibility of unknown confounding factors affecting our findings. We could not assess genetic factors that influence cholesterol metabolism, but we did not observe extremely high LDL-C levels (≥4.9 mmol/L) which would raise concerns of familial hypercholesterolaemia.[39 40] Although we had validated measures for screening potential risk of LEA and eating disorder symptoms, we had no clinical evaluation for REDs or eating disorders. The EDE-QS has not been validated in an athlete population. However, the original EDE-Q has shown a sensitivity of 90% and a specificity of 100% among athletes.[22] The current recommendation is that an individualised, clinical assessment of the diagnostic criteria of REDs should be done based on the LEAF-Q and REDs Clinical Assessment Tool (REDS-CAT

2[38]). Possible disordered eating patterns should also be assessed.[2] Our main study sample consisted of a mixed-sport sample, which may reduce the validity of the used questionnaires. We did, however, also conduct an analysis on participants representing lean sports.

We studied female athletes from a Nordic country. Further studies are needed to assess the generalisability of our findings among male athletes and among athletes from other cultural and ethnic backgrounds.

CONCLUSION

In this cross-sectional study of Finnish female athletes, we found that higher LEAF-Q and EDE-QS scores were associated with higher LDL-C levels among athletes representing lean sports. Further research is needed to assess the long-term effects of these changes in lipid metabolism on the cardiovascular health of athletes.

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Contributors All authors contributed to the design of the study. JIKS conducted the literature review, analysed the data and wrote the first draft of the manuscript. JIKS and JKI obtained funding for the study. JKI, MV and KM contributed to data acquisition. JIKS, JKI, MV and PNS contributed to the study conception or design or analysis or interpretation of the data. All authors contributed to critical revision of the manuscript for important intellectual content and approved the submitted manuscript. JIKS is the guarantor of this work.

Funding JIKS has been supported by the Finnish Heart Research Foundation, Paavo Nurmi Foundation, Finska Läkarsällskapet and Signe och Ane Gyllenberg Foundation during the conduct of the study. PNS has been supported by the Finnish Medical Foundation during the conduct of the study. JKI has been supported by the European Regional Fund and the European Social Fund Plus (ESF+). The data collection is supported by the Ministry of Education and Culture of Finland Grant (OKM/10/626/2021 to JKI) and the European Regional Development Fund (#A74999 to JKI). Open access funded by Helsinki University Library.

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Consent obtained directly from patient(s).

Ethics approval This study involves human participants. The Ethics Committee of the Central Finland Health Care District (MIIA 5U/2019) and the Ethics Committee of the University of Jyväskylä (NoRED-S 514/13.00.04.00/2021) approved the study. Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request. The data are not publicly available due to containing information that could compromise the privacy and consent of the participants, but anonymised data are available on reasonable request from JKI.

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