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Dietary Fibre Intake in Older Adults Is Inversely Associated With Serum Remnant Cholesterol Level: A Nationwide Population-Based Study

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Correspondence: Jung-Ha Kim (girlpower219@cau.ac.kr)**Received:** 25 July 2024 | **Revised:** 5 September 2025 | **Accepted:** 16 September 2025**Funding:** The authors received no specific funding for this work.**Keywords:** adequate intake | cardiovascular disease | dietary fibre | dyslipidaemia | older adults | serum remnant cholesterol

ABSTRACT

Many studies have shown that dietary fibre lowers cholesterol levels; however, to our knowledge, no study has examined the relationship between dietary fibre intake and remnant cholesterol, which are known risk factors for cardiovascular disease (CVD). Therefore, we aimed to investigate the association between dietary fibre intake and remnant serum cholesterol levels in older Korean adults. We used data from the 2016 to 2021 Korea National Health and Nutrition Examination Survey, which included 8212 older adults. Serum remnant cholesterol levels were calculated by subtracting the low-density lipoprotein cholesterol and high-density lipoprotein cholesterol levels from the total cholesterol level. Hyperremnant cholesterolaemia was defined as a serum remnant cholesterol level of ≥ 30 mg/dL. Dietary fibre intake was classified on the basis of adequate intake (AI). A multi-variate logistic regression analysis was performed to examine the association between dietary fibre intake and remnant serum cholesterol levels. The odds ratio of hyper-remnant cholesterol aemia was 1.26 times higher in older adults with fibre intake below AI than in those with fibre intake above AI (95% confidence interval 1.06–1.48, $p < 0.01$). This study revealed that dietary fibre intake was inversely associated with serum remnant cholesterol levels in older Korean adults. Therefore, dietary fibre can be considered a novel therapeutic strategy for lowering remnant cholesterol and may benefit older adults at risk of CVD in terms of the prevention and inhibition of progression.

1 | Introduction

The risk of cardiovascular disease (CVD) increases progressively with age, and older adults ≥ 65 years of age account for more than half of all cases of cardiovascular hospitalisations in the United States as well as 80% of all cardiovascular deaths (Mozaffarian et al. 2016). In South Korea, CVD is the leading cause of death, accounting for 1 in every 5 deaths (Shin et al. 2016). It is a major cause of chronic disability, loss of independence and impaired quality of life in older adults (Yazdanyar and Newman 2009). CVD remains the leading cause of morbidity and mortality among older adults, and its medical burden is rapidly increasing

worldwide (Rethemiotaki 2023). Therefore, preventing CVD in older adults is very important.

The modification of risk factors, such as traditional cholesterol, that is, total cholesterol (TC) and low-density lipoprotein (LDL) cholesterol, has been emphasised for CVD prevention (Expert Panel on Detection, Evaluation and Treatment of High Blood Cholesterol in Adults 2001). Recent robust evidence implicates remnant cholesterol (RC) as an important contributor to the development of atherosclerosis and CVD (Wadström et al. 2023; Gomez-Delgado et al. 2024). RC is a group of highly atherogenic lipids that includes several

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lipoproteins, such as intermediate-density lipoprotein cholesterol, very-LDL cholesterol and chylomicron remnants, which are triglyceride (TG)-rich lipoproteins that are direct precursors of atherogenic small, dense LDL (Castañer et al. 2020). In a pooled cohort of individuals without CVD, elevated RC levels were related to atherosclerotic CVD, independent of traditional risk factors such as LDL cholesterol (LDL-C) and apolipoprotein B levels (Quispe et al. 2021). It has emerged as a crucial residual risk factor for CVD, and the American Heart Association lists it as an emerging atherogenic risk factor (Chandra et al. 2016).

Several studies have shown that dietary fibre lowers traditionally known cholesterol levels, including LDL-C, in relation to CVD risk (Brown et al. 1999; Bazzano et al. 2003; Erkkilä and Lichtenstein 2006; Bazzano 2008; Anggadiredja et al. 2020). Dietary fibre significantly affects hepatic cholesterol metabolism, synthesis and processing in the intravascular compartment and lipoprotein catabolism has been proposed as the main mechanism (Fernandez 2001; Ramjiganesh et al. 2002; Bazzano 2008). However, no study has examined the relationship between dietary fibre intake and RC in older adults at a high risk of CVD. Furthermore, dietary fibre intake is low in older adults (Buil-Cosiales et al. 2014), and identifying the effects of increased dietary fibre intake on CVD is important for older adults who are vulnerable to developing CVD. Therefore, we hypothesised that dietary fibre intake and serum RC levels are inversely correlated. We used nationwide population-based data to investigate the association between dietary fibre intake and serum RC and to provide new ideas for the early prevention of CVD.

2 | Methods

2.1 | Study Population

This cross-sectional study used data from the 2016–2021 Korea National Health and Nutrition Examination Survey (KNHANES). The KNHANES is a nationwide survey of the general health and nutritional status of all civilian, non-institutionalised Koreans conducted by the Korean Ministry of Health and Welfare and the Division of Health and Nutrition Research and Analysis of the Korean Centers for Disease Control and Prevention (KCDC). In KNHANES, a complex, stratified, multistage sampling design was used to analyse the data according to statistics from the KCDC (Kim and Hwang 2018).

Among 46828 participants from the 2016–2021 KNHANES, 10241 were aged ≥ 65 years. After excluding those with missing data on lipid profiles or energy/nutrient intake, as well as individuals with implausible total energy intake levels (< 500 kcal or > 4000 kcal), the number of eligible participants was 8212 (Figure 1).

2.2 | Ethical Approval

This study was conducted according to the guidelines of the Declaration of Helsinki. All procedures involving human



FIGURE 1 | Flow chart of participant inclusion in the study.

subjects were approved by the institutional ethical review board of the KCDC. The KNHANES was exempt from an ethics review based on the Bioethics and Safety Act from 2016 to 2017, and received annual approvals thereafter (No. 2018-01-03-P-A in 2018, 2018-01-03-C-A in 2019, 2018-01-03-2C-A in 2020 and 2018-01-03-3C-A in 2021).

2.3 | Data Collection

Trained staff interviewed the participants using standardised health questionnaires that collected demographic and clinical information, including medical history, total energy and dietary intake, smoking status and anthropometric data. Income level was classified as lowest (Q1), mid-low (Q2), mid-high (Q3) and highest (Q4) according to the household income quartile, and occupation was classified as non-manual worker, service or sales worker, manual worker or unemployed (including housewives and students). Marital status was classified as married or unmarried (including those who were not currently married, such as those who were divorced) and educational level was classified as above or below high school graduation. Total energy and dietary intake levels were evaluated using the 24-h recall method. Trained nutritionists surveyed the types of food consumed and the portion size per person through direct interviews using food photos or pictures to minimise errors in the one-time self-reported method. In the 24-h recall method, the contents and portions of meals consumed during the previous day were recorded, including the food name, total amount of food cooked and consumed, food code and in the case of processed foods, the product and

manufacturer names were recorded. The data were converted into nutrient units using various recipes, nutritional ingredients and volume/weight conversion databases. Conversion coefficients were applied, particularly when aggregating foods in different physical states, based on their solid content (Ministry of Health and Welfare, The Korean Nutrition Society 2020). Subsequently, based on classified food groups, each nutrient's daily intake (g/day) was calculated using CAN-Pro 5.0, a nutritional assessment programme developed by the Korean Society of Nutrition (The Korean Nutrition Society 2019). Dietary fibre intake was classified based on achievement of the Korean adequate intake (AI, ≥ 25 g/day for older men, ≥ 20 g/day for older women) (Ministry of Health and Welfare, The Korean Nutrition Society 2020). Exercise was classified as aerobic exercise (AE), resistance exercise (RE) or walking exercise (WE). The Korean version of the Global Physical Activity Questionnaire (GPAQ) (Lee et al. 2020) and the KNHANES questionnaire were used to identify AE, WE and RE, respectively. WE was surveyed the number of days of walking at least 10 min and walking time during the past week, and RE was surveyed the number of days of RE such as push-ups, sit-ups, dumbbells, weightlifting or pull-ups during the past week (Korea Centers for Disease Control and Prevention 2016; Oh et al. 2021). AE was defined as practising 150 min of moderate-intensity physical activity or 75 min of high-intensity physical activity or an equivalent time of a combination of the two per week, while RE was defined as the number of days of RE per week and WE referred to > 150 min of walking per week (Armstrong and Bull 2006; World Health Organization [WHO] 2020). Current smoking was defined as smoking more than five packs (100 cigarettes) in a lifetime and currently smoking regularly; high-risk alcohol intake was defined as drinking twice or more times a week, with an average number of ≥ 7 drinks for men and ≥ 5 drinks for women each time (Korea Centers for Disease Control and Prevention 2016). Depression was defined using the Patient Health Questionnaire-9, a depression screening tool, with a total score of ≥ 10 indicating depression (Levis et al. 2019). Medical history, including hypertension, diabetes mellitus, stroke, myocardial infarction or angina, osteoarthritis or rheumatoid arthritis, thyroid disease, renal disease and cancer (stomach, liver, colon, breast, cervix, lung, thyroid or others), was defined as a diagnosis by a physician, while dyslipidaemia was defined as the use of lipid-lowering medications. Obesity was defined as a body mass index ≥ 25 kg/m² according to the World Health Organization (WHO)'s Asia-Pacific obesity criteria (World Health Organization. Regional Office for the Western Pacific 2000), calculated by dividing weight (kg) by the square of height (m²). Hypo-high-density lipoprotein (hypo-HDL)-cholesterolaemia was defined as a serum HDL-cholesterol (HDL-C) level ≤ 40 mg/dL and hyper-LDL cholesterolaemia as a serum LDL-C level ≥ 130 mg/dL (Pencina et al. 2019). Non-HDL-C was calculated by subtracting the HDL-C level from the serum TC level. Hyper-non-HDL cholesterolaemia was defined as serum non-HDL-C ≥ 160 mg/dL (Pencina et al. 2019). Serum RC was calculated by subtracting LDL-C and HDL-C levels from serum TC levels, and hyper-RC was defined as serum RC ≥ 30 mg/dL (Lee et al. 2023). Blood samples were collected after fasting for 12 h, and serum TC, TG, HDL-C and LDL-C levels were measured using an automatic analyser (Hitachi 7600; Hitachi, Tokyo, Japan).

3 | Statistical Analysis

The KNHANES is a cross-sectional survey that uses a stratified, multistage, clustered probability sampling method to select a representative sample of the non-institutionalised civilian Korean population. Therefore, the statistical analyses in this study were conducted by adopting stratification, clustering and weighting variables to represent the Korean population.

Participants' characteristics were stratified on the basis of fibre intake and reported as means and standard errors for continuous variables and as weighted percentages and standard errors for categorical variables. Continuous variables were compared using independent *t*-tests and categorical variables using the chi-square test. Multivariate logistic regression analysis was performed to examine the association between dietary fibre intake and hyperremnant cholesterolaemia. Odds ratios (ORs) and 95% confidence intervals (CIs) were determined. We adjusted for multiple variables that showed significant associations in the univariate analysis (*p*-values of < 0.05) and those with clinical relevance. The dependent variable was hyperremnant cholesterolaemia, and the main independent variable was dietary fibre intake. Model 1 was adjusted for age, sex and total energy and nutrient consumption (carbohydrate, protein, fat and sugar); Model 2 was adjusted for income level, education status, occupation, marital status, AE, RE, WE, current smoking, high-risk alcohol intake and obesity in addition to Model 1's variables; Model 3 was adjusted for subjective perception of health, depression, serum LDL-C level, diagnosis of hypertension, diabetes mellitus, stroke, myocardial infarction or angina, osteoarthritis or rheumatoid arthritis, thyroid disease, renal disease, cancer (stomach, liver, colon, breast, cervix, lung, thyroid or other) and dyslipidaemia on medication, in addition to the variables of Model 2.

All variables included in the logistic regression analysis were examined for multicollinearity, and only those with a variance inflation factor of < 5 were used. All statistical analyses were performed using the SAS statistical software version 9.3 (SAS Institute Inc., Cary, NC, USA). The level of statistical significance was set at two-tailed *p*-values of < 0.05 .

4 | Results

4.1 | Demographic Characteristics of the Participants

Tables 1 and 2 show the demographics, nutrient intake and laboratory characteristics of the 8212 participants. The mean age was 73.00 ± 0.08 years, and there were 4677 (56.94%) women. The mean intake of dietary fibre was 26.07 ± 0.25 g per day. The mean serum TC, LDL-C, HDL-C and RC levels were 181.97 ± 0.53 mg/dL, 107.97 ± 0.48 mg/dL, 48.61 ± 0.16 mg/dL and 25.38 ± 0.21 mg/dL, respectively. Approximately one quarter (27.38%, $n = 2330$) were classified as having hyperremnant cholesterolaemia. Compared with the group that consumed more fibre than the AI group, total energy and macronutrient intake were lower and serum TG and RC levels were higher in the group that consumed less fibre than in the AI group ($p < 0.001$).

TABLE 1 | Demographic characteristics according to fibre intake in older Korean adults from the KNHANES 2016–2021.

Variables	All	Group that consumes less fibre than AI (<i>n</i> = 3734)	Group that consumes more fibre than AI (<i>n</i> = 4478)	<i>p</i> -value
Age (years)	73.00 ± 0.08	73.90 ± 0.11	72.26 ± 0.10	< 0.001
Women	56.94 (0.55)	57.37 (0.91)	56.59 (0.75)	< 0.001
Income				
Q1 _{lowest}	45.38 (0.91)	52.77 (1.15)	39.26 (1.10)	< 0.001
Q2 _{mid-low}	27.94 (0.69)	26.23 (0.93)	29.36 (0.92)	
Q3 _{mid-high}	16.03 (0.62)	12.72 (0.72)	18.78 (0.86)	
Q4 _{highest}	10.65 (0.57)	8.28 (0.60)	12.61 (0.78)	
Education				
Above high school graduation	35.49 (0.83)	29.64 (1.04)	40.36 (1.06)	< 0.001
Occupation				
Non-manual worker	3.89 (0.29)	2.58 (0.34)	4.94 (0.43)	< 0.001
Service or sales worker	5.25 (0.32)	5.28 (0.48)	5.23 (0.43)	
Manual worker	25.87 (0.74)	25.98 (1.01)	25.77 (0.90)	
Unemployed ^a	64.99 (0.74)	66.16 (1.07)	64.05 (0.94)	
Married	65.26 (0.76)	59.65 (1.09)	69.92 (0.90)	< 0.001
Current smoking ^b	9.43 (0.42)	11.70 (0.69)	7.56 (0.46)	< 0.001
High-risk drinking ^c	4.75 (0.28)	4.56 (0.39)	4.90 (0.39)	0.74
Aerobic exercise				
None	43.82 (0.77)	50.32 (1.08)	38.58 (0.96)	< 0.001
Adequate	31.57 (0.68)	25.54 (0.88)	36.43 (0.94)	
Resistant exercise				
None	79.92 (0.56)	85.46 (0.72)	75.43 (0.76)	< 0.001
≥ 2 days per week	18.99 (0.54)	13.42 (0.69)	23.51 (0.75)	
Walking exercise				
None	22.01 (0.66)	28.01 (1.00)	17.01 (0.74)	< 0.001
More than 150 min per week	45.81 (0.78)	38.25 (1.00)	52.09 (1.02)	
Obesity ^d	30.76 (0.67)	29.70 (0.97)	31.65 (0.81)	< 0.001
Subjective perception of health				
Very good or good	22.84 (0.83)	18.31 (1.10)	26.54 (1.15)	< 0.001
Average	47.52 (0.70)	47.40 (1.01)	47.62 (0.95)	
Poor or very poor	29.64 (0.92)	34.29 (1.48)	25.84 (1.13)	
Depression ^e	2.39 (0.21)	3.08 (0.36)	1.82 (0.21)	< 0.001
Diagnosis				
Hypertension	55.94 (0.66)	59.00 (0.95)	53.40 (0.90)	< 0.001
Diabetes mellitus	22.68 (0.55)	21.99 (0.82)	23.25 (0.73)	0.25
Stroke	5.77 (0.31)	6.73 (0.51)	4.97 (0.36)	0.004

(Continues)

TABLE 1 | (Continued)

Variables	All	Group that consumes less fibre than AI (n = 3734)	Group that consumes more fibre than AI (n = 4478)	p-value
Myocardial infarction or angina	7.79 (0.34)	8.39 (0.53)	7.28 (0.43)	0.10
Osteoarthritis or rheumatoid arthritis	30.39 (0.61)	31.09 (0.90)	29.81 (0.79)	0.28
Thyroid disease	4.22 (0.26)	3.00 (0.32)	5.24 (0.38)	<0.001
Renal disease	1.01 (0.13)	0.88 (0.15)	1.11 (0.20)	0.36
Cancer ^f	9.06 (0.38)	8.33 (0.54)	9.67 (0.52)	0.08
Dyslipidemia on medication	28.78 (0.61)	26.46 (0.87)	30.70 (0.80)	<0.001

Note: Data were obtained from the 2016–2021 Korean National Health and Nutrition Examination Survey. *p*-values were calculated using an independent *t*-test or chi-square test. Continuous variables are expressed as means and standard errors, whereas categorical variables are expressed as weighted percentages and standard errors.

Abbreviations: AI, adequate intake; HDL, high-density lipoprotein cholesterol; KNHANES, Korea National Health and Nutrition Examination Survey; LDL-cholesterol, low-density lipoprotein cholesterol; SE, standard error.

^aIncludes housewives and students.

^bDefined as smoking more than five packs (100 cigarettes) in a lifetime and currently smoking.

^cDefined as two or more times a week, average number per time (≥ 7 drinks for men and ≥ 5 drinks for women).

^dDefined as body mass index ≥ 25 kg/m².

^eDefined as the Patient Health Questionnaire-9 (PHQ-9), a depression screening tool with a total score of 10 or higher.

^fDefined as stomach, liver, colon, breast, cervix, lung, thyroid or other cancer.

Intake of energy and macronutrients per day and serum lipid profile showed differences between men and women (data not shown). The intake of total energy, protein, carbohydrate, fat, sugar and fibre was significantly higher in men compared to women. The levels of serum TC, HDL-cholesterol, LDL-cholesterol and non-HDL-cholesterol were significantly higher in women compared to men. There was no significant difference in the levels of serum TG and RC.

4.2 | Association Between Dietary Fibre Intake and Serum RC Level

Table 3 shows the ORs and 95% CIs for hyperremnant cholesterolaemia according to dietary fibre intake relative to the AI among 8212 older Korean adults. The model was adjusted for age, sex, energy and macronutrient consumption (total energy, protein, fat, carbohydrate, sugar and fibre), income level, educational status, occupation, marital status, exercise type, current smoking status, high-risk alcohol intake, obesity, subjective perception of health, depression, serum LDL-C level, diagnosis of hypertension, diabetes mellitus, stroke, myocardial infarction or angina, osteoarthritis or rheumatoid arthritis, thyroid disease, renal disease, cancer (stomach, liver, colon, breast, cervix, lung, thyroid or other) and dyslipidaemia on medication. In the group with fibre intake below AI, the OR of hyperremnant cholesterolaemia was 1.26 times higher than that in the group with fibre intake above AI (95% CI: 1.06–1.48, $p < 0.01$, for Model 3). The ORs for hypo-HDL cholesterolaemia, hyper-LDL cholesterolaemia and hyper-non-HDL cholesterolaemia between the two groups were not significant.

5 | Discussion

This cross-sectional study based on data from the KNHANES 2016–2021 showed that dietary fibre intake was inversely

associated with serum RC levels in older Korean adults. To the best of our knowledge, this is the first study to investigate the association between dietary fibre intake and serum RC levels in older adults.

In recent years, dietary fibre has been widely prescribed, alone or in combination with lipid-lowering therapies, to reduce cholesterol levels (Hartley et al. 2016) and CVD risk (Liu et al. 2015). Epidemiological and experimental data suggest that increasing dietary fibre may help reduce LDL-C levels (Bazzano 2008). A randomised controlled clinical trial reported that a mean reduction of 9% in LDL-C can be achieved with the intake of different sources of soluble fibre (Fernandez 2001). A meta-analysis showed that the consumption of soluble fibre, oat fibre and psyllium, with approved health claims made by the Food and Drug Administration on their cholesterol-lowering effects, reduced TC and LDL-C levels (Brown et al. 1999).

Although dietary fibre intake has been reported to improve lipid metabolism through multiple mechanisms, the exact mechanism by which it lowers serum cholesterol levels is not completely understood (Han et al. 2019). Several studies have demonstrated that dietary fibre significantly affects hepatic cholesterol metabolism as well as the lipoprotein synthesis, processing in the intravascular compartment and catabolism (Fernandez 2001; Ramjiganesh et al. 2002; Bazzano 2008). The main outcome of fibre action is the lowering of hepatic cholesterol pools as a result of the alteration of bile acid homeostasis by interrupting enterohepatic circulation (Ramjiganesh et al. 2002). Lipoprotein metabolism is altered by the depletion of hepatic pools owing to fibre intake (Bazzano 2008). In addition, hepatic LDL receptors are upregulated to re-establish cholesterol balance in the liver and contribute to the lowering of LDL-C levels by removing LDL from the plasma (Fernandez 2001). A previous study reported that this process leads to a decrease in cholesteryl ester transfer proteins and cholesterol levels (Shrestha et al. 2007). Another

TABLE 2 | Nutrient intake and laboratory characteristics according to fibre intake in older Korean adults from the KNHANES 2016–2021.

Intake of energy and macronutrients per day	All	Group that consumes less fibre than AI (<i>n</i> = 3734)	Group that consumes more fibre than AI (<i>n</i> = 4478)	<i>p</i> -value
Total energy (Kcal)	1602.91 ± 9.61	1284.75 ± 9.65	1867.71 ± 11.69	<0.001
Protein (g)	54.92 ± 0.43	42.22 ± 0.42	65.49 ± 0.56	<0.001
Fat (g)	28.62 ± 0.34	21.50 ± 0.34	34.54 ± 0.48	<0.001
Carbohydrate (g)	270.96 ± 1.58	216.49 ± 1.51	316.29 ± 1.93	<0.001
Sugar (g)	49.32 ± 0.59	30.88 ± 0.44	64.68 ± 0.75	<0.001
Fibre (g)	26.07 ± 0.25	15.11 ± 0.10	35.20 ± 0.27	<0.001
Lipid profile				
Serum total cholesterol (mg/dL)	181.97 ± 0.53	182.42 ± 0.81	181.60 ± 0.69	0.43
Serum HDL-cholesterol (mg/dL)	48.61 ± 0.16	47.97 ± 0.23	49.16 ± 0.21	<0.001
Serum LDL-cholesterol (mg/dL)	107.97 ± 0.48	108.27 ± 0.72	107.73 ± 0.63	0.57
Serum Non-HDL-cholesterol ^a (mg/dL)	133.36 ± 0.52	134.46 ± 0.80	132.44 ± 0.66	0.05
Serum triglyceride (mg/dL)	130.48 ± 1.20	134.84 ± 1.77	126.84 ± 1.44	<0.001
Serum remnant cholesterol ^b (mg/dL)	25.38 ± 0.21	26.19 ± 0.32	24.71 ± 0.25	<0.001
Hypo-HDL-cholesterolaemia ^c	22.70 (0.58)	25.00 (0.84)	20.80 (0.78)	<0.001
Hyper-LDL-cholesterolaemia ^d	25.86 (0.58)	25.65 (0.88)	26.03 (0.74)	0.74
Hyper-non-HDL-cholesterolaemia ^e	23.84 (0.56)	24.44 (0.87)	23.34 (0.75)	0.34
Hyper-remnant cholesterolaemia ^f (%)	27.38 (0.60)	29.74 (0.92)	25.42 (0.76)	<0.001

Note: Data were obtained from the 2016–2021 Korean National Health and Nutrition Examination Survey. *p*-values were calculated using an independent *t*-test or chi-square test. Continuous variables are expressed as means and standard errors, whereas categorical variables are expressed as weighted percentages and standard errors.

Abbreviations: AI, adequate intake; HDL, high-density lipoprotein cholesterol; KNHANES, Korea National Health and Nutrition Examination Survey; LDL-cholesterol, low-density lipoprotein cholesterol; SE, standard error.

^aNon-HDL cholesterol was calculated by subtracting the HDL cholesterol level from the serum total cholesterol level.

^bSerum remnant cholesterol was calculated by subtracting low-density lipoprotein cholesterol and high-density lipoprotein cholesterol levels from the serum total cholesterol level.

^cHypo-HDL cholesterolaemia was defined as a serum HDL cholesterol level of <40 mg/dL.

^dHyper-LDL cholesterolaemia is defined as serum LDL-cholesterol ≥130 mg/dL.

^eHyper-non-HDL cholesterolaemia is defined as serum non-HDL cholesterol ≥160 mg/dL.

^fHyper-remnant cholesterolaemia is defined as serum remnant cholesterol ≥30 mg/dL.

mechanism is the colonic fermentation of soluble dietary fibre, which results in the production of short-chain fatty acids (SCFAs), such as acetate, propionate and butyrate. SCFAs regulate lipid metabolism by increasing the oxidation of fatty acids in brown adipose tissue, promoting the browning of white tissue or reducing the size of adipose cells morphologically (Newby et al. 2007). Moreover, dietary fibre intake has been shown to reduce the levels of C-reactive protein, a marker of chronic inflammation and an important part of the pathogenesis of CVD, and inhibit the expression of nuclear factor kappa-light-chain-enhancer of activated B cells (NF-κB) and tumour necrosis factor-α (TNF-α)

related to inflammation (Cao et al. 2024). Unlike LDL-C, RC, which passes through the vessel wall, easily forms foam cells, a well-known attribute of inflammation, because RC requires no modification to be trapped by macrophages (Dushkin 2012). In addition, RC could induce pro-inflammatory cytokines such as TNF-α and interleukin-1, 6, 8 (Yu et al. 2021); therefore, dietary fibre intake may be more effective in reducing RC than LDL-C in terms of anti-inflammatory effects. Furthermore, a high-fibre diet enhances insulin sensitivity, which is associated with lowering the risk of CVD (Pandey et al. 2024). The combination of all these mechanisms results in a consistent hypocholesterolaemic

TABLE 3 | Unadjusted and adjusted ORs (95% CI) of hyper-remnant cholesterolaemia^a according to dietary fibre intake in older Korean adults from the KNHANES 2016–2021.

Multivariable model	Unadjusted		Model 1		Model 2		Model 3	
	OR (95% CI)	<i>p</i>	OR (95% CI)	<i>p</i>	OR (95% CI)	<i>p</i>	OR (95% CI)	<i>p</i>
Hypo-HDL-cholesterolaemia ^a								
Above AI	1		1		1		1	
Below AI	1.28 (1.12–1.46)	<0.01	1.17 (0.99–1.38)	0.07	1.09 (0.92–1.30)	0.34	1.11 (0.93–1.32)	0.25
Hyper-LDL-cholesterolaemia ^b								
Above AI	1		1		1		1	
Below AI	0.97 (0.86–1.09)	0.62	1.06 (0.91–1.23)	0.49	1.06 (0.91–1.23)	0.45	1.01 (0.85–1.19)	0.94
Hyper-non-HDL-cholesterolaemia ^c								
Above AI	1		1		1		1	
Below AI	1.05 (0.92–1.20)	0.47	1.13 (0.96–1.33)	0.14	1.13 (0.96–1.33)	0.14	1.09 (0.91–1.30)	0.37
Hyper-remnant cholesterolaemia ^d								
Above AI	1		1		1		1	
Below AI	1.26 (1.12–1.43)	<0.001	1.28 (1.09–1.50)	0.003	1.26 (1.07–1.48)	0.007	1.26 (1.06–1.48)	0.007

Note: Data were obtained from the 2016–2021 Korean National Health and Nutrition Examination Survey. Model 1 was adjusted for age, sex and energy and macronutrient consumption (total energy, protein, fat, carbohydrates, sugar and fibre). Model 2 was adjusted for income level, education status, occupation, marital status, aerobic exercise, resistance exercise, walking exercise, current smoking, high-risk alcohol intake and obesity, in addition to the variables in Model 1. Model 3 was adjusted for subjective perception of health, depression, serum low-density lipoprotein cholesterol level, diagnosis of hypertension, diabetes mellitus, stroke, myocardial infarction or angina, osteoarthritis or rheumatoid arthritis, thyroid disease, renal disease, cancer (stomach, liver, colon, breast, cervix, lung, thyroid or other) and dyslipidaemia on medication, in addition to the variables in Model 2.

Abbreviations: AI, adequate intake; CI, confidence interval; HDL-cholesterol, high-density lipoprotein cholesterol; KNHANES, Korean National Health and Nutrition Examination Survey; LDL-cholesterol, low-density lipoprotein cholesterol; OR, odds ratio.

^aHypo-HDL cholesterolaemia is defined as serum HDL-cholesterol <40 mg/dL.

^bHyper-LDL cholesterolaemia is defined as serum LDL-cholesterol ≥130 mg/dL.

^cHyper-non-HDL cholesterolaemia is defined as serum non-HDL cholesterol ≥160 mg/dL.

^dHyper-remnant cholesterolaemia is defined as serum remnant cholesterol ≥30 mg/dL.

effect induced by dietary fibre (Fernandez 2001), and the mechanism by which dietary fibre intake lowers serum RC levels is similar. In addition, RC may be more atherogenic than LDL-C owing to its pro-inflammatory effects and persistent retention time in the vasculature (Ganda 2023). Accumulated RC is absorbed by macrophages and smooth muscle cells, resulting in the formation of foam cells and the development of atherosclerotic plaques (Burnett et al. 2020; Quispe et al. 2021). Consequently, thickened blood vessel walls and narrowed vessels may hamper the supply of sufficient nutrition and oxygen to the entire body (Milutinović et al. 2020). Therefore, dietary fibre intake may contribute to the reduction of intravascular RC in the blood vessels.

A previous study reported that a high-fibre diet was associated with a decreased risk of CVD independent of dietary fat, energy and other dietary factors (Caggiula et al. 1996). In our study, even after adjusting for the intake of total energy and nutrients including fat, the negative association between dietary fibre intake and serum RC levels was significant. The results of our study provide robust evidence on the link between dietary fibre intake and CVD.

This study has some limitations. First, it was a cross-sectional study. Therefore, a causal relationship could not be established. Further prospective longitudinal studies with larger sample sizes are required to determine the precise interrelationships. Second,

we did not directly measure the RC levels but instead calculated them. However, the estimated RC correlates well with direct measurements and can be applied in clinical practice (Varbo et al. 2015); no significant difference was observed between the directly calculated and measured RC levels in previous studies (Faridi et al. 2019). In addition, one study reported that the calculated RC is strongly correlated with an increased risk of major adverse cardiovascular events (Jepsen et al. 2016). Therefore, the calculation of the RC as an alternative method is more convenient and easier to implement in clinical diagnosis and therapy, given the significantly reduced time and economic costs (Wang et al. 2022). Third, nutrient intake was calculated using the 24-h recall method in our study. In the KNHANES, trained nutritionists surveyed the types of food consumed and the portion size per person through direct interviews using food photos or pictures to minimise errors in the self-reported method, and the difference between the amount of food consumed every day and the usual intake was determined. In addition, according to a study that evaluated the accuracy of the 24-h recall method using the doubly labelled water method in elderly Korean men, it concluded that it was appropriate for evaluating the average energy intake of the group (Jeon et al. 2018). However, a one-time test does not reflect the subject's usual intake. Since the accuracy of the 24-h recall method may vary depending on the number of survey days (Lee et al. 2003), to minimise under-reporting, dietary assessments should be conducted over at least three non-consecutive days and include weekends (Ma

et al. 2009). Therefore, further studies, including a 24-h recall method repeated three times and having a representative sample of days, would increase the reliability of the nutrient intake data. Fourth, dietary fibre was classified into soluble and insoluble fibres. The decrease in serum LDL-C levels and reduced risk of CVD of relevance in prospective epidemiologic studies are mainly associated with soluble fibre (Bazzano et al. 2003). Since our study analysed the total dietary fibre intake, future research should target soluble fibre to yield meaningful results.

Nevertheless, our study has several strengths. First, we used data from the KNHANES, which has a homogeneous ethnicity and a large contemporary population, with data collected using validated questionnaires and assessments. Therefore, the current study provides valuable information on the effect of dietary fibre on serum RC levels. Second, our study models were fully adjusted for important potential confounders such as dietary intake and lipid-lowering agents, increasing the robustness of our results.

In conclusion, this quantitative cross-sectional analysis of data from the KNHANES 2016–2021 revealed that dietary fibre intake above the AI was significantly associated with low RC levels in older Korean adults. Our results underscore the association between dietary fibre intake and CVD, which imposes a critical burden on ageing societies. Based on the results of our study, intake of dietary fibre can be proposed as an important therapeutic strategy to reduce RC in an easily accessible, economically useful and convenient manner, which may benefit older adults at risk of CVD worldwide by preventing and inhibiting progression. Moreover, further research is needed to determine the precise dietary fibre intake levels for CVD prevention. Furthermore, the underlying mechanistic pathways must be explored in future studies to confirm the association between dietary fibre intake and serum RC.

Author Contributions

Conceptualisation: H.J.L., W.S., J.-H.K. Data curation: H.J.L., J.-H.K. Formal analysis: J.-H.K. Investigation: H.J.L. Methodology: H.J.L., J.-H.K. Project administration: J.-H.K. Resources: H.J.L. Software: J.-H.K. Supervision: J.-H.K. Validation: J.-H.K. Visualisation: H.J.L., W.S. Writing – original draft: H.J.L., W.S. Writing – review and editing: H.J.L., W.S., J.-H.K. All authors have read and approved the final version of the manuscript: H.J.L., W.S., J.-H.K.

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The authors have nothing to report.

Consent

Written informed consent was obtained from all the subjects.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data supporting the findings of this study are openly available from the Korea National Health and Nutrition Examination Survey (KNHANES) database at <https://knhanes.cdc.go.kr/knhanes/index.do>.

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