Category: Method paper

Title:
Measurement of cholesterol levels of the major serum lipoprotein classes by anion-exchange high-performance liquid chromatography with perchlorate ion-containing eluent

Abbreviated title:
HPLC measurement of cholesterol in serum lipoprotein classes

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ABSTRACT:

We have developed a high-performance liquid chromatographic (HPLC) method for measurement of cholesterol in the major classes of serum lipoproteins, i.e., high-density lipoprotein (HDL), low-density lipoprotein (LDL), intermediate-density lipoprotein (IDL), very-low-density lipoprotein (VLDL) and chylomicrons. Lipoproteins in serum were separated on a column containing diethylaminoethyl-ligand nonporous polymer-based gel by elution with a step gradient of sodium perchlorate concentration, and detected by postcolumn reaction with a reagent containing cholesterol esterase and cholesterol oxidase. The within-day assay and between-day assay coefficients of variation for cholesterol concentration in lipoproteins were in the ranges of 0.9-6.4 % and 1.1-11.9 %, respectively. The correlation coefficients between the values of HDL, LDL, IDL, VLDL, and chylomicron cholesterol measured by the HPLC method and those estimated by an ultracentrifugation method were 0.892, 0.921, 0.840, 0.930, and 0.873, respectively. Values of remnant-like particle cholesterol measured by an immunoseparation technique (Japan Immunoresearch Laboratories, Japan) were significantly correlated with VLDL and chylomicron cholesterol values measured by
the HPLC method ($r=0.883$ and $r=0.729$, respectively). This rapid and accurate HPLC method was successfully applied to the analysis of plasma lipoproteins of patients with hyperlipidemia.

KEY WORDS:
lipoprotein, cholesterol, chromatography
INTRODUCTION:

Hyperlipidemia is a risk factor for atherosclerotic events (1). Low-density lipoprotein (LDL) cholesterol plays a causal role in the development of atherosclerosis, and the guidelines adopted by the National Cholesterol Education Adult Treatment Panel in 1988 (ATP-I) recommended that normal values of LDL cholesterol are <3.36 mmol/L (2, 3). Updated guidelines released in 1993 (ATP-II) recognized high-density lipoprotein (HDL) cholesterol as an independent risk factor for coronary artery disease (CAD), recommending that HDL cholesterol of <0.91 mmol/l be considered high risk for CAD, while ≥1.56 mmol/l be considered protective against CAD (4). The latest guidelines adopted in 2001 (ATP-III) describe triglyceride (TG) as an independent risk factor, and recommend that TG values of <1.7 mmol/l are considered normal (5).

It is well known that the major classes of human lipoproteins are HDL, LDL, intermediate-density lipoprotein (IDL), very-low-density lipoprotein (VLDL) and chylomicrons (6, 7). Numerous studies have investigated the relationship between IDL level and the risk of CAD (8 - 12). Krauss et al. (11) reported that IDL mass and ratios of HDL cholesterol (HDL-C) to
total cholesterol (TC) or LDL cholesterol (LDL-C) were predictors for progression of CAD. Tarami et al. (8) reported that high IDL cholesterol level was associated with a high frequency of CAD. Various methods for analysis of lipoproteins by ultracentrifugation (6, 7, 13), electrophoresis (14 - 16), gel-permeation chromatography (17, 18), and anion-exchange chromatography (19) have been reported. The cholesterol levels of all the major classes of lipoproteins in serum can be measured by ultracentrifugation, but it takes a long time to perform the analysis (6, 7, 13). The other methods have poor ability to measure IDL cholesterol level (14 - 19).

It is generally thought that remnant lipoproteins promote atherosclerosis. Remnant lipoproteins are products of partially catabolized chylomicrons and VLDL, generated by lipoprotein lipase. Recently, an immunoseparation method was developed in order to determine serum levels of cholesterol of remnant-like particles (RLP-C) (20). These remnant-like particle (RLP) fractions consist of chylomicron remnants and a fraction of VLDL enriched in apolipoprotein E (21 - 23). RLP-C levels have been found to be high in sera of patients with CAD (24, 25), type III hyperlipoproteinemia (26), and diabetic nephropathy (27).
We have developed a new method for lipoproteins analysis by anion-exchange chromatography on a diethylaminoethyl-ligand column. The use of a sodium perchlorate concentration gradient in the eluting solution allowed easy and rapid separation and determination of HDL, LDL, IDL, VLDL and chylomicrons in serum. The obtained cholesterol levels of lipoproteins were compared with RLP-C levels. This high-performance liquid chromatographic (HPLC) method was confirmed to be eligible for the rapid and accurate analysis and determination of the five major lipoprotein classes in hyperlipidemic sera.

MATERIALS AND METHOD:

Materials and chemicals

The enzymatic cholesterol reagent for HPLC was the commercially available Cholesterol-E test Wako kit (Wako Pure Chemical Industries, Osaka, Japan). TC, TG, HDL-C, and LDL-C in samples were determined enzymatically using commercially available kits, Tcho-L, TG-LH (Wako Pure Chemical Industries, Osaka, Japan), Cholestest N HDL, and Cholestest LDL (Daiichi Pure Chemicals Co., Tokyo, Japan), respectively. RLP-C levels
were also determined with a commercially available kit (Jimro-II, Japanese Immunoresearch Laboratories Company, Gunma Japan).

Chromatography

The HPLC system was composed of two pumps, an anion-exchange column, a post-column reactor and a photometer. The column, which contained 2.5 µm nonporous polymer-based gel with diethylaminoethyl ligands, was 4.6 mm I.D. x 20 mm in size. The column was replaced after three hundred samples had been analyzed. Eluent A (50 mM Tris-HCl + 1 mM ethylenediamine tetraacetic acid, disodium salt, dihydrate, pH 7.5) and eluent B (50 mM Tris-HCl + 500 mM sodium perchlorate + 1 mM ethylenediamine tetraacetic acid, disodium salt, dihydrate, pH 7.5) were used to separate the lipoproteins. We used a pump (CCPM-II, Tosoh Corp., Tokyo, Japan) for eluents A and B, which are delivered through two pump heads for gradient elution. The flow rate was 0.8 ml/min. Eluents A and B were mixed on-line. The step gradient patterns for separation of the lipoprotein classes were 20.5 % eluent B for 0-3.5 min, 24.5 % eluent B for 3.5-7.0 min, 27.5 % eluent B for 7.0-9.0 min, 32.5 % eluent B for
9.0-12.0 min, 100 % eluent B for 12-13 min, and
20.5 % eluent B for 13-20 min. Therefore, it took 20
min to complete the assay of one sample. The eluent
flowed into the photometer after 6 min. Fig.1 show a
representative chromatogram of hyperlipidemic serum during
the changes in the step gradient indicated by a hatched
line. An auto sampler (AS-8021, Tosoh Corp., Tokyo,
Japan) was used. The temperature of the column was
maintained at 25 °C with a column oven (CO-8020,
Tosoh Corp., Tokyo, Japan). The eluate from the column
was mixed with an enzymatic cholesterol reagent, which
contained cholesterol esterase, cholesterol oxidase, peroxidase,
4-aminoantipyrine and N-ethyl-N-(2-hydroxy-3-sulfopropyl)-
3,5-dimethoxyaniline, sodium salt. The flow rate of the
enzymatic cholesterol reagent was set at 0.4 ml/min by
using a pump (DP-8020, Tosoh Corp., Tokyo, Japan).
The mixed solution reacted at 37 °C for 5 min in a
Teflon coil (0.5 mm I.D. x 31 m). A reactor (CO-8020,
Tosoh Corp., Tokyo, Japan) was used for the
post-column reaction. The eluate from the reactor was
monitored at 600 nm using a photometer equipped with
a flow cell (UV-8020, Tosoh Corp., Tokyo, Japan).
Chromatograms were recorded by a data processor
SC-8020 (Tosoh Corp., Tokyo, Japan). It is confirmed
that the concentration of sodium perchlorate in eluent B did not interfere of enzymatic activities in the cholesterol reagent (data not shown).

Control serum (TC = 4.42 mmol/l, TG = 1.63 mmol/l, LDL-C = 1.89 mmol/l, and HDL-C = 1.50 mmol/l) was stored at -60 °C. The cholesterol concentration of each lipoprotein peak in chromatograms of hyperlipidemic sera was calculated by proportion of the peak area of each lipoprotein to the chromatogram’s total area reflecting the total cholesterol level. Total cholesterol levels of hyperlipidemic sera were calculated by proportion of these chromatogram’s total area of lipoprotein peaks of sample sera to total area of chromatogram peak of the control serum with known concentration of total cholesterol.

Samples

Serum from a healthy subject (TC = 4.42 mmol/l, TG = 1.63 mmol/l, LDL-C = 1.89 mmol/l, and HDL-C = 1.50 mmol/l), described above as the control serum, and sera from two hyperlipidemic patients (patient 1, TC = 5.87 mmol/l, TG = 4.16 mmol/l, LDL-C = 1.99 mmol/l, and HDL-C = 0.98 mmol/l; patient 2, TC = 7.40 mmol/l, TG = 6.14 mmol/l, LDL-C = 4.45 mmol/l,
and HDL-C = 0.91 mmol/l) were used for separation of HDL, LDL, IDL, VLDL and chylomicrons by ultracentrifugation. Thirty-six hyperlipidemic sera were used to examine correlations between the data obtained by the HPLC method and by an ultracentrifugation method. The data for the hyperlipidemic sera were as follows:

TC (mean = 6.59 mmol/l, S.D. = 1.10 mmol/l, max-min = 8.97-4.75 mmol/l), TG (mean = 5.42 mmol/l, S.D. = 1.99 mmol/l, max-min = 12.02-0.43 mmol/l), HDL-C (mean = 2.60 mmol/l, S.D. = 0.98 mmol/l, max-min = 4.57-1.03 mmol/l), and LDL-C (mean = 1.47 mmol/l, S.D. = 0.78 mmol/l, max-min = 4.12-0.72 mmol/l).

Sera of 9 healthy subjects and 19 hyperlipidemic patients were used for the comparison of lipoprotein cholesterol data obtained by the HPLC method and RLP-C values. The 28 sera were obtained from venous blood samples drawn after a 12-h fast. The sera were stored at 4 °C, and analyzed within 3 days. In sera of the healthy subjects, TC and TG were less than 5.66 mmol/l and 1.68 mmol/l, respectively. The healthy group excluded subjects with diabetes mellitus, hypertension, heart disease, thyroid disorder, liver dysfunction or renal dysfunction. The 19 hyperlipidemic patients had serum
levels of TC > 6.21 mmol/l or TG > 1.70 mmol/l.

**Ultracentrifugation method**

Sequential ultracentrifugation of serum lipoproteins was performed by the method reported previously (6, 7). The flotation rates of chylomicrons and VLDL were set at >400, and 20-400, respectively, in a solution of 1.745 mol/l sodium chloride (d=1.063 g/ml). Densities of IDL, LDL, and HDL were set as follows: 1.006<d<1.019 g/ml, 1.019<d<1.063 g/ml, and 1.063<d g/ml, respectively.

An SCP70H2 ultracentrifuge (Hitachi Koki Co., Tokyo, Japan) and an RP55T angle rotor (Hitachi Koki Co., Tokyo, Japan) were used.

**Linearity and precision tests**

To test for linearity, hyperlipidemic serum (TC = 6.65 mmol/l, TG = 13.11 mmol/l, LDL-C = 3.13 mmol/l, and HDL-C = 1.03 mmol/l) was used. The samples were diluted serially with 0.05% bovine serum albumin solution, and 7 µl aliquots were injected. For the within-day assay and between-day assay precision tests, the hyperlipidemic serum was stored at 4 °C until used. The injected volume was 3.5 µl.
Correlation test

HDL, LDL, IDL, VLDL and chylomicron fractions from the 36 hyperlipidemic sera were separated by the sequential ultracentrifugation method. Cholesterol levels of each lipoprotein fraction and the whole serum were determined using an enzymatic cholesterol kit (Tcho-L, Wako Pure Chemical Industries, Osaka, Japan) with an automated chemical analyzer (Model 7350E, Hitachi Koki Co., Tokyo, Japan).

Statistics

The correlations between cholesterol values of each lipoprotein measured by the HPLC method and those estimated by an ultracentrifugation method or RLP-C values were evaluated in terms of Pearson product-moment correlation coefficients. Student’s unpaired t test was used for determining the statistical significance of differences (p<0.05) between cholesterol values of each lipoprotein and RLP-C values of the healthy group and those of the hyperlipidemic group.

RESULTS:

Chromatogram of the HDL, LDL, IDL, VLDL and
Chylomicron fractions separated by ultracentrifugation

Four peaks were identified in the chromatogram of serum from a healthy subject (Fig. 2f). These peaks were eluted at 20.5, 24.5, 27.5, and 32.5% eluent B, respectively, and were detected at 6.40, 10.26, 13.64, and 15.41 min, respectively (Fig. 2f). The HDL, LDL, IDL, VLDL and chylomicron fractions of the serum were analyzed by the HPLC method to identify the 4 peaks. Figures 2a-e show the chromatogram patterns of the individual lipoprotein fractions. The peaks of HDL, LDL, IDL, and VLDL derived from the healthy serum were eluted at 6.28, 10.48, 13.51, and 15.43 min, respectively (Figs. 2a-d). Figures 2a-d and f indicate that the major components of peaks 1, 2, 3, and 4 of the healthy serum are HDL, LDL, IDL, and VLDL, respectively. In the chromatogram, the lipoprotein peak of the chylomicron fraction was essentially absent, which is as expected, because the amount of chylomicrons in healthy serum is very small (Fig. 2e).

Five peaks were identified in chromatograms of hyperlipidemic sera (Fig. 3Af and 3Bf). These peaks were eluted at 20.5, 24.5, 27.5, 32.5, and 100% eluent B, respectively. The individual lipoprotein fractions of the hyperlipidemic sera were analyzed by the HPLC method.
to identify the 5 peaks. Figs. 3Aa-e and 3Ba-e show the chromatogram patterns of the individual lipoprotein fractions. The peaks of HDL, LDL, IDL, and chylomicrons in the serum of hyperlipidemic patient 1 were eluted at 6.29, 9.95, 13.50, and 18.05 min, respectively (Figs. 3Aa-c, 3Ae). In the serum of hyperlipidemic patient 2, the lipoprotein peaks were eluted at 6.27, 10.56, and 18.04 min, respectively (Figs. 3Ba-b and 3Be). The major peaks of VLDL in the serum from hyperlipidemic patient 1, and IDL and VLDL in the serum from hyperlipidemic patient 2 were eluted at 15.45, 13.61, and 15.50 min, respectively (Figs. 3Ad and 3Be-d). Figures 3Aa-f and 3Ba-f indicate that the major components of peaks 1, 2, 3, 4 and 5 of the hyperlipidemic sera are HDL, LDL, IDL, VLDL, and chylomicrons, respectively.

In the IDL fraction of serum from hyperlipidemic patient 2, minor peaks were found at 15.27 and 18.12 min (Fig. 3Bc). The peaks of IDL observed in the healthy serum and the serum of hyperlipidemic patient 1 were broader than the peaks of HDL and LDL (Figs. 3Aa-c and 2a-c), probably because IDL is heterogeneous. In the VLDL fraction of sera from hyperlipidemic patients 1 and 2, minor peaks were found at 18.25
and 18.22 min, respectively (Fig. 3Ad and 3Bd). The minor peak was not found in the VLDL fraction of the healthy serum (Fig. 2d).

**Linearity and precision of the HPLC method**

Fig. 4A shows a chromatogram of the hyperlipidemic serum used for performing the linearity test. Linear relationships were found between the peak area of each lipoprotein class (peaks 1, 2, 3, 4 and 5) and total peak area and dilution ratio in the range up to 8 times (Fig. 4B and C). Table 1 shows the precision of this HPLC method applied to a hyperlipidemic serum. The values of within-day assay and between-day assay coefficients of variation (C.V.) of cholesterol concentration of each lipoprotein class were less than 6.4, and 11.9 %, respectively. The reproducibility was satisfactory. Within-day assay and between-day assay C.V. values of retention time were less than 1.1 %, which is excellent.

The good linearity of the relationships between peak area of each lipoprotein class and dilution ratio, in addition to the high precision, indicate that the cholesterol levels of each lipoprotein class and total lipoproteins in sera can be reliably determined by this
Correlations between cholesterol concentrations of serum lipoproteins obtained by the HPLC method and those estimated by an ultracentrifugation method

Correlations between the values of HDL, LDL, IDL, VLDL and chylomicron cholesterol and total cholesterol in 36 hyperlipidemic sera, measured by the two methods, are shown in Figs. 5A-F. The cholesterol concentrations were calculated from the peak areas of the lipoprotein classes. Total cholesterol was calculated from total peak area of the chromatogram. The linear regression equations and the coefficients of correlation between values of HDL-C, LDL-C, IDL cholesterol, VLDL cholesterol, chylomicron cholesterol and TC found by the HPLC method and those estimated by using ultracentrifugation and an automated chemical analyzer were $y=0.988x-0.0012$ ($r=0.892$), $y=0.885x+0.467$ ($r=0.921$), $y=1.369x+0.0504$ ($r=0.840$), $y=0.983x-0.015$ ($r=0.930$), $y=0.856x-0.091$ ($r=0.873$) and $y=1.050x-0.073$ ($r=0.954$), respectively. The satisfactory correlations between the results of the two different methods support the usefulness of our HPLC method for determination of cholesterol levels in HDL, LDL, IDL, VLDL, chylomicrons and total lipoproteins.
Comparison of cholesterol levels of each lipoprotein measured by the HPLC method and RLP-C level

Samples used for this comparison were sera from 9 healthy subjects and 19 hyperlipidemic patients. Table 2 shows the characteristics of the two groups. There were 7 males and 2 females in the healthy group and 10 males and 9 females in the hyperlipidemic group. Mean LDL-C levels were similar. Hyperlipidemic patients had significantly lower levels of HDL-C, and higher cholesterol levels of IDL, VLDL, chylomicrons, and RLP cholesterol than did healthy subjects (Table 2). The correlation between the cholesterol levels of the 5 lipoprotein classes obtained by the HPLC method and the RLP-C levels was examined. The correlation coefficients of HDL, LDL, IDL, VLDL, and chylomicrons were 0.493, 0.127, 0.166, 0.833, and 0.729, respectively (Fig. 6). Cholesterol concentrations of VLDL and chylomicrons obtained by the HPLC method were significantly correlated with RLP-C (p<0.00001 and p<0.00001, respectively).

DISCUSSION:

We showed that the 5 major classes of lipoproteins
(HDL, LDL, IDL, VLDL and chylomicrons) in serum can be separated within 20 min by means of a novel anion-exchange HPLC procedure involving elution with stepwise concentration changes of perchlorate ion. The sequential flotation ultracentrifugation method has the ability to separate major classes of lipoproteins and, moreover, subfractions of LDL, IDL and VLDL can be separated by using a cumulative flotation ultracentrifugation method (13). However, it takes 4 days to separate the 5 major classes of lipoproteins by sequential flotation ultracentrifugation (13). Several HPLC methods for separation of lipoproteins have been reported (16 - 19). Okazaki et al. developed a separation method of plasma lipoproteins using gel permeation chromatography, with which analysis of one sample takes 16 min (17). In this method, the separation between HDL and LDL was sufficient, but the separation between LDL and VLDL was apparently not sufficient for measurement of the cholesterol levels of each lipoprotein (17). VLDL, IDL and LDL in plasma from a patient with type III hyperlipidemia, in which IDL is a major lipoprotein class, formed one broad peak (17). Haginaka et al. reported that HDL, LDL and VLDL in plasma were completely separated within 20 min using an
anion-exchange HPLC method with step-gradient elution (19). However, they did not examine the separation of IDL in plasma (19).

In a previous paper, we reported a HPLC method for serum lipoprotein using a cation-exchange column with magnesium ion-containing eluents (28). It was shown that HDL, LDL, IDL and VLDL in hyperlipidemic serum were eluted in order from the column with a linear concentration gradient of magnesium nitrate, and that IDL did not form a distinct peak, being in part included in both the LDL and the VLDL peaks (28). Furthermore, IDL did not form a distinct peak in elution with a step gradient of magnesium nitrate concentration (data not shown). In contrast, we were able to separate HDL, LDL, IDL, VLDL and chylomicrons in hyperlipidemic sera by using an anion-exchange column eluted with a step gradient of sodium perchlorate concentration, obtaining distinct peaks. However, the serum lipoproteins were not separated with a step gradient of sodium chloride, ammonium nitrate or sodium sulfate concentration (data not shown). It is known that chaotropic ions such as perchlorate, iodide and thiocyanate disrupt and decrease hydrophobic bonds (29). It is likely that the weak hydrophobic interaction
between lipoproteins and the gel surface in the column was disrupted by the eluent containing perchlorate ion, a chaotropic ion. Additionally, lipoproteins in a hyperlipidemic serum were separated by using the reported anion-exchange HPLC system with a linear gradient of sodium perchlorate concentration. In the 0-155 mM linear gradient of sodium perchlorate, two HDL peaks, one broad LDL peak, one IDL peak, and one broad VLDL peak were separated (data not shown). In the eluent containing 500 mM sodium perchlorate, chylomicrons were eluted from the column. The two HDL peaks, and the broad forms of LDL and VLDL might reflect the subclasses of these lipoproteins, but this remains to be established.

The analysis of hyperlipidemic sera using agarose gel electrophoresis demonstrated that the chylomicrons were immobile (16). Therefore, chylomicrons do not carry a negative charge. In the present work, the chylomicrons in hyperlipidemic sera were bound to the gel, and eluted by 100% eluent B, containing a high concentration of perchlorate ion (Figs. 3Af and 3Bf). The chylomicrons probably were bound stronger than the other lipoproteins to hydrophobic part on the gel.

Previous reports have shown that LDL, IDL and
VLDL in hyperlipidemic sera are heterogeneous (30 - 35). We observed one major peak and two minor peaks in the IDL fraction of hyperlipidemic patient 2 (Fig. 3Bc), and serum from hyperlipidemic patient 1 showed a broad peak of IDL (Fig. 3Ac). In addition, the LDL fraction showed tailing (Figs. 2b and 3Bb), and the VLDL fraction showed a slight leading portion (Figs. 2d and 3Ad). Therefore, the IDL peak appears to contain small amounts of LDL and VLDL, and this may be the reason why the IDL cholesterol concentrations estimated by our HPLC method were larger than those measured by ultracentrifugation (Fig. 5C).

In the VLDL fraction of hyperlipidemic sera, minor peaks were detected at approximately 18 min (Figs. 3Ad and 3Bd). The chylomicron cholesterol concentrations confirmed by this HPLC method were similar to those estimated by the ultracentrifugation method. This result suggests that chylomicrons do not account for the minor peak observed in the VLDL fraction. Conceivably, serum lipoproteins were partially disrupted during separation by ultracentrifugation, thereby resulting generation of these minor peaks detected from the VLDL isolated by ultracentrifugation, but this remains to be examined.

It has been found that the cholesterol levels of
VLDL and chylomicrons found by the HPLC method were positively correlated with RLP-C levels (Fig. 6). Leary et al. reported that RLP-C was correlated more highly with VLDL cholesterol measured by an ultracentrifugation method than with IDL cholesterol (22). Their results are consistent with ours. RLP contains chylomicron remnants and VLDL enriched in apolipoprotein E (21 - 23). It was reported that VLDL enriched in apolipoprotein E has higher cholesterol level, and smaller particle size compared with the average values of the VLDL fraction (34, 35). These findings are consistent with the strong correlation between VLDL cholesterol and RLP-C. It is known that chylomicron remnants are products of partially catabolized chylomicrons in which some triglycerides have been hydrolyzed by lipoprotein lipase, and most of the cholesteryl esters of chylomicrons are retained in chylomicron remnants (36). Conceivably, most of the cholesterol esters of the chylomicron fraction in hyperlipidemic sera are included in chylomicron remnants. If so, this would support the correlation between chylomicron cholesterol and RLP-C (Fig. 6), but this remains to be examined.

In conclusion, this study showed that the 5 major classes of lipoproteins in human sera can be separated
by a novel anion-exchange chromatography procedure involving step-gradient elution with an eluent containing chaotropic ions, and that cholesterol levels in each lipoprotein can be determined. We validated the HPLC method by examining its linearity and precision, and the correlation of values measured by the HPLC method with data estimated by a sequential flotation ultracentrifugation method. The results suggest that the method presented here is suitable for rapid and accurate evaluation of cholesterol levels of HDL, LDL, IDL, VLDL and chylomicrons in human hyperlipidemic sera.
REFERENCES:


Figure legends:

**FIG. 1** Chromatogram of hyperlipidemic serum and pattern of step gradient. The patterns of lipoprotein profile and step gradient were indicated by solid line and dotted line, respectively. Sample for chromatogram was serum of hyperlipidemic patient 2. Retention times of peaks 1, 2, 3, 4, and 5 were 6.15, 10.20, 13.60, 15.60, and 18.28 min, respectively.

**FIG. 2** Chromatograms of lipoproteins separated from healthy serum by ultracentrifugation. Samples for chromatograms a, b, c, d, and e were HDL, LDL, IDL, VLDL, and chylomicrons separated by the ultracentrifugation method, respectively. Chromatogram f is that of whole healthy serum. Retention times of peak 1 in a, b, c, and d were 6.28, 10.48, 13.51, and 15.43 min, respectively. Retention times of peaks 1, 2, 3, and 4 in f were 6.40, 10.26, 13.64, and 15.41 min, respectively.

**FIG. 3** Chromatograms of lipoproteins separated from hyperlipidemic sera by ultracentrifugation. A, Samples for chromatograms a, b, c, d, and e were HDL, LDL,
IDL, VLDL, and chylomicrons separated from serum of hyperlipidemic patient 1 serum by the ultracentrifugation method, respectively. Chromatogram f is that of the whole serum. Retention times of peak 1 in a, peak 1 in b, peak 1 in c, peaks 1 and 2 in d, and peak 1 in e were 6.29, 9.95, 13.50, 15.45, 18.25, and 18.05 min, respectively. Retention times of peaks 1, 2, 3, 4, and 5 in f were 6.13, 10.35, 13.65, 15.45, and 18.20 min, respectively. B, Samples for chromatograms a, b, c, d, and e were HDL, LDL, IDL, VLDL, and chylomicrons separated from serum of hyperlipidemic patient 2 by the ultracentrifugation method, respectively. Chromatogram f is that of the whole serum. Retention times of peak 1 in a, peak 1 in b, peaks 1, 2, and 3 in c, peaks 1 and 2 in d, and peak 1 in e were 6.27, 10.56, 13.61, 15.27, 18.12, 15.50, 18.22, and 18.04 min, respectively. Retention times of peaks 1, 2, 3, 4, and 5 in f were 6.15, 10.20, 13.60, 15.60, and 18.28 min, respectively.

FIG. 4 Linearity of peak areas of each lipoprotein. A, A hyperlipidemic serum was analyzed. The retention times of peaks 1, 2, 3, 4, and 5 were 6.38, 10.70, 13.77, 15.67, and 18.45 min, respectively. The sample diluted 2
times with 0.05 % bovine serum albumin solution was 
analyzed using an injection volume of 7 µl. B, The 
data are areas of peaks 1 (triangle), 2 (circle) and 5 
(square) from 7 µl samples diluted up to 8 times. C, 
The data are areas of peak 3 (square), peak 4 
(triangle) and total peaks (circle) in 7 µl samples 
diluted up to 8 times.

**FIG. 5** Correlation of HDL-C, LDL-C, IDL cholesterol, 
VLDL cholesterol, chylomicron cholesterol, and TC values 
obtained by the HPLC method with those obtained by 
using ultracentrifugation and an automated chemical 
analyzer. Aliquots of 3.5 µl of 36 hyperlipidemic sera 
were analyzed by the HPLC method, and the cholesterol 
concentration of each lipoprotein was determined. Each 
lipoprotein fraction in the 36 hyperlipidemic sera was 
separated by ultracentrifugation, and cholesterol levels in 
the lipoprotein fraction and the whole serum were 
measured using a commercial enzyme kit. A, B, C, D, 
E and F show the correlations for HDL-C, LDL-C, 
IDL cholesterol, VLDL cholesterol, chylomicron cholesterol, 
and TC, respectively. Linear regression equations and 
correlation coefficients were as follows: A, HDL-C 
\( y=0.988x-0.0012 \quad r=0.892 \); B, LDL-C \( y=0.885x+0.467 \quad r-
FIG. 6 Correlation of HDL-C, LDL-C, IDL cholesterol, VLDL cholesterol, and chylomicron cholesterol values obtained by the HPLC method with RLP-C values. Aliquots of 3.5 µl of 28 sera were analyzed by the HPLC method, and the cholesterol concentration of each lipoprotein was determined. RLP-C values in these sera were determined by using a commercial kit (Jimro-II, Japanese Immunoresearch Laboratories Company, Gunma Japan). The data obtained for 9 healthy sera and 19 hyperlipidemic sera are represented by closed circles and open circles, respectively. A, B, C, D, and E show the correlations for HDL-C, LDL-C, IDL cholesterol, VLDL cholesterol, and chylomicron cholesterol, respectively. Linear regression equations and correlation coefficients were as follows: A, HDL-C \( (y=-1.883x+1.682 \ r=0.493) \); B, LDL-C \( (y=1.250x+2.944 \ r=0.127) \); C, IDL cholesterol \( (y=0.234x+0.230 \ r=0.166) \); D, VLDL cholesterol \( (y=3.005x+0.049 \ r=0.833) \); E, chylomicron cholesterol \( (y=0.507x+0.020 \ r=0.729) \).
Footnotes:

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2 Abbreviations used: HPLC, high-performance liquid chromatography (or chromatographic), HDL, high-density lipoprotein, LDL, low-density lipoprotein, IDL, intermediate-density lipoprotein, VLDL, very-low-density lipoprotein, TC, total cholesterol, TG, triglyceride, HDL-C, HDL cholesterol, LDL-C, LDL cholesterol, S.D., standard deviation, C.V., coefficient of variation, CAD, coronary artery disease, RLP, remnant-like particles, RLP-C, cholesterol level of remnant-like particles.
<table>
<thead>
<tr>
<th>Lipoprotein</th>
<th>HDL (mmol/l)</th>
<th>LDL (mmol/l)</th>
<th>IDL (mmol/l)</th>
<th>VLDL (mmol/l)</th>
<th>Chylomicrons (mmol/l)</th>
<th>Total (mmol/l)</th>
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<td>Within Assay (n = 10)</td>
<td>Mean</td>
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<td>S.D.</td>
<td>0.017</td>
<td>0.033</td>
<td>0.015</td>
<td>0.020</td>
<td>0.024</td>
<td>0.059</td>
</tr>
<tr>
<td>C.V. (%)</td>
<td>1.76</td>
<td>1.20</td>
<td>4.19</td>
<td>0.93</td>
<td>6.40</td>
<td>0.89</td>
</tr>
<tr>
<td>Between Assay (n = 5)</td>
<td>Mean</td>
<td>1.00</td>
<td>2.79</td>
<td>0.37</td>
<td>2.17</td>
<td>0.32</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.017</td>
<td>0.108</td>
<td>0.037</td>
<td>0.025</td>
<td>0.038</td>
<td>0.110</td>
</tr>
<tr>
<td>C.V. (%)</td>
<td>1.72</td>
<td>3.78</td>
<td>9.75</td>
<td>1.12</td>
<td>11.82</td>
<td>1.61</td>
</tr>
<tr>
<td>Retention Time Within Assay (n = 10)</td>
<td>Mean (min)</td>
<td>6.42</td>
<td>10.58</td>
<td>13.76</td>
<td>15.68</td>
<td>18.50</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.030</td>
<td>0.048</td>
<td>0.045</td>
<td>0.032</td>
<td>0.016</td>
<td>—</td>
</tr>
<tr>
<td>C.V. (%)</td>
<td>0.47</td>
<td>0.46</td>
<td>0.33</td>
<td>0.21</td>
<td>0.09</td>
<td>—</td>
</tr>
<tr>
<td>Between Assay (n = 5)</td>
<td>Mean (min)</td>
<td>6.47</td>
<td>10.61</td>
<td>13.81</td>
<td>15.73</td>
<td>18.53</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.070</td>
<td>0.084</td>
<td>0.050</td>
<td>0.040</td>
<td>0.058</td>
<td>—</td>
</tr>
<tr>
<td>C.V. (%)</td>
<td>1.08</td>
<td>0.79</td>
<td>0.36</td>
<td>0.25</td>
<td>0.31</td>
<td>—</td>
</tr>
</tbody>
</table>

*The sample used was the same as that for the linearity test (Fig. 3A).

b HDL, LDL, IDL, VLDL, and chylomicrons lipoprotein are peaks 1, 2, 3, 4, and 5 in Fig. 3A, respectively.

c Total cholesterol concentration was calculated from the total peak area of lipoproteins.

d S.D. is the abbreviation for standard deviation.

e C.V. is the abbreviation for coefficient of variation.
### TABLE 2
Characteristics of healthy subjects and hyperlipidemic patients

<table>
<thead>
<tr>
<th></th>
<th>Healthy subjects (n=9)</th>
<th>Hyperlipidemic patients (n=19)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>49.9 ± 21.6</td>
<td>60.2 ± 12.6</td>
</tr>
<tr>
<td>Sex (male/female)</td>
<td>7 / 2</td>
<td>10 / 9</td>
</tr>
<tr>
<td>Total cholesterol (mmol/l)</td>
<td>4.77 ± 0.76</td>
<td>5.97 ± 1.05</td>
</tr>
<tr>
<td>Total triglyceride (mmol/l)</td>
<td>0.95 ± 0.36</td>
<td>3.01 ± 0.91</td>
</tr>
<tr>
<td>HDL cholesterol (mmol/l)</td>
<td>1.49 ± 0.24</td>
<td>1.15 ± 0.42</td>
</tr>
<tr>
<td>LDL cholesterol (mmol/l)</td>
<td>2.94 ± 0.90</td>
<td>3.36 ± 1.08</td>
</tr>
<tr>
<td>IDL cholesterol (mmol/l)</td>
<td>0.21 ± 0.10</td>
<td>0.31 ± 0.16</td>
</tr>
<tr>
<td>VLDL cholesterol (mmol/l)</td>
<td>0.33 ± 0.13</td>
<td>0.91 ± 0.30</td>
</tr>
<tr>
<td>Chylomicron cholesterol (mmol/l)</td>
<td>0.073 ± 0.023</td>
<td>0.163 ± 0.070</td>
</tr>
<tr>
<td>RLP cholesterol (mmol/l)</td>
<td>0.13 ± 0.04</td>
<td>0.27 ± 0.09</td>
</tr>
</tbody>
</table>

Values are presented as mean ± S.D.

Total cholesterol and total triglyceride were determined enzymatically using the commercial kits. HDL, LDL, IDL, VLDL and chylomicron cholesterol were determined by the HPLC method.

a, b, c The data were compared with those of healthy subjects by Student's unpaired t-test:

- * p < 0.05,  ** p < 0.01,  *** p < 0.001.
hirowatari Fig. 3
hirowatari Fig. 4
Fig. 5

Total cholesterol (mmol/l) by automated chemical analyzer and HPLC method.

HDL cholesterol (mmol/l) by ultracentrifugation and HPLC method.

LDL cholesterol (mmol/l) by ultracentrifugation and HPLC method.

IDL cholesterol (mmol/l) by ultracentrifugation and HPLC method.

VLDL cholesterol (mmol/l) by ultracentrifugation and HPLC method.

Chylomicron cholesterol (mmol/l) by ultracentrifugation and HPLC method.

Total cholesterol (mmol/l) by automated chemical analyzer.

hirowatari Fig.5
A

HDL cholesterol (mmol/l) by HPLC method

RLP cholesterol (mmol/l)

B

LDL cholesterol (mmol/l) by HPLC method

RLP cholesterol (mmol/l)

C

IDL cholesterol (mmol/l) by HPLC method

RLP cholesterol (mmol/l)

D

VLDL cholesterol (mmol/l) by HPLC method

RLP cholesterol (mmol/l)

E

Chylomicron cholesterol (mmol/l) by HPLC method

RLP cholesterol (mmol/l)

hirowatari Fig.6