Low High-Density Lipoprotein Cholesterol as a Risk Factor in Coronary Heart Disease
A Working Group Report

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A working group meeting was convened from January 7 to 8, 2000, in Naples, Florida, to assess low HDL cholesterol (HDL-C) concentration as a risk factor for coronary heart disease (CHD). The 30 speakers and discussants at this 2-day meeting included specialists in epidemiology, endocrinology, molecular biology, public health, lipid metabolism, cardiovascular medicine, and preventive cardiology from the United States, Europe, and Australia (Appendix). The group's wide-ranging presentations and discussions considered the latest knowledge on HDL metabolism and the effects of interventions for raising HDL-C levels on the development of atherosclerosis. It was generally accepted that low HDL-C may be a marker for the metabolic syndrome, an enhanced atherosclerotic disease state that is also associated with an impaired response to insulin, hypertriglyceridemia, and abdominal obesity. Therefore, beyond risk assessment based on LDL cholesterol (LDL-C) alone, the case has been made for considering HDL-C in tandem with triglycerides (TG) as synergistic coronary risk factors.1 The following article summarizes the participants' discussion of low HDL-C as an independent CHD risk factor and identifies areas requiring further research.

Influence of Genetic Factors and Environment on the Atherogenicity of Low HDL-C

Although population studies indicate that a high level of HDL-C in general protects against CHD,2,3 a high HDL-C concentration in any given individual may not necessarily confer cardioprotection. The atherogenicity of low HDL-C seems to be influenced by an array of genetic and environmental factors.

Tangier disease, a disorder caused by mutations in the ATP-binding cassette transporter 1 (ABCI) gene,4 is characterized by the absence of normal HDL, with only a very small quantity of abnormal HDL present. However, early atherosclerosis (before 40 years) is not a consistent feature of this disorder.5 In men of Japanese ancestry in Hawaii, mutations in the gene for plasma cholesteryl ester transfer protein (CETP), which transfers cholesteryl ester from HDL to TG-rich lipoproteins, have been shown to result in elevated HDL-C levels.6 However, subjects carrying heterozygous CETP gene mutations had a moderately increased CHD risk, despite higher HDL-C levels. Elevated HDL-C caused by a common mutation in the CETP gene also increases the risk of ischemic heart disease in Danish women.7 This and other evidence indicates that both genetic and environmental factors influence the atherogenicity of low HDL-C and that an increase in HDL-C due to impaired CETP activity may be atherogenic.

New Insights Into HDL Metabolism

The HDL lipid-protein complex comprises 2 major sub-classes in terms of density: the HDL2 particle is larger and less dense, whereas the HDL3 particle is smaller and more dense.8 In addition, HDL3 is richer in particles that contain apoA-I without apoA-II, whereas HDL2 is richer in particles that contain both apoA-I and apoA-II.9 Recent work suggests that the cardioprotective properties of HDL-C particles may be altered by their size and apolipoprotein composition.10 There is some controversy regarding whether this antiatherogenic effect is primarily associated with the A-I subclass alone or with the A-I/A-II subclass. In CHD patients, both types of particles seem to be reduced compared with controls.

The cardioprotective effect of HDL has been largely attributed to its role in reverse cholesterol transport (RCT), in which cholesterol that has been synthesized or deposited in peripheral tissues is returned to the liver (Figure). Analysis of various genetic causes of low HDL-C has provided insights into the multiple mechanisms involved in RCT and the relationships of these mechanisms to CHD risk.

ABC1 has been identified by inference as the major apoA-I-mediated pathway for the efflux of cellular cholesterol.10 Mutations in the ABCI gene result in defective lipoprotein pre-β-HDL, rapid catabolism of this poorly lipidated HDL, and low plasma HDL levels.

The cholesterol-esterifying enzyme lecithin:cholesterol acyltransferase (LCAT) plays a key role in the metabolism of HDL and cholesterol. Although both complete and partial
Mechanisms of HDL metabolism. A-I indicates apoA-I; ABC1, ABC1 protein; B, apoB; C-II, apoC-II; CE, cholesteryl esters; CM, chylomicron; CMR, chylomicron remnant; FC, free cholesterol; HL, hepatic lipase; IDL, intermediate-density lipoprotein; LDLR, LDL receptor; LPL, lipoprotein lipase; and VLDL, very-low-density lipoprotein.

LCAT deficiencies markedly reduce HDL-C (to <10 mg/dL [<0.3 mmol/L]) and apoA-I concentrations,11 neither of which is commonly associated with premature CHD.

Several genetic causes of high HDL-C concentrations have been reported, including defects in the genes for CETP and hepatic lipase and polymorphism of lipoprotein lipase. CETP facilitates the transfer of cholesteryl esters among lipoproteins,9 and genetic CETP deficiency leads to delayed catabolism of both cholesteryl ester and apoA-I, resulting in marked increases in HDL-C and apoA-I concentrations.12 Despite the expected protective effects of these elevations, evidence suggests that impaired cholesterol transport resulting from genetic CETP deficiency may be associated with an increased risk of premature CHD.13

Another important component of the RCT process is phospholipid transfer protein (PLTP). PLTP facilitates the transfer of phospholipids between lipoproteins and induces HDL conversion, which remodels the homogeneous HDL fraction into populations of large and small particles similar to pre-β-HDL particles, the initial acceptors of membrane cholesterol.14 By producing initial cholesterol esters among lipoproteins, PLTP increases the capacity of the RCT process.15 Investigations in PLTP knockout mice6,17 have indicated that the transfer of phospholipids to HDL may play an essential role in HDL maturation and that when this process is absent, particles are catabolized at an increased rate. Therefore, it seems that 2 steps may be involved in HDL formation. The first involves catalyzation by ABC1 acting on apoA-I to form pre-β-HDL particles, and the second involves catalyzation by PLTP and LCAT acting on pre-β HDL to produce mature HDL.

Hepatic lipase, another key enzyme involved in HDL metabolism, is localized mainly to hepatocytes of the hepatic sinusoids, where it hydrolyses TG and the phospholipid of HDL, causing a reduction in HDL particle size. This in turn leads to an increase in HDL catabolism and the lowering of HDL levels.12,18

In mice and rats, the scavenger receptor, class B, type I (SR-BI) has a role in determining plasma HDL-C and biliary cholesterol levels, in mediating the delivery of HDL-C to the liver and to steroidogenic tissues, and in maintaining oocyte development and female fertility.19-22 This cellular receptor may perform similar functions in humans. Hepatic overexpression of SR-BI has been shown to decrease atherosclerosis significantly in mice,22 suggesting that interventions that promote HDL-C transport and thus promote HDL-C turnover may suppress atherosclerosis. Such an effect would be associated paradoxically with a decrease in HDL-C due to enhanced clearance.

Other mechanisms besides RCT, such as inhibition of LDL oxidation (possibly mediated by paraoxonase) and stabilization of prostacyclin production, may also account for the cardioprotective effects of HDL. Although evidence indicates that paraoxonase, an HDL-associated, calcium-dependent enzyme, may be responsible for the antioxidant activity of HDL,23 antioxidant effects of HDL have also been observed under calcium-free conditions, suggesting that paraoxonase may not be the only mechanism by which HDL can inhibit LDL oxidation.24 HDL also seems to stabilize the production of prostacyclin by macrovascular endothelial cells in vitro,25 which may have some influence on vascular function in disease states such as atherosclerosis.

What Is the Optimal Strategy for Treating Patients With Low HDL-C?

Nonpharmacological Interventions for Raising HDL-C

The National Cholesterol Education Program (NCEP) guidelines emphasize lifestyle modifications (eg, exercise, moderate alcohol use, smoking cessation, and monounsaturated fat in the diet) as first-line therapy for low HDL-C.26 Moderate- and high-intensity cycle ergometer training has been shown to increase HDL2 levels significantly in hypercholesterolemic men,27 and moderate-intensity aerobic exercise significantly increased HDL2 levels in healthy women.28

Recommendations to include alcohol consumption in a lifestyle program are controversial given the risks of overconsumption and abuse. Furthermore, no data from prospective, randomized, clinical trials have associated reductions in atherosclerotic events with alcohol consumption.

Many patients will not substantially increase their HDL-C levels or lower their LDL-C levels with nonpharmacological treatment alone.

Pharmacological Therapy in Patients With Low HDL-C

Four classes of lipid-lowering drugs are currently available for clinical use: bile acid sequestrants (resins), nicotinic acid (niacin), fibric acid derivatives (fibrates), and 3-hydroxy 3-methyl glutaryl coenzyme A reductase inhibitors (statins). The resins have only a marginal effect on HDL-C and will not be discussed here.

Niacin

Niacin is efficacious for raising HDL-C concentrations29 and for lowering TGs and LDL-C.30 However, no large, randomized, clinical trials have evaluated the use of niacin in the treatment of isolated low HDL-C. Dose-dependent hepatotoxicity occurs more often with sustained-release niacin preparations than with regular (crystalline) niacin,31 but a new intermediate-release form of niacin seems to be as safe as the regular form.32
Fibrates
Fibrates lower TGs substantially and raise HDL-C levels by 5% to 15%; these increases are comparable to or may exceed those achieved with statins.\(^{33}\) Fibrates also have shown cardiovascular benefits in patients with high TG levels and low HDL-C levels (Helsinki Heart Study subgroup analyses\(^{34}\) and the Bezafibrate Infarction Prevention trial\(^{35}\)), as well as in patients with normal LDL-C levels and low HDL-C levels (the Veterans Affairs High-Density Lipoprotein Cholesterol Intervention Trial\(^{36}\)). A new fibrate, fenofibrate,\(^{37}\) was recently approved by the US Food and Drug Administration, and clinical-event data are pending.

In the Helsinki Heart Study,\(^{34}\) \(>4000\) high-risk middle-aged men with dyslipidemia were treated with gemfibrozil 600 mg BID for 5 years. Treatment significantly reduced the risk for nonfatal myocardial infarction (MI) or CHD death by 34% \((P<0.02)\), with a >10% increase in HDL-C, a 10% decrease in LDL-C, and a 43% decrease in TGs compared with baseline. The study demonstrated that for every 1-mg/dL \((0.3\text{-mmol/L})\) increase in HDL-C, the CHD risk decreased by 2% to 3%, independent of changes in LDL-C.

In the Veterans Affairs High-Density Lipoprotein Cholesterol Intervention Trial,\(^{36}\) \(>2500\) men with CHD and LDL-C levels \(<40\text{ mg/dL (}<1.1\text{ mmol/L})\), LDL-C levels \(<140\text{ mg/dL (}<3.6\text{ mmol/L})\), and TG levels \(<300\text{ mg/dL (}<3.4\text{ mmol/L})\) were treated with gemfibrozil 600 mg BID or placebo for a median follow-up period of 5.1 years. After 1 year, the mean HDL-C level was 6% higher in the gemfibrozil group than in the placebo group and the total TG level was 31% lower \((P<0.001\) for each comparison), whereas the LDL-C level remained unchanged. Gemfibrozil was associated with a significant 22% reduction in the risk of fatal and nonfatal CHD \((P=0.006)\), and it significantly reduced the relative risk of investigator-designated stroke \((-29\%\); \(P=0.04)\).

In the Bezafibrate Infarction Prevention trial,\(^{35}\) bezafibrate 400 mg/d or placebo was administered to 3090 patients with prior MI or stable angina, total cholesterol levels between 180 and 250 mg/dL \((4.7\text{ to } 6.5\text{ mmol/L})\), HDL-C levels \(<45\text{ mg/dL (}<1.2\text{ mmol/L})\), TG levels \(<300\text{ mg/dL (}<3.4\text{ mmol/L})\), and LDL-C levels \(<180\text{ mg/dL (}<2.7\text{ mmol/L})\) or \(<160\text{ mg/dL (}<4.1\text{ mmol/L})\) in subjects aged \(<50\) years. The mean follow-up period was 6.25 years. Subjects receiving active treatment showed an 18% increase in HDL-C and a 21% decrease in TG. Bezafibrate, however, significantly reduced \((-39.5\%\); \(P=0.03)\) the study’s combined primary end point (fatal or nonfatal MI and sudden death) in only a small subgroup of patients with high baseline TG \((\approx 200\text{ mg/dL (}\approx 2.3\text{ mmol/L)})\).

Statins
Two recent reports provide information about statin therapy in patients with low HDL-C. In the small Lipoprotein and Coronary Atherosclerosis Study involving fluvastatin, the greatest angiographic benefit was observed in a subgroup of patients with HDL-C concentrations \(<35\text{ mg/dL (}<1\text{ mmol/L})\).\(^{38}\) Furthermore, in these patients, fluvastatin treatment was associated with improved event-free survival, although the study was not designed to address clinical benefit.

Results from the Air Force/Texas Coronary Atherosclerosis Prevention Study (AFCAPS/TexCAPS)\(^{39}\) affirm the findings of the Lipoprotein and Coronary Atherosclerosis Study sub-study and extend the coronary benefit of statin therapy in primary prevention to generally healthy individuals at a low-to-moderate risk of CHD who have cholesterol levels comparable with the national average.\(^{29}\) Lipid enrollment criteria resulted in a study cohort with reduced HDL-C concentrations; the mean values were 36 mg/dL \((0.9\text{ mmol/L})\) for men and 40 mg/dL \((1\text{ mmol/L})\) for women. Compared with baseline levels, lovastatin 20 to 40 mg/d with diet background reduced LDL-C by 25%, increased HDL-C by 6%, and decreased TGs by 15%. At 5 years, active treatment significantly reduced the rates of first acute major coronary events (ie, fatal or nonfatal MI, unstable angina, and sudden cardiac death; \(-37\%; \(P=0.00008)\), fatal or nonfatal MI \((-40\%; \(P=0.002)\), unstable angina \((-32\%; \(P=0.02)\), and revascularization \((-33\%; \(P=0.001)\). The greatest relative risk reduction with lovastatin was observed among participants in the lower 2 tertiles of baseline HDL-C, reinforcing the significance of low HDL-C in this cohort.\(^{40}\)

Estrogen
The Heart and Estrogen/Progestin Replacement Study,\(^{41}\) the first prospective investigation of hormone replacement for CHD prevention, has raised serious concerns about the use of such treatment. More than 2700 postmenopausal women with established CHD received either 0.625 mg of conjugated equine estrogen plus 2.5 mg of medroxyprogesterone acetate in 1 tablet daily or a placebo for an average follow-up period of 4.1 years. Primary CHD events occurred in 172 women \((12\%)\) in the group treated with hormone replacement therapy \((33.1/1000\text{ women per year})\) compared with 176 women \((13\%)\) in the placebo-treated group \((33.6/1000\text{ women per year};\text{ relative hazard, }0.99)\). The log rank \(P\) value for primary CHD events was 0.91. Thus, in this population of postmenopausal women with established CHD (and an average age of 67 years), daily estrogen plus progestin did not reduce the incidence of primary CHD events compared with placebo. Moreover, in addition to providing no overall cardiovascular benefit, hormone replacement therapy increased the risk of venous thromboembolic events and gall bladder disease.

Implications for Therapy
When HDL-C is low, LDL-C is moderately elevated, and other CHD risk factors are present, the statins seem to be the agents of choice. Statins act primarily by reducing LDL-C, but they also have moderate effects on HDL-C. These agents of choice. Statins act primarily by reducing LDL-C, but they also have moderate effects on HDL-C. These agents...
Potential Targets for Antiatherogenic Treatments

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Cellular and cell-surface proteins that influence HDL metabolism

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LDL-C values (130 to 159 mg/dL [3.4 to 4.1 mmol/L]) do not necessarily suggest high risk.

The NCEP’s emphasis on LDL-C as the principal determinant of treatment intensity may discount the risk associated with low HDL-C and other major CHD risk factors, such as obesity, smoking, and diabetes. Harper and Jacobson have argued for increased use of multifactorial risk models, such as the Framingham risk-prediction chart, in the clinical setting to better identify individuals with isolated low HDL-C who may benefit from treatment.

Thus, low HDL-C as a risk factor for CHD should not be considered in isolation. The many established risk factors must be included in clinical decision-making for individual patients. Those with “low” HDL-C (<35 mg/dL, [≤1 mmol/L], according to current NCEP guidelines) but without elevated LDL-C may not require HDL-C-raising therapy in the absence of concomitant risk factors. Furthermore, the ratio of LDL-C to HDL-C may be a more clinically relevant measurement than HDL-C alone, although there is some controversy regarding its use. Because a “target” HDL-C value has not been identified, it may be appropriate to match patients to populations enrolled in published clinical studies and to treat them accordingly.

Conclusions

Recent research has greatly expanded our knowledge of the complex genetic and molecular mechanisms involved in HDL-C metabolism. As the mechanisms involved in this process are further elucidated, investigators will be able to identify new targets for antiatherogenic treatments (Table). Increasing the expression of the ABC1 gene, for example, may offer the potential for raising HDL-C levels by enhancing both cholesterol efflux and plasma apoA-I. Elevating HDL-C levels by increasing the synthesis of apoA-I or by decreasing its metabolism also seems to hold promise, as does inhibiting hepatic lipase, which may decrease apoA-I catabolism without affecting HDL catabolism of cholesterol ester.

On the basis of the available clinical data, CHD-free individuals with low HDL-C and ≥2 other risk factors and diabetic individuals with LDL-C ≥130 mg/dL (≥3.36 mmol/L) should be considered for LDL-C-lowering therapy. In these patients, the statins seem to be the agents of choice. For secondary prevention in patients with low HDL-C, statin or fibrate treatment may be used, with the fibrate being reserved for patients without concomitant LDL-C elevation.

HDL-C is an important modifier of CHD risk, but the goals of treating patients with low HDL-C have not yet been firmly established. When considering the potential benefits of raising plasma HDL-C with diet or drugs, clinicians must be aware of the complicated processes involved in lipid metabolism, the effects of such interventions on specific genes and metabolic pathways, and the importance of modifying concomitant risk factors.

Appendix

Dr Goto chaired the Working Group Meeting “Assessing HDL as a Risk Factor in Coronary Heart Disease.” Guest speakers were Gerd Assmann, MD, Münster, Germany; Philip J. Barter, MD, PhD, Adelaide, Australia; Thomas P. Bersot, MD, PhD, San Francisco, California; H. Bryan Brewer, Jr, MD, Bethesda, Maryland; Eliot A.
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