Cholesteryl Ester Transfer Protein
A Novel Target for Raising HDL and Inhibiting Atherosclerosis


Abstract—Cholesteryl ester transfer protein (CETP) promotes the transfer of cholesteryl esters from antiatherogenic HDLs to proatherogenic apolipoprotein B (apoB)–containing lipoproteins, including VLDLs, VLDL remnants, IDLs, and LDLs. A deficiency of CETP is associated with increased HDL levels and decreased LDL levels, a profile that is typically antiatherogenic. Studies in rabbits, a species with naturally high levels of CETP, support the therapeutic potential of CETP inhibition as an approach to retarding atherosclerosis. Studies in mice, a species that lacks CETP activity, have provided mixed results. Human subjects with heterozygous CETP deficiency and an HDL cholesterol level >60 mg/dL have a reduced risk of coronary heart disease. Evidence that atherosclerosis may be increased in CETP-deficient subjects whose HDL levels are not increased is difficult to interpret and may reflect confounding or bias. Small-molecule inhibitors of CETP have now been tested in human subjects and shown to increase the concentration of HDL cholesterol while decreasing that of LDL cholesterol and apoB. Thus, it seems important and timely to test the hypothesis in randomized trials of humans that pharmacological inhibition of CETP retards the development of atherosclerosis. (Arterioscler Thromb Vasc Biol. 2003;23:●●●●.●●●.)

Key Words: HDL ■ LDL ■ reverse cholesterol transport ■ genetic CETP deficiency

The possibility that cholesteryl ester transfer protein (CETP) might be proatherogenic and that inhibition of its activity might be antiatherogenic was first raised 10 years ago.1 The potential atherogenicity of CETP relates to its ability to transfer cholesteryl esters from the antiatherogenic HDLs to the proatherogenic VLDL and LDL fractions. However, there is also evidence that CETP may be involved in reverse cholesterol transport (RCT). Thus, theoretically, CETP may be either proatherogenic or antiatherogenic. Most experimental evidence in animals favors a proatherogenic role for CETP and supports a view that inhibition of CETP is antiatherogenic.

It has also been suggested that CETP has the potential to inhibit atherogenesis by enhancing the rate of RCT. The pathway by which cholesterol in peripheral tissues is transported to the liver for elimination in the bile involves an initial uptake of cell cholesterol by HDL, where it is esterified by lecithin:cholesterol acyltransferase (LCAT). A proportion of the HDL cholesteryl esters is delivered directly to the liver, whereas another proportion is transferred by CETP to LDL and VLDL. The cholesteryl esters in the VLDL/LDL pool are subsequently delivered to the liver via the LDL receptor pathway.

The available clinical data in humans are incomplete and do not permit a definite conclusion about the relation of CETP deficiency to the risk of coronary heart disease (CHD). In this article, we review the totality of evidence on CETP and suggest further research.

What Is CETP and What Does It Do?

CETP is a hydrophobic glycoprotein that is secreted mainly from the liver and that circulates in plasma, bound mainly to HDL.2 It promotes the redistribution of cholesteryl esters, triglycerides, and, to a lesser extent, phospholipids between plasma lipoproteins. CETP transfers lipids from 1 lipoprotein particle to another in a process that results in equilibration of lipids between lipoprotein fractions.3 Most of the cholesteryl esters in plasma originate in HDL in the reaction catalyzed by LCAT, and the majority of the triglycerides enter the plasma as a component of chylomicrons and VLDLs (triglyceride-rich lipoproteins [TRLs]). The overall effect of CETP is a net mass transfer of cholesteryl esters from HDLs to TRLs and LDLs and of triglycerides from TRLs to LDLs and HDLs (Figure 1). Thus, CETP-mediated transfers from HDL to VLDL and LDL provide a potential indirect pathway by...
which HDL cholesteryl esters can be delivered to the liver. In a high-CETP species such as the rabbit, this indirect pathway may account for as much as 70% of the cholesteryl esters that originate in HDL.4

Under usual conditions, the rate of CETP-mediated cholesteryl ester transfer is rapid relative to the rate of HDL and LDL catabolism.3 As a consequence, the pools of cholesteryl esters in HDLs and LDLs approach equilibrium in vivo. Thus, whereas an increase in the activity of CETP beyond physiological levels would further increase the rate of bidirectional transfers between HDLs and LDLs, the effect on the distribution of cholesteryl esters between the 2 lipoprotein fractions would be relatively small. In contrast, if CETP were inhibited, then there would be a point beyond which its activity was rate limiting. Under these circumstances, the level of CETP activity may have an important role in determining the distribution of cholesteryl esters between LDLs and HDLs. In the case of transfers between HDLs and the much more rapidly catabolized VLDLs, the amount of CETP in plasma is almost certainly rate limiting under most conditions. Indeed, when the concentration of VLDLs is increased, the quantity of CETP is demonstrably the limiting factor in the rate at which cholesteryl esters are transferred from HDLs.5

When the level of VLDLs is normal, CETP-mediated transfers of HDL cholesteryl esters are directed preferentially

Figure 1. Role of CETP in plasma lipid transport. CETP promotes bidirectional transfers of cholesteryl esters (CE) and triglyceride (TG) between plasma lipoproteins. Because most of the CEs in plasma originate in HDL in the reaction catalyzed by LCAT and the majority of the TG enters plasma as a component of TRLs secreted either from the liver (VLDL) or intestine (chylomicrons), the overall effect of CETP is to promote a net mass transfer of CE from HDL to TRL and LDL and of TG from TRL to LDL and HDL. Pathways of RCT that deliver plasma CE to the liver include the hepatic uptake from HDL via the scavenger receptor B-1 (SRB-1) or the hepatic uptake of LDL via the LDL receptor (LDL-R).

Figure 2. Effects of CETP in normotriglyceridemia (Normo TG) and hypertriglyceridemia (Hyper TG). The magnitude of the net flux of cholesteryl esters (CE) and TGs between lipoproteins is dependent, in large part, on the relative sizes of the TRL, LDL, and HDL pools. In Normo TG, net CE flux to LDLs from HDLs predominates, with minor transfer to TRLs. In contrast, in Hyper TG, increased particle numbers of large VLDLs exhibit elevated acceptor activity for CETP. Under these conditions, there are high net transfer rates of CEs from HDLs to TRLs and of TGs from TRLs to both HDLs and LDLs. TG-enriched LDLs and HDLs are substrates for hepatic lipase (HL) that hydrolyzes phospholipid (PL) and TGs to form small, dense LDL and small, dense HDL, respectively.
to LDLs6 (Figure 2). In contrast, when the concentration of VLDLs is increased, as in patients with type 2 diabetes, HDL cholesteryl esters are preferentially transferred by CETP to larger VLDL particles that become cholesterol rich and thus, potentially more atherogenic.6 Transfers of cholesteryl esters to TRLs are enhanced in the postprandial state.7,8 The rate of cholesteryl ester transfer to TRLs and LDLs and the mass of CETP are increased in patients with a range of atherogenic dyslipidemias.9

CETP contributes to an atherogenic lipid phenotype in several ways. It increases the cholesteryl ester content and thus, the atherogenicity of VLDLs. It also interacts with triglyceride lipases to generate small, dense LDLs10 and HDLs11 (Figure 2). The CETP-mediated reduction in HDL particle size is accompanied by the dissociation of lipid-poor apolipoprotein A-I (apoA-I) from the particle.12-14 When the number of circulating acceptor VLDL and LDL particles is reduced in vivo by treatment with a 3-hydroxy-3-methylglutaryl coenzyme A reductase inhibitor, there is retention of cholesteryl esters in the HDL fraction and an increase in the proportion of larger HDL2 particles.15

Natural Inhibitors of CETP in Human Plasma

The presence of natural inhibitors of CETP has been reported in human plasma. One such protein, initially referred to as lipid transfer inhibitor protein, has recently been identified as apoF.16 This protein preferentially suppresses transfers involving LDLs but has less effect on transfers involving HDLs. CETP inhibitory activity within the HDL fraction has been identified as apoC-I.9

Role of CETP in the Development of Atherosclerosis in Animals

Expression of CETP in Transgenic Mice

Several species, including mice and rats, are naturally deficient in CETP. Introduction of the human CETP gene into mice results in a dose-related reduction in HDL levels and a small increase in VLDL and LDL cholesterol and apoB levels.16,19 Mice are relatively resistant to the development of diet-induced atherosclerosis and must clearly accomplish RCT by pathways that do not involve CETP activity. In fact, in studies of bile salt and cholesterol-fed, C57-B16 mice, the introduction and expression of the simian cetp gene resulted in enhanced formation of fatty streak lesions compared with nonexpressing controls.20 It was concluded that the enhancement of lesion development by CETP was secondary to a redistribution of cholesterol from HDLs to the VLDL/LDL fraction.

In another study,21 the human CETP gene was introduced into chow-fed, apoE-knockout mice and also into Western diet–fed, LDL receptor–knockout mice, both of which develop spontaneous atherosclerosis. CETP expression in these animal models redistributed cholesterol from HDLs to the VLDL/LDL pool and also increased the development of atherosclerosis. These results again support a view that CETP is proatherogenic, possibly by virtue of reducing the concentration of HDLs and redistributing cholesteryl esters from HDLs to the VLDL/LDL pool. However, when the CETP gene was overexpressed in apoE-knockout mice that also overexpressed human apoA-I, the effect of CETP on the development of atherosclerosis was nonsignificant, despite being associated with a major reduction in the concentration of HDL cholesterol.21

There are some circumstances in which the expression of CETP in mice has been reported to be antiatherogenic rather than proatherogenic. An antiatherogenic effect of CETP has been observed in mice that have been engineered to overexpress human apoC-III.22 These animals have high levels of triglyceride-rich remnant lipoproteins and develop small fatty-streak lesions. Introduction and expression of the CETP gene into these animals appeared to reduce the extent of the lesions.22 In this and a more recent study in a hypertriglyceridemic mouse model (produced by streptozotocin-induced diabetes and lipoprotein lipase deficiency), CETP was antiatherogenic, probably by decreasing the concentration of cholesterol in small VLDL remnants.23 Whether a comparable situation ever prevails in humans is uncertain. Another example of an antiatherogenic effect of CETP is seen in transgenic mice expressing human LCAT.24 These LCAT-transgenic mice have an increased concentration of HDL cholesterol but paradoxically, also an increased susceptibility to atherosclerosis. Expression of simian cetp in these animals reduces the atherosclerosis.25 It has been speculated, though not tested, that the cholesteryl ester–enriched HDLs that circulate in LCAT-transgenic mice may be less able to accept cholesteryl from cells. If this were proved to be so, then the introduction of CETP would provide a means for transferring cholesteryl esters from the HDLs, possibly restoring their efficiency as acceptors of cell cholesterol and thus, as inhibitors of the development of atherosclerosis. This speculation is consistent with studies of rabbits, a species with a naturally high level of CETP. Transgenic expression of the human LCAT gene in rabbits increases the level of HDL cholesterol, reduces the concentration of LDL cholesterol, and, in contrast to mice, reduces diet-induced atherosclerosis.26

Inhibition of CETP in Rabbits

Rabbits are highly susceptible to the development of diet-induced atherosclerosis. Rabbits also have a naturally high level of CETP. Furthermore, it has been demonstrated in several rabbit models of atherosclerosis that inhibiting CETP results in a marked reduction in atherosclerosis.

In cholesterol-fed rabbits, the inhibition of CETP by injection of antisense oligodeoxynucleotides (ODNs) against CETP resulted in a reduction in CETP mRNA and mass in the liver, a reduction in plasma total cholesterol, and an increased concentration of HDL cholesterol.27 There was also an increase in LDL receptor mRNA associated with the antisense ODNs. These changes were accompanied by a marked reduction in aortic cholesterol content as a marker of the extent of atherosclerosis.

It is also possible to inhibit CETP in vivo by infusing anti-CETP antibodies into rabbits.28 This study showed an effect of CETP on the distribution of cholesteryl esters between HDLs and VLDLs/LDLs but did not investigate the effects of inhibition on the development of atherosclerosis. In
a more recent report, a vaccine approach has been used to generate auto-antibodies against CETP in vivo in rabbits. In a study of cholesterol-fed rabbits, animals that were immunized against CETP had a reduced plasma activity of CETP and a substantial increase in the concentration of HDL cholesterol. They also had a modest decrease in LDL cholesterol concentration and a significant reduction in aortic atherosclerotic lesions. This study demonstrates that long-term inhibition of CETP is not only possible but also, at least in rabbits, reduces the susceptibility to atherosclerosis.

A newly developed chemical inhibitor of CETP has been used in another recent study of cholesterol-fed rabbits. This inhibitor reduced CETP activity in rabbits by >90%, almost doubled the level of HDL cholesterol, and decreased the non-HDL cholesterol by ~50%. There was an accompanying 70% reduction in atherosclerotic lesions in the aortas of these animals. It was not possible to determine the relative importance of the increased HDL versus the decreased LDL in the reduction of atherosclerosis observed in these rabbit studies. It was speculated that short-term treatment of humans with the same CETP inhibitor would result in a 40% to 45% increase in HDL cholesterol and a 15% to 20% decrease in LDL cholesterol.

**CETP, Lipoprotein Metabolism, and Atherosclerosis in Humans**

**Genetic CETP Deficiency in Humans and Effects on Lipoprotein Metabolism**

Several mutations of the *CETP* gene have been identified as a cause of CETP deficiency and elevated levels of HDL cholesterol. These include a G-to-A mutation at the +1 position of intron 14, a mutation that is present in up to 2% of the overall Japanese population and in as many as 27% of people in the Omagari area of Japan. Individuals homozygous for this mutation have no measurable CETP mass or activity in their plasma but do have elevated concentrations of both HDL lipids (cholesterol and phospholipid; 3- to 4-fold) and apoA-I (1.7-fold). A second common functional mutation of the *CETP* gene, present in up to 7% of the Japanese population, involves a D-to-G substitution at the 442 position of exon 15 that also results in increased HDL levels. However, subjects homozygous for this D442G mutation have only a partial rather than a complete CETP deficiency, and HDL levels are elevated 1- to 2-fold.

Subjects with a homozygous CETP deficiency have elevated concentrations of HDL cholesterol, apoA-I, apoA-II, and apoE. The HDL fraction is especially enriched in larger, less dense, cholesteryl ester and apoE-enriched HDL_{2} particles. The increased HDL concentration is due to a reduction in the rate of catabolism, with a markedly delayed catabolism of both apoA-I and apoA-II. In contrast, the synthesis of both apoA-I and apoA-II is similar to that in control subjects. Despite the delayed catabolism of apoA-I and apoA-II, it has not been established whether the net flux of cholesterol to the liver is decreased in patients with CETP deficiency. In fact, there are no data to suggest that the rate of HDL apolipoprotein turnover is directly correlated with the net flux of cholesterol to the liver.

The ability of HDLs from homozygous CETP-deficient individuals to promote the efflux of cholesterol from macrophages has been investigated. The large, apoE-rich HDLs were poor acceptors of macrophage cholesterol, but the apoE-free HDL_{2} and the HDL_{3} from these subjects functioned normally as acceptors of macrophage cholesterol.

In addition to the elevation of HDL that accompanies CETP deficiency, in homozygotes there is a substantial reduction (~40%) in the concentration of LDL cholesterol and apoB. These individuals have a polydisperse LDL fraction extending across the whole LDL density range. Human CETP deficiency is associated with both a decreased rate of production of apoB and an increase in its rate of catabolism, consistent with an upregulation of the LDL receptor in these subjects. When preparations of LDL isolated from CETP-deficient patients and from control subjects were injected into control subjects, the CETP-deficient LDL had a delayed catabolism. This result is consistent with the observation of decreased affinity of the CETP-deficient LDLs for the LDL receptor. One plausible explanation consistent with both the LDL kinetic studies and the LDL receptor–binding studies is that the LDLs from CETP deficient patients are altered. However, these results are difficult to interpret in terms of atherogenic potential, because any rapidly cleared particles would be underrepresented. Furthermore, it is not known whether the net mass of cholesteryl esters cleared is altered when the particle number is reduced.

**Atherosclerosis in CETP-Deficient Human Subjects**

The relation between mutations of the *CETP* gene and susceptibility to premature atherosclerosis is complex. In the Honolulu Heart Study, many of the participants of Japanese origin were heterozygous for the D442G mutation in the *CETP* gene and had reduced levels of CETP. Those in whom the CETP deficiency coincided with HDL cholesterol concentrations of 41 to 60 mg/dL (1.0 to 1.5 mmol/L) had an apparent 50% increase in CHD, although the total number of events in this group was too low to enable firm conclusions to be drawn. When the CETP deficiency was associated with higher HDL cholesterol levels (>60 mg/dL; >1.5 mmol/L), there was no evidence of an increase in CHD. Rather, in this subgroup, there was a low rate of CHD, comparable to that observed in the subjects in whom an elevated HDL cholesterol level was not associated with a deficiency of CETP.

A recent analysis of the 7-year prospective data from the Honolulu Heart Study revealed no statistically significant relation between heterozygous mutations of *CETP* and CHD or stroke, a finding at variance with the previous suggestion from prevalence data of increased risks (A.R Tall et al, in preparation). In fact, prospective analysis of the data has revealed a nonsignificant trend toward a lower incidence of cardiovascular events in subjects with CETP mutations.

Results similar to those from the Honolulu Heart Study were found in another study of Japanese subjects. Individuals with HDL cholesterol levels >80 mg/dL were genotyped for intron 14 and D442G mutations. Subjects with and without *CETP* gene mutations (homozygous or heterozygous) who had HDL cholesterol levels >80 mg/dL had a very low
risk of CHD. Given that the plasma level of CETP is, if anything, lower in deficient subjects with the highest HDL cholesterol levels, it is difficult to implicate CETP deficiency per se as a cause of increased CHD. It is possible that a deficiency of CETP is protective, so long as it induces a substantial increase in HDL cholesterol.

HDLs may inhibit the development of atherosclerosis by mechanisms independent of their involvement in RCT. These include antioxidant and anti-inflammatory properties of HDL, both of which have an antiatherogenic potential that may be enhanced when the concentration of HDL is increased in CETP-deficient states.

**CETP Polymorphisms and Susceptibility to Atherosclerosis in Humans**

There are several reported restriction fragment length polymorphisms (RFLPs) in the human CETP gene (Table 1). Although many of these studies have demonstrated associations between CETP single-nucleotide polymorphisms and small changes in plasma CETP and HDL levels, the relation between these polymorphisms and susceptibility to atherosclerosis is variable (Table 2). Indeed, no consistent picture has emerged from numerous studies examining the relation between polymorphisms and atherosclerotic cardiovascular disease.

The best-studied RFLP is Taq1B in intron 1. In 1 study, the Taq1B polymorphism accounted for 5.8% of the variance in HDL cholesterol. Subjects homozygous for the B1 allele in the Framingham Offspring Study had higher levels of CETP and lower levels of HDL cholesterol when compared with either B1B2 or B2B2 subjects. Men with the B2 allele appeared to have a reduced risk of CHD, although there was no significant association in women. A similar result was obtained in the VA-HIT study in men with CHD and low HDL. The Taq1B genotype is associated with some of the variation in response to statin therapy, as measured by the progression of coronary atherosclerosis by angiography. Several other studies investigating the effects of the Taq1B polymorphism are summarized in Table 1. Overall, studies of the Taq1B polymorphism have been consistent and supportive of a view that a lower level of CETP is associated with increased HDL cholesterol and possibly a decreased risk of CHD in men.

Results from studies of other polymorphisms have not demonstrated consistent associations between CETP genotype and either atherosclerosis or CHD. In an investigation of the common I405V polymorphism among 576 men of Japanese ancestry, plasma CETP concentrations were 1.95 μg/mL for those with the II genotype, 1.91 μg/mL for the IV genotype, and 1.77 μg/mL for the IV genotype. HDL levels were highest among those with the II genotype and lowest among those with the II genotype, although the increase was significant only in VW heterozygotes with plasma triglyceride levels >165 mg/dL (1.9 mmol/L). There were no differences in CHD risk among the 3 genotypes in the total population, although in a subset of individuals with high plasma triglyceride levels, the CHD risk was higher in those with the VW genotype than in those with the IV or II genotype (38% vs 27% vs 18%, respectively; P<0.05 for an interaction of genotype and plasma triglyceride levels). Though not significant, the apparent trend was opposite in those with triglyceride levels <165 mg/dL (1.9 mmol/L).

In an analysis of the I405V polymorphism in participants of the Copenhagen City Heart Study, women heterozygous or homozygous for the presence of valine at position 405 had increased levels of HDL cholesterol but also a paradoxical increased risk of CHD. There was no association between the I405V polymorphism and either HDL cholesterol levels or CHD risk in the men in this study. In another investigation of the I405V polymorphism in the Stanislas cohort study, the I405V polymorphism was not related to any lipid parameter.

A further report from Copenhagen focused on the A373P and R451Q polymorphisms. All carriers of 451Q also carried the 373P allele. Carriers of the 451Q/373P alleles had reduced levels of HDL cholesterol and a paradoxically lower CHD risk when compared with the overall study population. The reasons for these apparently conflicting observations remain unclear but may be related, at least in part, to uncontrolled confounding by other genes or environmental factors.

Another possibly functional polymorphism has recently been reported in the promoter region of the CETP gene (−629A/C). The mass of CETP was higher and the concentration of HDL cholesterol lower in individuals with the A allele than in those with the C allele, although the HDL cholesterol concentration was not correlated significantly with CETP mass. In studies of possible mechanisms whereby the polymorphism influenced CETP mass, it was found that repressor transcription factors that bind to the A allele did not bind to the C allele. An interaction between CETP polymorphisms and lifestyle factors is suggested by 2 recent reports that alcohol consumption greatly influences the apparent effects of several of the CETP polymorphisms.
TABLE 2. Relationship of Human CETP Polymorphisms to Atherosclerosis and CHD

<table>
<thead>
<tr>
<th>Study</th>
<th>No. of Subjects</th>
<th>CETP Measure</th>
<th>Effect on Atherosclerosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Honolulu Heart Program (1996), cross-sectional</td>
<td>3469 men</td>
<td>CETP gene polymorphism, primarily D442G</td>
<td>50% increased risk of CHD among men with CETP mutation and HDL 41 to 60 mg/dL; similar risks among those with and without mutation at high HDL (&gt;60 mg/dL)</td>
</tr>
<tr>
<td>Omagari population (1997), cross-sectional</td>
<td>879 men and women</td>
<td>No direct measure of CETP mutations</td>
<td>U-shaped curve of ischemic changes on ECG—highest among men without mutation and low HDL and among men with mutation and high HDL; however, this study was not controlled for alcohol intake</td>
</tr>
<tr>
<td>Kochi prefecture (1998), cross-sectional</td>
<td>48,531 men and women</td>
<td>Common CETP polymorphisms</td>
<td>Prevalence of CHD lower among those with HDL &gt;60 mg/dL; no difference in prevalence among those with high HDL and mutation or high HDL and no mutation</td>
</tr>
<tr>
<td>Honolulu Heart Program (1998) Cross-sectional</td>
<td>576 men</td>
<td>I405V polymorphism</td>
<td>HDL levels highest among men with WV genotype; possible increase in prevalence of CHD among W men with TGs &gt;165 mg/dL</td>
</tr>
<tr>
<td>Kakko et al (2000), cross-sectional</td>
<td>515 men and women</td>
<td>I405V polymorphism</td>
<td>Increased intima media thickness of carotid arteries among men with WV genotype who were heavy drinkers; no increased risk among other groups of men or among women</td>
</tr>
<tr>
<td>Copenhagen City Heart Study (2000), cross-sectional</td>
<td>Men and women: 9168 healthy and 946 with IHD</td>
<td>I405V polymorphism</td>
<td>Increased risk of CHD among women with the IV or VV genotype not using HRT; no association of genotype and CHD risk among men</td>
</tr>
<tr>
<td>Framingham Offspring Study (2000), cross-sectional</td>
<td>2916 men and women</td>
<td>B2 allele of TaqIB polymorphism</td>
<td>Possible decreased risk of CHD among men with the B2 allele, although this may have been due to association between B2 allele and HDL levels; no effect in women</td>
</tr>
<tr>
<td>B2 allele of TaqIB polymorphism</td>
<td>568 men and women with MI and 668 controls</td>
<td>10 polymorphisms: −631, −629, intron1, intron7, C373, C405, C451, intron12, intron16, and +524</td>
<td>Variable influences on HDL; Reduced risk of MI among subjects who drank &gt; 75g/day and who were homozygous for the −629A allele</td>
</tr>
<tr>
<td>Copenhagen City Heart Study (2000), cross-sectional</td>
<td>8467 men and women</td>
<td>R451Q and A373P polymorphisms</td>
<td>Minor alleles associated with 10% lowering of HDL, no significant effect on IHD in men, effect in women only achieves significance when adjusted for HDL levels and segregated by menopausal/HRT status</td>
</tr>
<tr>
<td>Zhuang et al (2001), case-control</td>
<td>227 MI and stroke and 335 controls</td>
<td>Concentration of CETP</td>
<td>Higher levels of CETP among cases than controls</td>
</tr>
<tr>
<td>Stanislas cohort (2001), cross-sectional</td>
<td>161 healthy men and women</td>
<td>I405V polymorphism</td>
<td>Trend toward increased intima-media thickness among men homozygous for the Ile405 allele</td>
</tr>
<tr>
<td>Meguro et al (2001), case study</td>
<td>182 male DM men and women</td>
<td>TaqIB polymorphism</td>
<td>Increased CETP and macroangiopathy among those with the B1/B1 genotype</td>
</tr>
<tr>
<td>Goto et al (2001), cross-sectional</td>
<td>110 consecutive angiography patients</td>
<td>TaqIB polymorphism</td>
<td>No overall correlation between CETP mass and HDL levels or coronary atherosclerosis; lower CETP mass among individuals with B2B2 genotype in the lowest coronary score quartile</td>
</tr>
<tr>
<td>Reykjavik Study (2001), case-control</td>
<td>388 male MI survivors and 794 healthy controls</td>
<td>TaqIB and −629A/C polymorphisms</td>
<td>B1B1 homozygotes had lower HDL and higher MI risk (OR = 1.44, 95% CI: 1.10–1.87, &lt;0.01) compared with other genotypes combined, with MI experienced 2 years earlier in life</td>
</tr>
<tr>
<td>Physicians’ Health Study (2002)</td>
<td>384 men with first MI</td>
<td>TaqIB polymorphism</td>
<td>After adjustment for coronary risk factors (but not HDL), RR for first MI not significantly different across the three genotypes; men with high HDL (&gt;53 mg/dL) were at lower risk of first MI regardless of CETP genotype</td>
</tr>
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DM indicates diabetes mellitus; ECG, electrocardiogram; HRT, hormone replacement therapy; IHD, ischemic heart disease; MI, myocardial infarction; RR, relative risk.

**Inhibition of CETP in Humans: Effects on Plasma Lipoproteins**

A newly developed chemical inhibitor of CETP, JTT-705, has been tested in humans. In a 4-week, phase II, dose-response study, 198 healthy individuals with mild hyperlipidemia were randomly assigned to 300, 600, or 900 mg/d of JTT-705 or to placebo. Treatment with the highest dose was associated with a highly significant 37% decrease in CETP activity, a 34% increase in HDLs, and a 7% decrease in LDLs. Levels of triglycerides, phospholipid transfer protein,
Conclusions

Expression of CETP in transgenic mice, a species that is naturally deficient in this protein, has yielded inconsistent results, with reports of both an increased susceptibility and protection against atherosclerosis in different models. In contrast, the effects in rabbits have been remarkably consistent and strongly support the therapeutic potential of CETP inhibition for blunting or even halting the development and progression of atherosclerosis.

The available human data, though sparse, generally support the hypothesis that CETP deficiency, especially when associated with a high HDL level, is antiatherogenic. Those studies suggesting that atherosclerosis is increased in some individuals with a heterozygous CETP deficiency may reflect chance owing to small sample sizes, confounding by other risk factors, or biases inherent in the study design. There are no reliable data indicating that CETP inhibition in humans would be unsafe. Indeed, CETP inhibitors may provide a powerful therapeutic approach to raising HDL levels, lowering LDL levels, and reducing the development of atherosclerosis in humans. However, such a proposition is based on circumstantial evidence and will remain hypothetical until subjected to direct testing. The recent negative trials with postmenopausal estrogens (that also increase HDL and lower LDL levels) highlight the pitfalls of drawing therapeutic conclusions from circumstantial evidence.

Thus, the hypothesis that pharmacological inhibition of CETP reduces the risk of atherosclerosis should be directly tested in randomized trials with either surrogate or clinical end points. Such trials should be of sufficient size, dose, and duration to reliably test the hypothesis. Further multidisciplinary research efforts into the metabolism of HDL, the precise roles played by CETP, and its interactions with other components of lipid transport and metabolism are also necessary to complete the totality of evidence.86-95

References


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