Infusion of reconstituted high-density lipoproteins (rHDL) is being studied in clinical trials as an adjunctive therapy for gram-negative sepsis. Since no data are available on its possible effects in systemic candidiasis, we investigated the effect of rHDL infusion into volunteers on the growth of Candida albicans. C. albicans growth was 10- to 100-fold higher in the plasma of volunteers infused with 80 or 100 mg/kg rHDL than in plasma collected before infusion; administration of 60 mg/kg rHDL had marginal effects. In vitro, the isolated lipoprotein subfractions had a growth-promoting effect on C. albicans. These data suggest potential adverse effects of rHDL if infused into patients with systemic candidiasis. Thus, rHDL infusion into patients with sepsis caused by an unknown microorganism may be contraindicated.
Results

Growth of C. albicans in plasma of volunteers infused with rHDL. The total cholesterol and HDL concentrations in the group receiving 60 mg/kg rHDL increased from a basal level of 3.87 and 0.95 mmol/L, respectively, to 4.63 and 1.03 mmol/L at the end of the 4-hour infusion interval and to 4.72 and 1.32 mmol/L at 12 hours and 4.30 and 1.58 mmol/L at 24 hours after the start of the infusion. The total cholesterol and HDL concentrations in the group receiving 100 mg/kg rHDL increased from 3.58 and 1.12 mmol/L, respectively, to 4.38 and 1.30 mmol/L at the end of the 4-hour infusion interval and to 5.00 and 1.60 mmol/L at 12 hours and 4.50 and 2.33 mmol/L at 24 hours after the start of the infusion.

The control growth is represented by the growth of C. albicans in plasma obtained from volunteers before the start of rHDL infusion (time 0; figure 1). Infusion of 60 mg/kg rHDL had little effect on the growth of C. albicans, but C. albicans grew better in plasma obtained after infusion of 80 or 100 mg/kg rHDL (figure 1). The number of C. albicans colony-forming units grown in plasma obtained 24 hours after rHDL infusion was ~100-fold greater than that grown in control plasma. Similarly, infusion of 100 mg/kg rHDL at various infusion rates (4–12 hours) resulted in a significantly increased outgrowth of C. albicans, compared with the outgrowth of the yeast in plasma obtained before infusion (P < .05, Kruskal-Wallis test; data not shown).

Growth of C. albicans in freshly isolated human lipoprotein subclasses. As shown in figure 2A, C. albicans grew better in the lipoprotein emulsions from normal human donors than in lipoprotein-depleted plasma. Similarly, infusion of 100 mg/kg rHDL at various

Animals. Homozygous C57BL/6J mice lacking LDL receptors (LDLR−/−) and wild-type LDLR+/+ controls were obtained from Jackson Laboratories (Bar Harbor, ME) as mating pairs and bred in our local facility. LDL concentrations ± SD in the LDLR−/− mice were 4.92 ± 0.53 mmol/L, compared with 0.35 ± 0.11 mmol/L in control LDLR+/+ mice [11]. Blood was collected on EDTA from 6- to 8-week-old mice, and plasma was obtained for the use in C. albicans growth experiments. LPDP from LDLR−/− and control animals was prepared by ultracentrifugation, as described above. Plasma isolated from five LDLR−/− and five LDLR+/+ control mice was studied in three separate experiments.

C. albicans growth in vitro. C. albicans (American Type Culture Collection 10231; 10⁴ cfu/mL) was grown in the pooled plasma of rHDL-infused volunteers, as well as in the various lipoprotein subfractions or lipoprotein-depleted plasma from untreated volunteers, after 1:1 dilution in Sabouraud broth with 2% glucose. Similarly, C. albicans (10⁴ cfu/mL) was grown in a 1:1 mixture of Sabouraud broth with murine lipoprotein subfractions or lipoprotein-depleted murine plasma. After 24 and 48 hours of incubation at 37°C, aliquots of 40 μL were plated (Wasp spiral plater; DW Scientific, Shipley, UK) on Sabouraud dextrose agar. After another 24 hours of incubation at 37°C, the colonies were counted and the growth was expressed as the logarithm of colony-forming units per milliliter. Comparison between groups was done by use of the Mann-Whitney test. The Kruskal-Wallis test was used to compare the growth curves of C. albicans in depleted and nondepleted murine plasma.

Growth of C. albicans in plasma of volunteers before and after a 4-hour infusion with reconstituted high-density lipoproteins (rHDL). Plasma samples were collected from volunteers before (0 hours) and 4, 12, or 24 hours (h) after infusion with 60 mg/kg (square), 80 mg/kg (circle), or 100 mg/kg (triangle) rHDL. After 48 hours of incubation, C. albicans grew better in the plasma of volunteers who had received 80 or 100 mg/kg rHDL.
tein subfractions and in hyperlipoproteinemic plasma from LDLR−/− mice. These data are in agreement with our previous findings in hyperlipoproteinemic LDLR−/− mice, which were more susceptible to disseminated candidiasis because of an increased fungal outgrowth in their organs [6]. Although lipid profiles differ between mice and humans, the results of both studies suggest that hyperlipidemia can have deleterious effects by stimulating C. albicans growth in both species.

At least two different mechanisms seem to be responsible for the observed effects. First, in agreement with other reports showing increased growth of C. albicans in lipid emulsions used for parenteral feeding [7, 8], lipids themselves seem to promote the growth of Candida. Cholesterol may act as a nutrient for C. albicans, as has been demonstrated for other microorganisms, such as Staphylococcus aureus [12]. After infusion of rHDL, natural HDL has to be formed through extraction of cholesterol from cell membranes and other lipoprotein subfractions, since rHDL consists of phospholipids and recombinant apolipoprotein A-1 without cholesterol [2]. This process requires several hours, and this explains the increasing effect of rHDL on C. albicans growth at later time points after infusion. Indeed, the total cholesterol and HDL concentrations were found to be higher 12 and 24 hours after the start of the infusion than at the end of the 4-hour infusion interval.

Second, since the growth of C. albicans was enhanced in lipoprotein-depleted plasma of hyperlipoproteinemic mice, binding and neutralization of candidacidal factors, such as sphingosine [13], platelet microbicidal protein [14], or the calprotectin complex [15], by lipoproteins may contribute to the observed effect. Although no lipoproteins were present in lipoprotein-depleted plasma isolated from either LDLR−/− or normal mice, C. albicans growth was significantly increased in lipoprotein-depleted plasma isolated from either LDLR−/− mice, from which five-fold more lipoproteins had been extracted. This suggests that a candidacidal factor associates with lipoproteins, and because of this binding, the candidacidal effects of plasma may decrease. Indeed, it has been reported that cholesterol is able to inhibit the candidastatic capacity of sphingosine [13]. Association of an antimicrobial factor with HDL has been reported for S. aureus [16], and this may also explain the differences observed between HDL and VLDL effects on C. albicans growth, despite the higher cholesterol content of the VLDL subfraction (figure 2A).

Discussion

The results of the present study show that rHDL infusion (at 80 mg/kg) increases the growth of C. albicans in the plasma of human volunteers by 10- to 100-fold, compared with the basal growth curve in their plasma collected before rHDL administration. In contrast, there was no significant difference in the growth of C. albicans in plasma before and after infusion of a moderate amount of rHDL (60 mg/kg). Similarly, C. albicans growth was increased in the presence of freshly isolated human lipoproteins and extracted together with lipoproteins during the lipoprotein depletion procedure.

![Figure 2](https://academic.oup.com/cid/article-lookup/28/5/1148/324414). In vitro growth of Candida albicans in the presence of lipoproteins. A. C. albicans grows better in plasma containing freshly isolated very-low-density lipoproteins (VLDL), low-density lipoproteins (LDL), or high-density lipoproteins (HDL), diluted 1:1 in Sabouraud broth, than in lipoprotein-depleted plasma (LPDP). B. C. albicans grows significantly better in LPDP from mice lacking LDL receptors (•) than in that from control mice (■). Each point represents mean ± SD of 5 experiments. * P < .05 (Kruskal-Wallis test).
tentiates also the growth of other microorganisms, such as S. aureus [7–9], and the clinical implication of this phenomenon for rHDL infusion warrants further investigation.

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