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Statin Effects to Reduce Hepatosteatosis as Measured by Computed Tomography in Patients With Human Immunodeficiency Virus

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Hepatosteatosis is highly prevalent among patients living with human immunodeficiency virus (HIV)-infected patients [1]. Nonalcoholic fatty liver disease (NAFLD) is an important cause of liver damage and occurs more commonly in individuals living with HIV (30%–40%) than in the noninfected population (14%–31%) [2, 3]. Antiretroviral therapy (ART) is known to cause adverse changes in body composition including central fat accumulation, insulin, and elevated triglycerides [4, 5]. Such changes and chronic inflammation may lead to increased severity of NAFLD in HIV-infected patients. In a cross-sectional study, patients with HIV-associated NAFLD exhibited higher rates of steatohepatitis and increased severity of liver injury compared with age- and sex-matched non-HIV patients with NAFLD [6].

Given the increased risk of hepatosteatosis for individuals infected with HIV, effective therapies to limit the progression of NAFLD in this population are needed. In a randomized, placebo-controlled trial of 13 patients with HIV/hepatitis C virus coinfection, pioglitazone treatment reduced hepatic fat content measured by magnetic resonance spectroscopy [7]. Statins have been proposed to mitigate cardiac disease risk in HIV-infected patients [8], but no studies have yet assessed the effects of statins on NAFLD in the HIV population. Among non-HIV patients, limited studies suggest potential benefit of statins in patients with NAFLD [8–11]. In a Swedish open-label study, statin treatment significantly reduced fatty liver infiltration observed in liver biopsies collected at a 13.8-year follow-up of patients with NAFLD [9]. More recently, lower hepatosteatosis prevalence was reported in patients who received statins for more than 2 years, using observational data from the Rotterdam Study [11]. These reports highlight the need for data from controlled trials of statins on NAFLD in HIV-infected patients, a population with a particularly high prevalence of both NAFLD and cardiovascular disease.

In a 12-month randomized, placebo-controlled trial, we previously demonstrated significant reductions in coronary plaque in HIV-infected participants treated with atorvastatin versus placebo [8]. Leveraging computed tomography (CT) data obtained in the study, we now investigate the effects of atorvastatin on hepatosteatosis among HIV participants with NAFLD. We hypothesized that hepatosteatosis would improve after 1 year with atorvastatin.

METHODS

Study Design

We recruited 40 men and women with HIV on stable ART, no prior history of cardiovascular disease or cardiac symptoms, LDL cholesterol between 70 and 130 mg/dL, and evidence of subclinical coronary atherosclerosis on coronary CT angiography (CCTA). Full exclusion resistance criteria were previously reported [8]. Participants with aspartate aminotransferase (AST) or alanine aminotransferase (ALT) greater than 3 times the upper limit of normal and/or undergoing treatment for active liver disease were excluded. Participants were randomized in 1:1 ratio to either atorvastatin (starting at dose of 20 mg/day and escalating to 40 mg/day at 3-month visit if study drug was well tolerated) or placebo for 12 months. Thirty-seven of the 40 participants completed the study. In the current analysis, we assessed changes in hepatosteatosis measured by CT in response to atorvastatin. All participants provided written informed consent, and the study was approved by the institutional review board. The trial is registered on ClinicalTrials.gov (NCT00965185).

Noncontrast Computed Tomography (CT) and Contrast Coronary CT Angiography

Cardiac electrocardiogram (ECG)-gated CT was performed at enrollment and 1 year of follow up, using a Somatom Definition...
Flash 128 slice dual source CT scanner (Siemens) according to the guidelines of the Society of Cardiac Computed Tomography [12] as previously described [8]. The protocol included a noncontrast CT that was used to measure the density of liver and spleen.

Measurement of Liver and Spleen Density
Noncontrast CT allows for the noninvasive measurement of liver density (attenuation) in Hounsfield Units (HUs). Liver density is inversely correlated to fat content and has been validated as an accurate, reproducible means to characterize hepatosteatosis [13–16]. Liver density was measured on noncontrast ECG-gated CT images originally obtained for coronary artery calcium. A reader blinded to participant allocation, CCTA, and biomarker results measured the hepatic and splenic CT attenuation using a dedicated workstation (AQi; TeraRecon) [17, 18]. Hepatic density was measured by selecting 3 circular regions of interest with an area of at least 2 cm² on 3 axial CT slices, taking care to avoid the hepatic vessels and bile ducts. Likewise, 3 density measurements were taken in the spleen (Figure 1A). The spleen is visible on most liver CT slices, it is normally less dense than the liver, and it is used as an internal control for assessing liver density. The ratio of the mean liver measurements divided by the mean spleen measurements was calculated, with a liver/spleen ratio <1.0 defined as NAFLD [14, 16]. This definition is commonly used with good accuracy compared with liver biopsy and minimal intra- and interobserver variability [14, 16]. Reproducibility was assessed with the intraclass correlation coefficient (ICC) of mean liver attenuation, spleen attenuation, and liver/spleen ratio measurements used in the analysis compared with 20 randomly selected CTs remeasured by the same reader more than 6 months after the original measurements. The ICCs of mean liver and spleen attenuation were 0.977 and 0.986, respectively. The ICC for the liver/spleen ratio was 0.982.

Lipid Parameters
Direct LDL was measured by homogeneous enzymatic colorimetric assay (COBAS INTEGRA; Roche Diagnostics). Other

![Figure 1](image)

Figure 1. (A) Entry noncontrast computed tomography with regions of interest (ROI) placed over the liver (white circle, top left) and spleen (bottom right). The liver is visibly darker than the spleen, indicating that it is less dense. The liver/spleen ratio averaged over 3 ROIs was 0.38, compatible with hepatosteatosis. (B) Comparison of change in liver/spleen attenuation ratio between atorvastatin and placebo groups in patients with nonalcoholic fatty liver disease at baseline. Bar denotes mean and error bar denotes standard deviation. (C) Linear regression between change in liver/spleen ratio and direct low-density lipoprotein (LDL). Pearson correlation coefficient = –0.83 (P = .02).
lipid levels were determined using standard techniques. Blood was drawn after a 12-hour fast.

**Inflammatory, Metabolic, Biochemical, and Immunologic Assessments**
Monocyte chemoattractant protein-1 (MCP-1) was measured by ELISA (R&D Systems). Glucose and hemoglobin A1c were determined using standard techniques after 12-hour overnight fast. CD4⁺ T-cell counts were assessed by flow cytometry. Human immunodeficiency virus ribonucleic acid (RNA) was measured in real time using clinically available ultrasensitive reverse transcription-polymerase chain reaction.

**Body Composition and Dietary Assessment**
Abdominal visceral adipose tissue (VAT) and abdominal subcutaneous adipose tissue areas were quantified using noncontrast abdominal CT at the level of the L4 pedicle⁴⁶,⁴⁷.

**Statistical Analysis**
Comparisons between groups (atorvastatin vs placebo) were performed using Student’s t test for variables that were normally distributed and by Wilcoxon rank-sum test for variables that were not normally distributed. Comparisons between groups among those with NAFLD were assessed by Kolmogorov-Smirnov exact test. For investigating relationships between continuous variables, Pearson correlation coefficient was assessed for normally distributed variables. Two-tailed probability values are reported, and statistical significance was assumed when \( P < .05 \). Mean and standard deviation or median and interquartile range are used to describe baseline values depending on normality of distribution. Mean and 95% confidence intervals (CIs) are used to report change values. All statistical analyses were performed using SAS JMP and SAS (SAS Institute).

**RESULTS**

**Characteristics of the Participants at Baseline**
Baseline characteristics were similar between treatment groups (atorvastatin vs placebo) as previously reported. Baseline liver-to-spleen attenuation ratio was similar between the atorvastatin and placebo groups (1.28 ± 0.30 vs 1.25 ± 0.52, respectively, \( P = .82 \)). Participants were all on ART, and most had undetectable viremia with similar immunological and virological indices between groups as previously published [8].

**Characteristics of the Participants With Nonalcoholic Fatty Liver Disease**
Nonalcoholic fatty liver disease was identified in 9 participants at baseline using a liver-to-spleen HU attenuation ratio cutoff <1. The group with NAFLD (n = 9) and the group without NAFLD (n = 28) were similar in age, gender, alcohol consumption, body mass index (BMI), VAT, AST, ALT, fasting glucose, total cholesterol, HDL, triglycerides, and ART (Supplementary Table 1). None of the participants reported excessive alcohol consumption. Those with NAFLD had higher levels of MCP-1 compared with those without (406 ± 259 vs 285 ± 79, \( P = .04 \)), as well as higher levels of direct LDL (153 ± 36 vs 116 ± 30, \( P = .004 \)). Among the 9 participants with NAFLD, all 4 participants in the placebo group and 1 in the atorvastatin group were on nonnucleoside reverse transcriptase inhibitor-based regimens, 2 participants in the placebo group and 3 in the atorvastatin group were on protease inhibitor-based regimens, and 1 participant in the placebo group was on an integrase inhibitor-based regimen.

**Relationships to Liver-to-Spleen Attenuation Ratio at Baseline**
Among all participants, direct LDL significantly correlated negatively with liver-to-spleen attenuation ratio \( (r = −0.35, P = .03) \), suggesting that higher LDL was related to increased hepatosteatosis at baseline. Among those with NAFLD at baseline, VAT tended to correlate with liver-to-spleen attenuation \( (r = −0.61, P = .08) \), such that those with the most VAT tended to demonstrate more liver fat.

**Change in Liver/Spleen CT Attenuation and Lipids by Treatment Group in Participants With Nonalcoholic Fatty Liver Disease**
Among participants with NAFLD, change in liver/spleen ratio could be obtained for 7 participants (1 participant dropped out before the final CT scan, and another participant did not have a measurable spleen attenuation value), 3 of whom received atorvastatin. Those treated with atorvastatin demonstrated a mean increase in liver-to-spleen attenuation ratio of 0.46 (95% CI, .16−.77) compared with a mean decrease of −0.04 (95% CI, −0.30 to .22) in those who received placebo \( (P = .03) \) (Figure 1B). However, among those without NAFLD at baseline, the change in liver/spleen ratio did not differ between placebo (−0.02 ± 0.20) and atorvastatin groups (−0.07 ± 0.17) \( (P = .50) \). Atorvastatin significantly lowered direct LDL among all participants (−38 mg/dL vs 11 mg/dL, \( P < .001 \)). Atorvastatin also significantly lowered direct LDL in those with NAFLD, with a mean change of −57 mg/dL (95% CI, −89 to −25) vs 3 mg/dL (95% CI, −21 to 28) with placebo \( (P = .01) \). Changes in BMI, VAT, HDL, triglycerides, fasting glucose, AST, and ALT were similar between treatment groups among all participants and among those with NAFLD.

**Relationship of Change in Liver-to-Spleen Attenuation Ratio to Lipids in Participants With Nonalcoholic Fatty Liver Disease**
The change in liver-to-spleen attenuation ratio was significantly associated with change in LDL \( (r = −0.83, P = .02) \) (Figure 1C) but not other lipid, metabolic, or inflammatory parameters.

**DISCUSSION**
In this substudy of a randomized trial in participants with HIV and subclinical coronary atherosclerosis, atorvastatin reduced liver fat among HIV-infected participants with NAFLD, without a concurrent change in BMI or VAT. Of note, the change in hepatosteatosis in response to statin therapy was significantly correlated with decreases in LDL, corroborating a potential statin effect and suggesting a link with reduced lipid levels. To our knowledge, this is the first report of statin therapy reducing liver fat in the HIV population.
Our results support similar findings of atorvastatin and other statins in reducing hepatosteatosis in the general population. In a substudy of the St. Francis Heart Study, among participants with NAFLD defined as liver/spleen ratio <1, atorvastatin 20 mg daily in combination with vitamins C and E significantly improved liver/spleen ratio by 0.40 after 4 years of treatment [19]. In another study in patients with NAFLD who were randomized to atorvastatin, fenofibrate, or both drugs, the proportion of patients who no longer had evidence of NAFLD at the end of treatment was significantly higher in the atorvastatin groups than in the fenofibrate group [20]. Studies using other lipophilic statins have shown mixed results. A few studies suggest beneficial effects of pitavastatin. In one study, patients with biopsy-proven nonalcoholic steatohepatitis (NASH) treated with pitavastatin for 12 months showed significant improvement in ALT, γ-glutamyl transpeptidase, and lipid profiles [21]. In another study, both pitavastatin and atorvastatin reduced the severity of hepatosteatosis by CT [22]. On the other hand, a randomized placebo-controlled study of simvastatin in 16 patients with NASH demonstrated no statistically significant improvement in serum aminotransferases, hepatic steatosis, necroinflammatory activity, or stage of fibrosis with treatment, despite a 26% reduction in LDL in the simvastatin group [23]. Among the hydrophilic statins, rosuvastatin may have beneficial effects on NAFLD [24–26]. In a pilot study of 23 patients with NAFLD, rosuvastatin treatment for 8 months significantly improved the lipid profile and liver biochemical markers [24]. In another study, repeat liver biopsies and ultrasonography showed improvement of NASH in 19 of 20 patients after 12-month treatment with rosuvastatin [26]. These findings in the general population suggest that the beneficial effect on hepatosteatosis may not be limited to atorvastatin or lipophilic statins; however, there may be differential effects of different statins on NAFLD. Moreover, data on the effects of statins in the HIV population are lacking.

Statins reduce hepatosteatosis by inhibiting expression of the membrane-bound transcription factor, sterol regulatory element-binding protein-1c (SREBP-1c). Sterol regulatory element-binding protein-1c may play an important role in the pathogenesis of NAFLD as an explanatory link between metabolic dysregulation and triglyceride synthesis. When activated, SREBP-1c enters the nucleus where it upregulates enzymes involved in hepatic lipogenesis [27]. In humans, atorvastatin 80 mg given for 4 weeks reduced messenger RNA expression of SREBP-1c [28]. Thus, one potential mechanism through which statins reduce hepatosteatosis may involve downregulation of SREBP-1c and inhibition of triglyceride synthesis.

We found that MCP-1 concentrations are higher among HIV-infected participants with hepatosteatosis than those without steatosis, which is consistent with existing literature in the general population. In the general population, hepatic expression of MCP-1 has been shown to be upregulated in nonalcoholic fatty liver disease [29]. Thus, activation of the innate immune system in chronic HIV infection may play an important role in the development of NAFLD, and statins can help to reduce proinflammatory monocytes and macrophages.

This study has limitations. The CT liver density measurement technique assessed for diffuse hepatosteatosis, the most common manifestation of fatty liver. Areas of focal fatty deposition may have been missed, although this potential for sampling error is also shared by liver biopsy, the reference standard for hepatosteatosis [30]. This study was also limited by the small number of participants with NAFLD who could be included in the analysis. Larger trials are needed to corroborate this observed effect of statin therapy on hepatosteatosis in patients with HIV and NAFLD and to elucidate potential mechanisms, including LDL-lowering, metabolic, or inflammatory effects.

CONCLUSIONS

Leveraging CT data obtained from a randomized trial of atorvastatin, in this new analysis, we report an improvement in hepatosteatosis with statin therapy in HIV-infected participants with NAFLD, possibly related to a reduction in LDL or via effects on immune activation. This preliminary observation suggests that statins may confer potential beneficial effects on NAFLD through their effects on lipid metabolism and inflammation in the HIV patient population, warranting future investigation.

Supplementary Data

Supplementary material is available online at Open Forum Infectious Diseases online (http://OpenForumInfectiousDiseases.oxfordjournals.org/).

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