CLINICAL STUDY

Cholic acid for hepatic steatosis in patients with lipodystrophy: a randomized, controlled trial

Zahid Ahmad^{1,3}, Lalitha Subramanyam^{1,‡}, Lidia Szczepaniak^{3,†}, Vinaya Simha^{1,§}, Beverley Adams-Huet^{2,3} and Abhimanyu Garg^{1,3}

¹Division of Nutrition and Metabolic Diseases, Center for Human Nutrition, ²Department of Clinical Sciences and ³Department of Internal Medicine, UT Southwestern Medical Center, 5323 Harry Hines Boulevard, Dallas, Texas 75390, USA

(Correspondence should be addressed to A Garg at Division of Nutrition and Metabolic Diseases, Center for Human Nutrition, UT Southwestern Medical Center; Email: abhimanyu.garg@utsouthwestern.edu)

[†](L Szczepaniak is now at The Heart Institute, Cedars-Sinai Medical Center, Los Angeles, California, USA)

[‡](L Subramanyam is now at North Texas Associates END, Irving, Texas, USA)

[§](V Simha is now at Mayo Clinic, Rochester, Minnesota, USA)

Abstract

Objective: Hepatic steatosis is a common complication in patients with lipodystrophies and can lead to cirrhosis. There is no proven effective therapy for hepatic steatosis, but cholic acid (CA), a farnesoid X receptor agonist, has previously been shown to reduce hepatic triglyceride (TG) content in mice and serum TG in humans. Our objective was to assess clinical efficacy and tolerability of CA therapy in patients with lipodystrophy and hepatic steatosis.

Design: A randomized, double-blind, placebo-controlled, crossover study.

Methods: Eighteen patients with genetic or autoimmune lipodystrophies and elevated hepatic TG content participated in the study. The intervention was CA (15 mg/kg per day) compared with placebo for a period of 6 months each. Hepatic TG content, the primary outcome variable, was measured with ¹H magnetic resonance spectroscopy at baseline and at 3 and 6 months during each study period. Levels of serum alanine aminotransferase (ALT), aspartate aminotransferase (AST), gamma-glutamyl transpeptidase (GGT), and TG were secondary end points of the study.

Results: Compared with placebo, CA did not reduce (median (interquartile range) hepatic TG content (14.8% (9.4–19.0%) vs 15.9% (10.5–26.5%) respectively; $P=0.42$) or serum TG ((340 mg/dl (233–433 mg/dl) vs 390 mg/dl (233–595 mg/dl) respectively; $P=0.45$)). CA therapy also did not change AST, ALT, or GGT levels. Two patients developed diarrhea and excessive flatus while taking CA and these symptoms resolved after reducing the dose of CA.

Conclusion: CA was well tolerated but did not reduce hepatic TG content in patients with lipodystrophy.

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Introduction

Lipodystrophies are rare disorders characterized by selective loss of adipose tissue (1) and predisposition to metabolic complications such as diabetes mellitus, hypertriglyceridemia, and hepatic steatosis. Hepatic steatosis is a common complication in patients with genetic or acquired lipodystrophies (1, 2). Both cirrhosis requiring hepatic transplantation (3) and hepatocellular carcinoma (2), possibly due to long-standing hepatic steatosis, have been reported in patients with lipodystrophies. We and others have previously reported that recombinant leptin therapy reduced liver size and hepatic steatosis in hypoleptinemic patients with lipodystrophies (4, 5, 6, 7, 8, 9). However, many patients with lipodystrophy are not hypoleptinemic (10, 11). Therefore, there is a need to develop other

therapies for treatment of hepatic steatosis in patients with lipodystrophies.

There is no proven effective therapy for hepatic steatosis (12). A variety of drugs have been investigated including ursodeoxycholic acid (13), insulin sensitizers (metformin and thiazolidinediones) (14, 15), vitamin E (14), betaine (16), and probucol (17). Thus far, only vitamin E has been shown to improve histology in patients with hepatic steatosis (14). However, these results have not yet been replicated and concerns related to an increase in mortality with vitamin E (18) have limited its use.

Bile acids play a role in the metabolism of both serum and hepatic triglyceride (TG). Cholic acid (CA) has been reported to reduce serum TG by as much as 29% in patients with hyperlipoproteinemia (19, 20). Recently, it has been noted that bile acids, which are the

endogenous ligands of the farnesoid X receptor (FXR, NR1H4), activate transcription of several genes, particularly the atypical nuclear receptor small heterodimer partner, and thus can influence TG metabolism within hepatocytes (21). Both CA and chenodeoxycholic acid (CDCA), the endogenous primary bile acids, are potent ligands for FXR. Giving 0.5% CA for 3 weeks reduced hepatic TG content by over 50% in KK- A^y mice (a model for diet-induced hypertriglyceridemia) fed chow or high-fat diet (22). In addition, activation of FXR was shown to robustly attenuate liver steatosis in leptin-receptor-mutated Zucker *fa/fa* rats (a genetic model of insulin resistance and obesity-driven liver injury) (23). Therefore, FXR agonists may be beneficial for treating hepatic steatosis; however, there are no previous studies assessing their efficacy for reducing liver TG content in humans.

Thus, we designed a randomized, double-blind, placebo-controlled, crossover study to evaluate the efficacy and safety of CA therapy in treating hepatic steatosis in patients with lipodystrophy.

Materials and methods

Setting and participants

All patients were evaluated at the Clinical and Translational Research Center (CTRC) at UT Southwestern Medical Center (Dallas, Texas, USA). A written informed consent was obtained from all participants, and the study was approved by the Institutional Review Board of UT Southwestern. Thirty-seven patients with a clinical diagnosis of genetic or acquired autoimmune lipodystrophy (not HIV-associated) underwent screening with ^1H magnetic resonance spectroscopy (MRS) for liver fat. Ten subjects did not qualify after screening (eight had low levels of liver fat, one was too obese for the magnetic resonance imaging machine, one had a history of alcohol use), eight subjects lost interest, and one could not be contacted.

Inclusion criteria for the trial were as follows: patients with lipodystrophy as diagnosed by clinical criteria, hepatic steatosis ($>5.6\%$ hepatic TG content) as

demonstrated by ^1H MRS, age 10–70 years, and alcohol intake of <40 g/week. Patients with the following were excluded: other liver diseases such as chronic viral hepatitis, autoimmune hepatitis, primary biliary cirrhosis, biliary obstruction, Wilson's disease, hemochromatosis, or α -1-antitrypsin deficiency; treatment with drugs associated with steatohepatitis: corticosteroids, high-dose estrogens, methotrexate, amiodarone, calcium channel blockers, sulfasalazine, naproxen, or oxacillin in the 6 months before the study; decompensated liver disease; hepatocellular carcinoma; congestive heart failure, cerebrovascular disease, respiratory failure, renal failure (serum creatinine >2 mg/dl), acute pancreatitis, organ transplantation, serious psychiatric disease, and malignancy; acute medical illnesses; known HIV infection; current substance abuse; pregnant or lactating women; hematocrit of $<30\%$; weight loss during the past 3 months; and hypersensitivity or intolerance to CA or any components of its formulation. Additional exclusion criteria included the use of drugs that can potentially decrease hepatic steatosis: ursodeoxycholic acid, high-dose vitamin E, betaine, acetylcysteine, and choline. Thiazolidinediones were allowed if the dose had been stable for three months before screening.

Design overview, randomization, and interventions

This study was a randomized, double-blind, placebo-controlled, crossover trial (Fig. 1). Patients underwent a screening evaluation to determine their eligibility for the trial. For those who were found to be eligible, they continued their usual diet and other lifestyle measures without changing any medications for 1 month in order to establish a baseline state.

All patients were studied during three hospitalizations, each lasting for 3 days, and two outpatient visits (Fig. 1). One month after screening, patients were hospitalized to the CTRC for a period of 3 days, i.e. the baseline visit. Fasting blood samples were obtained on three consecutive days during the inpatient evaluation, and the average of the three measurements was used

Figure 1 Study design.

for data analysis. All patients underwent ^1H MRS to determine liver fat during this hospitalization. At 6 and 12 months, patients were again admitted for three consecutive days; during these visits, all the studies mentioned in the baseline visit were repeated. The patients returned at 3 and 9 months for fasting blood samples and liver ^1H MRS during outpatient visits.

Following the baseline hospitalization, the patients received CA or an identical placebo in the dose of 15 mg/kg per day (divided twice daily) for a period of 6 months and then received the other treatment (CA or placebo) for the next 6 months. The maximum dose of CA was 1500 mg/day. CA and matched placebo were supplied by Global Strategic Connections, LLC (Troy, MI, USA), in 250 mg capsules.

At each study visit, an inquiry was made about any side effects of medication, in particular, gastrointestinal side effects. Medication compliance was assessed by counting the remaining number of pills at the completion of each study period. If a patient was unable to tolerate the full dose, the dose could be reduced by the investigators. Patients were asked to keep doses of their other medications constant for the duration of the study.

Outcomes

The ^1H MRS studies were performed at least 4 h postprandially with the patients lying prone as described previously (24). Briefly, image-guided, proton-localized, MRS and high-resolution T1-weighted imaging were performed on a 1.5 T Gyroscan Intera whole-body system (Philips Medical Systems, Best, The Netherlands) with the following parameters: repetition time of 3 s, spin echo time of 25 ms, and 1024 data points over 1000 kHz spectral width. Volume of interest (voxel 30 mm³) was selected in the upper right hepatic lobe, taking care to avoid vascular structures. Spectra were processed and resonances quantified using a standard analysis package (NUTS; ACORNMR, Fremont, CA, USA). The hepatic TG content was expressed as the ratio of fat and water resonance peaks.

Blood was obtained after overnight (12 h) fast daily for chemistry profile (SMA-25) and lipoprotein levels while the patients were admitted. Serum chemistry profile including the aminotransferases, lipoproteins, gamma-glutamyl transpeptidase (GGT), electrolytes, etc were measured by autoanalyzer (Quest Diagnostics, Irving, TX, USA). HbA1c levels were measured by an immuno-turbidimetric colorimetric assay (Quest Diagnostics).

Figure 2 CONSORT 2010 flow diagram.

Primary and secondary endpoint variables The primary end point variable was reduction in the liver TG content as measured by ^1H MRS. Reductions in the levels of serum alanine and aspartate aminotransferases (ALT and AST), GGT, and TG were secondary end point variables of the study.

Statistical analysis

We determined that a sample of 12 patients completing the 12-month crossover study would provide a power of 0.80 at an α of 0.05 to detect an absolute treatment difference in hepatic fat content of 3.5% with the s.d. of the difference of 4.0%. We therefore planned to enroll at least 16 subjects assuming a maximum 30% rate of loss to follow-up.

A block randomization with block size of two was generated using SAS version 9.2 (SAS Institute, Cary, NC, USA). At the beginning of the study, a randomized treatment sequence was prepared by the study statistician who sent it directly to the investigative pharmacy. The pharmacist assigned participants to the interventions according to the treatment sequence. Patients were recruited by the study personnel. All participants and study personnel and those evaluating outcomes (e.g. ^1H MRS results) were blinded. Only the pharmacist was aware of the intervention sequence. The code was broken upon study completion.

All data on patients who had at least one 3-month measurement of hepatic TG content during the placebo or CA phase were included in the analysis ($n=15$). For continuous outcome variables, statistical analysis of this two-phase crossover study was performed using mixed linear model repeated measures analysis with the study subject modeled as a random effect. The mixed-effects analysis was also used to assess a possible treatment sequence effect. All hypothesis tests were two sided and a P value <0.05 was considered statistically significant. Results are reported as median and interquartile range. Statistical analyses were conducted using SAS.

Results

Patients

Recruitment began in December 2006, and the last patient finished the 12-month follow-up visit in April 2011. Eighteen patients were enrolled in the study and 12 of them completed both the CA and the placebo phases, whereas an additional three patients had 3-month data (Fig. 2). The six dropouts included three who were unable to be contacted, two who had hospitalizations and medication changes for unrelated illnesses, and one who had an implantable cardioverter-defibrillator placed for pre-existing cardiomyopathy due to which MRS could not be performed.

Table 1 Characteristics of all patients enrolled in the study. Values are given as mean (s.d.) unless otherwise noted.

	All enrolled ($n=18$)	Min-max
Age (years)	46.0 (15.3)	17–70
BMI (kg/m^2)	30 (6)	22–44
Male:female	7:11	
Diabetes	67%	
Hypertension	50%	
Dyslipidemia	100%	
Hepatic TG (%)	23.89 ^a (13.4)	6.1–60.3
Weight (kg)	80.7 (16)	56.0–109.0
Total cholesterol (mg/dl)	208.4 (64.9)	116.0–355.0
HDL-C (mg/dl)	33.0 (7.4)	18.0–51.7
TG (mg/dl)	389 ^a	155–3455
HbA1c (%)	6.8 (1.3)	5.3–9.1
Glucose (mg/dl)	125.6 (33.5)	80–199
AST (U/l)	29.4 (13.2)	12.0–55.0
ALT (U/l)	38.5 (35.0)	11.0–168.0
GGT (U/l)	35.4 (16.7)	16.0–72.0
Lipid-lowering agents (n)		
Statins	7	
Fibrates	7	
Fish oil	7	
Ezetimibe	3	
Niacin	1	
Diabetes medications (n)		
Metformin	10	
Insulin	7	
Sulfonylurea	5	
Thiazolidinediones	2	
GLP1 agonist	2	
DPP-4 inhibitor	1	

TG, triglycerides; HDL-C, HDL cholesterol; ALT, alanine aminotransferase; AST, aspartate aminotransferase; GGT, gamma-glutamyl transpeptidase. GLP, glucagon-like peptide; DPP, dipeptidyl peptidase.

^aMedian.

Table 1 describes the baseline characteristics of all patients enrolled in the study. At screening, the mean (s.d.) hepatic TG content was 23.9% (13.4%), and the range was 6.1–60.3%. Serum ALT concentration ranged from 11 to 168 U/l; AST ranged from 12 to 55 U/l; GGT ranged from 16 to 72 U/l; and serum TG concentration ranged from 155 to 3455 mg/dl. Twelve patients had a previous diagnosis of diabetes mellitus.

Nine patients had familial partial lipodystrophy of the Dunnigan variety (FPLD) due to mutations in the lamin A/C (LMNA) gene. Eight patients had other types of familial partial lipodystrophy. One patient had acquired generalized lipodystrophy.

Primary and secondary end points

The sequence in which the patients received CA or placebo had no effect on the results. Compared with placebo, CA therapy did not result in any significant reduction in hepatic TG concentration (geometric mean difference, 13.8%; 95% CI –19.7 to 61.1%). Similarly, there was no significant change in serum TG levels (11.4%; 95% CI –17.7 to 50.8%). Individual responses for hepatic TG concentration and serum TG levels are

Figure 3 Hepatic triglyceride content (A) and serum triglyceride levels (B) during the study. Connected open circles represent the 12 subjects who completed both the 6-month study periods. For three subjects with incomplete data, filled symbols represent subjects with placebo data only; inverted triangles represent 3-month data. Median values for each phase are shown as horizontal bars.

shown in Fig. 3 and overall results are reported in Table 2. CA therapy did not lower ALT (-3.0% ; 95% CI -24.3 to 24.2%), AST (2.5% ; 95% CI -17.6 to 27.7%), or GGT (1.6% ; 95% CI -18.0 to 26.0%) levels. Mean difference in HbA1c was 0.41% (95% CI -0.23 to 1.05%); however, it was not statistically significant ($P=0.18$). Absolute difference in weight was -0.23 kg (95% CI -2.02 to 1.56 kg) for CA relative to placebo; however, it was also not statistically significant.

Adverse events

CA was well tolerated except in two patients who developed diarrhea and excessive flatus while taking CA. Their symptoms resolved after reducing the dosage of CA to $5\text{--}10$ mg/kg per day. Three other patients reported mild diarrhea, which subsided within 1–2 weeks without any dose adjustment.

Four patients had adverse events during the trial. One patient developed gastroenteritis requiring i.v. fluids. Two patients developed flu-like symptoms with

vomiting and diarrhea and also required i.v. fluids for volume depletion. One patient with multiple co-morbidities had four hospitalizations for fluid accumulation due to heart failure, chronic obstructive pulmonary disease, and pneumonia. All these adverse events occurred while the patients were taking placebo.

Discussion

We hypothesized that CA would improve hepatic TG content in humans based on the report of $>50\%$ reduction in hepatic TG content in mice upon feeding 0.5% CA for 3 weeks (22). CA therapy restored liver morphology to normal with lower levels of unstained inclusions on hematoxylin and eosin staining and less accumulation of neutral lipids on Oil Red O staining. These effects seem to occur through SHP and liver X receptor-mediated downregulation of sterol regulatory element binding protein 1c (*SREBF1*) expression (22). These findings were recently replicated in rats (25). However, we were unable to observe any significant improvement in hepatic steatosis with CA therapy in lipodystrophic patients with markedly elevated hepatic TG content.

Recent data support the activation of FXR, a nuclear hormone receptor regulated by bile acids, for treatment of hepatic steatosis (26). FXR-deficient mice exhibit a hepatic phenotype similar to steatohepatitis patients with significant hepatic TG accumulation, hepatic inflammation and injury, and development of hepatocellular carcinoma (27, 28). WAY-362450, a potent, selective, and orally active synthetic FXR agonist, has been shown to protect against hepatic steatosis in mice fed a methionine- and choline-deficient diet (29). This hepatoprotection by WAY-362450 is abolished in FXR-deficient mice, demonstrating the requirement for functional FXR (29).

FXR activation alters the expression of many genes involved in lipid metabolism. While apolipoprotein C-1, apolipoprotein C-II, apolipoprotein C-IV, apolipoprotein

Table 2 Results of cholic acid vs placebo^a.

Measure	Baseline	Cholic acid		Placebo		P value
		3 months	6 months	3 months	6 months	
Hepatic TG (%)	18.7 (10–25.5)	11.6 (7.6–17)	15.9 (10.5–26.5)	15.6 (7.2–24.7)	14.8 (9.4–19)	0.42
HbA1c (%)	6.4 (5.6–7.4)	6.2 (5.8–7.1)	7.0 (5.4–8.3)	6.7 (5.8–7.7)	6.6 (5.6–7.6)	0.18
Weight (kg)	77 (67.1–90.9)	77 (65.8–94.5)	75 (66.2–89.6)	80.4 (68–91.1)	76.9 (65.7–84.5)	0.77
Glucose (mg/dl)	115 (91–134)	112 (99–152)	122 (87–152)	105 (90–131)	108 (92–140)	0.91
TG (mg/dl)	278 (238–489)	314 (217–532)	390 (233–595)	283 (220–400)	340 (233–433)	0.45
Total cholesterol (mg/dl)	214 (160–280)	176 (167–227)	196 (173–242)	186 (169–206)	200 (164–234)	0.31
HDL-C (mg/dl)	36 (31.9–42)	30 (28–37)	32.2 (24.7–36)	33 (28.6–37)	30.7 (24.7–37)	0.72
AST (U/l)	23 (18–31)	20 (15–25)	22 (15.5–28.5)	18 (14–34)	19 (14.7–32.3)	0.80
ALT (U/l)	26 (17.7–39.3)	25 (18–29)	25.1 (18.9–48)	24.5 (18–49)	22.8 (19.7–37.3)	0.79
GGT (U/l)	26.7 (21.7–30.3)	30 (21–38)	27.2 (21.8–41.1)	26 (22–44)	29.8 (23–47.3)	0.87

TG, triglycerides; HDL-C, HDL cholesterol; ALT, alanine aminotransferase; AST, aspartate aminotransferase; GGT, gamma-glutamyl transpeptidase.

^aValues are given as median (interquartile range) unless otherwise noted.

E, fatty acid synthase, and peroxisome proliferator-activated receptor α are upregulated, angiopoietin-like protein 3 (ANGPTL3), apolipoprotein A-1, apolipoprotein C-III, and SREBP1c (22, 30) are down regulated. All these changes may lead to reduction of hepatic steatosis and serum TG upon FXR activation.

Studies in FXR knockout mice show that FXR is involved in the regulation of insulin signaling pathways and appears to have a beneficial role in decreasing insulin resistance and gluconeogenesis, as well as in regulating TG, free fatty acid, and lipid levels (28, 31). This adds to the rationale for clinical testing of CA in subjects with chronic liver disease where insulin resistance is a major risk factor for progression to cirrhosis, e.g. nonalcoholic fatty liver disease and its more clinically significant subtype nonalcoholic steatohepatitis (26).

CA has been reported to reduce serum TG levels in patients with mild hypertriglyceridemia (19, 20). Administration of 15 mg/kg body weight per day of CA for 3 months decreased plasma TG in six out of eight patients with moderate hypertriglyceridemia. However, plasma TG levels (mean $\pm$ S.E.M.) declined by only 16% from 283 ± 27 to 239 ± 18 mg/dl ($P < 0.05$) (20), and in the study subjects with type 2a hyperlipoproteinemia, there was no change in plasma TG levels. Einarsson *et al.* (19) also reported a 29% reduction in serum TG from 411 ± 180 mg/dl (mean $\pm$ S.D.) to 291 ± 55 mg/dl after 2–3 weeks of therapy with 0.8–1.0 g CA. However, this study involved only five men with hypertriglyceridemia, and the results were not statistically significant. In addition, neither of these studies was a randomized, double-blind, placebo-controlled trial. More recently, Woollett *et al.* (32) administered CA (15 mg/kg per day) vs no bile acid supplement (control) to 12 healthy, normotriglyceridemic subjects who were being fed a controlled diet. They failed to find any lowering of plasma TG (78.5 ± 8.6 vs 73.9 ± 8.6 mg/dl, NS). Interestingly, although most of our patients with lipodystrophies were hypertriglyceridemic, we did not observe any significant lowering of serum TG with CA therapy, compared with placebo therapy. Our results do not confirm the TG-lowering effects of CA that were previously reported.

Although CDCA is a more potent FXR agonist than CA and can also lower serum TG (33, 34, 35, 36), CA was chosen over CDCA because of better tolerance and less hepatotoxicity (37). CA has been used, without any side effects, since 1994 at the Cincinnati Children's Hospital Medical Center for the treatment of inborn errors of bile acid metabolism (38). In addition, CA has previously been studied at doses as high as 20 mg/kg per day in adults to dissolve gallstones (39), to treat mild hypertriglyceridemia (19, 20), to study bile acid kinetics (40, 41, 42, 43), and to assess cholesterol absorption (32, 44). The only adverse effect reported in these studies was mild diarrhea. In our study, no major adverse events were attributed to CA, although a few

patients complained of diarrhea. Our results confirm that CA is not hepatotoxic and is overall well tolerated.

The major strength of this study is the robust study design. In view of the rare prevalence of lipodystrophies, we decided to use the randomized, double-blind, placebo-controlled, crossover design. This allowed us to achieve more power with fewer patients compared with the parallel design. We selected 6-month duration of treatment, which is long enough to detect effects of CA therapy on hepatic steatosis. Despite that, no effects of sequence in which the patients received CA or placebo therapy were observed. We also avoided using low dose of CA and selected to administer 15 mg/kg per day for a maximum of 1500 mg/day.

Several possibilities could explain why CA failed to reduce hepatic TG content as measured by ^1H MRS. First, hepatic steatosis in lipodystrophy patients may have different pathophysiology (45) and may not involve downregulation of FXR and thus may not respond to CA therapy. Secondly, as we did not perform liver biopsies, it is possible that some histological improvements occurred but did not result in an overall reduction of hepatic TG content. Finally, CA may not be a potent enough FXR agonist and other more potent FXR agonists, such as obeticholic acid (Intercept Pharmaceuticals, New York, NY, USA), which is ~ 100 times more potent than CDCA, GW4064 (GlaxoSmithKline), MFA-1 (Merck), and fexaramine, may prove to be efficacious in treating hepatic steatosis (46). In conclusion, CA was well tolerated but did not reduce hepatic TG content in patients with lipodystrophy.

Declaration of interest

The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

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