127 Russo MW, Goldsweig CD, Jacobson IM, Brown RS Jr. Interferon monotherapy for dialysis patients with chronic hepatitis C: an analysis of the literature on efficacy and safety. *Am J Gastroenterol* 2003; 98: 1610–5.
128 Fabrizi F, Dixit V, Messa P, Martin P. Interferon monotherapy of chronic hepatitis C in dialysis patients: meta-analysis of clinical trials. *J Viral Hepat* 2008; 15: 79–88.
129 Kamar N, Ribes D, Izopet J, Rostaing L. Treatment of hepatitis C virus infection (HCV) after renal transplantation: implications for HCV-positive dialysis patients awaiting a kidney transplant. *Transplantation* 2006; 82: 853–6.
130 KDIGO clinical practice guidelines for the prevention, diagnosis, evaluation, and treatment of hepatitis C in chronic kidney disease. Kidney Disease: Improving Global Outcomes (KDIGO). *Kidney Int Suppl* 2008; 109: S1–99.
131 Micallef JM, Kaldor JM, Dore GJ. Spontaneous viral clearance following acute hepatitis C infection: a systematic review of longitudinal studies. *J Viral Hepat* 2006; 13: 34–41.
132 Ikeda K, Arase Y, Kawamura Y *et al.* Necessities of Interferon Therapy in Elderly Patients with Chronic Hepatitis C. *Am J Med* 2009; 122: 479–86.
133 Ikeda K, Arase Y, Saitoh S *et al.* Interferon beta prevents recurrence of hepatocellular carcinoma after complete resection or ablation of the primary tumor-A prospective randomized study of hepatitis C virus-related liver cancer. *Hepatology* 2000; 32: 228–32.
134 Kubo S, Nishiguchi S, Hirohashi K *et al.* Effects of long-term postoperative interferon-alpha therapy on intrahepatic recurrence after resection of hepatitis C virus-related hepatocellular carcinoma. A randomized, controlled trial. *Ann Intern Med* 2001; 134: 963–7.
135 Shiratori Y, Shiina S, Teratani T *et al.* Interferon therapy after tumor ablation improves prognosis in patients with hepatocellular carcinoma associated with hepatitis C virus. *Ann Intern Med* 2003; 138: 299–306.
136 Mazzaferro V, Romito R, Schiavo M *et al.* Prevention of hepatocellular carcinoma recurrence with alpha-interferon after liver resection in HCV cirrhosis. *Hepatology* 2006; 44: 1543–54.
137 Kubo S, Nishiguchi S, Hirohashi K, Tanaka H, Shuto T, Kinoshita H. Randomized clinical trial of long-term outcome after resection of hepatitis C virus-related hepatocellular carcinoma by postoperative interferon therapy. *Br J Surg* 2002; 89: 418–22.
138 Shiratori Y, Ito Y, Yokosuka O *et al.* Antiviral therapy for cirrhotic hepatitis C: association with reduced hepatocellular carcinoma development and improved survival. *Ann Intern Med* 2005; 142: 105–14.
139 Nishiguchi S, Kuroki T, Nakatani S *et al.* Randomised trial of effects of interferon-alpha on incidence of hepatocellular carcinoma in chronic active hepatitis C with cirrhosis. *Lancet* 1995; 346: 1051–5.
140 Ikeda K, Saitoh S, Arase Y *et al.* Effect of interferon therapy on hepatocellular carcinogenesis in patients with chronic hepatitis type C: a long-term observation study of 1,643 patients using statistical bias correction with proportional hazard analysis. *Hepatology* 1999; 29: 1124–30.
141 Imai Y, Kawata S, Tamura S *et al.* Relation of interferon therapy and hepatocellular carcinoma in patients with chronic hepatitis C. Osaka Hepatocellular Carcinoma Prevention Study Group. *Ann Intern Med* 1998; 129: 94–9.
142 Arase Y, Ikeda K, Suzuki F *et al.* Prolonged-interferon therapy reduces hepatocarcinogenesis in aged-patients with chronic hepatitis C. *J Med Virol* 2007; 79: 1095–102.
143 Nomura H, Kashiwagi Y, Hirano R *et al.* Efficacy of low dose long-term interferon monotherapy in aged patients with chronic hepatitis C genotype 1 and its relation to alpha-fetoprotein: A pilot study. *Hepatol Res* 2007; 37: 490–7.
144 Shiffman ML, Hofmann CM, Contos MJ *et al.* A randomized, controlled trial of maintenance interferon therapy for patients with chronic hepatitis C virus and persistent viremia. *Gastroenterology* 1999; 117: 1164–72.
145 Saito Y, Saito H, Tada S *et al.* Effect of long-term interferon therapy for refractory chronic hepatitis c: preventive effect on hepatocarcinogenesis. *Hepatogastroenterology* 2005; 52: 1491–6.
146 Arase Y, Ikeda K, Suzuki F *et al.* Interferon-induced prolonged biochemical response reduces hepatocarcinogenesis in hepatitis C virus infection. *J Med Virol* 2007; 79: 1485–90.
147 Akuta N, Suzuki F, Kawamura Y *et al.* Efficacy of low-dose intermittent interferon-alpha monotherapy in patients infected with hepatitis C virus genotype 1b who were predicted or failed to respond to pegylated interferon plus ribavirin combination therapy. *J Med Virol* 2008; 80: 1363–9.
148 Imai Y, Kasahara A, Tanaka H *et al.* Interferon therapy for aged patients with chronic hepatitis C: improved survival in patients exhibiting a biochemical response. *J Gastroenterol* 2004; 39: 1069–77.
149 Iwasaki Y, Ikeda H, Araki Y *et al.* Limitation of combination therapy of interferon and ribavirin for older patients with chronic hepatitis C. *Hepatology* 2006; 43: 54–63.
150 Hiramatsu N, Oze T, Tsuda N *et al.* Should aged patients with chronic hepatitis C be treated with interferon and ribavirin combination therapy? *Hepatol Res* 2006; 35: 185–9.
151 Davis GL, Wong JB, McHutchison JG, Manns MP, Harvey J, Albrecht J. Early virologic response to treatment with peginterferon alfa-2b plus ribavirin in patients with chronic hepatitis C. *Hepatology* 2003; 38: 645–52.
152 McHutchison JG, Manns M, Patel K *et al.* Adherence to combination therapy enhances sustained response in genotype-1-infected patients with chronic hepatitis C. *Gastroenterology* 2002; 123: 1061–9.

153 Shiffman ML, Ghany MG, Morgan TR *et al.* Impact of reducing peginterferon alfa-2a and ribavirin dose during retreatment in patients with chronic hepatitis C. *Gastroenterology* 2007; 132: 103–12.
154 Reddy KR, Shiffman ML, Morgan TR *et al.* Impact of ribavirin dose reductions in hepatitis C virus genotype 1 patients completing peginterferon alfa-2a/ribavirin treatment. *Clin Gastroenterol Hepatol* 2007; 5: 124–9.
155 Shiffman ML, Salvatore J, Hubbard S *et al.* Treatment of chronic hepatitis C virus genotype 1 with peginterferon, ribavirin, and epoetin alpha. *Hepatology* 2007; 46: 371–9.
156 Oze T *et al.* Pegylated interferon alpha-2b affects early virologic response dose-dependently in patients with chronic hepatitis C genotype 1 during treatment with Peg-IFN alpha-2b plus ribavirin. *J Viral Hepat* 2009; 16: 578–85.
157 Hiramatsu N *et al.* Ribavirin dose reduction raises relapse rate dose-dependently in genotype 1 patients with hepatitis C responding to pegylated interferon alpha-2b plus ribavirin. *J Viral Hepat* 2009; 16: 586–94.
158 Weiland O, Hollamder A, Mattsson L *et al.* Lower-than standard dose peg-IFN alfa-2a for chronic hepatitis C caused by genotype 2 and 3 is sufficient when given in combination with weight-based ribavirin. *J Viral Hepat* 2008; 15: 641–5.
159 Inoue Y, Hiramatsu N, Oze T *et al.* Factors affecting efficacy in patients with genotype 2 chronic hepatitis C treated by pegylated interferon alpha-2b and ribavirin: reducing drug doses has no impact on rapid and sustained virological responses. *J Viral Hepat* (in press).
160 Omata M, Yoshida H, Toyota J *et al.* A large-scale, multicentre, double-blind trial of ursodeoxycholic acid in patients with chronic hepatitis C. *Gut* 2007; 56: 1747–53.
161 Suzuki H, Ohta Y, Takino T *et al.* Effects of glycyrrhizin on biochemical tests in patients with chronic hepatitis. Double blind trial. *Asian Med J* 1983; 26: 423–38.
162 Wildhirt E. Experience in Germany with glycyrrhizinic acid for the treatment of chronic viral hepatitis. In: Nishioka K, Suzuki H, Mishiro S, Oda T, eds. *Viral Hepatitis and Liver Disease*. Tokyo, Springer-Verlag, 1994; 658–61.
163 Arase Y, Ikeda K, Murashima N *et al.* The long term efficacy of glycyrrhizin in chronic hepatitis C patients. *Cancer* 1997; 79: 1494–500.
164 Ikeda K, Arase Y, Kobayashi M *et al.* A long-term glycyrrhizin injection therapy reduces hepatocellular carcinogenesis rate in patients with interferon-resistant active chronic hepatitis C: a cohort study of 1249 patients. *Dig Dis Sci* 2006; 51: 603–9.
165 Piperno A, Sampietro M, D'Alba R *et al.* Iron stores, response to alpha-interferon therapy and effects of iron depletion in chronic hepatitis C. *Liver* 1996; 16: 248–54.
166 Fong TL, Han SH, Tsai NC *et al.* A pilot randomized, controlled trial of the effect of iron depletionon long-term response to alpha-interferon in patients with chronic hepatitis C: *J Hepatol* 1998; 28: 369–74.
167 Herrera JL. Iron depletion is not effective in inducing a virologic response in patients with chronic hepatitis C who failed to respond to interferon therapy. *Am J Gastroenterol* 1999; 94: 3571–5.
168 Fontana RJ, Israel J, LeClair P *et al.* Iron reduction before and during interferon therapy of chronic hepatitis C: results of a multicenter, randomized, controlled trial. *Hepatology* 2000; 31: 730–6.
169 Di Bisceglie AM, Bonkovsky HL, Chopra S *et al.* Iron reduction as an adjuvant to interferon therapy in patients with chronic hepatitis C who previously not responded to interferon: a multicenter, prospective randomized, controlled trail. *Hepatology* 2000; 32: 135–8.
170 Yano M, Hayashi H, Yoshioka K *et al.* A significant reduction in serum alanine aminotransferase levels after 3-month iron reduction therapy for chronic hepatitis C: a multicenter, prospective, randomized, controlled trial in Japan. *J Gastroenterol* 2004; 39: 570–4.
171 Marchesini G, Bianchi G, Merli M *et al.* Nutritional supplementation with branched-chain amino acids in advanced cirrhosis: a double-blind, randomized trial. *Gastroenterology* 2003; 124: 1792–801.
172 McHutchison JG, Everson GT, Gordon SC *et al.* Telaprevir with peginterferon and ribavirin for chronic HCV genotype 1 infection. *N Engl J Med* 2009; 360: 1827–38.

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Original Article

A predictive model of response to peginterferon ribavirin in chronic hepatitis C using classification and regression tree analysis

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Aim: Early disappearance of serum hepatitis C virus (HCV) RNA is the prerequisite for achieving sustained virological response (SVR) in peg-interferon (PEG-IFN) plus ribavirin (RBV) therapy for chronic hepatitis C. This study aimed to develop a decision tree model for the pre-treatment prediction of response.

Methods: Genotype 1b chronic hepatitis C treated with PEG-IFN alpha-2b and RBV were studied. Predictive factors of rapid or complete early virological response (RVR/cEVR) were explored in 400 consecutive patients using a recursive partitioning analysis, referred to as classification and regression tree (CART) and validated.

Results: CART analysis identified hepatic steatosis (<30%) as the first predictor of response followed by low-density-lipoprotein cholesterol (LDL-C) (≥100 mg/dL), age (<50 and <60 years), blood sugar (<120 mg/dL), and gamma-glutamyltransferase (GGT) (<40 IU/L) and built decision tree model. The model consisted of seven groups with variable response rates from low (15%) to high (77%). The reproducibility of the model was confirmed by the independent validation group ($r^2 = 0.987$). When reconstructed into three groups, the rate of RVR/cEVR was 16% for low probability group, 46% for intermediate probability group and 75% for high probability group.

Conclusions: A decision tree model that includes hepatic steatosis, LDL-C, age, blood sugar, and GGT may be useful for the prediction of response before PEG-IFN plus RBV therapy, and has the potential to support clinical decisions in selecting patients for therapy and may provide a rationale for treating metabolic factors to improve the efficacy of antiviral therapy.

Key words: data mining, decision tree, HCV, low-density-lipoprotein-cholesterol, steatosis

INTRODUCTION

COMBINATION THERAPY WITH pegylated interferon (PEG-IFN) and ribavirin (RBV) is now recognized as a standard treatment for patients with chronic hepatitis C.[1] However, the rate of sustained virological response (SVR) to 48 weeks of PEG-IFN RBV combination therapy is only 50% in patients with hepatitis C virus (HCV) genotype 1b and high HCV RNA titer, so called difficult to treat chronic hepatitis C patients.[2,3] Within this difficult to treat group, the response to treatment sometimes can be highly heterogeneous for cases which are apparently equivalent in HCV RNA titer, making the prediction of response before treatment a difficult task. It has been suggested that early virological response (EVR), defined as either undetectable HCV RNA or a 2 log drop in HCV RNA at week 12, is a reliable means to predict SVR.[2,4] More recently, it has been suggested that patients with a rapid virological response (RVR: undetectable HCV RNA at week 4) and a complete EVR (cEVR: undetectable HCV RNA at week 12)

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achieve high SVR rates, while patients with a partial EVR (pEVR: 2 log drop in HCV RNA but still detectable at week 12) have lower rates of SVR.[5] Since PEG-IFN RBV combination therapy is costly and accompanied by potential adverse effects, the ability to predict the possibility of RVR or cEVR before therapy and identifying curable patients may significantly influence the selection of patients for therapy. Moreover, identification of baseline predictors of poor response is particularly important to establish a rationale for identifying therapeutic targets to improve the efficacy of antiviral therapy.

Data mining is a method of predictive analysis which explores tremendous volumes of data to discover hidden patterns and relationships in highly complex datasets and enables the development of predictive models. The classification and regression tree (CART) analysis is a core component of the decision tree tool for data mining and predictive modeling,[6] is deployed to decision makers in various fields of business, and currently is being used in the area of biomedicine.[7–13] The results of CART analysis are presented as a decision tree, which is intuitive and facilitates the allocation of patients into subgroups by following the flow-chart form.[14] CART has been shown to be competitive with other traditional statistical techniques such as logistic regression analysis.[15]

In the present study, we used the CART analysis to explore baseline predictors of response to PEG-IFN plus RBV therapy among clinical, biochemical, virological and histological pretreatment variables and to define a pre-treatment algorithm to discriminate chronic hepatitis C patients who are likely to respond to PEG-IFN plus RBV therapy.

MATERIALS AND METHODS

Patients

A TOTAL OF 419 chronic hepatitis C patients were treated with PEG-IFN alpha-2b and RBV at Musashino Red Cross Hospital between December 2001 and December 2007. Among them, 400 patients who fulfilled the following inclusion criteria were enrolled in the present study. (i) infection by genotype 1b (ii) HCV RNA higher than 100 KIU/mL by quantitative PCR (Cobas Amplicor HCV Monitor, Roche Diagnostic systems, CA) which is usually used for the definition of high viral load in Japan (iii) lack of co-infection with hepatitis B virus or human immunodeficiency virus (iv) lack of other causes of liver disease such as autoimmune hepatitis, primary biliary cirrhosis, or alcohol intake of more than 20 g per day, and (v) having completed at least 12 weeks of therapy with an early virological response that could be evaluated. Patients received PEG-IFN alpha-2b (1.5 microgram/kg) subcutaneously every week and were administered a weight adjusted dose of RBV (600 mg for <60 kg, 800 mg for 60–80 kg, and 1000 mg for >80 kg) which is the recommended dosage in Japan. Data from two third of patients (269 patients) were used for the model building set and the remaining one third of patients (131 patients) were used as a validation set. Consent in writing was obtained from each patient and the study protocol conformed to the ethical guidelines of the 1975 Declaration of Helsinki and was approved by the institutional review committee.

Laboratory tests

Blood samples were obtained before therapy, and at least once every month during therapy and analyzed for hematologic tests, blood chemistries, and HCV RNA. In the present study, RVR and cEVR was defined as undetectable HCV RNA by qualitative PCR with a lower detection limit of 50 IU/mL (Amplicor, Roche Diagnostic systems, CA) at week 4 and 12, respectively. SVR was defined as undetectable HCV RNA at week 24 after the completion of therapy.

Histological examination

For all patients, liver biopsy specimens were obtained before therapy and were evaluated independently by three pathologists who were blinded to the clinical details. If there was a disagreement, the scores assigned by the majority of pathologists were used for the analysis. Fibrosis and activity were scored according to the METAVIR scoring system.[16] Fibrosis was staged on a scale of 0–4: F0 (no fibrosis), F1 (mild fibrosis: portal fibrosis without septa), F2 (moderate fibrosis: few septa), F3 (severe fibrosis: numerous septa without cirrhosis) and F4 (cirrhosis). Activity of necroinflammation was graded on a scale of 0–3: A0 (no activity), A1 (mild activity), A2 (moderate activity) and A3 (severe activity). Percentage of steatosis was quantified by determining the average proportion of hepatocytes affected by steatosis and graded on a scale of 0–3: grade 0 (no steatosis), grade 1 (0–9%), grade 2 (10–29%), and grade 3 (over 30%) as we reported previously.[17]

Database for analysis

A pretreatment database of 72 variables was created containing histological findings (grade of fibrosis, activity, and steatosis), laboratory tests including the quantity of HCV RNA by Cobas Amplicor, and clinical information (age, gender, body weight, and body mass index).

The baseline characteristics and test results are listed in Table 1. The overall rate of RVR/cEVR was 43% in the model building set and 48% in the validation set. There were no significant differences in the clinical backgrounds between these two groups. Hepatitis C viral mutations, such as mutations in interferon-sensitivity determining region or core amino acid residues 70 and 91, were not included in the present analysis. The dataset of laboratory tests was based on the digitized records in this hospital. Continuous data was split into categorized data by increment of 10; For example, age was categorized into <30, 30–39, 40–49, 50–59, 60–69, and ≥70.

Statistical analysis

Based on this database, the recursive partitioning analysis algorithm referred to as CART was implemented to define meaningful subgroups of patients with respect to the possibility of achieving RVR/cEVR. The CART belongs to a family of nonparametric regression methods based on binary recursive partitioning of data. The software automatically explore the data to search for optimal split variables, builds a decision tree structure and finally classifies all subjects into particular subgroups that are homogeneous with respect to the outcome of interest.[18] During the CART analysis, first, the entire study population, and thereafter, all newly defined subgroups, were investigated at every step of the analysis to determine which variable at what cut-off point yielded the most significant division into two prognostic subgroups that were as homogeneous as possible with respect to estimates of RVR/cEVR possibilities. This algorithm uses the impurity function (Gini criterion function) for splitting.[19] A restriction was imposed on the tree construction such that terminal subgroups resulting from any given split must have at least 20 patients. The CART procedure stopped when either no additional significant variable was detected or when the sample size was below 20. The resulting final subgroups were most homogeneous with respect to the probability of achieving RVR/cEVR. For this analysis, data mining software Clementine version 12.0 (SPSS Inc, Chicago, IL) was utilized. SPSS 15.0 (SPSS Inc, Chicago, IL) was used for logistic regression analysis.

RESULTS

Factors associated with RVR/cEVR by standard statistical analysis

WE FIRST ANALYZED 72 variables by univariate and multivariate logistic regression analysis to find factors associated with RVR/cEVR (Table 2). Patients with RVR/cEVR were significantly younger than those without. Among histological findings, grade of steatosis and stage of fibrosis was significantly lower in RVR/cEVR. Among hematologic tests, hemoglobin and hematcrit was significantly higher in RVR/cEVR. Among blood chemistry tests, creatinine and low-density lipoprotein cholesterol (LDL-C) was significantly higher and gamma-glutamyltransferase (GGT), low-density-lipoprotein cholesterol (LDL-C), and blood sugar were significantly lower in RVR/cEVR. The level of HCV RNA was significantly lower in RVR/cEVR. There were no significant differences in other tests.

Multivariate logistic regression analysis was performed on age, fibrosis stage, steatosis, HCVRNA, creatinine, hemoglobin, GGT, LDL-C, and blood sugar: hematcrit was not included since it is closely associated with hemoglobin. On multivariate analysis, age, grade of steatosis, level of HCV RNA, creatinine, hemoglobin, GGT, and LDL-cholesterol remained significant whereas stage of fibrosis, hemoglobin and blood sugar were not.

The CART analysis

The CART analysis was carried out on the model building set of 269 patients using the same variables as logistic regression analysis. Figure 1 shows the resulting decision tree. The CART analysis automatically selected five predictive variables to produce a total of seven subgroups of patients. The grade of steatosis was selected as the variable of initial split with an optimal cut-off of 30%. The possibility of achieving RVR/cEVR was only 18% for patients with hepatic steatosis of 30% or more compared to 47% for patients with hepatic steatosis of less than 30%. Among patients with hepatic steatosis of less than 30%, the level of serum LDL-C, with an optimal cut-off of 100 mg/dL, was selected as the variable of second split. Patients with higher LDL-C level had the higher probability of RVR/cEVR (57% vs. 32%). Among patients with LDL-C of less than 100 mg/dL, age, with an optimal cut-off of 60, was selected as the third variable of split. Younger patients had the higher probability of RVR/cEVR (49% vs. 15%). Among patients younger than 60, the blood sugar, with an optimal cut-off of 120 mg/dL, was selected as the forth variable of split. Patients with lower blood sugar level had the higher probability of RVR/cEVR (71% vs. 31%). Among patients with hepatic steatosis of less than 30% and LDL-C of 100 mg/dL or more, age, with an optimal cut-off of 50, was selected as the third variable of split, younger being the predictor of higher RVR/cEVR probability (77% vs. 50%). Among patients older than 50,

Table 1 Clinical characteristics of patients

	Model set $n = 269$	Validation set $n = 131$	*P*-value
Sex (M/F)	127/142	55/76	0.325
Age (years)	57.7 ± 10.1	57.6 ± 10.0	0.932
Body weight (kg)	59.6 ± 11.0	57.5 ± 9.5	0.094
Body mass index (kg/m^2)	23.2 ± 3.1	23.3 ± 3.8	0.934
Total protein (g/dL)	7.6 ± 0.5	7.7 ± 0.6	0.558
Albumin (g/dL)	4.2 ± 0.3	4.2 ± 0.3	0.349
Globulin (g/dL)	3.4 ± 0.5	3.4 ± 0.6	0.989
Aspartate aminotransferase (IU/L)	58.1 ± 43.1	55.8 ± 37.5	0.601
Alanine aminotransferase (IU/L)	70.9 ± 49.2	66.4 ± 52.6	0.462
Gamma-glutamyltransferase (IU/L)	49.6 ± 44.0	45.2 ± 34.4	0.33
Lactate dehydrogenase (IU/L)	289.3 ± 112.3	301.5 ± 109.3	0.417
Total bilirubin (mg/dL)	0.71 ± 0.28	0.69 ± 0.23	0.317
Direct bilirubin (mg/dL)	0.23 ± 0.12	0.25 ± 0.10	0.147
Indirect bilirubin (mg/dL)	0.48 ± 0.21	0.44 ± 0.16	0.064
Alkaline phosphatase (IU/L)	290.9 ± 107.6	292.5 ± 107.6	0.917
Leucine aminopeptidase (IU/L)	64.3 ± 14.3	65.5 ± 12.3	0.543
Thymol turbidity test (KU)	7.1 ± 3.4	8.0 ± 3.7	0.062
Zinc sulfate turbidity test (KU)	15.4 ± 4.9	16.3 ± 5.4	0.188
Choline esterase (IU/L)	318.1 ± 81.7	321.1 ± 78.1	0.798
Ammonia (microg/dL)	39.7 ± 20.2	45.0 ± 15.6	0.668
Blood sugar (mg/dL)	125.9 ± 41.1	117.4 ± 47.9	0.081
Glycohemoglobin (%)	5.6 ± 1.6	5.4 ± 1.2	0.797
Total cholesterol (mg/dL)	170.8 ± 33.9	175.6 ± 36.8	0.170
Low-density-lipoprotein-cholesterol (mg/dL)	96.5 ± 25.2	100.9 ± 28.5	0.153
High-density-lipoprotein-cholesterol (mg/dL)	54.2 ± 15.9	55.2 ± 17.4	0.612
Triglyceride (mg/dL)	108.5 ± 47.8	102.8 ± 46.4	0.306
Creatinine (mg/dL)	0.72 ± 0.15	0.74 ± 0.17	0.236
Urea nitrogen (mg/dL)	14.1 ± 3.4	14.9 ± 3.9	0.123
Uric acid (mg/dL)	5.3 ± 1.2	5.2 ± 1.2	0.715
Sodium (mEq/L)	142.2 ± 2.0	142.4 ± 2.0	0.471
Potassium (mEq/L)	4.3 ± 0.3	4.3 ± 0.4	0.578
Chloride (mEq/L)	104.0 ± 2.2	104.0 ± 2.6	0.905
Calcium (mg/dL)	9.1 ± 0.4	9.2 ± 0.4	0.479
Phosphorus (mg/dL)	3.5 ± 0.5	3.5 ± 0.6	0.814
Magnesium (mg/dL)	2.2 ± 0.2	2.3 ± 0.3	0.390
Amylase (IU/L)	178.7 ± 125.8	175.1 ± 133.1	0.118
Creatine kinase (IU/L)	114.9 ± 147.6	119.3 ± 73.7	0.849
Iron (microg/dL)	104.7 ± 53.2	109 ± 37	0.726
Ferritin (ng/mL)	111.3 ± 103.3	59.7 ± 118.5	0.405
C-reactive peptide (mg/dL)	0.2 ± 1.1	0.1 ± 0.1	0.586
Immunoglobulin G (mg/dL)	1849 ± 426	1988 ± 525	0.129
Immunoglobulin M (mg/dL)	141 ± 69	205 ± 106	0.200
Immunoglobulin A (mg/dL)	323 ± 675	291 ± 81	0.784
Triiodothyronine (pg/mL)	2.3 ± 0.3	2.2 ± 0.3	0.358
Thyroxin (ng/dL)	0.9 ± 0.1	0.9 ± 0.1	0.872
Thyroid stimulating hormone (micro IU/mL)	1.8 ± 1.4	1.7 ± 0.7	0.939
White blood cell count (/microl)	5243 ± 1591	5286 ± 1101	0.843
Segmented neutrophils (%)	55.4 ± 10.8	57.0 ± 10.0	0.297
Band neutrophils (%)	1.5 ± 1.6	0.5 ± 0.6	0.250
Eosinophils (%)	2.9 ± 2.3	2.4 ± 1.4	0.127

Table 1 *Continued*

	Model set $n = 269$	Validation set $n = 131$	*P*-value
Basophiles (%)	0.6 ± 0.4	0.6 ± 0.3	0.727
Lymphocytes (%)	34.6 ± 9.6	34.0 ± 9.3	0.682
Monocytes (%)	6.6 ± 2.2	6.2 ± 2.6	0.149
Red blood cell count (10^4/microl)	458 ± 43	455 ± 47	0.643
Hemoglobin (g/dL)	14.4 ± 1.5	14.5 ± 1.5	0.618
Hematcrit (%)	42.7 ± 4.0	42.9 ± 4.4	0.717
Reticulocytes (%)	1.4 ± 0.4	1.4 ± 0.4	0.762
Mean corpuscular volume (fL)	93.3 ± 4.5	93.8 ± 5.41	0.466
Mean corpuscular hemoglobin concentration (pg)	31.5 ± 1.9	31.7 ± 2.3	0.583
Mean corpuscular hemoglobin concentration (g/dL)	33.8 ± 0.9	33.7 ± 1.3	0.910
Platelets (10^4/microl)	16.8 ± 5.4	16.3 ± 4.5	0.480
Prothrombin time (s)	11.7 ± 1.2	11.7 ± 0.9	0.762
Prothrombin time (activity %)	104.6 ± 14.4	102.6 ± 14.8	0.363
Prothrombin time (international normalized ratio)	1.0 ± 0.1	1.0 ± 0.1	0.387
Thrombin time (%)	97.2 ± 31.3	109 ± 31.5	0.231
Activated partial thromboplastin time (s)	29.7 ± 4.4	29.1 ± 2.7	0.260
Hepaplastin test (%)	97.8 ± 20.3	95.4 ± 19.4	0.523
Fibrinogen (%)	237 ± 44	225 ± 45	0.069
Hepatitis C virus RNA (<850/≥850 KIU/mL)	130/139	70/61	0.394
Histological grade of			
Activity (A1/A2/A3)	138/107/24	62/55/14	0.714
Fibrosis (F1/F2/F3/F4)	135/74/57/3	58/40/27/6	0.131
Steatosis (0%/1–9%/10–29%/30%≦)	89/109/37/34	49/45/21/16	0.643
Hepatitis C virus RNA negative at week 12 (yes/no)	116/153	63/68	0.349

the level of GGT, with an optimal cutoff of 40 U/L, were then selected as the fourth level of split, low levels being the predictor of higher RVR/cEVR probability (60% vs. 35%).

All five factors selected as significant variables in the CART analysis were also significantly associated with RVR/cEVR by univariate analysis (Table 2). In addition, steatosis, LDL-C, age and GGT were also independently

Table 2 Factors associated with rapid or complete early virological response by univariate and multivariate logistic regression analysis

Parameter	Category	Univariate			Multivariate		
		Odds	95% CI	*P*-value	Odds	95% CI	*P*-value
Age (years)	<50 vs. ≥50	2.65	1.51–4.65	<0.001	2.03	1.04–3.97	0.039
Fibrosis stage	F1-2 vs. F3-4	2.47	1.31–4.66	0.005	1.77	0.85–3.68	0.120
Steatosis (%)	<30 vs. ≥30	4.11	1.64–10.29	0.003	2.88	1.07–7.79	0.037
Hepatitis C virus RNA (KIU/mL)	<850 vs. ≥850	1.97	1.21–3.22	0.007	1.93	1.09–3.43	0.025
Creatinine (mg/dL)	≥0.8 vs. <0.8	3.30	1.96–5.56	<0.001	3.54	1.88–6.67	<0.001
Hemoglobin (g/dL)	≥14.5 vs. <14.5	1.76	1.08–2.87	0.023	1.38	0.74–2.57	0.320
Hematcrit (%)	≥43 vs. <43	1.75	1.07–2.84	0.003			
Gamma-glutamyltransferase (IU/L)	<40 vs. ≥40	2.06	1.26–3.37	0.004	2.45	1.32–4.56	0.005
Low-density-lipid cholesterol (mg/dL)	≥100 vs. <100	2.71	1.61–4.55	<0.001	2.21	1.21–4.06	0.010
Blood sugar (mg/dL)	<120 vs. ≥120	2.00	1.02–3.95	0.045	1.42	0.64–3.13	0.390

CI, confidence interval.

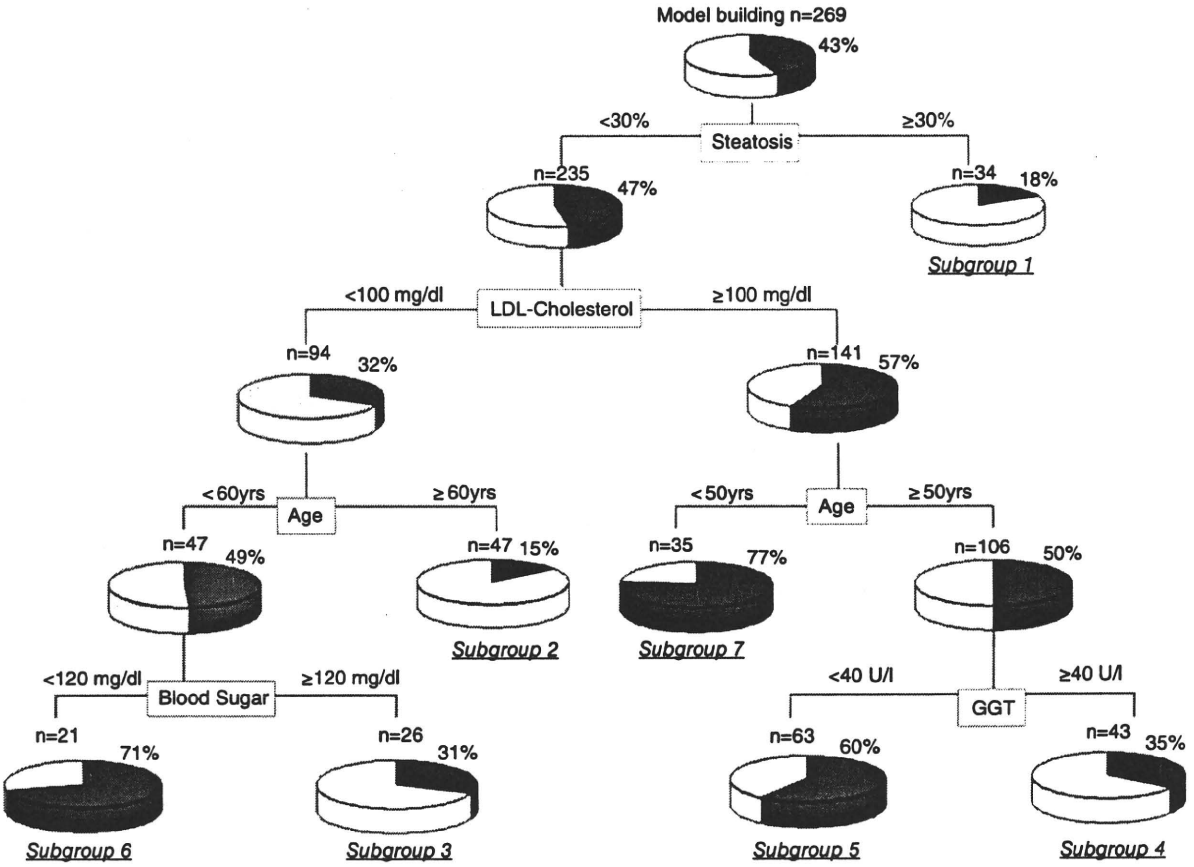

Figure 1 Classification and regression tree analysis. Boxes indicate the factors used for splitting and the cut-off value for the split. Pie charts indicate the rate of RVR/cEVR for each group of patients after splitting. Terminal subgroups of patients discriminated by the analysis are numbered from one to seven. GGT, gamma-glutamyltransferase; LDL, low-density-lipoprotein.

associated with RVR/cEVR by multivariate logistic regression analysis while blood sugar was not (Table 2). On the other hand, HCVRNA and creatinine which were significantly associated with RVR/cEVR by multivariate analysis were not selected as significant variables in CART analysis.

The probabilities of RVR/cEVR for the seven subgroups derived by this process were highly variable. The subgroup whose hepatic steatosis was less than 30%, serum LDL-C was 100 mg/dL or more and of an age less than 50 years (subgroup 7) showed the highest probability of RVR/cEVR (77%), while the subgroup whose hepatic steatosis more than 30% (subgroup 1) and the subgroup whose hepatic steatosis was less than 30% but serum LDL-C was less than 100 mg/dL and of an age greater than 60 years (subgroup 2) showed the lowest probability of RVR/cEVR (18% and 15%, respectively).

Validation of the CART analysis

The results of the CART analysis were validated with a validation dataset of 131 cases which is independent of the model building dataset. Each patient in the validation set was allocated to subgroups 1–7 using the flowchart form of the CART tree. The rates of RVR/cEVR were 20% for subgroups 1 and 2, 29% for subgroups 3, 38% for subgroup 4, 59% for subgroup 5, 71% for subgroup 6, and 85% for subgroups 7. The rates of RVR/cEVR for each subgroup of patients were closely correlated between the model building dataset and the validation dataset (Fig. 2).

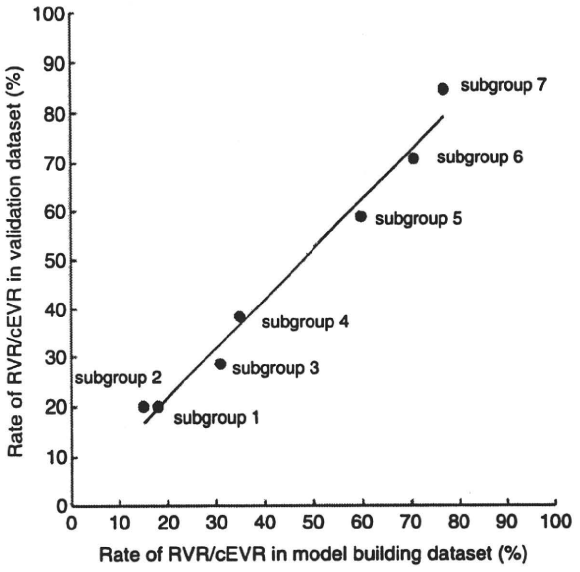

Figure 2 Validation of the classification and regression tree (CART) analysis: Subgroup stratified comparison of the rate of rapid or complete early virological response (RVR/cEVR) between the model building and validation datasets. Each patient in the validation set was allocated to subgroups 1–7 by following the flow-chart form of the CART tree and the rates of RVR/cEVR were calculated. The rate of RVR/cEVR in each subgroup was plotted. The *x*-axis represents the rate of RVR/cEVR in the model building datasets and the y-axis represents the rate of RVR/cEVR in the validation datasets. The rates of achieving RVR/cEVR in each subgroup of patients closely correlated between the model building dataset and the validation dataset ($r^2 = 0.987$).

Construction of 3 groups according to the probability of RVR/cEVR

If the seven subgroups were reconstructed into three groups according to their rate of RVR/cEVR, the rate of RVR/cEVR was 16% for low probability group (subgroup 1 and 2), 46% for intermediate probability group (subgroup 3, 4, and 5) and 75% for high probability group (subgroup 6 and 7; $P < 0.0001$).

Effect of adherence

Adherence of PEG-IFN and RBV was not included as a variable of analysis since the present study aimed to develop a pre-treatment model for the prediction of response. To analyze the possible effect of adherence on the result of CART analysis, three groups of patients divided by CART (low, intermediate and high probability group) were further stratified according to adherence of PEG-IFN and RBV. Poor adherence was defined as taking less than 80% planned dose of PEG-IFN or RBV at 12 weeks, and good adherence was defined as taking more than 80% planned dose of both PEG-IFN and RBV at 12 weeks. The result is shown in Figure 3. Among patients with good adherence, the rate of RVR/cEVR was 19% for low probability group, 52% for intermediate probability group and 77% for high probability group. Among poor adherence group, the rate of RVR/cEVR was 13% for low probability group, 41% for intermediate probability group and 73% for high probability group. Collectively, even after adjustment for adherence, 3 groups of patients divided by CART analysis still had low, intermediate and high probability of achieving RVR/cEVR, respectively.

DISCUSSION

IN THE PRESENT study, we performed the CART analysis and built a simple decision tree model for the pre-treatment prediction of response to PEG-IFN plus

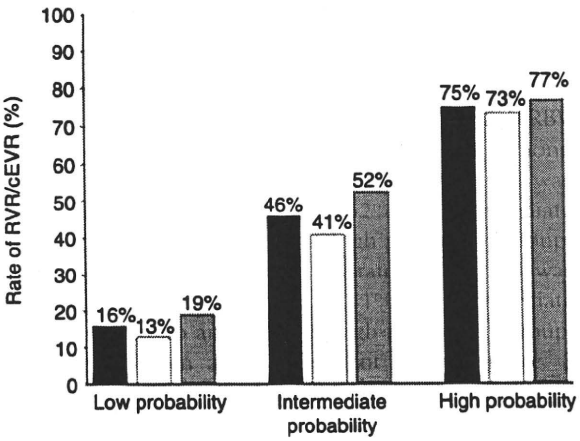

Figure 3 The rate of rapid or complete early virological response (RVR/cEVR) between the classification and regression tree (CART) groups stratified by adherence. The three groups of patients divided by CART (low, intermediate and high probability group) were further stratified according to adherence of peg-interferon (PEG-IFN) plus ribavirin (RBV). Black, white and gray boxes in the bar chart indicate total patients, patients with poor adherence (taking less than 80% planned dose of PEG-IFN or RBV at 12 weeks), and good adherence (taking more than 80% planned dose of both PEG-IFN and RBV at 12 weeks), respectively. Even after adjustment for adherence, 3 groups of patients divided by CART analysis still had low, intermediate and high probability of achieving RVR/cEVR, respectively.

RBV therapy. The analysis highlighted five host variables relevant to response: steatosis, LDL-C, age, blood sugar and GGT. Classification of patients based on these variables identified subgroups of patients with high probabilities of achieving RVR/cEVR among difficult to treat chronic hepatitis C patients. The reproducibility of the model was confirmed by the independent validation datasets. According to the result of the CART, patients were categorized into 3 groups: the rate of RVR/cEVR was 16% for low probability group, 46% for intermediate probability group and 75% for high probability group. The result of the CART analysis could be readily applicable to clinical practice because patients could be allocated to specific subgroups with a defined rate of response simply by following the flow-chart form. Although an early disappearance of serum HCV RNA is the prerequisite for achieving SVR, no reliable baseline predictors of response to PEG-IFN plus RBV therapy are established to date. Thus, this model may have the potential to support decisions in patient selection for PEG-IFN plus RBV therapy or to tailor treatment strategies for individual patients. Moreover, our result may provide a rationale for treating metabolic factors to improve the efficacy of antiviral therapy.

Among variables relevant to the prediction of RVR/cEVR, the grade of hepatic steatosis was selected as the variable of the first split. Previous studies suggested that steatosis induces resistance to IFN and RBV combination therapy[20,21] along with underlining metabolic factors such as insulin resistance or obesity.[21-24] In the present study, the grade of steatosis correlated positively with BMI and serum glucose level (data not shown) suggesting the etiologic role of metabolic factors. In addition, serum glucose level was selected as a predictor of RVR/cEVR at the fourth level of split. Serum GGT, which is associated with obesity,[25] insulin resistance[26] and response to IFN therapy,[27-30] was also selected as a predictor of RVR/cEVR at fourth level of splitting which may emphasize the importance of metabolic factors in therapeutic resistance. These findings raise the possibility that treatment of these metabolic factors may improve the virological response to the PEG-IFN plus RBV therapy. This hypothesis should be examined by a prospective study.

We and others have reported that steatosis, obesity and insulin resistance are associated with the progression of fibrosis,[17,31-33] which can interfere indirectly with the effect of IFN on hepatocytes. Other possible mechanisms of resistance by steatosis or metabolic factors include dysregulation of adipocytokines[34] or oxidative stress which may inhibit intracellular IFN signaling pathway.[35] Despite these findings, the precise mechanism of resistance is not established and further investigation is needed.

Another factor relevant in the prediction of RVR/cEVR was LDL-C. LDL-C was selected as the second factor for splitting by CART, and was an independent predictor of RVR/cEVR by logistic regression analysis. LDL-C recently has attracted attention as a novel predictor of response to IFN or PEG-IFN plus RBV.[30,36,37] Since *in vitro* study showed that LDL-C receptor acts as a receptor for HCV and LDL-C competitively inhibit the binding of HCV,[38] high level of serum LDL-C may inhibit HCV entry to hepatocytes and attenuate replication. LDL-C and its receptor may be a future therapeutic target.

Not all factors selected as significant variables in the CART analysis were also significantly associated with response by standard statistical analysis: blood sugar was associated with response by univariate analysis but not by multivariate logistic regression analysis On the other hand, HCVRNA and creatinine which were significantly associated with RVR/cEVR by multivariate analysis were not selected as significant variables in CART analysis. These differences may indicate both the unique feature and the limitations of the CART analysis. To note, blood sugar was significantly associated with RVR/cEVR within specialized subgroups of patients defined by the CART analysis: in subgroup of patients with steatosis <30%, LDL-C <100 mg/dL and younger than 60, which indicate the unique feature of the CART analysis that it could visualize significant predictors that specifically apply to selected patients. The limitation is that not all significant factors may be adopted in the decision tree since we applied the rule to stop CART procedure when the sample size was below 20. This rule was applied to avoid the generation of over-fit model which may lack universality. Therefore, it is possible that HCVRNA or creatinine may become a significant variable in the CART analysis if larger number of patients were included in the analysis. Stage of fibrosis was significantly associated with response to therapy by univariate analysis but not by multivariate analysis and not selected as a significant variable in the CART analysis. The possible reason is that advanced fibrosis is associated with older age as a confounding factor.

CART analyses are gaining acceptance in medical research in addition to biomedical field. Recent publications include the prediction of aggressive prostate cancer,[8] diabetic vascular complications,[19] prognosis of melanoma,[7,39] response to preoperative radiotherapy for rectal tumor,[9] prognostic groups in colorectal carcinoma,[12] and outcome after liver failure.[11] An advantage

of CART over traditional regression models is that it can identify prognostic subgroups that are useful in clinical practice. Because the results of CART analysis are presented as a decision tree, which is intuitive, they can be readily interpreted by medical professionals without any specific knowledge of statistics. The most important consideration is that five variables used in the decision tree were clinical parameters that are readily available by the usual work-up of patients before therapy. Especially, glucose, GGT and LDL-C are simple biochemical markers that are easily measured at a low cost. Using this model, we can rapidly develop an estimate of the response before treatment, which may facilitate clinical decision making.

In conclusion, we built a pre-treatment model for the prediction of virological response in PEG-IFN plus RBV therapy. Because this decision tree model was made up of simple host factors such as steatosis, LDL-C, age, blood sugar and GGT, it can be easily applied to clinical practice. This model may have the potential to support decisions in patient selection for PEG-IFN plus RBV therapy based on the possibility of response against a potential risk of adverse events or costs, and may provide a rationale for treating metabolic factors to improve the efficacy of antiviral therapy.

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REFERENCES

1 Strader DB, Wright T, Thomas DL, Seeff LB. Diagnosis, management, and treatment of hepatitis C. *Hepatology* 2004; 39: 1147–71.
2 Fried MW, Shiffman ML, Reddy KR *et al.* Peginterferon alfa-2a plus ribavirin for chronic hepatitis C virus infection. *N Engl J Med* 2002; 347: 975–82.
3 Manns MP, McHutchison JG, Gordon SC *et al.* Peginterferon alfa-2b plus ribavirin compared with interferon alfa-2b plus ribavirin for initial treatment of chronic hepatitis C: a randomised trial. *Lancet* 2001; 358: 958–65.
4 Davis GL, Wong JB, McHutchison JG, Manns MP, Harvey J, Albrecht J. Early virologic response to treatment with peginterferon alfa-2b plus ribavirin in patients with chronic hepatitis C. *Hepatology* 2003; 38: 645–52.
5 Lee SS, Ferenci P. Optimizing outcomes in patients with hepatitis C virus genotype 1 or 4. *Antivir Ther* 2008; 13 (Suppl 1): 9–16.
6 Breiman LJH, Friedman RA, Olshen CJ, Stone CM. *Classification and Regression Trees*. Calif: Wadsworth, 1980.
7 Averbook BJ, Fu P, Rao JS, Mansour EG. A long-term analysis of 1018 patients with melanoma by classic Cox regression and tree-structured survival analysis at a major referral center: Implications on the future of cancer staging. *Surg* 2002; 132: 589–602.
8 Garzotto M, Beer TM, Hudson RG *et al.* Improved detection of prostate cancer using classification and regression tree analysis. *J Clin Oncol* 2005; 23: 4322–9.
9 Zlobec I, Steele R, Nigam N, Compton CC. A predictive model of rectal tumor response to preoperative radiotherapy using classification and regression tree methods. *Clin Cancer Res* 2005; 11: 5440–3.
10 Jin H, Lu Y, Harris ST *et al.* Classification algorithms for hip fracture prediction based on recursive partitioning methods. *Med Decis Making* 2004; 24: 386–98.
11 Baquerizo A, Anselmo D, Shackleton C *et al.* Phosphorus ans an early predictive factor in patients with acute liver failure. *Transplantation* 2003; 75: 2007–14.
12 Valera VA, Walter BA, Yokoyama N *et al.* Prognostic groups in colorectal carcinoma patients based on tumor cell proliferation and classification and regression tree (CART) survival analysis. *Ann Surg Oncol* 2007; 14: 34–40.
13 Martin MA, Meyricke R, O'Neill T, Roberts S. Mastectomy or breast conserving surgery? Factors affecting type of surgical treatment for breast cancer – a classification tree approach. *BMC Cancer* 2006; 6: 98.
14 LeBlanc M, Crowley J. A review of tree-based prognostic models. *Cancer Treat Res* 1995; 75: 113–24.
15 Costanza MC, Paccaud F. Binary classification of dyslipidemia from the waist-to-hip ratio and body mass index: a comparison of linear, logistic, and CART models. *BMC Med Res Methodol* 2004; 4: 7.
16 Bedossa P, Poynard T. An algorithm for the grading of activity in chronic hepatitis C. The METAVIR Cooperative Study Group. *Hepatology* 1996; 24: 289–93.
17 Kurosaki M, Matsunaga K, Hirayama I *et al.* The presence of steatosis and elevation of alanine aminotransferase levels are associated with fibrosis progression in chronic hepatitis C with non-response to interferon therapy. *J Hepatol* 2008; 48: 736–42.
18 Segal MR, Bloch DA. A comparison of estimated proportional hazards models and regression trees. *Stat Med* 1989; 8: 539–50.
19 Miyaki K, Takei I, Watanabe K, Nakashima H, Omae K. Novel statistical classification model of type 2 diabetes mellitus patients for tailor-made prevention using data mining algorithm. *J Epidemiol* 2002; 12: 243–8.
20 Akuta N, Suzuki F, Tsubota A *et al.* Efficacy of interferon monotherapy to 394 consecutive naive cases infected with hepatitis C virus genotype 2a in Japan: therapy efficacy as consequence of tripartite interaction of viral, host and interferon treatment-related factors. *J Hepatol* 2002; 37: 831–6.

21 Poynard T, Ratziu V, McHutchison J *et al.* Effect of treatment with peginterferon or interferon alfa-2b and ribavirin on steatosis in patients infected with hepatitis C. *Hepatology* 2003; **38**: 75–85.
22 Bressler BL, Guindi M, Tomlinson G, Heathcote J. High body mass index is an independent risk factor for nonresponse to antiviral treatment in chronic hepatitis C. *Hepatology* 2003; **38**: 639–44.
23 Romero-Gomez M, Del Mar Viloria M, Andrade RJ *et al.* Insulin resistance impairs sustained response rate to peginterferon plus ribavirin in chronic hepatitis C patients. *Gastroenterology* 2005; **128**: 636–41.
24 Konishi I, Horiike N, Hiasa Y *et al.* Diabetes mellitus reduces the therapeutic effectiveness of interferon-alpha2b plus ribavirin therapy in patients with chronic hepatitis C. *Hepatol Res* 2007; **37**: 331–6.
25 Marchesini G, Avagnina S, Barantani EG *et al.* Aminotransferase and gamma-glutamyltranspeptidase levels in obesity are associated with insulin resistance and the metabolic syndrome. *J Endocrinol Invest* 2005; **28**: 333–9.
26 Fraser A, Ebrahim S, Smith GD, Lawlor DA. A comparison of associations of alanine aminotransferase and gamma-glutamyltransferase with fasting glucose, fasting insulin, and glycated hemoglobin in women with and without diabetes. *Hepatology* 2007; **46**: 158–65.
27 Mazzella G, Salzetta A, Casanova S *et al.* Treatment of chronic sporadic-type non-A, non-B hepatitis with lymphoblastoid interferon: gamma GT levels predictive for response. *Dig Dis Sci* 1994; **39**: 866–70.
28 Villela-Nogueira CA, Perez RM, de Segadas Soares JA, Coelho HS. Gamma-glutamyl transferase (GGT) as an independent predictive factor of sustained virologic response in patients with hepatitis C treated with interferon-alpha and ribavirin. *J Clin Gastroenterol* 2005; **39**: 728–30.
29 Berg T, Sarrazin C, Herrmann E *et al.* Prediction of treatment outcome in patients with chronic hepatitis C: significance of baseline parameters and viral dynamics during therapy. *Hepatology* 2003; **37**: 600–9.
30 Akuta N, Suzuki F, Kawamura Y *et al.* Predictive factors of early and sustained responses to peginterferon plus ribavirin combination therapy in Japanese patients infected with hepatitis C virus genotype 1b: amino acid substitutions in the core region and low-density lipoprotein cholesterol levels. *J Hepatol* 2007; **46**: 403–10.
31 Adinolfi LE, Gambardella M, Andreana A, Tripodi MF, Utili R, Ruggiero G. Steatosis accelerates the progression of liver damage of chronic hepatitis C patients and correlates with specific HCV genotype and visceral obesity. *Hepatology* 2001; **33**: 1358–64.
32 Ortiz V, Berenguer M, Rayon JM, Carrasco D, Berenguer J. Contribution of obesity to hepatitis C-related fibrosis progression. *Am J Gastroenterol* 2002; **97**: 2408–14.
33 Muzzi A, Leandro G, Rubbia-Brandt L *et al.* Insulin resistance is associated with liver fibrosis in non-diabetic chronic hepatitis C patients. *J Hepatol* 2005; **42**: 41–6.
34 Charlton MR, Pockros PJ, Harrison SA. Impact of obesity on treatment of chronic hepatitis C. *Hepatology* 2006; **43**: 1177–86.
35 Di Bona D, Cippitelli M, Fionda C *et al.* Oxidative stress inhibits IFN-alpha-induced antiviral gene expression by blocking the JAK-STAT pathway. *J Hepatol* 2006; **45**: 271–9.
36 Minuk GY, Weinstein S, Kaita KD. Serum cholesterol and low-density lipoprotein cholesterol levels as predictors of response to interferon therapy for chronic hepatitis C. *Ann Intern Med* 2000; **132**: 761–2.
37 Gopal K, Johnson TC, Gopal S *et al.* Correlation between beta-lipoprotein levels and outcome of hepatitis C treatment. *Hepatology* 2006; **44**: 335–40.
38 Agnello V, Abel G, Elfahal M, Knight GB, Zhang QX. Hepatitis C virus and other flaviviridae viruses enter cells via low density lipoprotein receptor. *Proc Natl Acad Sci USA* 1999; **96**: 12766–71.
39 Leiter U, Buettner PG, Eigentler TK, Garbe C. Prognostic factors of thin cutaneous melanoma: an analysis of the central malignant melanoma registry of the german dermatological society. *J Clin Oncol* 2004; **22**: 3660–7.

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Original Article

Hepatic steatosis in chronic hepatitis C is a significant risk factor for developing hepatocellular carcinoma independent of age, sex, obesity, fibrosis stage and response to interferon therapy

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Aim: Hepatic steatosis is linked to development of hepatocellular carcinoma (HCC) in non-viral liver disease such as non-alcoholic steatohepatitis. The present study aimed to assess whether hepatic steatosis is associated with the development of HCC in chronic hepatitis C.

Methods: We studied a retrospective cohort of 1279 patients with chronic hepatitis C who received interferon (IFN) therapy between 1994 and 2005 at a single regional hospital in Japan. Of these patients, 393 had a sustained virological response (SVR) and 886 had non-SVR to IFN therapy. After IFN therapy, these patients were screened for development of HCC every 6 months. The average period of observation was 4.5 years.

Results: HCC developed in 68 patients. The annual incidence of HCC was 2.73% for patients with a steatosis grade of 10% or greater and 0.69% for patients with a steatosis grade of 0–9%. On multivariate analysis, higher grade of steatosis was a significant risk factor for HCC independent of older age, male sex, higher body mass index (BMI), advanced fibrosis stage and non-SVR to IFN therapy. The adjusted risk ratio of hepatic steatosis was 3.04 (confidence interval 1.82–5.06, $P < 0.0001$), which was higher than that of older age (1.09), male sex (2.12), non-SVR to IFN (2.43) and higher BMI (1.69).

Conclusion: Hepatic steatosis is a significant risk factor for development of HCC in chronic hepatitis C independent of other known risk factors, which suggest the possibility that amelioration of hepatic steatosis may prevent hepatocarcinogenesis.

Key words: body mass index, fibrosis, sex, hepatocellular carcinoma, interferon, steatosis, virological response.

INTRODUCTION

HEPATOCELLULAR CARCINOMA (HCC) is one of the most common cancers worldwide and its incidence has been increasing. This recent increase in HCC incidence may likely be attributed to the higher prevalence of non-alcoholic fatty liver disease (NAFLD) and hepatitis C virus (HCV) infection.[1]

Non-alcoholic fatty liver disease is characterized by hepatic steatosis with or without inflammation in the absence of excessive alcohol consumption. Several studies have indicated the etiological association between NAFLD and development of HCC.[2–4] Other studies have shown that obesity or diabetes, a common etiology of non-alcoholic hepatic steatosis, is associated with development of HCC.[5–7] Although the mechanism of carcinogenesis in NAFLD has not been determined, an animal model showed that obesity-related hepatic steatosis leads to the development of hepatic

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hyperplasia, suggesting the possibility that hepatic steatosis is a pre-malignant condition.[8]

Another important etiological agent for HCC is HCV infection. Because steatosis is a common pathological feature of HCV-infected patients,[9] the important question is whether steatosis influences the progression of liver disease in hepatitis C, by analogy with NAFLD. Several studies, including ours[10] indicated that hepatic steatosis promotes the progression of hepatic fibrosis.[11–15] The association between hepatic steatosis and the development of HCC in chronic hepatitis C has been proposed[16] and was confirmed in two studies[17,18] while another study failed to show such an association.[19] The present study was conducted to analyze the association between hepatic steatosis and development of HCC in a large cohort of chronic hepatitis C patients, which enabled to adjust for known risk factors for HCC.

METHODS

Patients

A TOTAL OF 1437 chronic hepatitis C patients were treated with interferon (IFN) at Musashino Red Cross Hospital between October 1994 and October 2005. Among them, 1279 patients who fulfilled the following inclusion criteria were enrolled in this study: (i) positive for HCV RNA by reverse-transcription polymerase chain reaction before IFN therapy; (ii) absence of other causes of liver disease, such as co-infection with hepatitis B virus, autoimmune hepatitis or primary biliary cirrhosis; (iii) had undergone liver biopsy within the 12 months prior to IFN treatment; (iv) were followed for more than 1 year after the completion of IFN therapy; and (v) absence of HCC during and within 1 year after the completion of therapy. A total of 158 patients were excluded: two patients who were positive for hepatitis B surface antigen, 97 patients lacking liver biopsy, 53 patients with less than 1 year's duration of follow up, and six patients who developed HCC within 1 year of the completion of IFN therapy. The study protocol conformed to the ethical guidelines of the Declaration of Helsinki and was approved by the institutional ethics review committee.

Patients were followed up by regular visits to our hospital every 1–3 months. Six patients died of liver-unrelated disease (two patients with gastric cancer and one patient each with lung cancer, colon cancer, pancreatic cancer and leukemia). There were 122 patients who were lost to follow up because of relocation. We included their data in the analysis, censored at the time of their last visit. The start of follow up was defined as the date of completion of first IFN therapy and the end of follow up was defined as the date of diagnosis of HCC or the date of the last visit. The average period of follow up was 4.5 years.

Clinical characteristics and laboratory data were collected at the most recent time point before liver biopsy. Diabetes mellitus was diagnosed based on a fasting plasma glucose concentration that exceeded 126 mg/dL, a casual plasma glucose concentration that exceeded 200 mg/dL, or the need for insulin or oral anti-hyperglycemic drugs. Information regarding alcohol consumption was obtained through an interview. Body mass index (BMI) was calculated using the following formula: weight in kilograms/height in meters squared. The baseline clinical features of patients at enrollment are summarized in Table 1.

Histological examination

Liver biopsy specimens were obtained from all patients before therapy. The median length of liver biopsy specimens was 13 mm (range 10–42 mm) and median number of portal tracts was 11 (range 4–30). Histological findings were re-evaluated recently by three independent pathologists who were blinded to the clinical details to ensure consistency over time. Fibrosis and activity were scored according to the METAVIR scoring system.[20] Fibrosis was staged on a scale of 0–4: F0 (no fibrosis); F1 (mild fibrosis: portal fibrosis without septa); F2 (moderate fibrosis: few septa); F3 (severe fibrosis: numerous septa without cirrhosis); and F4 (cirrhosis). Activity of necroinflammation was graded on a scale of 0–3: A0 (no activity); A1 (mild activity); A2 (moderate activity); and A3 (severe activity). Percentage of steatosis was quantified by determining the average proportion of hepatocytes affected by steatosis and graded on a scale of 0%, 1–9%, 10–29% and 30% or greater as reported previously.[10] All three pathologists assigned the same scale in 85% of cases for fibrosis staging, 87% for inflammation grading and 95% for steatosis grading. If there was discordance, the scores assigned by two pathologists were used for the analysis.

Screening for HCC

At enrollment, no patient had HCC or any suspicious lesion on abdominal ultrasonography or computed tomography. Patients were examined for HCC by abdominal ultrasonography or computed tomography at least every 6 months. Suspicious lesions were examined further by a triphasic contrast-enhanced computerized tomography or magnetic resonance imaging,

Table 1 Clinical characteristics of patients

Male, *n* (%)	643 (50%)
Age (years)	54.2 ± 11.9
BMI (kg/m^2)	23.4 ± 3.1
Alcohol consumption ≥20 g/day, *n* (%)	44 (3%)
Diabetes Mellitus, *n* (%)	197 (15%)
AST level (IU/L)	68.9 ± 45.3
ALT level (IU/L)	92.9 ± 75.9
GGT level (IU/L)	41.2 ± 38.2
Platelet count (×10^{10}/L)	16.4 ± 5.2
HCV genotype, *n* (%)	
1b	873 (68.2%)
2a	236 (18.4%)
2b	139 (10.9%)
3	2 (0.2%)
Not determined	29 (2.3%)
Histological findings	
Grade of activity, *n* (%)	
A0	154 (12%)
A1	574 (45%)
A2	441 (34%)
A3	110 (9%)
Stage of fibrosis, *n* (%)	
F0	24 (2%)
F1	591 (46%)
F2	378 (30%)
F3	242 (19%)
F4	44 (3%)
Grade of steatosis, *n* (%)	
0%	384 (30%)
1–9%	543 (42%)
10–29%	215 (17%)
≥30%	137 (11%)
SVR to interferon therapy, *n* (%)	393 (31%)
Development of HCC, *n* (%)	68 (5%)

ALT, alanine aminotransferase; AST, aspartate aminotransferase; BMI, body mass index; GGT, γ-glutamyltransferase; HCC, hepatocellular carcinoma; SVR, sustained virological response.

angiography or tumor biopsy to confirm the diagnosis. Diagnostic criteria of HCC on radiological findings were hyper-vascularity at angiography or hyper-attenuation at triphasic contrast-enhanced computerized tomography or magnetic resonance imaging during the hepatic arterial phase.

Statistical analysis

The SPSS software package ver. 15.0 was used for statistical analysis. Categorical data were analyzed using Fisher's exact test. Continuous variables were compared with Student's *t*-test. The time for the development of HCC was defined as the time from the completion of IFN therapy to the time of diagnosis. Annual incidence of HCC was calculated using the person-years method. Effect of hepatic steatosis on time to development of HCC was analyzed by the Kaplan–Meier method and log–rank test, after stratification by age, sex, BMI, degree of fibrosis and response to IFN therapy, as well as multivariate analysis using Cox proportional hazards regression analysis. A *P*-value of less than 0.05 was considered statistically significant.

RESULTS

Background factors for steatosis

PATIENTS WITH A steatosis grade of 10% or greater were older (53.6 ± 12.6 vs 56.0 ± 9.8, $P = 0.001$), had a higher BMI (23.0 ± 3.0 vs 24.6 ± 3.3, $P < 0.0001$), higher frequency of diabetes (12% vs 24%, $P < 0.0001$), higher serum levels of aspartate aminotransferase (AST) (66 ± 46 vs 75 ± 43, $P = 0.002$), γ-glutamyltransferase (GGT) (37 ± 52 vs 52 ± 33, $P < 0.0001$), total cholesterol (173 ± 32 vs 179 ± 33, $P = 0.005$), triglycerides (123 ± 56 vs 145 ± 68, $P < 0.0001$), and a lower serum level of albumin (4.2 ± 0.3 vs 4.1 ± 0.3, $P = 0.005$) and lower platelet counts (16.6 ± 5.2 vs 15.7 ± 5.1, $P = 0.007$). Histological grade of activity (A2–3: 39% vs 54%, $P < 0.0001$), and stage of fibrosis (F3–4: 18% vs 34%, $P < 0.0001$) were higher. The proportion of non-sustained virological response (SVR) to IFN also was higher (35% vs 19%, $P < 0.0001$). These results indicate that hepatic steatosis in hepatitis C is related to metabolic factors and associated with other risk factors for the development of HCC such as older age, advanced stage of fibrosis, and non-SVR to IFN therapy.

Factors associated with the development of HCC

Hepatocellular carcinoma developed in 68 patients during follow up. An overall annual incidence of HCC development was 1.19% by person-years. The annual incidence of HCC development by person-years was higher in patients with higher grade of steatosis: 0.45% for patients without steatosis, 0.78% for patients with 1–9% of steatosis, 2.30% for patients with 10–29% of steatosis, and 3.56% for patients with 30% of steatosis. The relative risk of hepatic steatosis (grade of ≥10%) for HCC development was 4.39 (95% confidence interval 2.66–7.26, $P < 0.0001$). The difference remained significant, even after stratification for other risk factors such as IFN therapy, stage of fibrosis, age, sex and BMI (Fig. 1). When analyzed by the multivariate Cox proportional

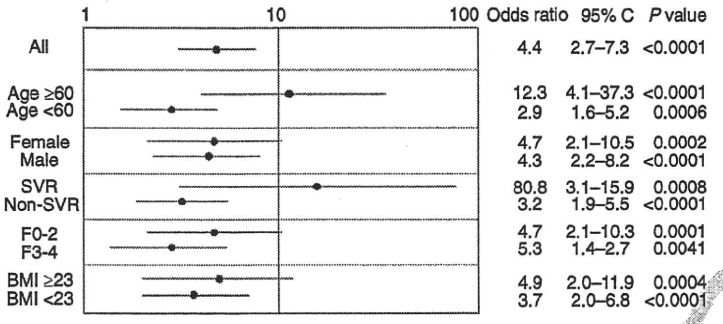


Figure 1 Relative risk differences of hepatocellular carcinoma (HCC) among patients with and without steatosis. The relative risk of hepatic steatosis (grade ≥10%) for HCC development was analyzed, after stratification for other risk factors such as interferon (IFN) therapy, stage of fibrosis, age, sex and body mass index (BMI). SVR, sustained virological response.

hazards regression method, a higher grade of steatosis, older age, male sex, higher BMI, an advanced stage of fibrosis and non-SVR to IFN therapy were independent risk factors associated with the development of HCC (Table 2). The adjusted risk ratio of hepatic steatosis was 3.04 (95% confidence interval 1.82–5.06, $P < 0.0001$). The presence of diabetes and consumption of ethanol were not significant. Figure 2(a) shows the Kaplan–Meier curve of the time to development of HCC in the entire cohort. The cumulative incidence of HCC was significantly higher with hepatic steatosis of 10% or greater. To adjust for other risk factors, patients were stratified according to response to IFN therapy, stage of fibrosis, age, sex and BMI. The difference remained significant, even after stratification for these confounding factors (Fig. 2b–f). Three patients died after the development of HCC. All were over 60 years old, and had significant steatosis. The impact of hepatic steatosis on the survival rate could not be analyzed due to the small number of death.

DISCUSSION

IN THIS STUDY, we have shown that the presence of significant steatosis is an independent risk factor for the development of HCC in chronic hepatitis C. Our study involved the largest number of patients, compared to previous reports, and this enabled us to adjust for

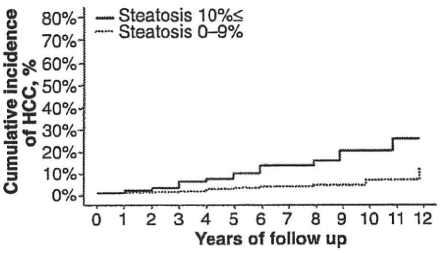
Table 2 Multivariate analysis of risk factors for hepatocellular carcinoma

Predictor		Odds ratio (95% CI)	*P*-value
Age	By every 10 years	1.09 (1.05–1.13)	<0.0001
Sex	Male vs female	2.12 (1.28–3.51)	0.004
Stage of fibrosis	F3–4 vs F0–2	4.30 (2.59–7.14)	<0.0001
Grade of steatosis	≥10% vs <10%	3.04 (1.82–5.06)	<0.0001
Response to IFN	Non-SVR vs SVR	2.43 (1.13–5.23)	0.023
Diabetes	Present vs absent	0.75 (0.42–1.33)	0.319
Ethanol consumption (g/day)	≥20 vs <20	0.50 (0.07–3.60)	0.478
BMI (kg/m2)	≥23 vs <23	1.69 (1.02–2.86)	0.043

BMI, body mass index; CI, confidence interval; IFN, interferon; SVR, sustained virological response.

Figure 2 Cumulative incidence of hepatocellular carcinoma (HCC) among patients with steatosis (solid line) and without steatosis (dotted line), stratified by other risk factors. The cumulative incidence of HCC was (a) significantly higher in patients with a steatosis grade of 10% or greater ($P < 0.0001$ by the log–rank test), even after (b) stratification by the response to interferon therapy ($P < 0.0001$ for sustained virological response [SVR] and non-SVR by the log–rank test), (c) stratification by the stage of fibrosis ($P < 0.0001$ for F0–2 and $P = 0.0036$ for F3–4 by the log–rank test), (d) stratification by age ($P = 0.0001$ for age ≥60 and $P < 0.0001$ for age <60 by the log–rank test), (e) stratification by sex ($P < 0.0001$ for men and women by the log–rank test), and (f) stratification by body mass index (BMI) ($P < 0.0001$ for BMI ≥23 kg/m^2 and <23 kg/m^2 by the log–rank test). The number of patients at risk is shown below each graph.

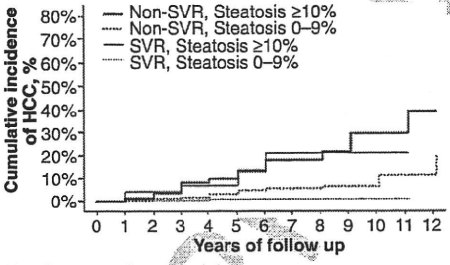
(a) **Entire cohort**



Number of patients at risk

Steatosis 0–9%	927	824	620	503	320	227	161	117	77	49	27	10
Steatosis ≥10%	352	271	207	157	113	83	54	48	32	17	9	1

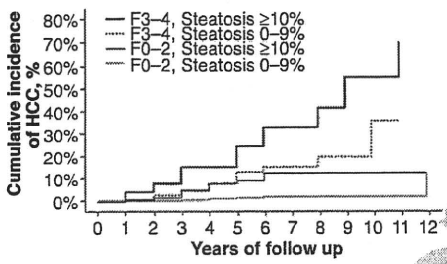
(b) **Stratified by response to IFN therapy**



Number of patients at risk

SVR												
Steatosis 0–9%	326	254	204	153	81	55	33	21	15	10	5	0
Steatosis ≥10%	67	50	34	22	14	10	4	4	4	2	2	0
Non-SVR												
Steatosis 0–9%	601	507	416	350	239	172	128	96	62	39	22	10
Steatosis ≥10%	285	221	173	135	99	73	50	44	28	15	7	1

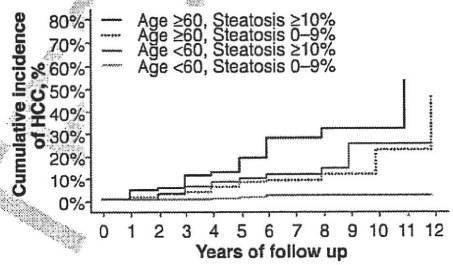
(c) **Stratified by stage of fibrosis**



Number of patients at risk

F0–2												
Steatosis 0–9%	759	623	509	415	266	188	137	99	64	39	25	10
Steatosis ≥10%	234	190	146	107	77	55	37	32	19	11	6	1
F3–4												
Steatosis 0–9%	118	81	61	50	36	28	17	16	13	6	3	0
Steatosis ≥10%	168	138	111	88	54	39	23	18	13	10	2	0

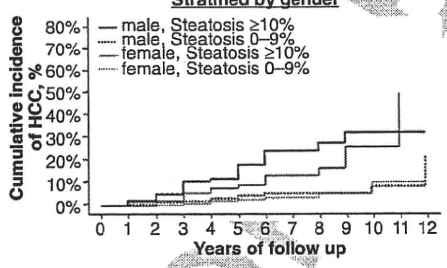
(d) **Stratified by age**



Number of patients at risk

Age <60												
Steatosis 0–9%	549	457	367	298	188	148	111	83	53	33	19	7
Steatosis ≥10%	193	154	111	83	61	48	34	31	23	12	6	1
Age ≥60												
Steatosis 0–9%	378	304	253	205	132	79	50	34	24	16	8	3
Steatosis ≥10%	159	117	96	74	52	35	20	17	9	5	3	0

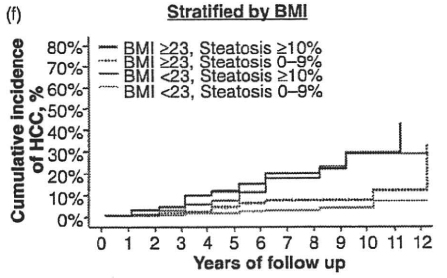
(e) **Stratified by gender**



Number of patients at risk

Male												
Steatosis 0–9%	470	389	319	265	169	126	90	65	46	30	17	7
Steatosis ≥10%	173	134	98	73	54	40	21	21	15	8	6	1
Female												
Steatosis 0–9%	457	372	301	238	151	101	71	52	31	19	10	3
Steatosis ≥10%	179	137	109	84	59	43	33	27	17	9	3	0

(f) **Stratified by BMI**



Number of patients at risk

BMI ≥23												
Steatosis 0–9%	417	346	269	213	129	94	66	49	31	19	8	4
Steatosis ≥10%	226	176	137	101	71	55	34	33	20	10	5	0
BMI <23												
Steatosis 0–9%	510	415	351	290	191	133	95	68	46	30	19	6
Steatosis ≥10%	126	95	70	56	42	28	20	15	12	7	4	1

other known risk factors for HCC. The impact of steatosis on HCC development remained significant even after adjusting for other risk factors such as older age, male sex, higher BMI, advanced fibrosis and non-SVR to IFN therapy. These findings indicate the need of intensive surveillance for HCC in patients with significant steatosis and provide an argument for therapeutic interventions aimed at reducing steatosis, in order to reduce the risk of HCC.

The association between hepatic steatosis and the development of HCC in chronic hepatitis C has been proposed and the possible mechanism has been discussed.[16] There are several cohort studies on this topic but their results are conflicting. The first report included 20 patients with SVR to IFN, 51 patients with non-SVR to IFN and 90 patients who did not receive IFN therapy.[17] In this cohort of 161 patients, older age, absence of IFN therapy, cirrhosis and steatosis were associated with HCC development. Another study involved 25 patients with HCC and an equal number of patients who did not develop HCC, matched for age, sex, HCV genotype and stage of fibrosis.[19] In this study, only ALT and albumin were identified as predictors of HCC and steatosis was not. The authors acknowledged the small size of the cohort as a limitation and emphasized the need for larger cohort studies. The third study analyzed explanted liver from cirrhotic patients who underwent liver transplantation and included 32 patients with HCC and 62 patients without HCC.[18] The authors found that older age, higher α-fetoprotein levels and steatosis were significantly associated with HCC. The major advantage of this study was the standardization of fibrosis stage to cirrhosis. On the other hand, a limitation was the retrospective nature of the study; steatosis was evaluated after the diagnosis of HCC, when cirrhosis already was present (fibrosis stage F4). Because steatosis has been reported to decrease once cirrhosis has developed, this study may have underestimated the grade of steatosis present prior to the development of HCC. Thus, we cannot simply apply their findings to a clinical setting where biopsies are usually obtained before the development of cirrhosis and years before the development of HCC. Based on that background, the principal aim of this study was to analyze the association between hepatic steatosis and the development of HCC in chronic hepatitis C patients, adjusting for known risk factors. We found that steatosis was an independent risk factor by the multivariate Cox proportional hazards regression analysis and by the Kaplan–Meier method and log-rank test after stratification by other risk factors. To our surprise, the adjusted risk ratio of hepatic steatosis was higher than that of older age, male sex, non-SVR to IFN and higher BMI.

How steatosis contributes to the development of HCC remains unclear. Several studies including ours,[10] indicated that hepatic steatosis promotes the progression of hepatic fibrosis,[11–15] which potentiates the risk of HCC indirectly. On the other hand, the ob/ob mouse model of NAFLD showed that hepatic neoplasia developed in the absence of advanced fibrosis, supporting the concept that metabolic abnormalities related to obesity initiate the neoplastic process.[8] Leptin, an adipocytokine related to steatosis in chronic hepatitis C,[21] was shown recently to be mitogenic in human liver[22] and thus may be a link between steatosis and HCC development. Otherwise, steatosis may be responsible for increased lipid peroxidation and reactive oxygen species which induce genetic damage.[23–25] Another study showed that mice transgenic for the HCV core gene developed hepatic steatosis early in life and thereafter HCC which indicates that the HCV core protein has a chief role in the development of both steatosis and HCC development.[26] The precise mechanism of the association between steatosis and carcinogenesis needs further investigation.

The higher incidence of HCC in patients with significant steatosis has important clinical implications. The most important question is whether therapeutic interventions aimed at reducing steatosis could reduce the risk of HCC in chronic hepatitis C. Because the adjusted risk ratio of hepatic steatosis was higher than that of older age, male sex, non-SVR to IFN and higher BMI, we hypothesize that modification of lifestyle and the amelioration of hepatic steatosis may efficiently prevent hepatocarcinogenesis in patients having concomitant risk factors. Apparently, further prospective studies focusing on this point are necessary. Weight reduction may provide an important treatment strategy because one study indicated that weight reduction in chronic hepatitis C leads to a reduction in steatosis and an improvement in fibrosis despite the persistence of HCV infection.[27] Alternatively, insulin resistance may be another target of therapy because a study showed that the administration of pioglitazone led to metabolic and histological improvement in subjects with non-alcoholic steatohepatitis.[28] A limitation of the present study was that data for the plasma insulin concentration was not available and thus insulin resistance could not be assessed. Whether insulin resistance plays a role in hepatocarcinogenesis or its amelioration could improve steatosis and ultimately prevent development of HCC in chronic hepatitis C awaits future investigation.

Another important finding of the present study was that steatosis was a significant risk factor for the development of HCC in patients with SVR to IFN therapy. Thus, steatosis may play a role in carcinogenesis in patients who have cleared HCV. Several studies have shown that the incidence of HCC is reduced but not eliminated in those with SVR to IFN.[29–31] Because the predictors of HCC development in SVR patients have not been established to date, steatosis may be used to identify patients who need intensive surveillance and long-term follow up, even after the clearance of HCV. In conclusion, we showed that hepatic steatosis is significantly associated with the development of HCC in chronic hepatitis C independent of age, sex, BMI, degree of fibrosis and response to previous IFN therapy. Steatosis may be a useful marker for identifying patients at higher risk for HCC. Further studies are needed to evaluate the hypothesis that therapeutic interventions aimed at reducing steatosis may prevent hepatocarcinogenesis.

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REFERENCES

1 El-Serag HB, Rudolph KL. Hepatocellular carcinoma: epidemiology and molecular carcinogenesis. *Gastroenterology* 2007; **132**: 2557–76.
2 Shimada M, Hashimoto E, Taniai M *et al.* Hepatocellular carcinoma in patients with non-alcoholic steatohepatitis. *J Hepatol* 2002; **37**: 154–60.
3 Bugianesi E, Leone N, Vanni E *et al.* Expanding the natural history of nonalcoholic steatohepatitis: from cryptogenic cirrhosis to hepatocellular carcinoma. *Gastroenterology* 2002; **123**: 134–40.
4 Marrero JA, Fontana RJ, Su GL, Conjeevaram HS, Emick DM, Lok AS. NAFLD may be a common underlying liver disease in patients with hepatocellular carcinoma in the United States. *Hepatology* 2002; **36**: 1349–54.
5 Calle EE, Rodriguez C, Walker-Thurmond K, Thun MJ. Overweight, obesity, and mortality from cancer in a prospectively studied cohort of U.S. adults. *N Engl J Med* 2003; **348**: 1625–38.
6 El-Serag HB, Tran T, Everhart JE. Diabetes increases the risk of chronic liver disease and hepatocellular carcinoma. *Gastroenterology* 2004; **126**: 460–8.
7 Davila JA, Morgan RO, Shaib Y, McGlynn KA, El-Serag HB. Diabetes increases the risk of hepatocellular carcinoma in the United States: a population based case control study. *Gut* 2005; **54**: 533–9.
8 Yang S, Lin HZ, Hwang J, Chacko VP, Diehl AM. Hepatic hyperplasia in noncirrhotic fatty livers: is obesity-related hepatic steatosis a premalignant condition? *Cancer Res* 2001; **61**: 5016–23.
9 Lefkowitch JH, Schiff ER, Davis GL *et al.* Pathological diagnosis of chronic hepatitis C: a multicenter comparative study with chronic hepatitis B. The Hepatitis Interventional Therapy Group. *Gastroenterology* 1993; **104**: 595–603.
10 Kurosaki M, Matsunaga K, Hirayama I *et al.* The presence of steatosis and elevation of alanine aminotransferase levels are associated with fibrosis progression in chronic hepatitis C with non-response to interferon therapy. *J Hepatol* 2008; **48**: 736–42.
11 Hourigan LF, Macdonald GA, Purdie D *et al.* Fibrosis in chronic hepatitis C correlates significantly with body mass index and steatosis. *Hepatology* 1999; **29**: 1215–19.
12 Adinolfi LE, Gambardella M, Andreana A, Tripodi MF, Utili R, Ruggiero G. Steatosis accelerates the progression of liver damage of chronic hepatitis C patients and correlates with specific HCV genotype and visceral obesity. *Hepatology* 2001; **33**: 1358–64.
13 Westin J, Nordlinder H, Lagging M, Norkrans G, Wejstal R. Steatosis accelerates fibrosis development over time in hepatitis C virus genotype 3 infected patients. *J Hepatol* 2002; **37**: 837–42.
14 Fartoux L, Chazouilleres O, Wendum D, Poupon R, Serfaty L. Impact of steatosis on progression of fibrosis in patients with mild hepatitis C. *Hepatology* 2005; **41**: 82–7.
15 Leandro G, Mangia A, Hui J *et al.* Relationship between steatosis, inflammation, and fibrosis in chronic hepatitis C: a meta-analysis of individual patient data. *Gastroenterology* 2006; **130**: 1636–42.
16 Koike K. Hepatitis C virus contributes to hepatocarcinogenesis by modulating metabolic and intracellular signaling pathways. *J Gastroenterol Hepatol* 2007; **22** (Suppl 1): S108–11.
17 Ohata K, Hamasaki K, Toriyama K *et al.* Hepatic steatosis is a risk factor for hepatocellular carcinoma in patients with chronic hepatitis C virus infection. *Cancer* 2003; **97**: 3036–43.
18 Pekow JR, Bhan AK, Zheng H, Chung RT. Hepatic steatosis is associated with increased frequency of hepatocellular carcinoma in patients with hepatitis C-related cirrhosis. *Cancer* 2007; **109**: 2490–6.
19 Kumar D, Farrell GC, Kench J, George J. Hepatic steatosis and the risk of hepatocellular carcinoma in chronic hepatitis C. *J Gastroenterol Hepatol* 2005; **20**: 1395–400.
20 Bedossa P, Poynard T. An algorithm for the grading of activity in chronic hepatitis C. The METAVIR Cooperative Study Group. *Hepatology* 1996; **24**: 289–93.
21 Romero-Gomez M, Castellano-Megias VM, Grande L *et al.* Serum leptin levels correlate with hepatic steatosis in chronic hepatitis C. *Am J Gastroenterol* 2003; **98**: 1135–41.
22 Ramani K, Yang H, Xia M, Ara AI, Mato JM, Lu SC. Leptin's mitogenic effect in human liver cancer cells requires induc-

tion of both methionine adenosyltransferase 2A and 2beta. *Hepatology* 2008; **47**: 521–31.
23 Okuda M, Li K, Beard MR *et al.* Mitochondrial injury, oxidative stress, and antioxidant gene expression are induced by hepatitis C virus core protein. *Gastroenterology* 2002; **122**: 366–75.
24 Cai D, Yuan M, Frantz DF *et al.* Local and systemic insulin resistance resulting from hepatic activation of IKK-beta and NF-kappaB. *Nat Med* 2005; **11**: 183–90.
25 Arkan MC, Hevener AL, Greten FR *et al.* IKK-beta links inflammation to obesity-induced insulin resistance. *Nat Med* 2005; **11**: 191–8.
26 Moriya K, Fujie H, Shintani Y *et al.* The core protein of hepatitis C virus induces hepatocellular carcinoma in transgenic mice. *Nat Med* 1998; **4**: 1065–7.
27 Hickman IJ, Clouston AD, Macdonald GA *et al.* Effect of weight reduction on liver histology and biochemistry in patients with chronic hepatitis C. *Gut* 2002; **51**: 89–94.
28 Belfort R, Harrison SA, Brown K *et al.* A placebo-controlled trial of pioglitazone in subjects with nonalcoholic steatohepatitis. *N Engl J Med* 2006; **355**: 2297–307.
29 Yoshida H, Shiratori Y, Moriyama M *et al.* Interferon therapy reduces the risk for hepatocellular carcinoma: national surveillance program of cirrhotic and noncirrhotic patients with chronic hepatitis C in Japan. IHIT Study Group. Inhibition of Hepatocarcinogenesis by Interferon Therapy. *Ann Intern Med* 1999; **131**: 174–81.
30 Nishiguchi S, Shiomi S, Nakatani S *et al.* Prevention of hepatocellular carcinoma in patients with chronic active hepatitis C and cirrhosis. *Lancet* 2001; **357**: 196–7.
31 Shiratori Y, Ito Y, Yokosuka O *et al.* Antiviral therapy for cirrhotic hepatitis C: association with reduced hepatocellular carcinoma development and improved survival. *Ann Intern Med* 2005; **142**: 105–14.