Acyclic retinoid inhibits diethylnitrosamine-induced liver tumorigenesis in obese and diabetic C57BL/KsJ-*db/db* mice

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Abbreviations: ACR, acyclic retinoid; AMPK, AMP-activated kinase; ANOVA, analysis of variance; BCAA, branched-chain amino acids; DEN, diethylnitrosamine; ERK, extracellular signal-regulated kinase; FCA, foci of cellular alteration; H&E, hematoxylin & eosin; HCC, hepatocellular carcinoma; MAPK, mitogen-activated

protein kinase; NAFLD, non-alcoholic fatty liver disease; NASH, non-alcoholic steatohepatitis; PPAR, peroxisome proliferator-activated receptor; RAR, retinoic acid receptor; RT-PCR, reverse transcription-PCR; RXR, retinoid X receptor; QUICKI, quantitative insulin sensitivity check index; TGF-β, transforming growth factor-β.

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Abstract

Obesity and the related metabolic abnormalities are associated with increased risk of hepatocellular carcinoma (HCC). Malfunctioning of RXRα due to phosphorylation by Ras/MAPK also plays a critical role in liver carcinogenesis. In the present study, we examined the effects of acyclic retinoid (ACR), which targets RXRα, on the development of diethylnitrosamine (DEN)-induced liver tumorigenesis in C57BL/KsJ-*db/db* (*db/db*) obese mice. Male *db/db* mice were given tap water containing 40 ppm DEN for 2 weeks, after which they were fed a diet containing 0.03% or 0.06% of ACR throughout the experiment. In mice treated with either dose of ACR for 34 weeks, the development of liver cell adenomas was significantly inhibited as compared to basal diet-fed mice. ACR markedly inhibited the activation of Ras and phosphorylation of the ERK and RXRα proteins in the livers of experimental mice. It also increased the expression of *RARβ* and $p21^{CIP1}$ mRNA, while decreasing the expression of *Cyclin D1*, *c-Fos*, and *c-Jun* mRNA in the liver, thereby restoring RXRα function. Administration of ACR improved liver steatosis and activated the AMPK protein. The serum levels of insulin decreased by ACR treatment, whereas the QUICKI values increased, indicating improved insulin sensitivity. The serum levels of TNF-α and the expression levels of *TNF-α*, *IL-6*, and *IL-1β* mRNA in the livers of DEN-treated *db/db* mice were decreased by ACR treatment, suggesting attenuation of the chronic inflammation induced by excessive fatty deposits. ACR may be, therefore, useful in the chemoprevention of obesity-related HCC.

Introduction

Hepatocellular carcinoma (HCC) is a serious healthcare problem worldwide. The risk factors associated with the development of HCC include chronic hepatitis B and/or hepatitis C infection, particularly with subsequent cirrhosis. Recent evidence also indicates that obesity and the related metabolic abnormalities, especially diabetes mellitus, increase the risk of HCC (1-3). In a rodent model, the occurrence of diethylnitrosamine (DEN)-induced liver tumorigenesis was found to be significantly higher in obese and diabetic C57BL/KsJ-*db/db* (*db/db*) mice compared to genetic control mice (4). Diabetes mellitus has been shown to increase the risk of primary HCC in patients with viral hepatitis (5). Insulin resistance is also significantly associated with the recurrence of stage I HCC after curative treatment (6). Non-alcoholic fatty liver disease (NAFLD) is a hepatic manifestation of the insulin-resistance syndrome, and in a subset of NAFLD patients, the condition progresses to non-alcoholic steatohepatitis (NASH), which involves severe inflammation and therefore poses the threat of HCC (7, 8). Coexistent obesity or steatosis exacerbates liver injury and fibrosis and thus is involved in liver tumorigenesis (9). Therefore, patients with obesity and insulin resistance comprise a high-risk group for HCC, and their treatment must target the prevention of this malignancy.

Acyclic retinoid (ACR, the same substance as NIK-333), a synthetic retinoid, apparently exerts chemopreventive effects on the development of HCC (10). ACR inhibits experimental liver carcinogenesis and suppresses the growth of HCC-derived cells by inducing apoptosis and causing cell cycle arrest in G_0-G_1 (11-15). These effects of ACR are associated with its agonistic activity for distinct nuclear retinoid receptors - retinoid X receptors (RXRs) and retinoic acid receptors (RARs), both of

which have 3 subtypes (α, β, and γ) (16) - and subsequent expression of the ACR target genes *RARβ* and $p21^{CIP1}$ (12-15). A clinical trial revealed that oral administration of ACR significantly reduced the incidence of post-therapeutic HCC recurrence and improved the survival rates of patients (17, 18). A phase II/III trial of ACR confirmed its effectiveness in preventing second primary HCC in hepatitis C virus-positive patients in a large-scale (n = 401) randomized placebo-controlled trial; hazard ratio for recurrence-free survival with ACR 600 mg/day versus placebo was 0.27 (95% confidence interval, 0.07 to 0.96) after 2 years randomization (19).

Among the retinoid receptors, RXRα is considered as one of the most important receptors with respect to the regulation of fundamental cell activities because it forms a heterodimer with other nuclear receptors and thereby acts as the master regulator of nuclear receptors (20). Recent studies indicate that phosphorylation of RXRα abolishes its ability to form a heterodimer with RARβ, and the accumulation of phosphorylated RXRα (p-RXRα, i.e., non-functional RXRα), which is caused by activation of the Ras/mitogen-activated protein kinase (MAPK)/extracellular signal-regulated kinase (ERK) signaling pathway, plays a critical role in the development of HCC (10, 21, 22). On the other hand, the effects of ACR in suppressing growth and inducing apoptosis in HCC cells depend on the inactivation of Ras-ERK signaling system and subsequent RXRα dephosphorylation (15, 23, 24). In the present study, we examined the effects of ACR on obesity-related liver tumorigenesis by focusing on the inhibition of RXRα phosphorylation. We also examined whether ACR treatment improves the insulin resistance, liver steatosis, and inflammatory condition caused by obesity by using DEN-treated *db/db* mice, a useful preclinical model, to evaluate the mechanisms underlying the inhibition of

obesity-related liver tumorigenesis by chemopreventive drugs (4).

Materials and Methods

Animals and chemicals. Four-week-old male *db/db* mice were obtained from Japan SLC, Inc., (Shizuoka, Japan). All mice received humane care and were housed at Gifu University Life Science Research Center in accordance with the Institutional Animal Care Guidelines. DEN was purchased from Sigma Chemical Co. (St. Louis, MO). ACR was supplied by Kowa Pharmaceutical Co. (Tokyo, Japan).

Experimental procedure. The experimental protocol, which was approved by the Institutional Committee of Animal Experiments of Gifu University, was as described previously (4). At 5 weeks of age, 40 *db/db* mice were randomly divided into 5 groups. All the mice in Groups 1 (n = 10), 2 (n = 10), and 3 (n = 10) were given tap water containing 40 ppm DEN for the first 2 weeks, which way is sufficient to develop liver neoplasms in *db/db* mice (4). After DEN treatment, the mice in Groups 2 and 3 were fed the basal diet CRF-1 (Oriental Yeast Co., Tokyo, Japan) containing 0.03% ACR (Group 2) or 0.06% ACR (Group 3), respectively, with free access to the feed till the end of experiment. Group 4 (n = 5) was fed the CRF-1 diet containing 0.06% ACR. The mice in Groups 1 and 5 (n = 5) were fed the CRF-1 diet throughout the experiment. The rationale for the doses (0.03% and 0.06%) selection of ACR was based on previous studies, where similar doses of ACR inhibited experimental liver carcinogenesis induced by chemical agents (25, 26). At 41 weeks of age (after 34 weeks of ACR treatment), all the mice were sacrificed by CO_2 asphyxiation in order to check for the development of HCC, liver cell adenoma, and foci of cellular alteration (FCA).

Histopathological analysis. At sacrifice, the livers were immediately removed and macroscopically inspected for the presence of neoplasms. Maximum

sagittal sections of each lobe (6 lobes) were used for histopathological examination. For all experimental groups, 4-μm-thick sections of formalin-fixed paraffin-embedded livers were stained routinely with hematoxylin & eosin (H&E) for histopathological examination. The presence of HCC, liver cell adenoma, and FCA was judged according to previously described criteria (27). The multiplicity of FCA was assessed on a per unit area (cm^2) basis.

Ras activation assay. Ras activity was determined using a Ras activation assay kit (Upstate Biotechnology; Lake Placid, NY) according to the manufacturer's instructions. Ras was precipitated in equivalent amounts of liver extract (50 μg) from DEN-treated mice (Groups 1 - 3) by using Raf-1/Ras-binding domain-immobilized agarose, which was then subjected to western blot analysis using anti-Ras antibody (24). The intensity of the blots was quantified using NIH imaging software version 1.62.

Protein extraction and western blot analysis. Total protein was extracted from the nontumor site of livers of DEN-treated mice, and equivalent amounts of proteins (30 μg/lane) were examined by western blot analysis (4). Previously described primary antibodies for RXRα (ΔN-197 and D-20), ERK, phosphorylated ERK (p-ERK), Stat3, p-Stat3, AMP-activated kinase (AMPK), p-AMPK, and GAPDH were used (15, 22, 28, 29). The ΔN-197 antibody is considered a specific antibody for the p-RXRα protein (22, 23). The GAPDH antibody served as a loading control.

RNA extraction and quantitative real-time reverse transcription-PCR. Total RNA was isolated from the nontumor site livers of DEN-treated mice by using the RNAqueous-4PCR kit (Ambion Applied Biosystems; Austin, TX). cDNA was amplified from 0.2 μg of total RNA by using the SuperScript III First-Strand Synthesis System (Invitrogen; Carlsbad, CA), and quantitative real-time reverse

transcription-PCR (RT-PCR) analysis was carried out as described previously (4). The specific primers used for amplification of the *TNF-α*, *IL-6*, *IL-1β*, and *β-actin* genes were as described previously (30). The primers for the amplification of *RARβ*, $p21^{CIP1}$, *Cyclin D1*, *c-Jun*, and *c-Fos* genes are listed in Supplementary Table S1.

Clinical chemistry. Before sacrifice, the mice were fasted for 6 hours, and at sacrifice, blood samples were collected for assaying the serum concentrations of insulin, glucose, and TNF-α, which was as described previously (4, 29). The serum TNF-α (Shibayagi; Gunma, Japan) levels were determined using an enzyme immunoassay according to the manufacturers' protocol. Insulin resistance was estimated by determining the insulin sensitivity check index (QUICKI) as follows; QUICKI = $1/[\log(I_0) + \log(G_0)]$, where I_0 is the fasting insulin level and G_0 is the fasting glucose level, which correlates with the glucose clamp method (31).

Hepatic lipid analysis. Approximately 200 mg of frozen liver was homogenized, and lipids were extracted using Folch's method (32). The triglyceride levels in the liver were measured using the triglyceride E-test kit (Wako Pure Chemical Co.; Osaka, Japan) according to the manufacturer's protocol. To visualize the intrahepatic lipids, Sudan III staining was conducted using the standard procedure with frozen sections.

Statistical analysis. The results are presented as the mean ± SD and were analyzed using the GraphPad Instat software program version 3.05 (GraphPad Software; San Diego, CA) for Macintosh. Differences among the groups were analyzed by either one-way ANOVA or, as required, by two-way ANOVA. When the ANOVA showed a statistically significant effect ($P < 0.05$), each experimental group was compared with the control group by using the Tukey-Kramer multiple comparisons

test. The differences were considered significant when the two-sided *P* value was <0.05.

Results

General observations. As shown in Table 1, no significant differences were observed in the body, kidney, and fat weights among the groups at the end of the study. A significant decrease in the liver weight was observed in the ACR-treated groups as compared with the basal diet-fed group ($P < 0.05$ or $P < 0.01$), irrespective of DEN treatment. Histopathological examination showed the absence of ACR toxicity in the liver, kidney, and spleen (data not shown).

Effects of ACR on DEN-induced liver tumorigenesis in db/db mice. Table 2 summarizes the incidence and multiplicity of liver neoplasms (adenoma and HCC) and FCA in the mice from all groups. FCA developed in the livers of mice from all groups, irrespective of DEN treatment. On the other hand, liver cell adenomas only developed in the DEN-treated *db/db* mice. HCCs also developed in all DEN-treated groups, however, the incidence (10% in each group) wan not high. These findings might be associated with experimental protocol because the duration of the experiments (41 weeks) was sufficient to develop adenoma but not HCC. In mice treated with either dose (0.03% and 0.06%) of ACR, the incidence ($P < 0.01$ in each comparison) and multiplicity of adenoma ($P < 0.05$ or $P < 0.01$) were significantly inhibited compared to ACR-untreated mice. The number of FCA was also significantly decreased by ACR treatment, irrespective of DEN treatment ($P < 0.001$ or $P < 0.05$).

Effects of ACR on Ras activity and phosphorylation of RXRα, ERK, and Stat3 proteins in the livers of DEN-treated db/db mice. ACR prevents the growth of HCC cells by inactivating Ras-ERK and dephosphorylating RXRα, thereby restoring RXRα function (10, 15, 23, 24). Stat3 is also an ACR target for the inhibition of cancer cell growth (28). Therefore, the effects of ACR on the inhibition of Ras activity

and phosphorylation of the RXRα, ERK, and Stat3 proteins were examined in this study by using an obesity-related liver tumorigenesis model. As shown in Fig. 1*A*, the activity of Raf-1-bound Ras in the liver was significantly inhibited by treatment with either dose of ACR ($P < 0.01$). The expression levels of the p-ERK and p-RXRα proteins were also decreased by ACR treatment (Fig. 1*B*), indicating that ACR inhibits the development of obesity-related liver neoplasms, at least in part, by dephosphorylating RXRα and thereby restoring its function. At both doses, ACR also decreased the expression levels of the p-Stat3 protein in the livers of DEN-treated *db/db* mice (Fig. 1*B*).

Effects of ACR on the expression levels of RARβ, p21^{CIP1}, Cyclin D1, c-Fos, and c-Jun mRNA in the livers of DEN-treated db/db mice. ACR inhibits the growth of HCC cells by increasing the cellular levels of RARβ and p21^{CIP1} but decreasing the levels of Cyclin D1, and these effects might be associated with the restoration of RXRα function (12-15). ACR also suppresses the growth of cancer cells by inhibiting the activity of AP-1, which comprises the Jun and Fos oncoprotein families (28). Therefore, the effect of ACR on the mRNA levels of these molecules was examined next. As shown in Fig. 1*C*, quantitative real-time RT-PCR analysis indicated that ACR treatment significantly increased the expression levels of *RARβ* and *p21^{CIP1}* mRNA, especially *RARβ* mRNA, in the livers of DEN-exposed *db/db* mice ($P < 0.01$). On the other hand, the expression levels of *Cyclin D1*, *c-Fos*, and *c-Jun* mRNA were significantly decreased by ACR treatment ($P < 0.01$).

Effects of ACR on hepatic steatosis and the activation of AMPK in the livers of DEN-treated db/db mice. Hepatic steatosis is considered a promoter of the development of HCC (8, 9). Therefore, whether ACR treatment enhances the

accumulation of lipids in the liver of experimental mice was examined. Examination of Sudan III-stained sections revealed that ACR treatment significantly improved macrovesicular steatosis in the livers of DEN-treated *db/db* mice (Fig. 2*A*, upper panels). The triglyceride levels in the liver were also significantly decreased in mice treated with ACR at either dose ($P < 0.05$) in comparison with those fed the basal diet (Fig. 2*A*, lower graph). Moreover, ACR markedly phosphorylated (activated) the AMPK protein, which is a critical serine/threonine kinase that monitors cellular energy status (33), in the livers of the experimental mice (Fig. 2*B*).

Effects of ACR on insulin resistance in DEN-treated db/db mice. Insulin resistance plays a critical role in the development of HCC (1-6). Therefore, the effects of ACR on the levels of serum insulin and QUICKI values, which indicate the degree of insulin sensitivity, were examined in DEN-treated *db/db* mice. As shown in Fig. 2*C*, the serum insulin level was decreased ($P < 0.05$), while the QUICKI value was increased in mice treated with 0.06% ACR ($P < 0.05$) compared to those in the basal diet-fed group. These findings suggest that ACR improves insulin resistance in obese and diabetic *db/db* mice.

Effects of ACR on the serum levels of TNF-α and hepatic expression of TNF-α, IL-6, and IL-1β mRNA in DEN-treated db/db mice. Because a state of chronic inflammation induced by excessive production of storage lipids and insulin resistance is associated with obesity-related liver carcinogenesis (34), the effects of ACR on the levels of the proinflammatory cytokines TNF-α, IL-6, and IL-1β in DEN-treated *db/db* mice were examined. As shown in Fig. 3*A*, the serum levels of TNF-α were decreased after ACR treatment ($P < 0.01$). Further, the expression levels of *TNF-α*, *IL-6*, and *IL-1β* mRNA in the livers of DEN-treated *db/db* mice were also

significantly decreased by ACR treatment ($P < 0.01$). The decrease was most apparent in the levels of *IL-6* mRNA: the inhibition rates were about 85% at both doses of ACR (Fig. 3*B*).

Discussion

In the present healthcare scenario, the effects of obesity, including the promotion of cancer, are critical issues that need to be resolved, and HCC is one of the representative malignancies influenced by excessive body weight and related metabolic abnormalities (1-3, 5, 6). A recent clinical trial revealed that supplementation of food with branched-chain amino acids (BCAA), which improves insulin resistance (35), reduced the risk of HCC in obese patients with chronic viral liver disease (3). BCAA supplementation also suppresses liver tumorigenesis in obese and diabetic *db/db* mice by improving insulin resistance and attenuating liver steatosis and fibrosis (4). The results of the present study clearly indicated that ACR also effectively prevents the development of obesity-related liver cell adenomas, and these effects are associated with improvement of hepatic steatosis and insulin resistance. Therefore, the findings of the present study, together with the results of previous studies using BCAA (3, 4), suggest that improvement of metabolic abnormalities by pharmaceutical or nutritional intervention might be an effective strategy for inhibiting obesity-related liver tumorigenesis.

Several biological effects of ACR are relevant to the prevention of obesity-related hepatotumorigenesis. First, it should be noted that ACR inhibits RXRα phosphorylation by suppressing the Ras-ERK signaling pathway in the livers of DEN-treated *db/db* mice. These findings are consistent with those of previous *in vitro* studies (15, 23, 24), but this is the first *in vivo* experiment, and the results seem to be significant because RXRα malfunction due to phosphorylation by Ras-ERK plays a role in liver carcinogenesis, and phosphorylated RXRα is therefore a critical target for HCC chemoprevention (10, 21). ACR suppresses the growth of HCC cells by inhibiting

RXRα phosphorylation and restoring its original function as a master regulator of nuclear receptors (15, 22-24). Therefore, the expression levels of the *RARβ*, *p21*^{CIP1}, *Cyclin D1*, *c-Fos*, and *c-Jun* genes, which are ACR targets (12-15, 28), were notably regulated by treatment with this agent. Among these molecules, RARβ appears to be the most important with respect to the induction of apoptosis (36). The upregulation of p21^{CIP1}, which negatively modulates cell cycle progression, also activates the promoter region of the *RARβ* gene (37). Because RARβ can form a heterodimer with RXRα and thus synergistically inhibit the growth of HCC cells (14, 15), RARβ induction might also have played a role in preventing the development of liver tumors in the present study. In addition, p21^{CIP1} induction, which might be caused by activation of transforming growth factor (TGF)-β, also contributes to prevent the development of liver neoplasms because TGF-β induces senescence and inhibits growth in HCC cells by upregulating p21^{CIP1} and ACR can activate latent TGF-β in liver stellate cells (38, 39).

Next, the effects of ACR in improving hepatic steatosis and insulin resistance, both of which accelerate HCC development (7-9), is discussed. These effects might also be associated with RXRα dephosphorylation since RXR can control insulin sensitization and lipid metabolism by forming a heterodimer with peroxisome proliferator-activated receptor (PPAR), an important molecule in the regulation of lipid homeostasis and energy metabolism (40). This speculation is interesting because the inhibition of RXRα phosphorylation and the activation of the RXR/PPAR heterodimer are also activities that cooperatively inhibit the growth of cancer cells (41). In addition, ACR might improve these metabolic abnormalities by activating AMPK, which increases glucose uptake and fatty acid oxidation but decreases fatty acid synthesis (33).

This is another positive finding with regard to the prevention of hepatotumorigenesis because decreased AMPK activation is implicated in tumor development and therefore may be a promising target for cancer chemoprevention (42, 43). For instance, a human study suggests that metformin, an AMPK activator used to treat type 2 diabetes mellitus, reduces the cancer risk in diabetic patients (44). Dietary energy restriction suppresses mammary tumorigenesis in rats by increasing the levels of activated AMPK (45). Pitavastatin, a lipophilic statin, was found to prevent obesity- and diabetes-related colon carcinogenesis in mice by activating AMPK in the colonic mucosa (29). These reports suggest the possibility that activation of AMPK by ACR aided in suppressing the development of obesity-related liver cells adenomas, as observed in the present study.

Insulin resistance and lipid accumulation in the liver produce inflammatory changes in the liver (7-9). ACR might decrease the serum levels of TNF-α and the expression levels of *TNF-α*, *IL-6*, and *IL-1β* mRNA in the livers of experimental mice by improving hepatic steatosis and insulin resistance. These findings are significant because obesity-related HCC development clearly depends on enhanced production of TNF-α and IL-6, which cause hepatic inflammation and activate ERK and Stat3 (34). TNF-α, which lies at the core of the association between obesity and insulin resistance (46), contributes to obesity-induced IL-6 production and hepatocarcinogenesis (34). IL-6 is a major Stat3 activator in the liver, and the activation of the IL-6-Stat3 axis plays a critical role in HCC development (47, 48). In addition, uncontrolled activation of the Ras-ERK and Jak-Stat pathways is essential for HCC development (49). In the present study, ubiquitous activation of Ras-ERK signaling presumably caused accumulation of the p-RXRα protein in the liver of the obese mice. Our findings indicate that the effects of ACR in improving the inflammatory response and inhibiting Ras-ERK and

Stat3 activation are crucial to prevent the development of obesity-related liver tumors.

Finally, it should be emphasized again that prevention of HCC by targeting hepatic steatosis, insulin resistance, and the state of chronic inflammation, which are caused by dysregulation of energy homeostasis, might be one of the promising strategies for treatment of obese individuals who are at an increased risk of developing HCC (3, 4). ACR appears to be potentially effective and critical candidate for this purpose because it can improve hepatic steatosis and insulin resistance, while also attenuating chronic inflammation. ACR inhibits RXRα phosphorylation induced by Ras-ERK activation, which might be associated with excess adipose tissue, and this effect is also important for preventing obesity-related liver tumorigenesis. The findings of the present study, together with the results of previous clinical trials indicating that ACR can significantly prevent the development of HCC in patients with viral cirrhosis without causing serious adverse effects (17-19), encourage the clinical usage of this agent for cirrhotic patients with obesity and diabetes. On the other hand, careful observation is required to apply a retinoid in clinical practice because of its potential toxicity. For instance, ACR may worsen hypertriglyceridemia in obese and diabetic subjects, which is a side effect observed in previous clinical trial (17), limiting the application of ACR to such subjects.

Conflicts of interest statement

The authors declare that no conflict of interests exists.

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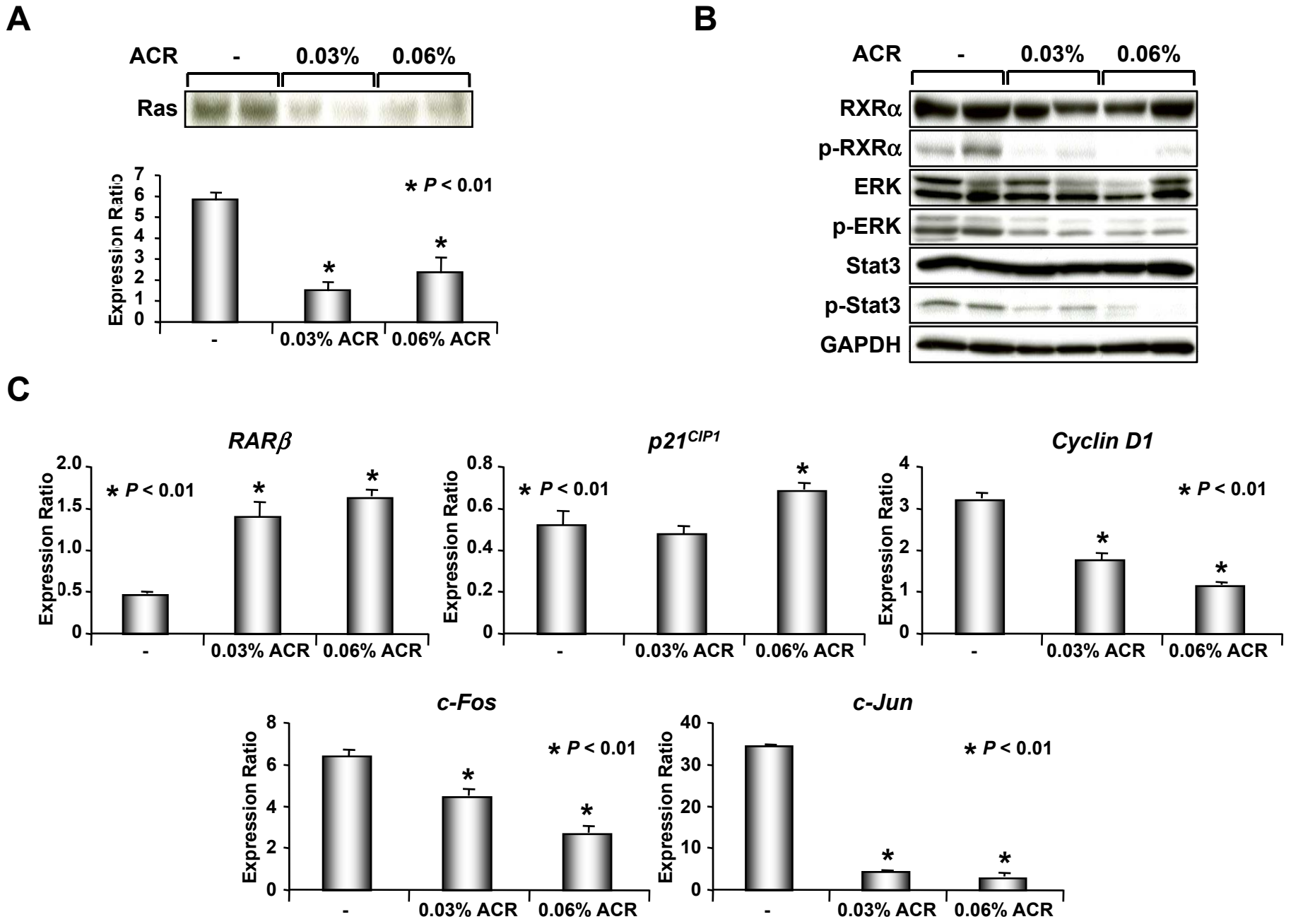
Figure Legends

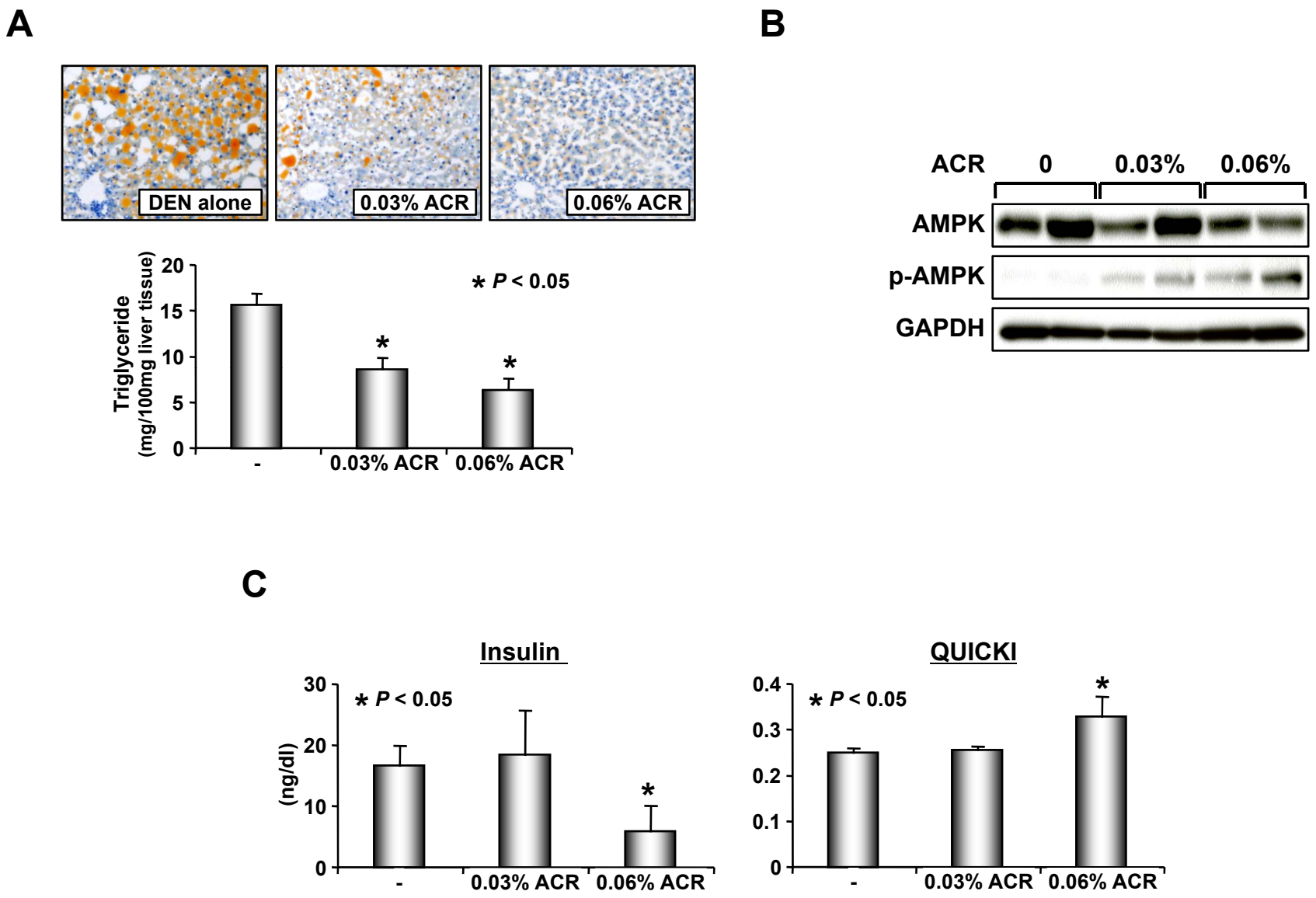
Figure 1: Effects of ACR on Ras activity; phosphorylation of RXRα, ERK, and Stat3 proteins; and the expression of target genes in the livers of DEN-treated *db/db* mice. The total proteins and mRNAs were extracted from the livers of DEN-treated mice. (*A*) The Ras activities were determined using a Ras activation assay kit (upper panel). The relative intensity of the blots was quantified by densitometry and is displayed in the lower graph. (*B*) The expression levels of the RXRα, p-RXRα, ERK, p-ERK, Stat3, and p-Stat3 proteins were examined by western blot analysis using the respective antibodies. Equal protein loading was verified by the detection of GAPDH. Two lanes represent protein samples from 2 different mice from each group. Repeat western blots yielded similar results. (*C*) The expression levels of *RARβ*, $p21^{CIP1}$, *Cyclin D1*, *c-Fos*, and *c-Jun* mRNA were examined by quantitative real-time RT-PCR using specific primers. β-actin was used as a control. Each experiment was performed in triplicate, and the average value was calculated. Values are the mean ± SD. * $P < 0.01$ vs. ACR-untreated group.

Figure 2: Effects of ACR on hepatic steatosis, the activation of the AMPK protein in the liver, and the levels of serum insulin and insulin sensitivity in DEN-treated *db/db* mice. (*A*) Frozen liver sections from DEN-exposed mice treated with or without ACR were stained with Sudan III to show steatosis (upper panels). Hepatic lipids were extracted from the frozen livers of these mice, and the triglyceride levels were measured (lower graph). (*B*) The total proteins were extracted from the livers of DEN-treated mice, and the expression levels of the AMPK and p-AMPK proteins were examined by western blot analysis using the respective antibodies. A GAPDH antibody served as a loading control. (*C*) The serum concentration of insulin was measured by enzyme

immunoassay (left graph). The QUICKI value was calculated to evaluate insulin sensitivity (right graph). Values are the mean ± SD. * $P < 0.05$ vs. ACR-untreated group.

Figure 3: Effects of ACR on the serum levels of TNF-α and the expression levels of *TNF-α*, *IL-6*, and *IL-1β* mRNA in the livers of DEN-treated *db/db* mice. (*A*) The serum concentration of TNF-α was measured by enzyme immunoassay. (*B*) The expression levels of *TNF-α*, *IL-6*, and *IL-1β* mRNA were examined by quantitative real-time RT-PCR using specific primers. The expression levels of these mRNAs were normalized to the level of the *β-actin* mRNA. Values are the mean ± SD. * $P < 0.01$ vs. ACR-untreated group.





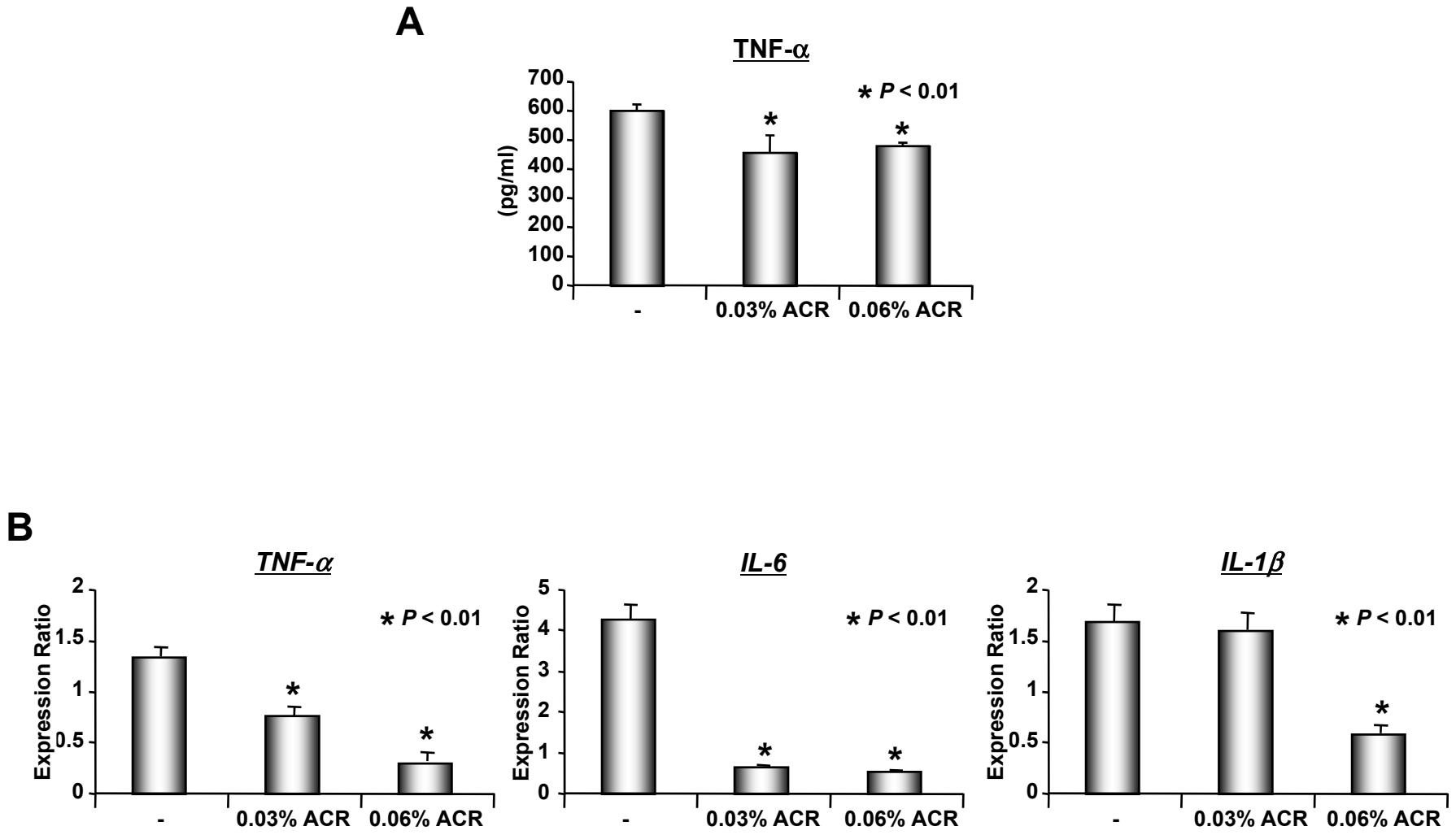


Table 1. Body, liver, kidney, and fat weights of the experimental mice

Group no.	Treatment	No. of mice	Weight (g)			
			Body	Liver	Kidney	Fat[a]
1	DEN alone	10	71.2±8.8[b]	4.5±0.8	0.9±1.0	7.5±2.2
2	DEN + 0.03% ACR	10	65.7±7.2	3.3±1.1[c]	0.5±0.1	6.0±1.5
3	DEN + 0.06% ACR	10	66.0±7.4	3.0±0.7[d]	0.5±0.1	5.7±1.3
4	0.06% ACR alone	5	66.0±7.4	3.0±0.7[e]	0.5±0.1	5.7±1.3
5	Basal diet	5	67.9±7.8	4.8±1.0	0.6±0.1	6.2±1.4

[a]White adipose tissue of the periorchis and retroperitoneum.

[b]Mean ± SD.

[c,d]Significantly different from group 1 by Tukey-Kramer Multiple Comparison Test ([c]$P<0.05$ and [d]$P<0.01$).

[e]Significantly different from group 5 by Tukey-Kramer Multiple Comparison Test ($P<0.05$) .

Table 2. Incidence and multiplicity of hepatic neoplasms and FCA in the experimental mice

Group no.	Treatment	No. of mice	Incidence		Multiplicity[a]		FCA[b] (No./cm^2)
			Adenoma	HCC[b]	Adenoma	HCC	
1	DEN alone	10	7/10 (70%)	1/10 (10%)	1.3±1.2[c]	0.1±0.3	15.1±3.5[d]
2	DEN + 0.03% ACR	10	1/10 (10%)[e]	1/10 (10%)	0.2±0.6[f]	0.1±0.3	6.6±2.5[g]
3	DEN + 0.06% ACR	10	1/10 (10%)[e]	1/10 (10%)	0.1±0.3[h]	0.1±0.3	2.8±1.8[g]
4	0.06% ACR alone	5	0/5 (0%)	0/5 (0%)	0	0	3.0±2.8[i]
5	Basal diet	5	0/5 (0%)	0/5 (0%)	0	0	8.0±1.2

[a]Number of neoplasms per mouse.

[b]FCA, foci of cellular alteration; and HCC, heaptocellular carcinoma.

[c]Mean ± SD.

[d,i]Significantly different from group 5 by Tukey-Kramer Multiple Comparison Test ([d]$P<0.001$ and [i]$P<0.05$).

[e]Significantly different from group 1 by Fisher's exact probability test ($P<0.01$).

[f-h]Significantly different from group 1 by Tukey-Kramer Multiple Comparison Test ([f]$P<0.05$, [g]$P<0.001$, and [h]$P<0.01$).

AACR American Association for Cancer Research

Cancer Prevention Research

Acyclic retinoid inhibits diethylnitrosamine-induced liver tumorigenesis in obese and diabetic C57BL/KsJ- *db/db* mice

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