DECREASE IN SERUM THYROXINE LEVEL BY PHENOBARBITAL IN RATS IS NOT NECESSARILY DEPENDENT ON INCREASE IN HEPATIC UDP-GLUCURONOSYLTRANSFERASE

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ABBREVIATIONS: ID-I, iodothyronine deiodinase; PB, phenobarbital; PCB, polychlorinated biphenyl; T₃, triiodothyronine; T₄, thyroxine; TTR, tranthyretin; TSH, thyroid-stimulating hormone; UDP-GT, UDP-glucuronosyltransferase.
Abstract

We have previously reported that there is a poor correlation between increase in the levels of UGT1A1 and UGT1A6 and decrease in the levels of serum total thyroxine (T4) and free T4 in phenobarbital (PB)-treated rats, although the PB-induced decrease in rats is generally thought to occur through induction of the UDP-glucuronosyltransferase (T4-UDP-GT: UGT1A1 and UGT1A6). In the present study, to clarify a relationship between the decrease in serum T4 level and the increase in the T4-UDP-GT activity by PB in rats, we examined the relationship using Gunn rats, a mutant strain of Wistar rats deficient in UGT1A isoforms. Levels of serum total T4, free T4 and total triiodothyronine (T3) were markedly decreased in not only Wistar rats but also Gunn rats 1 day after the final administration of PB (80 mg/kg, i.p., once daily for 4 days), and no significant difference in magnitude of the decrease between Wistar and Gunn rats was observed. On the other hand, the level and activity of T4-UDP-GT were significantly increased by treatment with PB in Wistar rats but not in Gunn rats. Furthermore, significant decrease in the activity of hepatic type-I iodothyronine deiodinase, which mediates the deiodination of T4 and T3, by PB treatment was observed in both Wistar and Gunn rats. In addition, no significant change in the level of serum thyroid-stimulating hormone, the activity of hepatic sulfotransferase and the binding of [125I]T4 to serum transthyretin and albumin by PB treatment was observed in either Wistar or Gunn rats. In conclusion, the present results demonstrate that the decrease in serum total T4 level by PB in Gunn rats is not dependent on the increase in hepatic T4-UDP-GT activity and suggest that even in Wistar rats, the PB-induced decrease in serum T4 level does not occur only through increase in hepatic T4-UDP-GT.
Introduction

Phenobarbital (PB) is well known to decrease the level of serum thyroid hormone and to increase the activities of hepatic drug-metabolizing enzymes in rats and mice (Hood et al., 2003; O’Connor et al., 1999). Furthermore, PB increases levels of serum thyroid-stimulating hormone (TSH) and thyroid gland growth in rats (Hood et al., 1999). As a possible mechanism for PB-induced decrease in level of serum thyroid hormone, enhancement of thyroid hormone metabolism by PB is considered (Capen 1997; McClain 1989). Especially, the decrease in the level of serum thyroxine (T₄) by PB in rats is thought to occur mainly through the induction of T₄-UDP-glucuronosyltransferase (T₄-UDP-GT) responsible for glucuronidation of T₄ (Barter and Klaassen, 1992a; Liu et al., 1995). This hypothesis is supported by the previous reports that a number of T₄-UDP-GT inducers, such as polychlorinated biphenyl (PCB), 3-methylcholanthrene, and pregnenolone-16α-carbonitrile, show ability to decrease serum thyroid hormone (Barter and Klaassen, 1994; De Sandro et al., 1992; Saito et al., 1991). However, the magnitude of decrease in level of serum total T₄ by PB is not necessarily correlated with that of increase in T₄-UDP-GT activity (Saito et al., 1991; Hood et al., 2003). Likewise, our preliminary study (Suzuki et al., 2004) has indicated that there is a poor correlation between increase in the levels of UGT1A1 and UGT1A6 and decrease in the levels of serum total T₄ and free T₄ in PB-treated rats.

In the present study, therefore, we examined a relationship between the decrease in serum total T₄ level and the increase in hepatic T₄-UDP-GT (UGT1A1 and UGT1A6) by PB using UGT1A-deficient Wistar rats (Gunn rats) and demonstrated that
PB-induced decrease in serum total T₄ level in rats was not necessarily dependent on the increase in hepatic T₄-UDP-GT activity.
Materials and Methods

Chemicals. PB was purchased from Nakakita Yakuhin Co., Ltd. (Aichi, Japan). The \(^{125}\text{I}\)-reverse triiodothyronine (T\(_3\)) and \(^{125}\text{I}\)T\(_4\), radiolabeled at 5' position of the outer ring, was obtained from PerkinElmer Life Sci., Inc. (Boston, MA). All other chemicals were obtained commercially in appropriate grades of purity.

Animal treatments. Male Wistar rats (160-200 g) and UGT1A-deficient Wistar rats (Gunn rats, 190-260 g) were obtained from Japan SLC., Inc. (Shizuoka, Japan). Male Wistar and Gunn rats were housed in three or four per cage with free access to commercial chow and tap water, maintained on a 12-h dark/light cycle (8:00 a.m.-8:00 p.m. light) in an air-controlled room (temperature: 24.5 ± 1°C, humidity: 55 ± 5%), and handled with human care under the guidelines of the University of Shizuoka (Shizuoka, Japan). Rats were received four consecutive intraperitoneal injection of PB (80 mg/kg) dissolved in 0.9% saline (5 ml/kg). Control animals were treated with a vehicle alone (5 mg/kg). All rats were killed by decapitation on 1 day after the final administration. The liver was removed, and hepatic microsomes and cytosols were prepared according to the method of Kato et al. (1995) and stored at –85°C until used. Blood was collected from each animal between 10:30 and 11:30 a.m. After clotting at room temperature, serum was separated by centrifugation and stored at –50°C until used.

Analysis of serum hormones. Levels of serum total T\(_4\), free T\(_4\), total T\(_3\) and TSH
were measured by radioimmunoassay using the Total T4 and Free T4 kit (Diagnostic Products Corporation; Los Angels, CA), T-3·RIABEAD (ABOTT JAPAN Co., Ltd.), and rTSH [125I] Biotrak assay system (Amersham Biosciences UK Limited; Little Chalfont, UK), respectively.

**Hepatic T4-metabolizing enzyme assays.** Amounts of proteins of hepatic subcellular fractions, microsomes and cytosols, were determined by the method of Lowry et al. (1951) with bovine serum albmin as a standard. The activity of microsomal UDP-GT toward T4 was determined by the methods of Barter and Klaassen (1992b). The activity of microsomal type-I iodothyronine deiodinase (ID-I) was determined by the method of Hood and Klaassen (2000). The activity of cytosolic sulfotransferase toward T4 was determined by the methods of Kaptein et al. (1997).

**Western blot analysis.** Polyclonal anti-peptide antibodies against the common region of UGT1A isoforms and specific antibodies against UGT1A1, UGT1A6, and UGT2B1 were used (Ikushiro et al. 1995, 1997). Western blot analyses for microsomal UGT isoforms were performed by the method of Luquita et al. (2001). Isolated proteins corresponding to UGT1A1, UGT1A6, and UGT2B1 were detected using chemical luminescence (ECL detection kit, Amersham Pharmacia Biotech), and the level of each protein was determined densitometrically with LAS-1000 (FUJIFILM, Japan).

**Analysis of [125I]T4 binding to serum proteins.** At 1 day after consecutive four day-treatment with PB, rats were anesthetized with 50 mg/ml sodium pentobarbital
combined 1:1 with 1 mg/ml potassium iodide at 2 mg/ml. The femoral artery was cannulated (Polyethylene tube SP31, NATUME Inc., Tokyo, Japan) and primed with heparinized saline (33 units/ml). Fifteen minutes later, rats were given 1 ml of \([^{125}\text{I}]T_4\) iv, at 15 µCi/ml in 10 mM NaOH saline + 1% normal rat serum. After the administration of \([^{125}\text{I}]T_4\), a portion (0.3 ml) of blood was sampled from the artery at the indicated time, and serum was collected and stored at -50°C for assay. Serum was diluted in 100 mM phosphate buffer (pH 7.4) containing 1 mM EDTA, 1 mM dithiothreitol and 30% glycerol, and subjected to electrophoresis on 4-20% gradient native polyacrylamide gels PAG Mid “DAIICHI” 4/20 (DAIICHI PURE CHEMICALS CO., LTD, Japan), using 0.025 M Tris (pH 8.4) containing 0.192 M glycine as running buffer, for 11 h at 20 mA at 4°C. Human albmin and tranthryretin (TTR), which were incubated with \([^{125}\text{I}]T_4\), were also applied on the gel as templates. After the electrophoresis, a gel was dried and radioautographed for 20 h at room temperature using Imaging Plate 2040 (Fuji Photo Film Co., Ltd, Japan). The levels of \([^{125}\text{I}]T_4\)-albmin and \([^{125}\text{I}]T_4\)-TTR complexes were determined by counting the gel fractions identified from Bio Imaging Analyzer (BAS-2000II IP Reader, Fuji Photo Film Co., Ltd, Japan).

**Statistics.** The data obtained were statistically analyzed according to Dunnett's test after the analysis of variance (ANOVA).
Results

Serum hormone levels. Constitutive levels of serum total T₄, free T₄, total T₃, and TSH were more than 1.8-fold higher in Gunn rats than in Wistar rats. Effects of PB on levels of serum thyroid hormones were next examined in Wistar and Gunn rats (Fig. 1). In both Wistar and Gunn rats, PB treatment resulted in decreases of serum total T₄, free T₄ and total T₃, and magnitude of the decrease in each serum thyroid hormone was almost the same in the both rats. On the other hand, no significant change in the level of serum TSH by PB treatment was observed in either Wistar or Gunn rats.

Hepatic T₄-metabolizing enzyme activities. It has been reported that T₄ glucuronidation is primarily mediated by UGT1A enzymes, UGT1A1 and UGT1A6, in the rat liver (Visser, 1996). Therefore, we examined effects of PB on hepatic microsomal T₄-UDP-GT activity in Wistar and Gunn rats. Constitutive activity of T₄-UDP-GT was more than 2.1-fold higher in Wistar rats than in Gunn rats. PB treatment resulted in significant increase of T₄-UDP-GT activity in Wistar rats but not in Gunn rats (Fig. 2).

Hepatic microsomal ID-I activity in both Wistar and Gunn rats was significantly decreased by PB (Fig. 3). On the other hand, no significant change in activity of hepatic sulfotransferase by PB treatment was observed in either PB-treated Wistar or Gunn rats (data not shown).

Immunoblot analysis for UGT1As. Levels of immunoreactive proteins responsible for UGT1A isoforms, UGT1A1 and UGT1A6, were increased by PB in Wistar rats but not
in Gunn rats (Figs. 4 and 5). In addition, no constitutive expression of the UGT1A isoforms was confirmed in Gunn rats. On the other hand, level of UGT2B1 was significantly increased by PB in both Wistar and Gunn rats, and magnitude of the increase was higher in Gunn rats than in Wistar rats (Figs. 4 and 5).

Serum protein binding of $[^{125}I]T_4$. Effect of PB on the binding of $[^{125}I]T_4$ to serum proteins, TTR and albumin, was examined in Wistar rats. No significant change in the binding level of $[^{125}I]T_4$ to each serum protein by PB treatment was observed with the exception of decrease in the level of $[^{125}I]T_4$-TTR complex at 120 min after $[^{125}I]T_4$ administration (Fig. 6).
Discussion

In the present study, we found that treatment with PB resulted in a drastic decrease in serum total T\textsubscript{4} and free T\textsubscript{4} levels in both Wistar and Gunn rats, although significant increase in the activity of T\textsubscript{4}-UDP-GT occurred only in Wistar rats but not in Gunn rats. The present findings demonstrate that in Gunn rats, PB-induced decrease in level of serum T\textsubscript{4} occurs in a hepatic T\textsubscript{4}-UDP-GT-independent fashion. In addition, constitutive levels of serum total T\textsubscript{4} and T\textsubscript{3} were more than 1.8-fold higher in Gunn rats than in Wistar rats, suggesting that the deficit of T\textsubscript{4} glucuronidation results in higher T\textsubscript{4} serum levels. Similar results and suggestions have been obtained by Benathan \textit{et al.} (1983).

In general, T\textsubscript{4}-UDP-GT inducers, including PB, clobazam, PCB, 3-methylcholanthrene and pregnenolone-16\alpha-carbonitrile, have been considered to decrease a level of serum T\textsubscript{4} through increase in hepatic T\textsubscript{4}-UDP-GT (Barter and Klaassen, 1994; Miyawaki et al., 2003; Van Birgelen et al., 1995). However, it has been reported that difference between rats and mice in magnitude of decrease in level of serum total T\textsubscript{4} by an inducer of T\textsubscript{4}-UDP-GT is not well correlated with that in increase in activity of T\textsubscript{4}-UDP-GT (Craft et al., 2002, Hood et al., 2003). Furthermore, we have reported previously that PCB-induced decrease in serum T\textsubscript{4} level might occur not only through increase in hepatic T\textsubscript{4}-UDP-GT activity but also via formation of hydroxylated PCB metabolites in rats (Kato et al., 2004) and that in PB-treated rats, there was a poor correlation between increase in the levels of UGT1A1 and UGT1A6 and decrease in the levels of serum total T\textsubscript{4} and free T\textsubscript{4} (Suzuki et al., 2004). These previous reports strongly support a possibility that decrease in serum total T\textsubscript{4} level by PB does not occur
only through increase in hepatic T₄-UDP-GT activity.

As possible mechanisms for the PB-induced decrease in serum T₄ level, changes in hepatic ID-I activity and serum TSH level might be considered. However, a significant decrease in activity of hepatic ID-I, which mediates the deiodination of T₄ and T₃, by PB treatment was observed in both Wistar and Gunn rats. Similar results have been reported in PB-treated Sprague-Dawley rats (Hood and Klassen, 2000; O’Connor et al., 1999). Accordingly, PB-induced decrease in serum T₄ level is thought to occur through an ID-I-independent pathway. Furthermore, in the present study, levels of serum TSH in both Wistar and Gunn rats were not significantly changed by PB, indicating that TSH is not related to the PB-induced decrease in serum T₄ level, although a significant increase in serum TSH level has been reported to occur in PB-treated rats (Hood et al., 1999; O’Connor et al., 1999). The difference between the previous results and our present results might be attributed to the difference in the dose examined.

Although it has been reported that the binding of PCB and its hydroxylated metabolites to TTR, a major T₄ transporting protein, might be attributed, in part, to decrease in level of serum T₄ in PCB-treated rats (Brouwer et al., 1998; Lans et al., 1993; Kato et al., 2004), displacement of T₄ from serum TTR by PB did not occur in PB-treated rats, with the exception of the slight displacement in Wistar rats at 120 min after PB treatment. Accordingly, decrease in the level of serum T₄ in PB-treated rats occurs in a TTR-independent pathway. In addition, no change in activity of hepatic sulfotransferase, which efficiently catalyzes the sulfation of iodothyronines (Kester et al., 1999), by PB treatment was observed in either Wistar or Gunn rats.
In conclusion, the present findings demonstrate that the decrease in serum total T₄ level by PB in Gunn rats occurs without increases in hepatic T₄-metabolizing enzymes (T₄-UDP-GT, ID-I and sulfotransferase), the binding of PB to serum TTR, and level of serum TSH, although an exact mechanism for the PB-induced decrease remains unclear. In Wistar rats, PB-induced T₄-UDP-GT might also contribute, in part, to the decrease in serum T₄ level. To clarify exact mechanisms for PB-induced decrease in serum thyroid hormones, further studies involving T₄-transporters, non hepatic T₄-UDP-GT and exchangeable thyroid hormone pools in non hepatic tissues would be necessary.
References


McClain RM (1989) The significance of hepatic microsomal enzyme induction and


Footnotes

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Legends for figures

**FIG. 1.** Effect of PB on levels of serum total thyroxine (T₄), free T₄, total triiodothyronine (T₃), and thyroid-stimulating hormone (TSH). Animals were killed 1 day after the final administration of PB (80 mg/kg, ip, once daily for 4 days), and levels of serum thyroid hormones were measured as described in Materials and Methods. Constitutive levels: total T₄ (μg/dl), 3.32 ± 0.21 (Wistar, N=7) and 7.99 ± 0.30 (Gunn, N=4); free T₄ (ng/dl), 1.54 ± 0.07 (Wistar, N=7) and 2.77 ± 0.07 (Gunn, N=4); total T₃ (ng/ml), 0.34 ± 0.03 (Wistar, N=6) and 0.96 ± 0.05 (Gunn, N=4); TSH (ng/ml), 8.37 ± 1.25 (Wistar, N=6) and 20.85 ± 1.79 (Gunn, N=4). Each column represents the mean ± SE (vertical bars) for four to seven animals. *P<0.01, significantly different from each control.

**FIG. 2.** Effect of PB on the activity of hepatic microsomal UDP-glucuronyltransferase. Each column represents the mean ± SE (vertical bars) for four animals. Constitutive levels: T₄-UDP-GT (pmol/mg protein/min), 12.60 ± 0.69 (Wistar) and 5.95 ± 1.06 (Gunn). *P<0.01, significantly different from each control.

**FIG. 3.** Effect of PB on the activity of hepatic microsomal type I iodothyronine deiodinase (ID-I). Each column represents the mean ± SE (vertical bars) for four animals. Constitutive levels: ID-I (pmol/mg protein/min), 161.8 ± 3.1 (Wistar) and 126.3 ± 9.5 (Gunn). *P<0.01, significantly different from each control.
FIG. 4. Representative Western blot patterns for hepatic microsomal UGT isoforms.

FIG. 5. Effect of PB on levels of hepatic microsomal UGT isoforms. After Western blot as shown in Figure 4, the isolated bands responsible for UGT isoforms were densitometrically quantified as described in Materials and Methods. The data are represented as the mean ± SE (vertical bars) for four animals. *P<0.05, significantly different from each control. ND, Not detectable.

FIG. 6. Effect of PB on the binding of [125I]T₄ to the serum proteins in Wistar rats. The binding of [125I]T₄ to the serum proteins was assessed by nondenaturing polyacrylamide gel electrophoresis, as described in Materials and Methods. Each column represents the mean ± SE (vertical bars) for three animals. *P<0.05, significantly different from each control.
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