Type 1 deiodinase is stimulated by iodothyronines and involved in thyroid hormone metabolism in human somatomammotroph GX cells

A Baur and J Köhrle
Klinische Forschergruppe der Medizinischen Poliklinik der Universität Würzburg, Röntgenring 11, D-97070 Würzburg, Germany
(Correspondence should be addressed to J Köhrle, Medizinische Poliklinik, Klinische Forschergruppe, Röntgenring 11, D-97070 Würzburg, Germany)

Abstract

Background: Local 5'-deiodination of l-thyroxine (T₄) to the active thyroid hormone, 3,3',5-tri-iodothyronine (T₃) via two deiodinase isoenzymes (D1 and D2) has an important role for various T₃-dependent functions in the anterior pituitary. However, no evidence has been presented yet for thyroid hormone inactivation via the 5-deiodinase (D3) in anterior pituitary models.

Methods: Using the human somatomammotroph cell line, GX, we analysed effects of T₃ and its 5'-deiodination product, 3,5-di-iodothyronine (3,5-T₂), on deiodinase activities, measuring release of iodide-125 (¹²⁵I) from phenolic-ring- or tyrosyl-ring-labelled substrates respectively.

Results: T₃ and 3,5-T₂ rapidly stimulated D1 activity in GX cells in the presence of serum in the culture medium, whereas D2 activity was not detectable under these conditions. However, when the cells were kept under serum-free conditions, specific activity of D2 reached levels similar to those of D1. With tyrosyl-ring labelled 3,5-[¹²⁵I]-3'-T₃ as substrate, a significant release of ¹²⁵I was observed in GX cell homogenates. This is comparable to the D1 activity of liver membranes, which preferentially catalyses 5'-deiodination, but to some extent also 5-deiodination, at the tyrosyl ring.

Conclusions: D1 activity of human GX cells is increased by T₃ and 3,5-T₂. Inactivation of T₃ in the anterior pituitary might occur by deiodination at the tyrosyl ring via D1, thus terminating the stimulatory thyroid hormone signal in human somatomammotroph cells.

Introduction

Thyroid hormones regulate various functions of the anterior pituitary (e.g. expression of thyroid-stimulating (TSH) and growth (GH) hormones), that are well characterized in the rat (1). Recently, a human pituitary cell line (GX) has been established that expresses GH and prolactin mRNA (2). In GX cells, GH mRNA synthesis is stimulated by tri-iodothyronine (T₃). T₃, the main active form of thyroid hormones, is generated by 5'-deiodination of l-thyroxine (T₄), the ‘prohormone’ secreted by the thyroid gland. Two distinct 5'-deiodinases (D1 and D2), which differ in reaction kinetics, substrate specificity, inhibitor sensitivity, and regulation, contribute to systemic and local formation of T₃ (3). In the pituitary gland of euthyroid rats, half of the T₃ bound to specific nuclear T₃-receptors (predominantly TR-β2) is derived from local, intrapituitary T₄-to-T₃ conversion via deiodinase isoenzymes (4). So far, no evidence has been presented for an inactivation pathway of thyroid hormones via the 5-deiodinase (D3) in anterior pituitary models (5). Recently, we demonstrated that D1 is expressed in rat anterior pituitaries, in reaggregates of rat anterior pituitaries, and in rat somatomammotroph GH3 cells. D1 is stimulated by T₃ and its 5'-deiodination product, 3,5-di-iodothyronine (3,5-T₂), and may serve a yet unrecognized, important function within the modulation of thyroid-hormone-dependent genes in the anterior pituitary (5, 6). Therefore, we have now examined the expression of D1 and its regulation by thyroid hormones in the human somatomammotroph cell line, GX.

Materials and methods

Chemicals

All chemicals were of biochemical or analytical grade. Cell culture media, fetal calf serum, horse serum and antibiotics were purchased from Gibco BRL-Life Technologies GmbH (Eggenstein, Germany). Additives for the serum-free culture medium and other chemicals were purchased from Boehringer (Mannheim, Germany), Merck (Darmstadt, Germany), Sigma (Munich, Germany)
and Baker Chemikalien (Groß-Gerau, Germany). 3,3',5'-[125I]-T3 (rT3) was purchased from DuPont (Bad Homburg, Germany) and 3,5-[125I]-3',5'-T2 from Formula GmbH (Berlin, Germany). Non-radioactive thyroid hormones and the analogue, N-acetyl-L-3-Bromotyrosyl-L-thyronine (HB 306), were kindly provided by Dr H Rokos (Henning Berlin, Germany). The purity of 3,5-T2 was greater than 99% and contamination by T3 or T4 was less than 0.1%, as determined by HPLC and thin layer chromatography.

**Cell culture**

GX cells (kindly provided by Dr I A Frohmann and Dr R D Kineman) (2) were cultured in α Minimal Essential Medium supplemented with 10% horse serum and 50 µg/ml gentamicin. Cells were maintained throughout at 37°C in an atmosphere of 5% CO₂ and 95% air saturated with water. For preparation of homogenates, cells were washed once with ice-cold PBS, scraped into ice-cold homogenization buffer (250 mmol/l sucrose, 20 mmol/l HEPES, 1 mmol/l EDTA, 1 mmol/l dithiothreitol (DTT), pH 7.0) and were sonicated (10 times, 0.5 s, 300 W).

**Biochemical assays**

Specific activities of type 1 and type 2 deiodinase (D1 and D2) were determined in parallel by the release of ¹²⁵I⁻ from rT3 in the absence or presence of 1 mmol/l 6-n-propyl-2-thiouracil (PTU) using 10 nmol/l rT3 as substrate and 20 mmol/l dithiothreitol. The fraction of iodide release blocked by 1 mmol/l PTU was assigned to D1 and the residual activity not inhibited by PTU was ascribed to D2. 5-Deiodination at the tyrosyl ring was determined by the release of ¹²⁵I⁻ from 3,5-[125I]-3',5'-dibromo-thyronine (HB 306, 10 µmol/l HB 306, 10 µmol/l iopanoate) using 10 nmol/l T3 at pH 8.0 in homogenates of GX cells, rat liver microsomes and homogenates of rat brain and placenta. PTU forms covalent intermediates with D1 in its oxidized state and is highly selective for reaction with D1 rather than with D2 or D3. ATG is also a potent inhibitor of D1, but also inhibits D2 and D3 to a minor extent. Iopanoate, an iodinated oral X-ray contrast agent, is a potent inhibitor of all deiodinase isoenzymes. The synthetic flavonoid, EMD 21388, shows conformational similarity to iodothyronine structure and acts by competition with D1 and D2 substrates, but does not inhibit D3 activity (3).

**Statistical analysis**

Data were analysed by multiple analysis of variance (ANOVA). When the main effect was significant, the Mann–Whitney U-test was applied post-hoc to determine individual differences between means.

**Results**

**Effects of T₃ and 3,5-T₂ on 5’-D1 activity in GX cells**

In the human somatomammotroph cell line GX, D1 is expressed, whereas D2 activities were not detectable when the cells were cultured in medium containing 10% horse serum. Incubation with T₃ (final concentration 3 nmol/l) for 72 h led to a 2.1-fold stimulation of D1 activity compared with control. 3,5-T₂ at a concentration of 3 nmol/l had no effect on D1 activity, but greater concentrations significantly increased D1 activity, with a maximum at 30 nmol/l 3,5-T₂ (1.9-fold stimulation over basal levels) (Fig. 1A). An increase in D1 activity was already apparent 6 h after administration of 30 nmol/l 3,5-T₂ (Fig. 1B). Basal D1 activities were increased during prolonged cultivation, dependent on cell confluence. When GX cells were kept under serum-free conditions

![Figure 1](https://example.com)
Table 1 Release of $^{125}$I$^-$ from 3,5-$^{125}$I$^-$,3'-T$_3$ at pH 8.0 by homogenates of GX cells, rat liver, rat brain and rat placenta in the absence (Control, 100% activity) or presence of deiodinase inhibitors. Values are means ± S.E.M. ($n = 4$, except for brain: $n = 1–3$).

<table>
<thead>
<tr>
<th>Tyrosyl ring deiodinase activity (% of control)</th>
<th>Control†</th>
<th>PTU$^a$ (1 mmol/l)</th>
<th>Iopanoate$^b$ (10 μmol/l)</th>
<th>ATG$^c$ (10 μmol/l)</th>
<th>EMD 21388$^d$ (10 μmol/l)</th>
<th>HB 306$^e$ (10 μmol/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GX cells</td>
<td>100</td>
<td>22 ± 8</td>
<td>34 ± 7</td>
<td>12 ± 5</td>
<td>14 ± 7</td>
<td>31 ± 4</td>
</tr>
<tr>
<td>Liver</td>
<td>100</td>
<td>54 ± 13</td>
<td>60 ± 4</td>
<td>21 ± 12</td>
<td>15 ± 4</td>
<td>56 ± 15</td>
</tr>
<tr>
<td>Brain</td>
<td>100</td>
<td>99 ± 0.7</td>
<td>n.d.</td>
<td>n.d.</td>
<td>100</td>
<td>55</td>
</tr>
<tr>
<td>Placenta</td>
<td>100</td>
<td>103 ± 6</td>
<td>37 ± 5</td>
<td>25 ± 8</td>
<td>100 ± 7</td>
<td>86 ± 8</td>
</tr>
</tbody>
</table>

n.d. = Not determined. † Absolute values (fmol/mg/min): GX cells 1.8 ± 0.2; liver 23.1 ± 1.8; brain 4.2 ± 1.6; placenta 27.3 ± 7.4.

$^a$ Selective inhibitor of D1; $^b$ potent inhibitor of all deiodinase isoenzymes; $^c$ potent inhibitor of D1, minor effect on D2 and D3; $^d$ does not inhibit D3; $^e$ inhibits D1 and, to some extent, D3.

for 3 days, specific D2 activities were measurable and were in a range similar to those of D1 (D1: 18.6 ± 1.1 fmol/mg/min; D2: 13.5 ± 0.9 fmol/mg/min).

**Deiodination at the tyrosyl ring**

With 3,5-$^{125}$I$^-$,3'-T$_3$ as substrate at pH 8.0, a significant release of $^{125}$I$^-$ was observed in the human GX cells, with reaction characteristics similar to those of the liver D1, which has some ‘wobble’ at the catalytic site and therefore preferentially catalyses 5'-deiodination, but to some extent also 5-deiodination at the tyrosyl ring (8). The D1 inhibitors PTU, iopanoate, ATG, EMD 21388 and HB 306 blocked the release of $^{125}$I$^-$ from T$_3$ with potencies comparable to those in liver membrane preparations containing D1; there was no evidence for a D3-type 5-deiodinase of T$_3$ (Table 1). The marked inhibition of $^{125}$I$^-$ release by PTU and EMD 21388 in GX homogenates indicates that deiodination is catalysed by a D1 activity with some ‘wobble’ at the catalytic site, similar to the findings in liver, but in contrast to those for brain and placenta, which preferentially exhibit D3 activity at this pH of incubation.

**Discussion**

The effects of thyroid hormones on gene expression in the anterior pituitary of rats have been well studied. Transcription of the TSH genes is suppressed (1) and transcription of the GH gene is increased by T$_3$ (9, 10). In both cases thyroid hormone receptors, binding to response elements (negative or positive, respectively) in the promoter regions of these genes, are involved in transcriptional regulation (11). In vivo observations indicated that thyroid hormones exert similar effects on GH secretion in human and in rats (12, 13), and Chomczynski et al. (2) demonstrated that T$_3$ stimulated GH gene transcription in the human somatomammotroph GX cell line, not requiring additional serum factors or other hormones. Therefore this cell line provides a good model for investigations of thyroid hormone action in the human pituitary.

In this study, we have demonstrated that deiodinase isoenzymes types 1 and 2 (D1 and D2) are expressed in GX cells and that D1 is induced by T$_3$ and 3,5-T$_2$. Recently, a complex, positive T$_3$-responsive element has been functionally characterized in the promoter of the human type 1 5'-deiodinase gene (14). When the cells are cultured in medium containing 10% horse serum, the activity of D2 is not measurable, but when the cells are kept under serum-free conditions, D2 activities are in a range similar to those of D1, which are lower under these conditions. This may be due to the presence of thyroid hormones in the serum, as pituitary D1 is stimulated and D2 inhibited by thyroid hormones (3, 5). Basal activities of D1 increase during culture with increasing cell confluence, implying that cell–cell contacts are involved in D1 stimulation. A similar increase in D1 with increasing confluence is also observed in liver and kidney cell lines (TC Jakobs, A Baur & J Körhle, unpublished observations). The stimulating effect of 3,5-T$_2$ on D1 activity revealed a bell-shaped dose–response curve. This could be due to inactivation of ligands by increased deiodination or other inactivating pathways, such as glucuronidation or sulphation, induced by the greater 3,5-T$_2$ concentrations. Recently, we reported that D1 is rapidly stimulated by T$_3$ and 3,5-T$_2$ in anterior pituitaries of euthyroid rats, reaggregates of rat anterior pituitaries, and in rat somatomammotroph GH3 cells (6). These observations suggest that D1 serves an important function in regulation of thyroid-hormone-dependent genes in the anterior pituitary and that local paracrine interactions between more abundant somatotrophs and thyrotrophs appear possible.

The demonstration of D1 and D2 in human somatomammotroph GX cells and their regulation by thyroid hormones indicate that similar mechanisms are involved in anterior pituitary regulation in humans. We have now also demonstrated that D1 of GX cells apparently catalyses 5-deiodination of thyroid hormones in a manner similar to that of liver D1, which has some ‘wobble’ at the catalytic site and therefore might be involved in the inactivation of thyroid hormones, thus terminating the thyroid hormone...
signal. So far, no detailed analysis of expression of deiodinase isozymes in the normal human anterior pituitary is available and only a few cases of deiodinase activity in adenomas have been reported (15). Therefore, extrapolation from the human GX somatomammotroph cell line to the normal or pathophysiological expression of deiodinases and regulation of thyroid-hormone-dependent gene expression is not yet possible, and further detailed studies are required. TSH-producing human adenomas are very rare and no other human pituitary cell lines have been established yet. Therefore, this new somatomammotroph human pituitary cell line, which expresses functional deiodinases and responds to T₃, is a rather valuable tool with which to further our understanding of the role of local T₃ production in human pituitary function.

Acknowledgements

This work was supported by a grant from the Deutsche Forschungsgemeinschaft (Kö 922/3–1/2).

References


Received 9 September 1998
Accepted 18 December 1998