Two patients with atypical low triiodothyronine syndrome: primary deiodinase abnormalities?

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Summary
Low triiodothyronine (T3) concentrations in the presence of normal thyroxine (T4) and TSH levels, referred to as the low T3 syndrome (LT3S), are common. LT3S may be caused by starvation, various non-thyroidal illnesses (NTIs) and some medications. Reverse T3 (rT3) concentrations are elevated in the more severely ill, and they characteristically fail to respond to exogenous levothyroxine (L-T4) therapy. The biochemical abnormalities have been explained on the basis of altered peripheral deiodinase activities. Herein, we report on two patients with hypothyroid symptoms who on testing were found to have LT3S. They were atypical clinically in not having LT3S due to any of the usual causes, had no increased rT3 concentrations, and had a normal negative TSH feedback response to L-T4. One (patient 1) had previously been diagnosed with Hashimoto’s autoimmune primary hypothyroidism and was on L-T4 therapy. Both had T4 concentrations in the reference range. TSH levels were elevated in patient 1 and in the reference range in patient 2. Starting or increasing L-T4 doses resulted in no clinical improvement and no increase in T3 levels in spite of a marked increase in T4 levels. It is suggested that in the absence of the usual causes, lack of elevated rT3 levels, response to treatment and intact negative TSH feedback these two patients differ from the usual secondary causes of decreases in deiodinase activity. It is speculated that they may represent primary alterations in deiodinase enzymes possibly due to genetic variations in the deiodinase-encoding genes.

Learning points:
- LT3S is commonly found secondary to starvation, NTIs and use of some medications.
- Low T3 levels are the result of alterations in the activity of deiodinase enzymes.
- LT3S without the usual causes may represent a primary disturbance in deiodinase activity.

Background
In normal, euthyroid individuals, 20% of the circulating active thyroid hormone triiodothyronine (T3) comes directly from the thyroid gland and 80% is produced in non-thyroidal tissues by the activation of the inactive prohormone thyroxine (tetraiodothyronine, T4) (1) (2). Low T3 concentrations are found during starvation and in various acute and chronic illnesses (3) (4) (5). This condition is variously referred to as the euthyroid sick syndrome (ESS), non-thyroidal illness (NTI) syndrome or the low T3 syndrome (LT3S) (4) (5) (6). In critically ill patients, T4 concentrations may also be low, and the degree of disturbance in the circulating thyroid hormone concentrations is related to the severity of the NTI, with a decrease in the T3 concentration only being more benign (5) (6). LT3S as found in ESS is caused by a decrease in enzymatic deiodination at the S’ position of the outer, phenol ring of the iodothyronines (2) (7). In more severe NTIs, there is a further reduction in T3 concentrations due to increased deiodination at the S position of the inner, tyrosyl ring reducing it to the inactive diiodothyronine (T2) and producing inactive reverse T3 (rT3) from T4, thereby yet...
further reducing $T_3$ generation because of decreased substrate availability (2) (7) (8). Evidence of a disturbance in the thyroid-stimulating hormone (TSH) feedback loop has also been found (4) (5) (6) (8). LT$_3$S is also found in response to some drugs, including propylthiouracil (PTU) (9), beta-blockers (10) and amiodarone (11) (12).

The enzymes responsible for these alterations are the deiodinases (D) D1, D2 and D3 (2) (7). D2 is an activating enzyme that converts $T_4$ to $T_3$ (and rT$_3$ to T$_2$) and is found in the endothelial reticulum of skeletal muscle, CNS, pituitary, thyroid, heart muscle and brown adipose tissue. D3 is a deactivating enzyme that converts $T_4$ to rT$_3$ and $T_3$ to T$_2$ and is found in the CNS and other tissues. D1 has both activating and deactivating activities and is found in the plasma membranes of liver, kidney, thyroid and pituitary tissue. Together, these three enzymes play a vital role in the maintenance of tissue and circulating thyroid hormone levels (2) (7).

The 5'-deiodinase activity of D1 is inhibited by fasting, PTU and amiodarone (3) (9) (11) (12). Melmed et al. (11) have shown that the decreased generation of $T_3$ caused by chronic amiodarone administration in euthyroid patients causes a compensatory increase in TSH and $T_4$ concentrations. It is accompanied by a more modest increase in rT$_3$ concentrations, which is partially explainable by the mass action effect of the marked increase in TSH-stimulated $T_4$ secretion by the thyroid gland, but in addition represents some increase in D1 activity through its increased half-life caused by the increased secretion of $T_3$ by the intact thyroid gland in response to the increased TSH concentration (2) (7).

Treatment of LT$_3$S secondary to NTIs with levothyroxine (L-T$_4$) has generally been found to be unsuccessful (4) (5) (6).

Herein, we report on two patients with clinical evidence of hypothyroidism and LT$_3$S without any of the usual causes.

**Case presentations**

**Case 1**

A 63-year-old man, diagnosed at the age of 31 years with primary hypothyroidism due to Hashimoto’s autoimmune thyroiditis when he received the first of two mitral valve replacements, was referred for continued severe cold intolerance, low physical energy and marked mental lethargy in spite of free $T_4$ concentrations being near the upper limit of the reference range on L-T$_4$ replacement. His weight was 98 kg. There was no goitre. He was on warfarin and on candesartan, verapamil, furosemide and digoxin therapy for hypertension and congestive heart failure and on allopurinol therapy for gout. There was no history of herpes or any other chronic viral infection.

**Case 2**

A 60-year-old woman was referred for the evaluation of fatigue, cold intolerance, muscle cramps, depression and obesity of long duration. Her weight was 99 kg. There was no goitre. She was on candesartan and nifedipine therapy for hypertension. There was no history of herpes or any other chronic viral infection.

**Investigation**

**Case 1**

Thyroid tests revealed elevated thyroid peroxidase antibody (TPOA) levels, free $T_4$ levels near the upper limit of the reference range, markedly elevated TSH levels and low free $T_3$ levels. The $T_4$:T$_3$ ratio was high, rT$_3$ concentrations were in the normal reference range, and the $T_4$:rT$_3$ ratio was more than double mid-normal. Plasma iodine concentration was within the reference range (Table 1).

**Case 2**

Thyroid tests revealed normal TPOA levels and TSH and $T_4$ levels within their reference ranges, but low $T_3$ concentrations and an elevated $T_4$:T$_3$ ratio (Table 1).

Thyroid hormone measurements were carried out by LifeLabs Laboratory Services, 3680 Gilmore Way, Burnaby, BC, V5G 4V8, Canada, using a competitive immunoassay with direct chemiluminescent technology for TSH, $T_4$ and $T_3$ and electrochemiluminescent immunoassay for TPOA. The rT$_3$ concentration was measured by Associated Regional and University Pathologist (ARUP), Inc., 500 Chipeta Way, Salt Lake City, UT, 84108, USA, using a competitive RIA. Plasma iodine measurement was carried out by the London Laboratory Services Group, PO Box 5010, London, ON, N6A 5W9, Canada, using high-resolution inductively coupled plasma mass spectroscopy.

**Treatment**

**Case 1**

Increasing L-T$_4$ dose to 100 $\mu$g had no effect on the symptoms in spite of free $T_4$ concentrations rising to supraphysiological levels, TSH concentrations falling to half
their previous levels, a minimal to no increase in T₃ concentrations, and a further rise in the T₄:T₃ ratio. The rT₃ concentration rose minimally and continued to fall within the reference range, and the T₄:rT₃ ratio remained more than double normal (Table 1). Because of the patient’s heart failure, it was thought inadvisable to further increase the dose of L-T₄.

Case 2

Treatment with 150 μg L-T₄ had no clinical effect, increased T₄ concentrations and T₄:T₃ ratio, and suppressed TSH concentrations, but had no effect on T₃ concentrations. The rT₃ concentration remained within the reference range, and the T₄:rT₃ ratio was near the mid-normal level (Table 1).

Discussion

Herein, we report on two patients with atypical LT₃S in that they reported none of the usual causes such as NTIs, including chronic viral infections, starvation and medications known to cause impaired T₃ generation or its increased destruction. Their rT₃ concentrations were not elevated, as is the case in more severe NTIs or if on amiodarone therapy (2) (7) (8) (11) (12). In both patients, the negative TSH feedback mechanism was intact in that their TSH levels fell in response to increasing doses of L-T₄, albeit that in patient 1 the levels remained markedly elevated. Both presented with clinical symptoms of hypothyroidism, but neither responded clinically to elevating the T₄ concentrations to supraphysiological levels, and nor was there a consistent increase in T₃ concentrations.

The findings in patient 1 are reminiscent of those found in euthyroid patients on amiodarone therapy as reported by Melmed et al. (11) and Rosene et al. (12), except that TSH levels remained markedly elevated even at supraphysiological concentrations of T₄ and that the T₄:rT₃ ratio was elevated (Table 1). It is consistent with an absent response of the thyroid gland to elevated TSH levels because of the patient’s primary hypothyroidism. In fact, he might not have come to attention if he had not also had primary hypothyroidism in that the elevated TSH levels would presumably have resulted in increased secretion of thyroid hormones and suppression of TSH secretion. Inhibition of the deiodinases due to elevated serum iodine levels was ruled out (Table 1). The findings are most consistent with a marked decrease in D1 activity including normal rT₃ concentrations, which might be considered inappropriately low given the elevated T₄ concentrations, resulting in a high T₄:rT₃ ratio (Table 1).

Patient 2 had previously not been diagnosed with hypothyroidism and had a negative TPOA concentration. Unlike in patient 1, the rT₃ concentration at the upper limit of the reference range was appropriate for the elevated concentration of its substrate T₄, as indicated by the mid-normal T₄:rT₃ ratio (Table 1). It is evidence that the activity of D1 at the 5 position of the inner ring was not impaired. As the enzymatic activities of D1 at the 5 and 5' positions have been shown to proceed in an equimolar fashion (2), it makes decreased D1 activity an unlikely cause of the low circulating T₃ levels, suggesting impaired D2 activity as a more likely alternative. She also differed from patient 1 in not having an elevated TSH concentration, albeit that the 1.5 concentration was higher than expected for a T₄ concentration at the upper limit of the reference range (Table 1). It has long been known that TSH secretion is controlled by a negative

<table>
<thead>
<tr>
<th>Patient, age, gender and treatment</th>
<th>TSH (mU/l)</th>
<th>T₄ (pmol/l)</th>
<th>T₃ (pmol/l)</th>
<th>T₄/T₃ (Ratio)</th>
<th>rT₃ (nmol/l)</th>
<th>T₄:rT₃ (Ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 63 years, male and TTPH on 75 μg L-T₄</td>
<td>38.8</td>
<td>19.2</td>
<td>3.0</td>
<td>6.4</td>
<td>36.5</td>
<td>17.5</td>
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<tr>
<td>Repeat on 75 μg L-T₄</td>
<td>20.6</td>
<td>23.6</td>
<td>3.4</td>
<td>6.9</td>
<td>14.7</td>
<td>22.5</td>
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<tr>
<td>On 100 μg L-T₄</td>
<td>1.50</td>
<td>19.8</td>
<td>3.4</td>
<td>5.8</td>
<td>&lt;0.06</td>
<td>21.6</td>
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<tr>
<td>Repeat on 100 μg L-T₄</td>
<td>20.6</td>
<td>23.6</td>
<td>3.4</td>
<td>6.9</td>
<td>14.7</td>
<td>22.5</td>
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<tr>
<td>On 150 μg L-T₄</td>
<td>1.50</td>
<td>19.8</td>
<td>3.4</td>
<td>5.8</td>
<td>&lt;0.06</td>
<td>21.6</td>
</tr>
<tr>
<td>2. 60 years, female and before treatment</td>
<td>1.50</td>
<td>19.8</td>
<td>3.4</td>
<td>5.8</td>
<td>&lt;0.06</td>
<td>21.6</td>
</tr>
</tbody>
</table>

Analytical units

Normal reference range
- TSH: 0.38–5.5
- T₄: 10.5–20
- T₃: 3.5–6.5
- T₄/T₃: 0.14–0.54
- rT₃: 0.34
- T₄:rT₃: 45

Mid-normal values
- TSH: 1.5
- T₄: 15.3
- T₃: 5.0
- T₄/T₃: 3.1
- rT₃: 0.54
- T₄:rT₃: 40.0


TTPH, thyroxine-treated primary hypothyroidism. Analyte levels are given in bold if outside the reference range. Patient 1: plasma iodine: 0.29 (n: 0.24–0.63 μmol/l).
feedback mechanism responsive to circulating T₄ concentrations (1). It is the concentration of T₃ at the nuclear T₃ receptors of the thyrotrophs produced by the resident D1 and D2 enzymes as well as the T₃ from the circulation that ultimately controls TSH secretion (2). Christoffolete et al. (13) have demonstrated a unique behaviour of D2 in thyrotrophs in being able to overcome ubiquitination, thereby sustaining net increased T₃ production at increasing T₄ concentrations. One might speculate that in patient 2 the postulated decreased D2 activity might be sufficiently ameliorated by its atypical expression in the thyrotrophs to result in no or only minimally elevated TSH levels. An additional possible mechanism may be that reduced T₃ levels in the hypothalamus caused by decreased D2 activity in the third ventricle tanyctyes have reset the TSH response of the thyrotrophs (14). The lack of a markedly elevated TSH concentration in patient 2 may be akin to what has been observed in patients on amiodarone therapy in whom after an initial elevation in TSH concentrations in response to impaired deiodinase activity (11) (12), there is a gradual return to normal or nearly normal levels.

The theoretically possible alternative cause for the low circulating T₄ levels of a deficiency in T₃ production by the thyroid gland is not applicable in patient 1 who had Hashimoto’s primary hypothyroidism, while in patient 2 the 32% observed reduction from mid-normal levels exceeds the 20% of the total T₃ contributed by the thyroid (1) (2), and nor would it explain the lack of an increase in T₃ concentrations as the T₄ concentration rose in response to increasing the dose of L-T₄. Furthermore, no such case has been reported. It was not ruled out in either patient that further increases in their T₄ concentrations by increased doses of L-T₄ might have resulted in an increase in T₃ concentrations.

The fact that both patients responded with a decrease in TSH concentrations in response to an increase in circulating T₄ concentrations indicated an intact negative TSH feedback axis, supporting evidence for the lack of NTIs as a potential cause for the abnormalities found (4) (6) (8). This, together with the lack of clinical evidence that their LT₃S was secondary to fasting, NTIs or drugs, suggests that the alterations in circulating thyroid hormone levels were not secondary, but might represent primary abnormalities in deiodinase activity. In support of this speculation, Peeters et al. (15) have demonstrated polymorphism of deiodinases associated with circulating iodothyronine concentrations and their ratios, while Panicker et al. (16) using a similar approach of nucleotide measurement of genes involved in thyroid hormone metabolism found that 26% of patients with primary hypothyroidism on replacement therapy had polymorphism in the DIO2 gene resulting in a decreased T₄:T₃ ratio and clinical manifestations. Considering this frequency in genetic polymorphism, it is not unexpected that patients might be encountered with primary D2 and D1 enzyme abnormalities causing LT₃S.

Declaration of interest
The author declares that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

Funding
This research did not receive any specific grant from any funding agency in the public, commercial or not-for-profit sector.

Patient consent
Written consent was obtained from both patients to publish the case report.

Author contribution statement
The author was the only contributor. The author is a consultant endocrinologist and was and continues to be the physician responsible for the endocrine care of both patients. Both were referred by the family physician.

Acknowledgements
The author expresses his gratitude to the two patients for allowing the publication of this case report about their illness, to Drs Geoff Inman, Maureen Sweeney and Marlene Muller for referring the patients, to Kevin Campbell of LifeLabs for making arrangements for the reverse T₃ assays to be done at ARUP Laboratories, and to Dr John Penman of the Vancouver Island Health Authorities Laboratory for making arrangements for the measurement of plasma iodine at the London Laboratory Services Group.

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