Determinants of serum T₄ and T₃ at the time of diagnosis in nosological types of thyrotoxicosis: a population-based study

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Abstract

Objective: To characterize thyroid hormone levels at the time of diagnosis in the nosological types of thyrotoxicosis diagnosed in the population and to analyze determinants for serum thyroxine (T₄) and tri-iodothyronine (T₃).

Design: Population-based study of thyrotoxicosis at disease onset.

Methods: In the period 1997–2000, we prospectively identified all patients diagnosed with incident primary overt thyrotoxicosis in a Danish population cohort and classified patients into ten well-defined nosological types of disease (n=1082). Untreated levels of serum T₃, T₄, and T₃:T₄ ratio were compared and related to sex, age, level of iodine deficiency, smoking status, alcohol intake, iodine supplement use, co-morbidity, and TSH receptor antibodies (TRAbs) in multivariate models.

Results: Graves’ disease (GD) patients had much higher levels of T₃ and higher T₃:T₄ ratio at diagnosis compared with other thyrotoxic patients, but with a profound negative association between hormone levels and age. In GD, patients diagnosed in the area with more severe iodine deficiency had lower levels of T₃ and T₄. TRAb-negative GD patients had biochemically mild thyrotoxicosis. Higher age was also associated with lower degree of biochemical thyrotoxicosis in nodular toxic goiter. We found no association between serum T₃ and T₄ and sex, smoking habits, iodine supplements, alcohol intake, or co-morbidity in any type of thyrotoxicosis.

Conclusions: The study gives new insight into the hormonal presentation of thyrotoxicosis and showed that young age, positive TRAb levels, but also residency in the area with higher iodine intake was positively associated with biochemical disruption in GD.

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amiodarone-associated thyrotoxicosis, post-radioiodine thyrotoxicosis, lithium-associated thyrotoxicosis, painless thyroiditis (PT), and thyroiditis due to surgical manipulation of the thyroid gland.

Subjects and methods

Identification, verification, and subtype classification of thyrotoxic patients

The study is part of DanThyr, which is an ongoing monitoring of the Danish iodine fortification program (11). This study deals with the period 1997–2000 just before the mandatory iodine fortification in Denmark, where we identified all new cases of primary overt thyrotoxicosis in two well-defined population cohorts (12). The two regions of inhabitancy were an area of mild iodine deficiency in Copenhagen in eastern Denmark (n = 227,632, median urinary iodine excretion (UIE) in the population not taking vitamin supplements was 61 μg/l) and an area of moderate iodine deficiency around Aalborg in western Denmark (n = 311,102, median UIE was 45 μg/l (13)). The process of identification, verification, and subtype classification of cases with primary overt thyrotoxicosis has been described in detail (12,14). In brief, patients were prospectively identified using a system monitoring the four diagnostic laboratories that performed all thyroid function tests requested by hospital and primary care institutions in the study areas: (i) Aalborg Hospital Laboratory; (ii) Bispebjerg Hospital Laboratory; (iii) Frederiksborg Hospital Laboratory; and (iv) Laboratory of General Practitioners in Copenhagen. (ii–iv all in Copenhagen). Results of thyroid function tests were on a daily basis imported from the laboratory databases into a register database, and subjects with blood tests fulfilling the criteria of incident overt, biochemical thyrotoxicosis were identified for individual evaluation.

We subsequently gathered information from hospital medical records, general practitioners, additional laboratory tests performed, and thyroid scintigraphy, and used these data to verify and classify thyrotoxicosis (n = 1082) into well-defined nosological types as previously defined in detail (15).

TSH, T3, and T4 assays

All TSH, T3, and T4 serum concentrations in this study were obtained at the time of diagnosis of thyrotoxicosis, i.e. before treatment was started (1). Aalborg Hospital Laboratory analyzed TSH by Immunoluminometric LUMItest from BRAHMS (Berlin, Germany), reference interval 0.3–4.5 mU/l; total T4 and total T3 by means of competitive RIA Amerlex-m T4 and T3 RIA kit by Ortho-Clinical Diagnostics (part of Johnson-Johnson, New Brunswick, NJ, USA), T4 reference interval 60–140 nmol/l, and T3 reference interval 1.2–2.7 nmol/l. Bispebjerg Hospital Laboratory analyzed TSH by Microparticle Enzyme Immunoassay, AxSYM Ultrasensitive hTSH II by Abbott Laboratories, reference interval 0.15–5.0 mU/l; T4 by Fluorescence Polarization Immunoassay, AxSYM by Abbott Laboratories, reference interval 60–140 mU/l; and T3 by Microparticle Enzyme Immunoassay, AxSYM T3 by Abbott Laboratories, reference interval 1.2–2.3 nmol/l. Frederiksborg Hospital Laboratory analyzed TSH by Time-resolved Fluoroimmunoassay based on direct sandwich technique, AutoDelfia hTSH Ultra Kit by Wallac (Turku, Finland), reference interval 0.15–4.5 mU/l; T4 and T3 by Fluoroimmunoassay based on competitive reaction, AutoDelfia T4 and T3 Kit by Wallac, T4 reference interval 60–160 nmol/l, and T3 reference interval 0.9–2.7 nmol/l. T4 results above 300 nmol/l from this laboratory were recorded as >300 nmol/l (n = 18). For calculations, they were given the value 339 mU/l, which corresponds to the median of T4 values >300 nmol/l from the other three laboratories providing quantified T4 levels also in this range. T3 levels above 10 nmol/l from the same laboratory were recorded as >10 nmol/l (n = 5), and in this study, they were given the value 11.89 nmol/l, which was the median value of T3 >10 nmol/l from the other three laboratories. The Laboratory of General Practitioners in Copenhagen analyzed TSH by Two-sided Chemiluminometric Immunoassay, Ciba Corning Diagnostics (Medfield, MA, USA) ACS TSH by Ciba Corning Diagnostics, reference interval 0.2–5.0 mU/l; T4 and T3 were analyzed using Competitive Immunoassay (Ciba Corning ACS T4 and T3 by Ciba Corning Diagnostics), T4 reference interval 60–140 nmol/l, and T3 reference interval 1.1–2.6 nmol/l. A detailed assay description including comparison between the four diagnostic laboratories has been given previously (14,15). Of the 1082 thyrotoxic patients in this study, 1060 were diagnosed based on a combination of suppressed serum TSH and elevated T3 and/or T4. The remaining 22 patients were diagnosed solely on the basis of TSH and free thyroid hormones.

TRAb assay

TRAb levels were measured using DYNOtest TRAK human by Brahms. TRAb was measured within a short time after thyrotoxicosis was diagnosed (median (interquartile range defined as the 25–75% range): 51 (37–79) days). TRAb measurements >1.0 IU/l were regarded as antibody positive (TRAb+) (16). Patients with diffuse and good scintigraphic uptake and no measurable TRAb were classified as TRAb-negative GD.

Additional patient information

We obtained funding to perform comprehensive investigation of patients newly diagnosed with thyrotoxicosis during the study period 1997–2000. In periods where funding was available, patients with newly diagnosed
thyrotoxicosis \((n=685)\) were invited, and 68.5\% \((n=469)\) joined a comprehensive investigation (GD, \(n=288\); MNTG, \(n=111\); STA, \(n=34\); other subtypes, \(n=36\)). This included collection of information on lifetime smoking habits, alcohol consumption, and intake of vitamin supplements and estrogens (oral contraceptives (OC) or postmenopausal hormone replacement therapy (HRT)). Patients were asked whether they had suffered from non-thyroidal diseases, and co-morbidity was defined present if they had previously suffered from acute myocardial infarction, angina pectoris, cardiac arrhythmia, hypertension, cerebral stroke, epilepsy, diabetes mellitus, asthma, chronic obstructive pulmonary disease, or gastrointestinal ulcer.

**Statistical analysis**

We used Statistical Package for Social Sciences version 15.0 (SPSS) for the calculations. Comparisons between groups were performed using Mann–Whitney \(U\) test and Kruskal–Wallis test. Multivariate linear regression analyses including hormonal status (log \(T_3\), log \(T_4\), or \(T_3/T_4\), all normally distributed) as dependent variables were performed in two models. Model A included sex, age, and region as explanatory variables and was performed in all patients diagnosed with the three most common types of thyrotoxicosis: GD \((n=484)\), MNTG \((n=405)\), and STA \((n=71)\). Model B, comprising those who attended the comprehensive investigational program and had filled out questionnaires (GD \((n=288)\), MNTG \((n=111)\), and STA \((n=34)\)), included as explanatory variables also smoking habits, alcohol consumption, intake of vitamin supplements, co-morbidity, and TRAb concentrations. In models, we excluded variables that did not meet \(P<5\%\). In multivariate regression exploring eight variables, the \(P\) value to be significant was \(<0.64\%\) (Bonferroni’s correction \((17), P=1−8/0.95\).

**Ethical approval**

This study was approved by the Regional Ethics Committee in North Jutland and Copenhagen. Registry permission was obtained from the Danish Data Protection Agency. All participants of the comprehensive investigational program gave their written informed consent. No conflicts of interest have occurred during implementation or completion of the study.

**Results**

The age and gender distributions of patients suffering from ten well-defined nosological subtypes of thyrotoxicosis are given in Table 1. Median age at diagnosis of the various types spanned from 30.7 years in women diagnosed with \textit{post partum} thyrotoxicosis up to 69.6 years in patients suffering from MNTG. Most subtypes were more common in women \((1)\).

**Table 1 Number of patients, age, and sex in ten types of thyrotoxicosis.**

<table>
<thead>
<tr>
<th>Nosological subtype of thyrotoxicosis</th>
<th>(n)</th>
<th>Age (median and IQR(^a))</th>
<th>Sex (F/M, women %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All types, combined</td>
<td>1082</td>
<td>54.2 (39.5–69.8)</td>
<td>890/192 (82.3)</td>
</tr>
<tr>
<td>GD</td>
<td>484</td>
<td>44.2 (32.8–56.5)</td>
<td>398/86 (82.2)</td>
</tr>
<tr>
<td>MNTG</td>
<td>405</td>
<td>60.6 (54.6–77.6)</td>
<td>350/55 (86.6)</td>
</tr>
<tr>
<td>STA</td>
<td>71</td>
<td>65.8 (51.9–72.4)</td>
<td>46/25 (64.8)</td>
</tr>
<tr>
<td>SAT</td>
<td>38</td>
<td>44.5 (37.7–49.5)</td>
<td>31/7 (81.6)</td>
</tr>
<tr>
<td>PPTD(^b)</td>
<td>37</td>
<td>30.7 (25.5–33.4)</td>
<td>37/0 (100)</td>
</tr>
<tr>
<td>Amiodarone-associated</td>
<td>14</td>
<td>51.6 (40.9–74.2)</td>
<td>3/1 (21.4)</td>
</tr>
<tr>
<td>Post radioiodine</td>
<td>12</td>
<td>64.0 (46.8–66.8)</td>
<td>10/2 (83.3)</td>
</tr>
<tr>
<td>Lithium associated</td>
<td>11</td>
<td>56.5 (40.2–70.7)</td>
<td>9/2 (81.8)</td>
</tr>
<tr>
<td>PT(^c)</td>
<td>9</td>
<td>44.3 (32.0–78.6)</td>
<td>0/9 (0)</td>
</tr>
<tr>
<td>Manipulation thyroiditis(^d)</td>
<td>1</td>
<td>53.5</td>
<td>1/0 (100)</td>
</tr>
</tbody>
</table>

GD, Graves’ disease; MNTG, multinodular toxic goiter; PT, painless thyroiditis; STA, solitary toxic adenoma.

\(^{a}\)Interquartile range (IQR) depicting 25 and 75\% percentiles.

\(^{b}\)First-time thyrotoxicosis within 1 year after delivery (PPTD, \textit{post partum} thyroid dysfunction).

\(^{c}\)Criteria for subtype classification were thyroid scintigraphic picture with no uptake, no signs/symptoms suggesting subacute thyroiditis (SAT), no delivery within 1 year, no contrast media given within 1 year, and no recent neck surgery.

\(^{d}\)Transient thyrotoxicosis was diagnosed 2 days after surgery for a PTH-producing adenoma.

**Serum \(T_3\) and \(T_4\) in subtypes of thyrotoxicosis**

Ordered comparison of serum \(T_3\), serum \(T_4\), and \(T_3/T_4\) ratio in each of the ten subtypes of thyrotoxicosis is depicted in Fig. 1. Serum \(T_3\) concentrations were particularly high in GD patients (Fig. 1a), whereas patients with amiodarone-associated thyrotoxicosis had the highest \(T_4\) concentrations (Fig. 1b). The highest \(T_3/T_4\) ratios were found in patients with GD, whereas a relatively low serum \(T_3/T_4\) ratio was present in manipulation thyroiditis, SAT, amiodarone-induced thyrotoxicosis, and PT (Fig. 1c).

The distributions of serum \(T_3\), serum \(T_4\), and \(T_3/T_4\) ratio in patients suffering from the three main subtypes of thyrotoxicosis (GD, MNTG, and STA) are shown in Fig. 2. Evidently, patients with Graves’ thyrotoxicosis had higher and more dispersed concentrations of serum \(T_3\) (Fig. 2a) but also of serum \(T_4\) (Fig. 2b). They also exhibited higher \(T_3/T_4\) ratios than patients suffering from MNTG and STA (Fig. 2c) but with a considerable overlap. The hormone levels in MNTG and STA were comparable.

**\(T_3\), \(T_4\), and \(T_3/T_4\) in subgroups**

The levels of \(T_3\), \(T_4\), and \(T_3/T_4\) in GD, MNTG, and STA stratified on sex, age, region of inhabitancy, smoking habits, alcohol intake, iodine-containing vitamin supplements, co-morbidity, and TRAb (positive/negative) are depicted in Table 2. Young patients had high serum \(T_3\) levels in both GD and MNTG, and \(T_3/T_4\) ratios were highest in patients aged below 60 years.
In GD, alcohol abstainers had somewhat lower T3 and T3/T4 and marginally lower T4 values. Finally, GD patients categorized as TRAb positive (91.8% of those who had TRAb measured) had higher T3 and T4 compared with those without measurable TRAb. We found no differences in hormone levels after stratification on sex, smoking habits, iodine supplementation, or comorbidity.

Notably, patients diagnosed with PPTD had somewhat higher T3/T4 ratios compared with patients with SAT or silent thyroiditis thyrotoxicosis. A putative mechanism might be that thyroglobulin contained a relatively higher T3 than T4 during the post partum period caused by worsening of iodine deficiency during pregnancy and lactation (18, 19). Another mechanism might be misclassification. Of all 1082 patients, 59 were diagnosed post partum, and 22 of these suffered from GD, leaving 37 patients with PPTD. Of those, 24 were classified with certainty to suffer from PPTD (spontaneous normalization of TSH, T3, and T4 without treatment and/or no 99-Technetium uptake on thyroid scintigraphy), whereas no information on TRAb, scintigraphy, or later thyroid function tests was available in 13 patients. However, we found no difference in T3/T4 levels between certain and possible PPTD patients (18.6 vs 20.9, P = 0.11).

At the time of diagnosis, a few patients were pregnant (GD, n = 3; MNTG, n = 1; and no STA patients), and some received OC (GD, n = 49; MNTG, n = 18; and STA, n = 9) or postmenopausal HRT (GD, n = 11; MNTG, n = 9; and STA, n = 4). As might be expected, serum T3 and T4 levels were higher in these patients. In GD, use of OC was associated with higher serum T4 levels (OC users vs non-OC users, 256 vs 202 nmol/l, P < 0.001) and higher serum T3 levels (7.20 vs 5.00, P = 0.02). However, exclusion of patients who were pregnant or received estrogens did not alter the pattern of differences between types of disease or the association with the other variables investigated.

**Determinants for hormonal levels in GD, MNTG, and STA**

In the multivariate regression analyses, we explored which variables were associated with serum T3, T4, and T3:T4 ratio. Results are embedded in Table 2, and we confirmed in the models that high age was a strong determinant for low levels of thyroid hormone (especially serum T3, but also T4) in GD, MNTG, and STA and that patients living in the region with higher iodine intake had higher biochemical degree of thyrotoxicosis. Positive TRAb was positively associated with level of serum T3 in particular, but also with serum T4, and the T3:T4 ratio.

In GD, alcohol abstainers had somewhat lower T3 and T3/T4 and marginally lower T4 values. Finally, GD patients categorized as TRAb positive (91.8% of those who had TRAb measured) had higher T3 and T4 compared with those without measurable TRAb. We found no differences in hormone levels after stratification on sex, smoking habits, iodine supplementation, or comorbidity.

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**Discussion**

Patients newly diagnosed with thyrotoxicosis present with a spectrum of biochemical abnormalities that may
depend on type of disease as well as various patient characteristics. Our study is the first to describe such diversity in a cohort of thyrotoxic patients diagnosed in a population.

**Serum T3 and T4 in subtypes of thyrotoxicosis**

Many studies have reported T3 and T4 levels in patients diagnosed with all types of thyrotoxicosis combined (20) or in a few (4, 21, 22, 23) or even up to four nosological subtypes of thyrotoxicosis (24). In this study, comparing ten nosological types of thyrotoxicosis, GD patients presented the highest T3 level and T3:T4 ratio, which is in accordance with other studies (4, 22, 23, 25). Similarly, amiodarone-associated thyrotoxicosis was dominated by high serum T4 levels as previously reported by Martino et al. (26). In general, our patients had somewhat lower serum T3 and T4 levels than in many other studies. A likely reason for this difference is the population-based nature of our study, whereas other studies have been based on patients referred from primary care (27). Other possible causes may be earlier detection of Graves’ hyperthyroidism in Denmark, differential disease classification, different iodine intake levels, or different ages of patients at onset. Low T3:T4 ratios below 20 have been reported in thyrotoxic patients suffering from SAT (25, 28) and PT (21, 25). This is confirmed in our study where we calculated mean T3:T4 ratios to be 16.0 in SAT and 15.0 in PT. In addition, we found that GD patients had higher T3 and T4 levels compared with MNTG but not among those aged 80+ years. It must be emphasized that there is a considerable overlap in serum T3 and T4 in the different subtypes both in this and in other studies (5, 25, 29). However, a serum T3 ≥ 5.0 nmol/l (approximately twice the upper reference limit) was nearly only seen in patients with GD, where 52.6% had such severe abnormality compared with only 4.0/5.2% of patients newly diagnosed with MNTG/STA.

**Determinants for hormonal levels in GD, MNTG, and STA**

Age was a strong determinant for thyroid hormone levels in patients suffering from GD, MNTG, and STA. A few studies also found lower T3 (30, 31) and T4 (30) levels among the elderly thyrotoxic patients not classified into specific subtype of disorder. Aizawa et al. (2) studying 371 GD patients and Allahabadia et al. (3) reporting on 536 GD patients also found lower T3 and T4 concentrations among elderly patients.

Several studies have reported a connection between iodine intake and the prevalence of T3 and T4 toxicosis, the former being more prevalent in iodine-deficient areas (4, 32) and the latter dominating in areas with a higher iodine intake (33). We found that T4 was higher in GD and MNTG patients diagnosed in the region with the highest iodine intake.
Table 2 Serum T3, serum T4, and molar T3:T4 ratio at the time of diagnosis in three common types of overt hyperthyroidism (GD, MNTG, and STA). Values of serum T3, serum T4, and molar T3:T4 ratio were stratified on sex, age, region, smoking status, alcohol intake, iodine supplements, co-morbidity, and TRAb.

<table>
<thead>
<tr>
<th></th>
<th>GD (n=484)</th>
<th>MNTG (n=405)</th>
<th>STA (n=71)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Serum T3 b</td>
<td>Serum T4 b</td>
<td>T3 / T4 × 10^5</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women</td>
<td>5.03 (3.73–7.38)</td>
<td>217 (177–266)</td>
<td>23.9 (20.3–29.5)</td>
</tr>
<tr>
<td>Men</td>
<td>5.02 (3.20–7.14)</td>
<td>218 (171–281)</td>
<td>24.9 (19.6–29.1)</td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–40</td>
<td>6.30 (4.29–8.70)</td>
<td>237 (193–287)</td>
<td>26.4 (22.2–32.0)</td>
</tr>
<tr>
<td>40–60</td>
<td>4.93 (3.70–6.69)</td>
<td>203 (172–254)</td>
<td>23.8 (20.4–28.9)</td>
</tr>
<tr>
<td>Above 60</td>
<td>3.95 (2.96–5.53)</td>
<td>202 (163–228)</td>
<td>23.9 (16.7–25.1)</td>
</tr>
<tr>
<td>Smoking status</td>
<td></td>
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</tr>
<tr>
<td>Current smoker</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-smoker</td>
<td>5.00 (3.80–7.20)</td>
<td>212 (174–269)</td>
<td>24.2 (20.3–29.0)</td>
</tr>
<tr>
<td>Alcohol intake</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 units/week</td>
<td>4.30 (3.33–6.35)</td>
<td>194 (168–250)</td>
<td>22.8 (19.2–26.8)</td>
</tr>
<tr>
<td>≥ 1 units/week</td>
<td>5.60 (3.90–7.44)</td>
<td>219 (174–274)</td>
<td>24.8 (21.9–29.9)</td>
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<tr>
<td>Iodine supplements</td>
<td></td>
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<tr>
<td>0 μg/day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1–149 μg/day</td>
<td>5.40 (3.87–7.78)</td>
<td>218 (181–281)</td>
<td>24.6 (20.2–30.7)</td>
</tr>
<tr>
<td>≥ 150 μg/day</td>
<td>4.93 (3.61–6.82)</td>
<td>204 (162–269)</td>
<td>23.5 (20.1–29.0)</td>
</tr>
<tr>
<td>Co-morbidity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>4.80 (3.50–7.15)</td>
<td>204 (166–251)</td>
<td>24.0 (23.0–29.0)</td>
</tr>
<tr>
<td>No</td>
<td>5.59 (3.88–7.60)</td>
<td>219 (177–276)</td>
<td>24.3 (21.8–29.4)</td>
</tr>
<tr>
<td>TRAb</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRAb + (≥ 1 kU/L)</td>
<td>5.35 (3.90–7.42)</td>
<td>212 (176–271)</td>
<td>24.4 (21.8–29.8)</td>
</tr>
<tr>
<td>TRAb –</td>
<td>2.90 (2.64–3.46)</td>
<td>156 (148–179)</td>
<td>18.8 (17.4–20.5)</td>
</tr>
</tbody>
</table>

aInformation on sex, age, and region of inhabitancy was obtained for all patients diagnosed with Graves’ disease (GD)/multinodular toxic goiter (MNTG)/solitary toxic adenoma (STA) (n=484/405/71). Information on remaining variables was obtained for those patients (GD/MNTG/STA, n=288/111/26) who attended the investigational program except for a few missing values.

bMultivariate linear regression analysis including hormonal status (log T3, log T4, or T3/T4) as dependent variables, and sex, age, region, smoking habits, alcohol consumption, intake of vitamin supplements, co-morbidity, and TRAb concentrations as explanatory variables.

cTwo regions represented moderate iodine deficiency (Aalborg; n=311 102; median urinary iodine excretion (UIE) in the population was 45 μg/l) and mild iodine deficiency (Copenhagen; n=227 632; median UIE was 61 μg/l) in people with no intake of vitamin supplements.

dSmoking status was dichotomized into current and non-current smokers. Validity of smoking status has been verified in a previous DanThyr study (8).

eAlcohol intake (units/week) of wine, beer, spirits, and liquor were added into a variable of total weekly alcohol consumption.

fInformation on vitamin supplement intake was obtained from questionnaire. No patient diagnosed with GD, MNTG, or STA received iodine-containing medication.

gCo-morbidity was defined present if patients had previously suffered from acute myocardial infarction, angina pectoris, cardiac arrhythmia, hypertension, cerebral stroke, epilepsy, diabetes mellitus, asthma, chronic obstructive pulmonary disease, or gastrointestinal ulcer.

hAll patients with MNTG and STA were TRAb negative.
This may possibly be caused by iodine being available for 
T₄ production with higher iodine intake. On the 
other hand, we found no association between iodine 
intake from vitamin supplements and the degree of 
biochemical thyrotoxicosis at disease onset. Finally, 
TRAb-negative GD patients had mild thyrotoxicosis, 
which is in accordance with most (34, 35, 36) but not 
all studies (5).

Based on our findings, two extremes of GD patients 
were identified: a group of women aged <40 years 
living in Copenhagen with only mild iodine deficiency 
and having measurable TR Ab (high T₃ group), and at 
the other end of the spectrum a group of TR Ab-negative 
patients aged ≥40 years who lived in and around 
Aalborg with moderate iodine-deficiency (low T₃ 
group). Comparison between these two groups revealed 
that the first group had 2.7 times higher serum T₃ (6.97 
vs 2.61, P < 0.001, data not shown).

**Pathophysiological mechanisms**

In euthyroid subjects, around 20% of circulating T₃ is 
secreted by the thyroid gland, whereas 80% originates 
from peripheral deiodination from T₄ (37). However, in 
several pathological states, a relatively higher fraction of 
T₃ production takes place in the thyroid gland (18). The 
mechanisms are several, including a relatively high 
T₃ content in thyroglobulin (38, 39) and especially a 
very active deiodination of T₄ to T₃ by type I 
iodothyronine deiodinase in the hyperactive thyroid 
gland (23). Moreover, enhancement of intrathyroidal 
iodine deficiency caused by the high thyroidal hormone 
production and turnover may play a role (40). High T₃ 
content of thyroglobulin (41) and high thyroidal type I 
iodothyronine deiodinase activity (23) may also be the 
major mechanisms behind the relatively high serum T₃ 
in nodular thyroid disease.

Our study gives no insight into the mechanism behind 
the severe biochemical thyrotoxicosis often observed 
among young patients. It may be speculated that the 
higher serum T₃ in young patients may arise from a more 
responsive thyroid gland to stimulation, to differences in 
metabolism of thyroid hormones, or perhaps due to the 
higher number of thyroid function tests performed among 
elderly patients consulting their general practitioner for 
unspecific complaints. In GD, Vos et al. (6) illustrated 
higher TR Ab levels in the young. We found some evidence 
for the latter explanation, as median TR Ab levels 
were 9.6, 7.5 and 6.1 IU/l among GD patients aged 
<40, 40–60 and 60+ years of age respectively 
(P = 0.038, data not shown).

The low T₃:T₄ ratios found in SAT and silent 
thyroiditis may be due to the fact that T₄ leaving the 
damaged thyroid gland escapes the thyroidal deiodi-
nases, but it may also be due to a relatively low activity 
of the deiodinases, as these enzymes are inhibited by 
interferon and interleukins (42).

**Strengths and limitations**

A major strength of this study is that all patients 
diagnosed with thyrotoxicosis in a defined population 
were included, both patients diagnosed in hospital and 
patients referred from primary care to hospital, but 
also the large fraction of patients entirely taken care of 
by the general practitioners. Most other studies were 
based on patients referred to hospital, and it may be 
difficult to compare studies, as the referral pattern may 
differ (27). This study identified patients who for some 
reason had thyroid testing performed. Thus, we missed 
patients who never had their thyroid function tested. 
A major limitation is that information on smoking 
habits, alcohol intake, iodine supplementation, use of 
estrogens, and co-morbidity was obtained only by 
questionnaires and in a limited subset of patients.

Another limitation is that we had only total T₃ and T₄ 
available, as changes in thyroid hormone binding

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![Figure 3](https://example.com/figure3.png)

**Figure 3** Age-stratified serum (a) T₃ and (b) T₄ concentrations 
in Graves' disease (GD; n=484) and nodular toxic goiter 
(multinodular toxic goiter and solitary toxic adenoma combined, 
n=405+71). Plots indicate geometric mean±SEM of total T₃ 
and T₄ concentrations. Patients diagnosed with GD compared with 
those with nodular toxic goiter: *P<0.01 and **P<0.001.
capacity may influence iodothyronine concentrations (43). Principal findings were unaltered when we excluded patients with high estrogen levels from pregnancy or estrogen intake.

We included a number of possible confounders as explanatory variables. However, cancer was not asked for in the questionnaires. Therefore, our co-morbidity index is not fully comparable with, e.g. Charlson’s co-morbidity index.

One possible determinant for hormonal levels not investigated in this study is selenium. Selenium status has been proposed to have an effect on occurrence of thyroid disease (44), and in euthyroid subjects, a low T3/T4 had strong association with low selenium among the elderly (45).

**Conclusion**

This is the first study describing the phenomenology throughout the entire spectrum of thyrotoxic entities. We found that young patients suffering from GD and MNTG had a much higher degree of biochemical thyrotoxicosis compared with the elderly patients. This may challenge the diagnostic process in elderly subjects, who may only show subtle signs and symptoms suggestive of a thyrotoxic state.

**Declaration of interest**

The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

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**Author contribution statement**

Drs P Laurberg and A Carlé had full access to all data in the study and take full responsibility for the integrity of the data and the accuracy of all analyses. P Laurberg, H Perrild, N Knudsen, L Ovesen, L B Rasmussen, I B Pedersen, and A Carlé were involved in study concept and design. A Carlé, I B Pedersen, and N Knudsen involved in acquisition of data. A Carlé, P Laurberg, N Knudsen, I B Pedersen, L Ovesen, H Perrild, and L B Rasmussen were involved in analysis and interpretation of data. A Carlé drafted the manuscript. P Laurberg, H Perrild, N Knudsen, L Ovesen, L B Rasmussen, and I B Pedersen performed critical revision of the manuscript for important intellectual content and final approval. Statistical analyses were performed by A Carlé and P Laurberg. A Carlé, P Laurberg, H Perrild, N Knudsen, L Ovesen, L B Rasmussen, and I B Pedersen obtained funding.

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