Peripheral markers of thyroid function: the effect of T4 monotherapy vs T4/T3 combination therapy in hypothyroid subjects in a randomized crossover study

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Abstract

Background: A recent randomized controlled trial suggests that hypothyroid subjects may find levothyroxine (L-T4) and levotriiodothyronine combination therapy to be superior to L-T4 monotherapy in terms of quality of life, suggesting that the brain registered increased T3 availability during the combination therapy.

Hypothesis: Peripheral tissue might also be stimulated during T4/T3 combination therapy compared with T4 monotherapy.

Methods: Serum levels of sex hormone-binding globulin (SHBG), pro-collagen-1-N-terminal peptide (PINP), and N-terminal pro-brain natriuretic peptide (NT-proBNP) (representing hepatocyte, osteoblast, and cardiomyocyte stimulation respectively) were measured in 26 hypothyroid subjects in a double-blind, randomized, crossover trial, which compared the replacement therapy with T4/T3 in combination (50 μg T4 was substituted with 20 μg T3) to T4 alone (once daily regimens). This was performed to obtain unaltered serum TSH levels during the trial and between the two treatment groups. Blood sampling was performed 24 h after the last intake of thyroid hormone medication.

Results: TSH remained unaltered between the groups ((median) 0.83 vs 1.18 mU/l in T4/T3 combination and T4 monotherapy respectively; \( P = 0.534 \)). SHBG increased from (median) 75 nmol/l at baseline to 83 nmol/l in the T4/T3 group \( (P = 0.015) \) but remained unaltered in the T4 group (67 nmol/l); thus, it was higher in the T4/T3 vs T4 group \( (P = 0.041) \). PINP levels were higher in the T4/T3 therapy (48 vs 40 μg/l \( (P < 0.001) \)). NT-proBNP did not differ between the groups.

Conclusions: T4/T3 combination therapy in hypothyroidism seems to have more metabolic effects than the T4 monotherapy.

Key Words
- Thyroid hormones
- substitution
- extrathyroid effects
Introduction

Triiodothyronine ($T_3$) is regarded as the main metabolic active thyroid hormone. Available intracellular $T_3$ is dependent on the transport of $T_3$ from circulation as well as intracellular deiodination of thyroxine ($T_4$) (1). In healthy euthyroid subjects, $\sim 20\%$ of $T_3$ is derived from thyroidal secretion and the remaining from local production (2). By contrast, hypothyroid subjects substituted with levothyroxine ($L-T_4$) monotherapy demonstrated higher plasma $T_4/T_3$ ratio due to lack of thyroidal secretion of $T_3$ (3). This might implicate different thyroid hormone actions at the cellular level in healthy euthyroid subjects compared with $T_4$-substituted hypothyroid patients. In animal studies, $T_4$ replacement therapy does not seem to result in adequate $T_3$ concentrations in all tissues when compared with those obtained during $T_4/T_3$ combination therapy (4, 5).

Many studies have compared the effect of conventional $T_4$ monotherapy to $T_4/T_3$ combination therapy in substituted hypothyroid subjects and have concluded that $T_4/T_3$ combination therapy is not beneficial (6). However, several of these studies have compared them without obtaining similar levels of serum TSH (7, 8). In a recent double-blind, randomized crossover trial, we compared the effect of two regimens in patients with hypothyroidism with the intention of keeping TSH stable and comparable within the two treatment groups (7). We found that $T_4/T_3$ combination therapy is superior to $T_4$ monotherapy with respect to quality of life (QOL), depression and anxiety rating scales, and the patients’ own preference. Our results indicate that peripheral extrapituitary tissues can register the addition of $T_3$ to the own preference. Our results indicate that peripheral extrapituitary tissues can register the addition of $T_3$ to the

We consequently questioned whether peripheral tissues react differently to $T_4/T_3$ combination therapy than to conventional $T_4$ monotherapy. Thus, markers of peripheral tissue function, which are known to be sensitive to changes in thyroid function, were studied (10, 11, 12, 13). The markers include sex hormone-binding globulin (SHBG) representing liver function, N-terminal pro-brain natriuretic peptide (NT-proBNP) representing cardiac function, and pro-collagen-1-N-terminal peptide (PINP) representing collagen production during bone formation.

Materials and methods

Subjects

This study has been described in detail previously (7). Briefly, the design was a double-blind, randomized, crossover study using block-randomization. In the first 12 weeks, 50 μg of the usual $T_4$ dose was replaced with either 20 μg $T_3$ or 50 μg $T_4$ (tablets were identical), followed by a crossover for another 12 weeks. Due to the short half-life period of $T_3$ and the risk of precipitating overt hypothyroidism, no washout period was included. The $T_4$ dose was regulated if needed to withhold steady serum TSH levels. All patients were treated in each arm for exactly 12 weeks.

Inclusion criteria of the patients are i) overt, spontaneous hypothyroidism with serum TSH levels $> 20$ mU/l, serum $T_4 < 60$ nmol/l, and positive thyroid peroxidase antibodies ($> 60$ U/ml) at the time of diagnosis; ii) euthyroidism at the time of screening, including unaltered $T_4$ substitution for at least 6 months; and iii) age between 18 and 76 years. Exclusion criteria are i) pregnancy or planning pregnancy, ii) patients with any other chronic disease, iii) any previous $T_3$ treatment, iv) active post partum thyroiditis, and v) hypothyroidism due to surgery or radioiodine treatment.

Patients included in this study were recruited from the same center, and blood samples were collected in the fasting state and before the intake of medicine (i.e. 24 h after the last intake of medication) at baseline, at crossover, and at the end of the study. Samples were frozen immediately at $-80$ °C. Twenty-six patients participated in the study and their characteristics are given in Table 1. Euthyroidism had been obtained for 24 months (6–100). Fourteen started on $T_4/T_3$ combination and 12 on $T_4$ monotherapy, followed by a crossover after 3 months. The study was approved by the local ethics committee, and the study was registered in www.clinicaltrials.gov (2007-09-18, Study ID: T4-T3 hypothyroidism).

Biochemical parameters

SHBG was measured by ELISA (DRG, International, Inc., Springfield, NJ, USA) (intra-assay coefficient of variation (CV): 5%), NT-proBNP was measured by a chemiluminescence enzyme immunoassay (Innolite 2500) (intra-assay CV < 5%), PINP was measured by RIA (Orion Diagnostica, Espoo, Finland) (intra-assay CV 8%), and thyroid function parameters were measured by chemiluminescence enzyme immunoassays (Innolite 2500), and intra-assay CV were TSH: 5%; $T_3$: 7%; $T_4$: 5%; $T_3$-
uptake: 4%. Free T₄ and T₃ indices (FT₄I and FT₃I) were calculated by multiplying the total hormone concentration with the T₃ uptake test.

Statistical analyses

Non-parametrical statistical analyses, such as Friedman repeated measures ANOVA on ranks (Friedman test) and Wilcoxon test, were used. The significance level was 0.05.

Results

TSH levels neither changed over time (baseline vs treatment: T₄/T₃ combination: \(P=0.101\); T₄ monotherapy: \(P=0.322\)) nor between groups (\(P=0.534\)) (Table 2). Individual TSH levels are presented in Fig. 1. The ratio FT₄I/FT₃I was calculated and was found to be similar before randomization (in median 80) and after T₄ monotherapy (78), whereas the ratio decreased remarkably (29) during combination therapy reflecting both decreasing FT₄I and increasing FT₃I.

SHBG levels were different between groups testing for trends (\(P=0.011\)) due to significant higher SHBG in the T₄/T₃ combination group. Similarly, PINP levels also differed between groups (\(P=0.001\)) due to its higher level in the T₄/T₃ combination group. NT-proBNP levels were not affected by the different treatment regimens.

Table 1 Clinical characteristics of the 26 l-T₄ substituted hypothyroid subjects participating in the study (values are presented as median (range))

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>T₄ monotherapy</th>
<th>T₄/T₃ combination therapy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (females/males)</td>
<td>23/3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>42.5 (19–69)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.8 (18–38)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre/postmenopausal status</td>
<td>15/8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T₄ dose (μg/day)</td>
<td>132 (50–200)</td>
<td>125 (75–225)</td>
<td>75 (25–75)</td>
</tr>
<tr>
<td>T₃ dose (μg/day)</td>
<td>–</td>
<td>–</td>
<td>20 (20–20)</td>
</tr>
</tbody>
</table>

Table 2 Thyroid hormone levels and peripheral markers of thyroid function in 26 l-T₄-substituted hypothyroid subjects, treated with either T₄/T₃ combination of T₄ monotherapy for 3 months in a prospective, randomized, crossover design (median (range))

<table>
<thead>
<tr>
<th></th>
<th>Before randomization (1)</th>
<th>T₄ monotherapy (2)</th>
<th>T₄/T₃ combination therapy (3)</th>
<th>Analysis for trend P value (Friedman test)</th>
<th>Paired test between groups (Wilcoxon test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSH (mU/l)</td>
<td>1.13 (0.13–5.67)</td>
<td>1.18 (0.01–3.08)</td>
<td>0.83 (0.02–7.93)</td>
<td>1 vs 2: (P=0.322)</td>
<td>1 vs 2: (P=0.101)</td>
</tr>
<tr>
<td>FT₄I (units)</td>
<td>133 (46–168)</td>
<td>139 (64–200)</td>
<td>80 (32–191)</td>
<td>(&lt;0.001)</td>
<td>1 vs 3: (P &lt; 0.001)</td>
</tr>
<tr>
<td>FT₃I (units)</td>
<td>1.56 (1.03–3.28)</td>
<td>1.71 (1.20–4.40)</td>
<td>2.71 (0.95–5.20)</td>
<td>(&lt;0.001)</td>
<td>2 vs 3: (P &lt; 0.001)</td>
</tr>
<tr>
<td>Ratio FT₄I/FT₃I</td>
<td>80 (45–125)</td>
<td>78 (33–124)</td>
<td>29 (9–162)</td>
<td>(&lt;0.001)</td>
<td>2 vs 3: (P &lt; 0.001)</td>
</tr>
<tr>
<td>SHBG (nmol/l)</td>
<td>74.5 (18–254)</td>
<td>66.5 (19–260)</td>
<td>82.5 (23–260)</td>
<td>0.011</td>
<td>1 vs 3: (P=0.015)</td>
</tr>
<tr>
<td>NT-proBNP (ng/l)</td>
<td>63.5 (20–156)</td>
<td>55.5 (20–257)</td>
<td>56.5 (23–241)</td>
<td>0.446</td>
<td>2 vs 3: (P=0.041)</td>
</tr>
<tr>
<td>PINP (μg/l)</td>
<td>37.8 (8.1–193)</td>
<td>40.4 (8.5–88.9)</td>
<td>48.1 (13.6–171)</td>
<td>0.001</td>
<td>2 vs 3: (P &lt; 0.001)</td>
</tr>
</tbody>
</table>

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The availability of active thyroid hormones (mainly, T₃) is a complex process. These hormones reach tissues via circulation, active transmembrane transport, intracellular regulatory metabolism, through three active deiodinases: types 1- and 2-deiodinase activate T₄ into T₃ and type 3-deiodinase inactivate T₃, and finally, by binding to specific thyroid hormone nuclear receptors (1). Different tissues have different metabolic pathways, making it difficult to quantify the actual effect of the total thyroid hormones on a specific tissue at a given time (1).

In this study, we aimed to examine whether T₄/T₃ combination therapy vs conventional T₄ monotherapy resulted in a change in the sensing of the local thyroid hormone action on different peripheral tissues. We measured SHBG, PINP, and NT-proBNP as all these markers have been shown to be sensitive parameters of changes in peripheral thyroid hormone action. SHBG levels reflected stimulation of hepatic function (11), PINP levels reflected a stimulation of collagen production during bone formation (12), and NT-proBNP levels reflected the direct stimulation of cardiomyocytes (13, 14).

Our data demonstrated that both SHBG and PINP increased when the patients received T₄/T₃ combination therapy compared with standard treatment with T₄ monotherapy. However, NT-proBNP levels did not change. Thus, treatment with either of the therapies in presumably equipotent doses with respect to pituitary sensing as measured by circulating TSH levels, indeed, seems to result in different sensing of thyroid hormone action at the peripheral tissue level and in different tissues, such as hepatocytes and osteoblasts. This suggests that the two regimens have more widespread differences in intracellular thyroid hormone availability.

Understanding our findings might be related to T₃ kinetics and T₃ formulations used. T₃ was given at a standard dose of 20 μg once daily in the morning. Blood samples were drawn in the morning and before the intake of the thyroid hormone, which gives ~24-h abstinence from medicine. The short half-life time (10–15 h) of T₃ compared with T₄ (~5 days) results in relative over-exposure of T₃ in the T₄/T₃ group vs the T₄ only group during the early hours of absorption, and consequently, relative underexposure in the next morning when the blood sampling was performed. Although not precisely known, the plasma half-life time of especially PINP and SHBG are considerably longer than that of TSH (days vs minutes). This means that increased levels of PINP and SHBG might be due to a previous period of overexposure of T₃ in peripheral tissues, including the absorption period. The latter probably has less effect on serum TSH as measured the next morning, which was not clarified by this study design. Our data on mental health, which was published previously, demonstrated a long-lasting beneficial effect of T₄/T₃ combination therapy with respect to QOL, depression, and anxiety rating scales (7). We might have unknowingly overtreated the patients for a short period during the T₃ absorption phase, but the data on mental health point to a beneficial effect of combination therapy. Thus, the optimal replacement regimen would be to divide the dose, give a slow release preparation, or prescribe T₃ in a dose, resulting in a fixed ratio of the actual T₄ dose.

In a recent randomized, double-blind, crossover trial, hypothyroid subjects on stable T₄ replacement therapy were switched to either T₄ or T₃ monotherapy, both given as thrice daily regimens in order to reduce excursions in T₄ and T₃ serum levels (15). Serum thyroid hormone levels were measured every 4 h. Even on a thrice daily regimen, serum T₃ levels fluctuated showing individual levels above the normal range especially in the absorption periods, although mean values remained within the normal range. Thyroid hormone doses were regulated by keeping serum TSH levels similar in the two groups. The study demonstrated a distinct metabolic effect during T₃ replacement, which was not seen during T₄ replacement. It indicated
a significant weight loss and a reduction in total and LDL cholesterol, shortened isovolumic relaxation time of the heart, and increased serum SHBG concentrations. Thus, these data also demonstrated a differential effect of T3 vs T4 on SHBG levels. At a glance, these data suggest a beneficial effect of T3. However, the data might also be interpreted as a result of slightly overtreatment of the subjects with T3 during periods of T3 absorption.

A previous study demonstrated that hypothyroid subjects on stable T4 monotherapy had lower SHBG levels than controls with similar TSH levels, and the authors hypothesized that T3 availability was reduced in the hypothyroid group as expressed by a high T4/T3 ratio in plasma (16). Similarly, treatment with 20 μg T3 once daily to euthyroid, obese subjects resulted in unaltered and normal TSH levels but an increase in serum SHBG levels (17).

Whether increased SHBG levels represent a metabolically beneficial process is not clear; however, reduced SHBG levels are associated with insulin resistance and obesity (18). In a recent study on healthy women, SHBG was suggested as a causal role of developing type 2 diabetes: the lower the levels, the higher the risk (19).

PINP levels reflect collagen production during bone formation and have been previously shown to be elevated in hyperthyroid subjects (20). Treating nontoxic goiter patients with small doses of T4 or T3 as a once daily regimen for a similar and a modest reduction in TSH levels without inducing overt hyperthyroidism resulted in increased PINP levels (12). This is in agreement with the well-known enhanced bone turnover in subclinical hyperthyroidism, both exogenous (due to T4 treatment) and endogenous (21). However, no difference was found in the PINP levels of patients on T4 vs T3 monotherapy (12). It is not clear whether our findings are beneficial to bone health. Osteoblast stimulation, as evidenced by increased PINP levels, leads to increased bone formation, but also bone degradation as a secondary event, which is evident after a few months of bone stimulation (22). This is independent of menopausal status. We had measured PINP after 3 months of treatment. Therefore, bone turnover might have been stimulated at that time, which might be regarded as an adverse effect to T3 substitution leading to bone loss, although reversible after cessation of the T3 treatment (22). Thus, increased PINP levels seen after T4/T3 combination might reflect a subtle and beneficial increase in bone formation or an adverse effect on bone tissue due to increased bone turnover.

The production of NT-proBNP seems to be stimulated mainly by T3 in a dose-dependent manner (14). Serum NT-proBNP levels are elevated in subclinical hyperthyroidism and reduced in subclinical hypothyroidism, both normalizing when treated to obtain normal serum TSH levels (13). Thus, its secretion seems sensitive to small changes in thyroid hormone availability. Stimulation of NT-proBNP (and BNP being secreted in equipotent amounts to NT-proBNP) production is probably beneficial since BNP results in reduced cardiac after load due to vasodilatation. However, we could not find any difference between the two treatment regimens in this study.

Our main message, as discussed earlier, is that adding T3 to a thyroid hormone substitution regimen seems to result in a different pattern in the thyrometabolic status of different tissues compared with the traditional T4 monotherapy regimen. Clearly, further studies are needed in order to elucidate the potential long-term effect of T3 treatment either as monotherapy or in combination with T4.

Limitations: the number of subjects studied was relatively small, which, however, was counteracted by the study design. It was difficult to keep serum TSH stable, which is a known problem in the daily clinical work-up on T4-treated subjects. This meant that although mean TSH levels were kept unchanged during the two study periods, a few patients had TSH levels outside the normal range (Fig. 1). Whether this affected our results is not clear; however, we decided to include these subjects in the statistical analyses.

No washout period was inserted between the two dosing regimens as it would develop overt hyperthyroidism during this period, which would probably affect the results. In our main study, presented in 2009 (7), an analysis on the QOL and depression scores between the two treatment periods did not disclose any carryover effect.

Conclusion

Despite similar TSH levels, several peripheral tissues seem to register different T3 availability during T4/T3 combination substitution to hypothyroid subjects. Both hepatic function and collagen production during bone formation seem to be stimulated. Our study, as well as other recent studies, encourages the development of prolonged T3 formulations and testing in the clinical setting. However, the benefits of our findings are still unclear.

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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