Relationship between serum TSH levels and intrarenal hemodynamic parameters in euthyroid subjects

Akihiro Tsuda1,2, Masaaki Inaba1,2, Mitsuru Ichii1,2, Akinobu Ochi1,2, Yoshiteru Ohno1,2, Shinya Nakatani1,2, Shinsuke Yamada1,2, Katsuhito Mori1,2, Hideki Tahara1,2 and Eiji Ishimura1,2

Departments of 1Nephrology and 2Metabolism, Endocrinology and Molecular Medicine, Osaka City University Graduate School of Medicine, 1-4-3, Asahi-machi, Abeno-ku, Osaka 545-8585, Japan

(Correspondence should be addressed to A Tsuda; Email: naranotsudasu@infoseek.jp)

Abstract

Objective: Low thyroid function may be associated with a reduced glomerular filtration rate (GFR) calculated on the basis of creatinine metabolism. Thyroid hormone directly affects serum creatinine in muscle and low thyroid function might exert a similar direct effect in the kidney. The goal of the study was to evaluate this possibility by assessment of the inulin-based GFR and to examine the mechanism underlying the reduction of GFR.

Patients and methods: Renal and glomerular hemodynamics were assessed by simultaneous measurements of plasma clearance of para-aminohippurate (CPAH) and inulin (Cin) in 26 patients with serum creatinine <1.00 mg/dl and without thyroid disease. All subjects were normotensive with or without antihypertensive treatment and were kept in a sodium-replete state. Renal and glomerular hemodynamics were calculated using Gomez's formulae.

Results: Serum TSH, including within the normal range (0.69–4.30 mIU/ml), was positively correlated with vascular resistance at the afferent arteriole (Ra) (r = 0.609, P = 0.0010), but not at the efferent arteriole (Re). Serum TSH was significantly and negatively correlated with renal plasma flow (RPF), renal blood flow (RBF), and GFR (r = −0.456, P = 0.0192; r = −0.438, P = 0.0252; r = −0.505, P = 0.0086 respectively). In multiple regression analysis, serum TSH was significantly positively associated with Ra after adjustment for age and mean blood pressure.

Conclusions: These findings suggest that low thyroid function, even within the normal range, is associated with reduced RPF, RBF, and GFR, which might be caused by a preferential increase in Ra.

Introduction

Clinically overt and subclinical hypothyroidism is associated with a high rate of chronic kidney disease (CKD) (1, 2, 3, 4, 5, 6, 7) and is an established cardiovascular risk factor (1). Subclinical hypothyroidism occurs in 5–15% of the general population and is highly prevalent in women over 60 years of age (1, 2). We have found that patients with this condition have a significantly increased pulse wave velocity (PWV) (8), which suggests that subclinical hypothyroidism is a significant and independent cardiovascular risk factor (4), although the mechanism is uncertain. As these patients become older, the prevalence of CKD, a definite cardiovascular risk factor, increases along with an age-related increase in serum TSH levels (9).

A high serum TSH, even within its reference range, was recently found to be associated with a reduced glomerular filtration rate (GFR) calculated from formulae based on creatinine levels in serum and urine (6). Alteration in thyroid function affects muscle metabolism and may influence the creatinine-based GFR, independently of its effect on the kidney, through an effect on metabolism of creatinine, which preferentially localizes in type II fibers in the muscle (10). Therefore, high serum TSH, even within the normal range, might directly suppress renal function and contribute to acceleration of atherosclerotic changes in subclinical hypothyroidism.

In this study, we examined the relationship of subtle changes in serum TSH within the normal range with inulin clearance (Cin), which is normally used for measurement of GFR. To examine the mechanism through which high serum TSH might reduce GFR, we simultaneously measured para-aminohippurate (PAH) clearance (CPAH).

Patients and methods

Study design and patients

The study protocol was approved by the Ethics Committee of Osaka City University Graduate School of Medicine. The study was performed as a single-center
study at Osaka City University Hospital between January 2010 and August 2011. Written informed consent was obtained from each patient.

The subjects were 26 patients (55.4 ± 14.7 years old, 8 males and 18 females) who were admitted to Osaka City University Hospital for a medical checkup. Of these patients, 21 had diabetes, but none exhibited macroalbuminuria and all had a serum creatinine level <1.00 mg/dl. The mean serum TSH level was 1.720 ± 0.885 mU/ml and all patients were within the normal range of 0.69–4.30 mU/ml. Serum-free thyroxine (FT4) and free triiodothyronine (FT3) levels were also within the respective normal limits of 1.20 ± 0.182 ng/dl and 2.92 ± 0.38 pg/ml.

**Measurement of Cin and CPAH and calculation of intrarenal hemodynamic parameters**

Renal plasma flow (RPF) and GFR were determined by the constant input clearance technique using PAH and inulin respectively. As shown in Fig. 1, continuous i.v. infusion of 1% inulin and 0.5% PAH from the antecubital vein was performed in the morning after an overnight fast, based on the method of Horio et al. (11). Cin and CPAH were simultaneously measured using a simple method based on a single urine collection. In brief, patients received 500 ml water orally 15 min before infusion. After a priming dose of PAH and inulin, the rates of infusion were set at 300 ml/h for the first 30 min and 100 ml/min for the remaining time. To maintain hydration, 180 ml water was given. Patients completely emptied the bladder at 45 min after the start of the test and urine was collected for measurement of urinary inulin and PAH. The urine collection period was set at 90 min to increase the accuracy of the clearance study. Blood samples for measurement of serum inulin and PAH were taken at the beginning and end of the clearance period.

Cin and CPAH were calculated by the UV/P method (U, concentration in urine; V, urine volume (ml/min); P, concentration in plasma) using the mean of the serum inulin concentrations at the beginning and end of the clearance period. Plasma PAH and inulin concentrations were determined colorimetrically using the N-1 naphthylethylenediamine and anthrone method respectively, with a Corning 258 spectrophotometer (4, 12, 13). The clearance values were not corrected for body surface area, partly because Turner & Reilly (14) have shown that adjusting renal hemodynamic variables for body surface may lead to inappropriate inferences and obscure gender-related differences.

Direct measurement of glomerular hemodynamics in humans is not feasible, but formulae introduced by Gomez (15) (Table 1) allow indirect assessment of glomerular hemodynamics, as recently discussed in detail by Guidi et al. (16). These formulae were designed for quantitative estimation of filtration pressure across the glomerular capillaries (ΔPg), glomerular hydrostatic pressure (P glo), and afferent and efferent glomerular resistances (Ra and Re respectively) using measured blood pressure, GFR measured by Cin, RPF measured by CPAH, hematocrit, and plasma protein concentrations under the assumptions that: i) intrarenal vascular resistances can be divided into three compartments: afferent, efferent, and venular; ii) hydrostatic pressures in the venules, interstitium, renal tubules, and Bowman’s space (P Bow) are in equilibrium at a value of ~ 10 mmHg; iii) the gross filtration coefficient (KGF) is 0.0406 ml/s per mmHg per kidney; and iv) a filtration disequilibrium is postulated along the glomerular capillaries (15, 16).

From Ohm’s law:

\[ R_a = ((MBP - P_{glo})/RBF) \times 1328. \]

\[ R_e = (GFR/K_{FG} \times (RBF - GFR)) \times 1328. \]

In these equations, 1328 is the conversion factor to dyne/s per cm² and GFR, RPF, and renal blood flow (RBF) are expressed in ml/s.

**Statistical analysis**

Results are expressed as means ± s.d. Correlations between two variables were examined using Spearman’s correlation coefficient. Multiple regression analyses
indicating thyroid disease, such as diffuse goiter, and a significant negative relationship between patients treated with a renin–angiotensin–aldosterone (RAS) system inhibitor and those who did not receive a RAS inhibitor (6406.8 ± 4540.9 vs 5572.2 ± 3592.6, P = 0.6080).

**Table 2** Clinical characteristics of patients.

<table>
<thead>
<tr>
<th>Item</th>
<th>Value (mean ± s.d.)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>59.5 ± 14.0</td>
<td>22–78</td>
</tr>
<tr>
<td>Gender (m/f)</td>
<td>8/18</td>
<td></td>
</tr>
<tr>
<td>Type 2 diabetes mellitus (yes/no)</td>
<td>21/5</td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>26.2 ± 4.5</td>
<td>18.3–35.0</td>
</tr>
<tr>
<td>Mean blood pressure (mmHg)</td>
<td>90.5 ± 10.7</td>
<td>71.3–119.3</td>
</tr>
<tr>
<td>Systolic blood pressure (mmHg)</td>
<td>127.1 ± 16.7</td>
<td>98–162</td>
</tr>
<tr>
<td>Diastolic blood pressure (mmHg)</td>
<td>72.2 ± 0.9</td>
<td>54–100</td>
</tr>
<tr>
<td>Serum creatinine (mg/dl)</td>
<td>0.692 ± 0.174</td>
<td>0.4–0.98</td>
</tr>
<tr>
<td>Blood urea nitrogen (mg/dl)</td>
<td>14.7 ± 2.8</td>
<td>9.0–21.0</td>
</tr>
<tr>
<td>Insulin clearance (ml/min)</td>
<td>72.7 ± 18.3</td>
<td>24.7–106.8</td>
</tr>
<tr>
<td>PAH clearance (ml/min)</td>
<td>362.6 ± 145.2</td>
<td>131–842</td>
</tr>
<tr>
<td>Albumin (g/dl)</td>
<td>4.1 ± 0.4</td>
<td>3.0–4.7</td>
</tr>
<tr>
<td>Plasma glucose (mg/dl)</td>
<td>122.6 ± 34.2</td>
<td>570–185.0</td>
</tr>
<tr>
<td>HbA1c (%)</td>
<td>7.6 ± 1.6</td>
<td>4.8–10.5</td>
</tr>
<tr>
<td>TSH (μU/ml)</td>
<td>1.720 ± 0.885</td>
<td>0.69–4.30</td>
</tr>
<tr>
<td>FT4 (pg/ml)</td>
<td>2.924 ± 0.376</td>
<td>2.3–3.91</td>
</tr>
<tr>
<td>FT3 (ng/dl)</td>
<td>1.200 ± 0.182</td>
<td>0.37–1.6</td>
</tr>
</tbody>
</table>

PAH, para-aminohippurate.

**Results**

**Baseline characteristics**

Baseline characteristics of the 26 patients are shown in Table 2. The mean age was 59.5 ± 14.0 years old and eight patients (30.8%) were male. The mean levels of serum creatinine and blood urea nitrogen (BUN) were 0.692 ± 0.174 and 14.7 ± 2.8 mg/dl respectively and GFR estimated from C\text{in} was 72.7 ± 18.3 ml/min. The mean blood pressure was normal (90.5 ± 10.7 mmHg), but 12 patients (46%) were receiving antihypertensive therapy with an angiotensin receptor blocker (n = 11), angiotensin converting enzyme (ACE) inhibitor (n = 3), or a calcium channel blocker (n = 5). The plasma glucose and HbA1C values were 122.6 ± 34.2 mg/dl and 7.6 ± 1.6% respectively with 21 patients diagnosed with type 2 diabetes mellitus (DM) based on the history of diabetes or on criteria in the Report of the Expert Committee on the Diagnosis and Classification of Diabetes Mellitus. There was no significant difference in GFR between patients with and without type 2 DM (DM vs non-DM: 70.9 ± 19.0 vs 80.1 ± 13.5 ml/min, P = 0.3203). All subjects had no physical findings indicating thyroid disease, such as diffuse goiter, and the serum levels of FT4, FT3, and TSH were within the respective normal ranges of 1.200 ± 0.182 ng/ml, 2.924 ± 0.376 pg/ml, and 1.720 ± 0.885 μU/ml.

**Relationship of serum FT4, FT3, and TSH with R\text{a}, R\text{e}, and glomerular hemodynamics**

Serum TSH, even within its normal range, showed a significant positive correlation with R\text{a} (r = 0.609, P = 0.0010), but no correlation with R\text{e} (r = 0.013, P = 0.9494) (Fig. 1), and had significant negative correlations with C\text{in}-based GFR (r = −0.505, P = 0.0086), RPF (r = −0.456, P = 0.0192), and RBF (r = −0.438, P = 0.0252) (Fig. 2). An age-related increase in serum TSH has been reported (17), but we found no significant correlation between age and R\text{a} (r = 0.259, P = 0.2015) or R\text{e} (r = 0.311, P = 0.0647). Collectively, these data suggest that a subtle change in serum TSH, even within its normal range might suppress glomerular hemodynamics, particularly by increasing vascular resistance at afferent arterioles, independent of age. Neither FT4 nor FT3 showed a significant relationship with R\text{a}, R\text{e}, C\text{in}-based GFR, RPF, or RBF (data not shown).

**Association of TSH with renal hemodynamics**

Mean blood pressure was significantly positively correlated with R\text{a} (r = 0.422, P = 0.0319), but not with R\text{e} (r = 0.043, P = 0.8361) (Fig. 3), suggesting that an increase in blood pressure might cause an increase in R\text{a}, but not in R\text{e} (15, 16). Mean blood pressure did not correlate significantly with RPF (r = 0.057, P = 0.7812) or RBF (r = 0.105, P = 0.6098), or with serum FT4 (r = 0.207, P = 0.3106), FT3 (r = 0.194, P = 0.4004), or TSH (r = 0.064, P = 0.7648). There was no significant difference in R\text{a} between patients treated with a renin–angiotensin–aldosterone (RAS) system inhibitor and those who did not receive a RAS inhibitor (6406.8 ± 4540.9 vs 5572.2 ± 3592.6, P = 0.6080).

\[
\text{FF} = \frac{\text{GFR}}{\text{RPF}} \times (\text{MPF} - \text{P}_{\text{out}}) \times 1328
\]

\[
\text{R}_{\text{a}} = \frac{\text{GFR} \times (\text{K}_{\text{f}} \times \text{RPF})}{\text{GFR} \times (\text{GFR} + \text{K}_{\text{f}}) \times 1328}
\]

\[
\Delta P_{\text{f}} = \Delta P_{\text{f}} - \Delta P_{\text{out}} + \pi \text{G}
\]

\[
\Delta P_{\text{f}} = \frac{\text{GFR} \times \text{K}_{\text{f}}}{\text{GFR}}
\]

\[
\pi \text{G} = 5 \times (\text{CM} - 2)
\]

\[
\text{CM} = \frac{\text{TP} \times (1 + \pi \text{G})}{\text{FF} \times (1/\text{FF})}
\]

GFR, glomerular filtration rate (ml/min); RPF, renal plasma flow (ml/min); MPF, mean perfusion pressure; P_{\text{out}}, arterial (arteriolar) resistance (dyne s/cm²); R_{\text{a}}, afferent (arteriolar) resistance (dyne s/cm²); MBF, mean blood flow calculated as (2 \times \text{diastolic BP} + \text{systolic BP})/3; K_{\text{f}}, gross filtration coefficient (s/mmHg); R_{\text{in}}, glomerular hydrostatic pressure (mmHg); ΔP_{\text{f}}, filtration pressure across the glomerular capillaries (mmHg); R_{\text{Bow}}, hydrostatic pressure in Bowman’s space (10 mmHg); G, oncotic pressure within glomerular capillaries (mmHg); CM, plasma protein concentration within the glomerular capillaries (g/dl); TP, total protein concentration (g/dl).
Multiple regression analysis of factors independently associated with $R_a$ and $R_e$

The results of multiple regression analysis to identify factors significantly associated with $R_a$ and $R_e$ are shown in Table 3. In models including serum TSH, age, and mean blood pressure as independent variables, serum TSH alone emerged as a significant factor with a positive association with $R_a$ but had no association with $R_e$.

Discussion

In this study, we clearly demonstrated that the high serum TSH, even within normal range, as reflected by a subtle increase in TSH within its normal range, was significantly correlated with reduction of GFR, RPF, and RBF, estimated from $C_{in}$ and $C_{PAH}$. Our results may indicate a possible direct effect of TSH on the kidney, as it has been reported that TSH receptor is also expressed in a variety of extrathyroidal tissues including the kidney (18). Our results may be consistent with the report by Sun et al. (19), who demonstrated that TSH is an independent factor for determining renal function and CKD in normoglycemic euthyroid adults. The underlying mechanism of our results may involve increased vascular resistance at afferent arterioles, based on the significant and independent association of high serum TSH with increased $R_a$, independent of age and mean blood pressure, but not with $R_e$. The parameters for renal hemodynamics were calculated from $C_{in}$ and $C_{PAH}$ which are independent of creatinine metabolism. Therefore, this shows that the effect of low thyroid function on creatinine metabolism in muscle and the resultant changes of serum and urinary creatinine levels are not responsible for low GFR in patients with low normal thyroid function. Causality is not conclusively determined, but it is likely that low thyroid function may reduce GFR, RPF, and RBF by increasing $R_a$, as it has been shown that T4 replacement therapy increases GFR in hypothyroid patients (20) and that treatment of Graves’ patients with anti-thyroid drugs decreases GFR (21). Our study may also be consistent with the results that TSH positively correlated with creatinine in hypothyroid subjects (22). Low cardiac output may also be associated with decreased RBF in hypothyroidism (23).

We have previously reported a significant increase in arterial wall stiffening, as represented by an increase in PWV, in patients with subclinical hypothyroidism (24) and clinically overt hypothyroidism (25). As the current study raised the possibility that CKD might develop due to low thyroid function, it is possible that development of CKD in patients with low thyroid function (but within the normal range) might be an early event that accelerates atherosclerotic changes, which develop no earlier than subclinical hypothyroidism (26). Therefore,
CKD due to low thyroid function may contribute to development of atherosclerotic changes in subclinical hypothyroidism.

In humans, it is not possible to measure glomerular hemodynamic variables directly; thus, the evidence for this pathogenetic mechanism is indirect and is based mainly on therapeutic interventions that are believed to lower glomerular pressure and filtration, such as a low-protein diet or ACE inhibitors (27). However, in 1951, Gomez (15) published a series of formulae for indirect evaluation of glomerular hemodynamics in humans. These formulae (slightly modified for animal studies) have been used to calculate glomerular hemodynamics in various conditions, including untreated and treated essential hypertension (15, 28), rat models of hypertension (28), renovascular hypertension (29), primary aldosteronism (30), and supraventricular tachycardia (31). In this study, on the basis of these formulae, we found that reduced GFR, RPF, and RBF mainly result from increased vascular resistance at afferent arterioles, as reflected by increased $R_a$.

This study has some limitations. First, the study was performed in a small number of Japanese patients, and a large-scale study is needed to confirm that the subtle reduction of thyroid function within euthyroidism increases $R_a$ and decreases $C_t$. Secondly, some of the patients took antihypertensive drugs, including RAS inhibitors. However, these inhibitors mainly affect efferent arterioles and decrease $R_e$ (32, 33), and their use cannot explain the increase in $R_a$. Thirdly, diabetic patients were included in the study. However, in our recent study, glycemic control indices were significantly positively associated with $R_e$, but not with $R_a$ (data not shown). Also, patients with DM did not show microalbuminuria and there was no significant difference in GFR between diabetic and non-diabetic patients, which indicates that diabetic nephropathy did not influence the results. Lastly, the formulae used to evaluate glomerular hemodynamics in humans are based on several assumptions, but many studies have validated the clinical utility of these formulae, as described earlier.

In conclusion, the results of the study demonstrate that low thyroid function, even within the normal range, is associated with reduced GFR, RPF, and RBF, resulting from increased $R_a$, and thus suggest that development of CKD might promote atherosclerotic changes in the early stage of hypothyroidism.

**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.

**Funding**

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

**References**


Received 13 January 2013

Revised version received 7 April 2013

Accepted 12 April 2013