A comparative study of serum total thyroxine estimation on unextracted serum by radioimmunoassay and by competitive protein binding

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SYNOPSIS A rapid and precise radioimmunoassay (RIA) for serum total thyroxine (T₄) on as little as 1-10 μl of unextracted serum is described. Results in hypothyroidism (overt and borderline), in euthyroid subjects, in pregnant and oestrogen-medicated subjects, and in hyperthyroidism (overt and borderline) are compared with the results on the same sera by an established competitive protein-binding technique (Ames' Tetrulute) on unextracted serum from a different laboratory. The correlation between the two methods was excellent (r = 0.94) and no significant difference between overall results or results in any subgroup was found. In the hypothyroid range the radioimmunoassay appeared to measure total T₄ reliably in sera containing only 1.3 or 2.6 nmol/l. Both methods predicted the clinical outcome in borderline hypothyroidism and borderline hyperthyroidism equally well and both gave normal results in T₃-toxicosis. It is concluded that both techniques reliably measure total T₄. RIA appears to have advantages of sensitivity and precision (especially in the hypothyroid range), of simplicity, and of low cost.

The determination of serum total thyroxine (T₄) is still the most widely used single measurement employed in the clinical assessment of thyroid function (Chopra, 1972). Until recently the methods available largely relied on prior extraction of serum followed by competitive protein-binding (CPB) assay (Murphy, 1965) though CPB analyses on unextracted serum have recently been described (Bauer et al., 1970; Braverman et al., 1971). A new approach has been the use of radioimmunoassay (RIA) on unextracted serum for the measurement of total serum T₄ and such techniques have been described by several authors (Chopra, 1972; Mitsuma et al., 1972; Beckers et al., 1973). However, discrepancies have been observed between the values of total T₄ found by RIA and by CPB techniques. Chopra (1972) found that values in euthyroid and hyperthyroid subjects were higher by RIA; the difference was not thought to be due simply to losses in the extraction procedure employed in the CPB technique and was attributed to the presence in some sera of T₄ which was linked by covalent bonds to serum proteins and not extracted by butanol/ethanol. Similarly, Beckers et al. (1973) found higher values in hyperthyroid subjects but not in euthyroid subjects or in pregnant women, and Ratcliffe et al. (1974) found higher values by RIA in hyperthyroid subjects. However, Mitsuma et al. (1972), in a comparison of results from hypothyroid, euthyroid, and hyperthyroid subjects, found excellent agreement (coefficient of correlation 0.98).

This paper compares total T₄ estimation on unextracted serum by RIA and CPB techniques performed in two different laboratories.

Methods

Total thyroxine (T₄) was measured by RIA on unextracted serum using the method of Mitsuma et al. (1972) modified as stated below. ¹²⁵I-T₄ (S.A. 25-50 mCi/mg) was obtained from the Radiochemical Centre, Amersham instead of from Abbott Laboratories, Illinois; 25 pg was used as label in the assay without further purification and counting time adjusted to give 20 000 counts above background in the zero control tubes. Mitsuma et al. (1972) used 50 pg of ¹³¹I-T₄.
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8-Anilino, 1-naphthalene sulphonate acid (ANS), Eastman Kodak Corp, was used to block T₄ binding to TBG in a dose of 200 μg per assay tube (instead of 175 μg) and was included both in standards and in diluted unknown sera. The assay was conducted in barbitone buffer 0·08 mol/l to block T₄ binding to thyroxine-binding pre-albumin (TBPA). The use of human serum freed from T₄ and tri-iodothyronine (T₃) by charcoal stripping (Mitsuma et al, 1972) was obviated by using high dilutions of serum in buffer (100 μl of 1/10-1/100 dilution of test serum routinely, but even higher dilutions for some hyperthyroid sera). At these high dilutions the slope of the curve formed by the serial dilution of a hyperthyroid serum (serum T₄ concentration 282 nmol/l) followed exactly the standard curve constructed in buffer (fig 1). Figure 2 shows a comparison of standard curves made up in buffer and in three dilutions of T₄-free serum; at dilutions of serum less than 1:10 the standard curve was displaced from the standard curve constructed in buffer but at serum dilutions of 1/10 or higher the curve was parallel. Owing to the sensitivity of the method specimens from hypothyroid, euthyroid, or hyperthyroid subjects could be appropriately diluted so that the percentage bound fraction fell on the steep portion of the standard curve (area of greatest precision), and even at the lowest dilution (1/10) non-specific interference by serum is avoided. A hyperthyroid serum assayed in multiple dilutions from 1/25 (4 μl of serum) to 1/800 (0·125 μl of serum) showed a value of 282 nmol/l with a coefficient of variation of 9·6%. A hypothyroid serum assayed in multiple dilutions from 1/10 (10 μl of serum) to 1/25 (4 μl of serum) had a mean value of 4·7 nmol/l with a coefficient of variation 14·9%. Non-radioactive standards of T₄ (12·5-500 pg/tube routinely) were derived by serial dilution in buffer of T₄ (10 mg of free acid) from Sigma Chem Co., dissolved initially in 0·13 M NaOH in 70% ethanol (20 ml) and stored at −20°C. This stock solution was renewed monthly. Standards were made up fresh for each assay by serial dilution from the stock solution. Mitsuma et al (1972) used standards of T₄ of 0·1-5 ng per assay tube.

Antiserum to T₄ was produced in rabbits by injection of T₄ conjugated to bovine serum albumin prepared by the method of Gharib et al (1971). The antiserum showed 8% cross-reactivity with T₃ as assessed by comparison of the doses of T₄ and T₃ required to inhibit binding by 50% from the zero control. Even if serum from a hyperthyroid patient with a serum T₄ concentration of 6·0 ng/ml were used at a dilution of only 1/10, which would be unusual, the T₃ content (60 pg) would cause a negligible depression of the percentage bound fraction. Cross-reactivity with mono- and di-iodothyronine was not significant. The assay regularly detected 12·5 pg T₄ equivalent to a serum concentration of 1·6 nmol/l.

**Assay Procedure**

100 μl ¹²⁵I-T₄ (25 pg)
100 μl antiserum at 1/100 initial dilution
100 μl diluted serum sample or T₄ standard
200 μl ANS (200 μg).

The assay was run in barbitone buffer. Incubation was at 37°C for 1½ hours in a shaking water-bath.

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**Fig 1** The curve formed by serial dilution of a hyperthyroid serum (T₄ content 282 nmol/l) assayed at 1/25 to 1/800 was parallel to the standard curve constructed without T₄-free serum.

**Fig 2** Standard curves constructed in the presence of T₃-free serum (T₃FS) at dilutions greater than 1:10 were parallel with a standard curve not containing T₃FS. At greater serum concentrations the standard curve was displaced.
Separation of bound from free T₄ was achieved by a
dextran-charcoal system essentially as described by
Mitsuma et al (1972). The percentage bound fraction
was counted overnight on a Packard Autogamma
counter. The assay takes three hours apart
from the counting and results are available the
following morning.

**RECOVERY**

Recoveries were calculated by the addition of T₄ to
euthyroid and hyperthyroid sera of which the basal
T₄ content was also measured. For final T₄ con-
centrations of 87.5-1588 nmol/l the mean recovery
was 96% (range 91-105%) in 10 experiments. Re-
coversies were also calculated in two experiments,
by the addition of T₄ to T₄-free serum and found to
be 95 and 102%.

**PRECISION**

For hypothyroid, euthyroid, and hyperthyroid sera
the within-batch SD of duplicate analyses was
2.7, 5.3, and 14.8 nmol/l, representing coefficients of
variation of 19.8, 5.3, and 7.5% respectively. The
between-batch SD was 2.2, 5.2, and 17.5
nmol/l for hypothyroid, euthyroid and hyperthyroid
sera respectively analysed in duplicate on consecutive
assays. A quality control serum analysed over
six assays had a coefficient of variation of 9% (mean
value 295 nmol/l).

**COMPETITIVE PROTEIN-BINDING**

Total T₄ by CPB was measured by the Ames
Tetralute Sephadex column method (Howorth and
McKerron, 1974) which included the modifi-
cations described by Gyde et al (1973). The coefficient of
variation within-batch was 9-8% and between-batch
was 12-7% (52 and 38 duplicate analyses re-
spectively). Separate aliquots of the specimens were
analysed by the two methods by separate labora-
tories over a period of several months, being kept
depth frozen at -20°C pending analysis.

**Subjects**

Fourteen of the hypothyroid subjects were overt
clinical cases of myxoedema and all have shown a
good response to subsequent treatment with T₄.
Four subjects had dubious clinical evidence of
hypothyroidism but all had an elevated serum TSH
concentration; on follow-up three patients developed
overt hypothyroidism responsive to treatment and
one remained unchanged for a prolonged period. Of
30 euthyroid subjects, 16 were normal healthy
volunteers and 14 were clinically euthyroid hospital
outpatients.

Twelve subjects were taking contraceptive
preparations containing 50 μg of oestrogen and
another 12 were pregnant.

Of the 18 hyperthyroid subjects, 14 were overt
clinical cases of thyrotoxicosis and four cases were
considered to be clinically borderline. The diagnosis
in all cases was established by response to anti-
thyroid medication. All 18 patients had an elevated
serum T₃ concentration measured by RIA on un-
extracted serum (Marsden and McKerron, 1975).

**Results**

Excellent overall agreement was found between the
two methods with a correlation coefficient of 0.94
(see fig 3).

The mean and SD of total T₄ by each method in
each subgroup of subjects is shown in the table.
None of these differences is significant and there was
no overall significant difference (p > 0.05).

**COMPARISON WITH CLINICAL DATA**

On the assumption that the normal range of 51.5-
141.6 nmol/l for total T₄ established by the CPB
technique (Howorth and McKerron, 1974) applies
to both methods, the two methods were compared for
their ability to predict clinical thyroid status.

**HYPOTHYROIDISM**

In overt hypothyroidism RIA gave 13/14 and CPB
14/14 results below 51.5 nmol/l. In borderline hypo-
thyroidism each method gave the same results,
three within the normal range and one below; one
patient out of the four remained clinically un-
changed for two years despite an elevated serum

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![Fig 3](http://jcp.bmj.com/) Correlation of serum T₄ concentrations (nmol/l) by radioimmunoassay (T₄ RIA) and competitive protein binding (T₄ CPB) in different groups of subjects. The normal range is indicated by the interrupted lines.
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<table>
<thead>
<tr>
<th>Hypothyroid</th>
<th>Borderline Hypothyroid</th>
<th>Euthyroid</th>
<th>Oral Oestrogens or Pregnancy</th>
<th>Hyperthyroid</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overt</td>
<td>(14)</td>
<td>(30)</td>
<td>(24)</td>
<td>(18)</td>
<td>(90)</td>
</tr>
<tr>
<td>RIA</td>
<td>7.7 ± 9.0</td>
<td>51.5 ± 24.5</td>
<td>81.1 ± 14.2</td>
<td>114.5 ± 24.5</td>
<td>182.8 ± 55.3</td>
</tr>
<tr>
<td>CPB</td>
<td>14.2 ± 15.4</td>
<td>52.8 ± 18.0</td>
<td>88.8 ± 20.6</td>
<td>115.8 ± 20.6</td>
<td>195.6 ± 55.3</td>
</tr>
</tbody>
</table>

Table: Comparison of the mean and SD of total serum T₄ measured by radioimmunoassay (RIA) and competitive protein binding (CPB) techniques on unextracted serum

Figures in parentheses indicate numbers of subjects; units in nmol/l

TSH concentration (T₄ normal by both methods); the other three patients became overtly hypothyroid despite normal T₄ concentrations in two of them by both methods.

**Euthyroid subjects**

Each method gave only one value below 51.5 nmol/l, otherwise all results were within the normal range.

**Oestrogens**

All 12 subjects on oral contraceptives fell within the normal range by RIA, 11 of them by CPB. Of 12 pregnant subjects, three were above the normal range by RIA and one by CPB.

**Hyperthyroid subjects**

For the four clinically borderline subjects RIA gave two results within the normal range and CPB gave three. In one of the clinically overt cases the CPB method gave a T₄ slightly above and RIA slightly below the upper limit of normal; in the remainder results by both methods were elevated above normal.

**Discussion**

The radioimmunoassay described here is precise, simple, and cheap. Consumables and reagents cost approximately £360 per annum, to which may be added the estimated labour cost of £500 per annum (one-quarter of a technician's salary). The costing for the competitive protein-binding technique on the same basis was £360 for consumables and reagents, and £1000 for labour provided Sephadex columns are reutilized. Both methods are considerably cheaper than 'kits' commercially available. The annual sample load for the CPB method at the time of costing was 3000 samples and the RIA accommodates this number or more on the cost analysis given.

A new methodological feature is the non-dependence on T₄-free human serum which other assays have employed (Mitsuma et al, 1972) on this assay would result in RIA concentrations appearing falsely higher than values by competitive protein-binding, which is clearly not the case.

A further feature of the RIA resulting from the sensitivity of the method is the opportunity to dilute the specimen so that the T₄ content falls on the steep (precise) portion of the standard curve. The sensitivity and precision are greater than those reported for most CPB techniques and are of particular value in the measurement of hypothyroid specimens. The use of such small volumes of serum as described here may well be of advantage in paediatrics or other circumstances where it is difficult to obtain blood by routine venepuncture, or in experimental work employing small animals.

Other workers have described higher values for total T₄ by RIA than by CPB as mentioned in the introduction. The CPB techniques employed have largely relied on a prior extraction of serum and it has recently been shown that the recovery of T₄ may fall off progressively with higher total serum T₄ concentrations when using such a technique (Hehrmann and Schneider, 1974). The very close agreement in total T₄ concentrations and in prediction of clinical status found over a wide range of subjects by the two assays described here, which are both performed on unextracted serum, suggests that the previously described difference between the two techniques may well be an artefact of extraction procedures, particularly as identity of results has been described when T₄ is measured by RIA and CPB on extracts of serum (Chopra, 1972) or when T₄ is measured by direct RIA and by RIA on extracts of serum after correction with an extraction factor (Hehrmann and Schneider, 1974). Excellent recovery is reported with this assay at extremely high total T₄ concentrations (1588 nmol/l). Our findings would therefore suggest that both RIA and CPB techniques on unextracted serum reliably quantitate total serum T₄.

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