A critical review and meta-analysis of the association between overt hyperthyroidism and mortality

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Abstract
Background: Overt hyperthyroidism has been associated with cardiac arrhythmias, hypercoagulopathy, stroke, and pulmonary embolism, all of which may increase mortality. Some, but not all, studies show an increased mortality in patients with hyperthyroidism. This inconsistency may be due to differences in study design, characteristics of participants, or confounders. In order to test whether hyperthyroidism influences mortality, we performed a critical review and statistical meta-analysis.

Methods: Based on an electronic PubMed search, using the Medical Subject Heading words such as hyperthyroidism, thyrotoxicosis, and mortality or survival, case–control and cohort studies were selected and reviewed. Using meta-analysis, an overall relative risk (RR) of mortality was calculated.

Results: Eight studies fulfilled the inclusion criteria, six of which showed an increased all-cause mortality; seven studies, including 31 138 patients and 4 000 000 person years at risk, allowed calculation of mortality in a meta-analysis. Based on this, the RR of overall mortality was 1.21 (95% confidence interval: 1.05–1.38). Analyses including studies considering setting, treatment, and control for co-morbidity did not significantly alter this finding. As the measured heterogeneity (I²) ranges from 89.1 to 98.3%, which is much higher than the 50% generally viewed on as a threshold, the statistical heterogeneity is very pronounced in the included studies.

Conclusion: In patients diagnosed with hyperthyroidism, mortality is increased by 20%. Future studies need to address the cause of hyperthyroidism, impact of type of therapy, time dependency, as well as the potential influence of confounding or genetic susceptibility before the question of causality can be answered.

Introduction
Overt hyperthyroidism is common and affects 2–5% of the population (1, 2). Hyperthyroidism is due to complex interactions between genetic susceptibility and environmental triggers such as the level of iodine intake and magnitude of smoking. Biochemically, the disorder is defined by a suppressed serum level of TSH and elevated concentrations of the thyroid hormones thyroxine and/or triiodothyronine. Irrespective of its cause (Graves’ disease or nodular toxic goiter), hyperthyroidism is associated with conditions such as atrial fibrillation (3), stroke (4), pulmonary embolism (5), and hypercoagulopathy (6), which, theoretically, could lead to an increased mortality. Several studies have investigated the relationship between overt hyperthyroidism and mortality. Nevertheless, conflicting data from these studies have led an ongoing debate regarding the consequences of overt hyperthyroidism with respect to mortality. This inconsistency has been explained by differences in study design, characteristics of participants, treatment effect and modalities, or the influence of confounding factors (7).

In order to evaluate whether there is an association between overt hyperthyroidism and mortality, we performed a critical review and meta-analysis using the available data.

Methods

Search method
On October 1st 2010, we performed a MEDLINE database search using the PubMed search engine with the Medical Subject Heading (MeSH) words such as hyperthyroidism or thyrotoxicosis and mortality or survival. Only abstracts written in English were taken into account, but there were no restrictions with respect to publication date, treatment modality, study design, study setting (hospital or primary health care), gender, or age. Abstracts were reviewed independently by two
authors (F B and T H B), and differences were resolved by discussion. Inclusion criteria were case–control or cohort studies published in peer-reviewed journals, investigating whether overt hyperthyroidism is associated with mortality. Exclusion criteria were duplication of data, if patients were not diagnosed with overt hyperthyroidism (e.g. subclinical hyperthyroidism), or lack of a relevant control group. Furthermore, to avoid missing any relevant study, the reference lists of studies included in this review were screened in search of overlooked publications. Characteristics of the participants, type of intervention, study design, and confounders were obtained from the included studies.

Analysis of studies

In order to evaluate homogeneity and identify bias, all included studies were compared with focus on selection of patients, reliability of diagnosis (self-reported or biochemical testing), comparability of the control groups (age, gender, and morbidity), type of treatment, and major confounders (smoking and co-morbidity). In case of an overlap of subjects in two or more studies, the largest study was used for further analysis. By combining relevant studies for the meta-analysis, we evaluated various clinically relevant scenarios such as whether the studies were hospital or primary care based, only radioiodine or all treatments were chosen for therapy, and whether co-morbidity (often cardiovascular disease, diabetes, and cancer) was registered. This procedure was used instead of quality-rating scales, since none of them has been shown to be superior to analysis based on clinical relevant parameters (8). Unfortunately, it was not possible to reevaluate the studies in respect to disease phenotype, time point of diagnosis, and effectiveness of treatment since generally no such data could be obtained from the included studies.

Statistical analysis

Because of substantial qualitative and quantitative differences across studies, all analyses were performed using a random effect model (assumes that all studies are heterogeneous). The number of deaths and number of expected deaths were extracted from eligible studies and the relative risk (RR) of mortality, with 95% confidence interval (CI), was calculated by using the method of DerSimonian & Laird (9). Results were significant when the range of the 95% CI excluded the value 1. To avoid an overestimate of mortality, patients lost to follow-up were considered as being alive. The statistical heterogeneity was assessed by the squared-I value, which describes the total variation across studies attributable to heterogeneity rather than to chance. A value above 25, 50, and 75% indicates low, moderate, and high heterogeneity respectively (10). We assessed publication bias by Egger’s regression test (11).

Results

Selection and characteristics of the studies

As outlined in Fig. 1, 551 studies were identified by a PubMed search using the MeSH words such as hyperthyroidism or thyrotoxicosis and mortality or survival. In total, 19 studies matched our additional

![Flow chart outlining the process of search criteria and study selection.](image-url)
criteria (case–control or cohort studies) (12–30). Following review, studies were excluded because of an overlap with subjects from other studies (16, 19, 20); because reviews were not providing original data (12, 13, 22); due to inclusion of very few (n < 10) hyperthyroid individuals to meaningfully allow calculation of the mortality risk (23, 25); because of lack of overall mortality data (17); based on inclusion of a control group that was also hyperthyroid (30); or, finally, because evaluation of thyroid status was solely based on serum TSH (21) (Fig. 1). Details of the remaining eight (14, 15, 18, 24, 26–29) studies on which our review is based are shown in Table 1.

Seven of the eight studies are cohort studies (14, 15, 18, 24, 26, 28, 29) and one is a case–control study (27). In most studies, patients were ascertained from registers, where they have been either listed due to treatment with radioiodine (15, 18, 24, 29) or based on treatment of hyperthyroidism at a hospital unit (14) or in primary care (26). In one study, patients participated in an osteoporosis survey of middle-aged women where information on thyroid status was self-reported using questionnaires (28).

In the majority of studies, the clinical features and underlying cause or severity of hyperthyroidism were not reported in detail. Most studies were performed in Europe, either in the UK (18, 24, 26, 27) or in Scandinavia (15, 29). Two studies were from the USA (14, 28). The first study was published in 1990 (14) and the last three in 2007 (27–29). The largest study comprised 10 646 persons (15), amounting to 152 406 person years at risk, while the smallest was a case–control study with 393 individuals (27). In four studies, the patients were treated with radioiodine (15, 18, 24, 29), whereas all therapy options were used in another four studies (14, 26–28). All surveys took age and sex into consideration as potential confounders, while smoking was considered in only three studies (14, 27, 28). Selected co-morbidities, such as co-existing diabetes or cardiovascular disease, were taken into account in four studies (14, 26, 27, 29). Although all studies included an age- and gender-matched control group, the choice of control population was very inhomogeneous. Most studies calculated expected death rates based on national death registers (14, 15, 18, 26) or have chosen controls from a population register (29). On the other hand, controls were also included from hospital employees (27), a group of women over 65 years of age included in an osteoporosis survey (28), or patients treated in the same year as the cases, for a non-thyroid disease at a hospital (24).

### Mortality

Six of the eight studies reported a higher mortality in the hyperthyroid patients compared with the corresponding control group (14, 15, 18, 27–29) while no or a non-significant difference was reported in two other studies (23, 25). Details of the studies are shown in Table 1.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Country, setting</th>
<th>Design</th>
<th>Mean follow-up</th>
<th>Number of subjects</th>
<th>Treatment modality</th>
<th>Adjusted confounders</th>
<th>Risk estimate</th>
<th>Control group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goldman et al.</td>
<td>USA, Hospital</td>
<td>Cohort</td>
<td>317,713 women</td>
<td>2300 women</td>
<td>All</td>
<td>Age, sex, smoking, age and sex</td>
<td>SMRa</td>
<td>Death register USA</td>
</tr>
<tr>
<td>Franklyn et al.</td>
<td>UK, Hospital</td>
<td>Cohort</td>
<td>105,028 people</td>
<td>7772 women</td>
<td>Radioiodine (1950–1989)</td>
<td>Age and sex</td>
<td>SMRb</td>
<td>Death register England and Wales</td>
</tr>
<tr>
<td>Hall et al.</td>
<td>Sweden, Hospital</td>
<td>Cohort</td>
<td>160,485 persons</td>
<td>10,646 women</td>
<td>Radioiodine (1950–1975)</td>
<td>Age and sex</td>
<td>SMRb</td>
<td>Death register Sweden</td>
</tr>
<tr>
<td>Flynn et al.</td>
<td>Scotland, Primary care</td>
<td>Cohort</td>
<td>109,285 persons</td>
<td>4690</td>
<td>All types</td>
<td>Age and sex, diabetes</td>
<td>SMRa</td>
<td>Population Tayside, Scotland</td>
</tr>
<tr>
<td>Nyrienda et al.</td>
<td>Scotland, Hospital</td>
<td>Cohort</td>
<td>30,669 person years</td>
<td>3346</td>
<td>Radioiodine (1981–2001)</td>
<td>Age and sex, smoking, alcohol, and medication</td>
<td>SMRc</td>
<td>Mortality register of Scotland</td>
</tr>
<tr>
<td>Bauer et al.</td>
<td>USA, Hospital</td>
<td>Cohort</td>
<td>25,883 person years</td>
<td>891 women</td>
<td>Radioiodine (1999–2002)</td>
<td>Age and sex, CVD, diabetes, and smoking</td>
<td>SMRc</td>
<td>Death register Finland</td>
</tr>
<tr>
<td>Metso et al.</td>
<td>Finland, Hospital</td>
<td>Cohort</td>
<td>30,669 person years</td>
<td>2793</td>
<td>Radioiodine (1965–2002)</td>
<td>Age, sex, CVD, diabetes, and smoking</td>
<td>RRc</td>
<td>Death register Finland</td>
</tr>
<tr>
<td>Osman et al.</td>
<td>UK, Hospital</td>
<td>Case–control</td>
<td>369</td>
<td>393</td>
<td>Radioiodine or medication</td>
<td>Age, sex, CVD, diabetes, and smoking</td>
<td>ORb</td>
<td>Sex- and age-matched controls</td>
</tr>
</tbody>
</table>

n.sp., not specified; CVD, cardiovascular disease. **Mortality odds ratio.** RR, Relative risk.
studies (24, 26). Interestingly, the only two studies, which failed to show a significant increase in mortality risk, were in contrast to other studies, either performed in primary care (26) or included controls from a hospital morbidity register after they had been admitted with a non-thyroid disease (24).

Seven of the eight studies could be pooled as only one study (27) did not provide the exact count of deaths but only risk estimates. Together, these seven studies comprised 31,138 patients corresponding to ~400,000 person years at risk. Irrespective of whether all studies (1.21, 95% CI 1.05–1.38), only studies controlling for co-morbidity (1.21, 95% CI 1.01–1.44), or only studies performed in a hospital setting (1.24, 95% CI 1.07–1.44), were pooled, there was a significantly higher mortality in the hyperthyroid group. An increased, but statistically non-significant, mortality risk remained when pooling all studies treating with radioiodine (Table 2 and Fig. 2).

Six studies (14, 15, 18, 26, 27, 29) reported cardiovascular mortality, four of which found a significantly raised mortality (14, 18, 27, 29). When pooling these six studies, there was a higher mortality in subjects with hyperthyroidism compared with the control population (RR 1.19; 95% CI 1.00–1.29).

As the squared-I ranges from 89.1 to 98.3%, which is much higher than the 50% generally viewed on as a threshold, the statistical heterogeneity is very pronounced in the included studies (Fig. 2). On the other hand, no evidence of publication bias was detected (Egger’s test, P = 0.409).

Discussion

Six of the eight eligible studies showed significantly increased overall mortality. A trend toward higher mortality in patients with hyperthyroidism compared with controls was also found in the remaining two studies. Our meta-analysis based on seven studies (24, 26) found in the remaining two studies. Our meta-analysis based on seven studies (24, 26) was also found in the remaining two studies.

Table 2 Number of deaths/expected deaths and calculated relative risk of mortality.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Observed number of deaths</th>
<th>Expected number of deaths</th>
<th>Observed number of cardiovascular deaths</th>
<th>Expected number of cardiovascular deaths</th>
<th>RR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goldman et al. (14)</td>
<td>790</td>
<td>564</td>
<td>359</td>
<td>256</td>
<td>1.40 (1.28, 1.53)</td>
</tr>
<tr>
<td>Franklyn et al. (18)</td>
<td>3681</td>
<td>3186</td>
<td>1955</td>
<td>1577</td>
<td>1.13 (1.09, 1.17)</td>
</tr>
<tr>
<td>Hall et al. (15)</td>
<td>5400</td>
<td>3673</td>
<td>3274</td>
<td>1984</td>
<td>1.47 (1.42, 1.52)</td>
</tr>
<tr>
<td>Flynn et al. (26)</td>
<td>565</td>
<td>539</td>
<td>386</td>
<td>368</td>
<td>1.05 (0.94, 1.17)</td>
</tr>
<tr>
<td>Nyrienda et al. (24)</td>
<td>568</td>
<td>548</td>
<td>n.sp.</td>
<td>n.sp.</td>
<td>1.04 (0.94, 1.15)</td>
</tr>
<tr>
<td>Bauer et al. (28)</td>
<td>n.sp.</td>
<td>n.sp.</td>
<td>n.sp.</td>
<td>n.sp.</td>
<td>Not calculated</td>
</tr>
<tr>
<td>Metso et al. (29)</td>
<td>1390</td>
<td>1299</td>
<td>794</td>
<td>697</td>
<td>1.07 (1.01, 1.13)</td>
</tr>
<tr>
<td>Osman et al. (27)</td>
<td>26</td>
<td>12</td>
<td>7</td>
<td>4</td>
<td>2.17 (1.11, 4.23)</td>
</tr>
<tr>
<td>All</td>
<td>12,350</td>
<td>9821</td>
<td>6,775</td>
<td>4,886</td>
<td>1.21 (1.05, 1.38)</td>
</tr>
</tbody>
</table>

n.sp.: not specified.
associated with an increased mortality due to cancer, fractures, respiratory distress, infectious diseases, cardiovascular diseases, and endocrine diseases (14, 18). With respect to causality, the association between clinically overt hyperthyroidism and mortality is strong, consistent, biologically plausible, and probably dose dependent. In combination, these features indicate a causal relationship between clinically overt hyperthyroidism and mortality.

Accepting that the association between overt hyperthyroidism and mortality is likely to be causal, the influence of the clinical phenotype and environmental and/or genetic confounders is virtually unknown. In most cases, thyrotoxicosis is due to either Graves’ disease or toxic nodular goiter. Clearly, there are major differences in epidemiology and clinical features of these two phenotypes. Graves’ disease is the most common cause of hyperthyroidism in iodine-sufficient areas whereas toxic nodular goiter is the dominant cause in iodine-deficient areas (35). The age distribution is also different, toxic nodular goiter often affects older subjects, while Graves’ disease is more common in younger subjects. Thus, it is likely that the consequences of these two phenotypes, with respect to mortality, differ. Unfortunately, an evaluation of a possible difference between Graves’ disease and toxic nodular goiter with respect to mortality is not possible since it has only been investigated in two studies (24, 29). However, the interpretation of these is unclear, as the study by Nyrienda et al. (24) failed to show a significant association between mortality and any of the two phenotypes. In contrast, the study by Metso et al. (29) demonstrated a significantly increased RR for mortality in patients with toxic nodular goiter, but not in patients with Graves’ disease. It follows that future investigations need to clarify the impact of the cause of hyperthyroidism on the association between clinically overt hyperthyroidism and mortality. Another major drawback is the lack of taking environmental and genetic confounders into consideration in the majority of studies. It is important to realize that hyperthyroidism and mortality are shared genetic or environmental factors affecting, independently, the development of hyperthyroidism and mortality. Future research should take these factors into account (40).

Importantly, the increased mortality, found in this meta-analysis, is based on an RR estimate. However, this statistical parameter does not specify the time-span between diagnosis and death, number of days or years lost, or whether patients diagnosed with hyperthyroidism tend to die at a younger age. Clearly, a better evaluation of the time-span between diagnosis of
hyperthyroidism and death will lead to a better understanding of the mechanisms involved. The study by Hall et al. (15) found a 2.65 times higher risk of mortality in the first year after radiiodine treatment, calculated by the standard mortality rate. The value was reduced to 1.49 in the following 8 years. But these data do not allow speculations as to time-span between diagnosis and death, due to the lack of information regarding the delay between diagnosis and treatment.

Finally, since our meta-analysis is based on seven large studies that are inhomogeneous both clinically and methodologically, heterogeneity is to be expected. In line with this, the squared-I values in our analyses range from 89 to 98%, reflecting a high degree of heterogeneity (41). The main reason for this is, however, not related to clinical or methodological differences but to the use of very large cohorts. In the studies included in our meta-analysis (14, 15, 18, 24, 26, 27, 29), the risk estimates for death is between 1.04 and 2.17, and due to the large number of patients in each study, the CI of these risk estimates is quite narrow. Thus, although the risk estimates point in the same direction (i.e. increased mortality), there is a statistically significant difference with respect to the size of the risk estimates between studies. It follows that a low-squared-I value strengthens the result of a meta-analysis, but still high values do not necessarily arise from pronounced clinically and methodologically heterogeneity.

In conclusion, patients diagnosed with hyperthyroidism have an increased mortality of about 20% in this meta-analysis. Although the precise mechanism(s) by which hyperthyroidism leads to an increased mortality remains to be defined, the association between clinically and methodologically, heterogeneity is to be expected. In line with this, the squared-I values in our analyses range from 89 to 98%, reflecting a high degree of heterogeneity (41). The main reason for this is, however, not related to clinical or methodological differences but to the use of very large cohorts. In the studies included in our meta-analysis (14, 15, 18, 24, 26, 27, 29), the risk estimates for death is between 1.04 and 2.17, and due to the large number of patients in each study, the CI of these risk estimates is quite narrow. Thus, although the risk estimates point in the same direction (i.e. increased mortality), there is a statistically significant difference with respect to the size of the risk estimates between studies. It follows that a low-squared-I value strengthens the result of a meta-analysis, but still high values do not necessarily arise from pronounced clinically and methodologically heterogeneity.

Declaration of interest

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

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