Amiodarone-induced thyroid disorders: a clinical review

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Summary
Although amiodarone is regarded as a highly effective anti-arrhythmic agent, its use may lead to alterations in thyroid gland function and/or thyroid hormone metabolism, partly because of its rich iodine content. Patients treated with amiodarone may manifest altered thyroid hormone profile without thyroid dysfunction, or they may present with clinically significant amiodarone-induced hypothyroidism or amiodarone-induced thyrotoxicosis. The former results from the inability of the thyroid to escape from the Wolff-Chaikoff effect. It prevails in areas with high dietary iodine intake, and it is readily managed by discontinuation of amiodarone or thyroid hormone replacement. Amiodarone-induced thyrotoxicosis occurs more frequently in areas with low iodine intake; it may arise from iodine-induced excessive thyroid hormone synthesis (type I) or destructive thyroiditis with release of preformed hormones (type II). Type I should be treated with thionamides alone or in combination with potassium perchlorate, whereas type II benefits from treatment with glucocorticoids. Surgery may be a feasible option for patients who require long-term amiodarone treatment.

Keywords: amiodarone; hyperthyroidism; hypothyroidism, thyroiditis

Amiodarone is a highly effective agent used for the treatment of various cardiac arrhythmias, ranging from paroxysmal atrial fibrillation to life-threatening ventricular tachyarrhythmias. However, the use of amiodarone is associated with several side-effects, including photosensitivity, corneal microdeposits, pulmonary toxicity, hepatotoxicity, peripheral neuropathy, hyperthyroidism and hypothyroidism. The purposes of this review are to summarise expected and abnormal changes in thyroid function and thyroid hormone metabolism in patients taking amiodarone, and to suggest guidelines for the diagnosis and management of amiodarone-induced thyroid dysfunction.

Amiodarone and thyroid physiology
Amiodarone is a benzofuran derivative containing two atoms of iodine per molecule (figure 1). This amounts to 37.5% of organic iodine by molecular weight, of which 10% is de-iodinated to yield free iodine. It has the potential to cause thyroid dysfunction because of this iodine-rich chemical structure. In the body, it is stored in adipose tissue, myocardium, liver, and lung and has an elimination half-life of about 2–3 months. Hence, a normal daily maintenance dose of amiodarone (200–400 mg) generates about 6–12 mg of free iodine per day. This results in an iodine load that far exceeds the World Health Organisation’s recommended optimal iodine intake of 0.15–0.3 mg per day. In patients treated with amiodarone, urinary and plasma levels of inorganic iodide are found to increase up to 40-fold, whereas thyroidal iodide uptake and clearance decrease significantly.

Amiodarone has many effects on thyroid physiology as well as the peripheral metabolism of thyroid hormones (box 1). These effects are also observed in amiodarone-treated patients who remain euthyroid, and are largely explicable in terms of the physiological effects of iodide excess and inhibition of 5’-deiodinase activity. Indeed, more than 50% of patients who receive long-term amiodarone therapy show abnormal results on thyroid function test, and the majority remain clinically euthyroid. Occasionally, amiodarone can also cause goitre without apparent thyroid dysfunction.

Effect on thyroid hormone synthesis
The large amount of iodide released during the metabolism of amiodarone leads to an adaptive blockage of further thyroidal iodide uptake and thyroid hormone biosynthesis, the so-called Wolff-Chaikoff effect. Although this is apparent within the first 2 weeks of treatment, further exposure to iodine leads to normal resumption of thyroid hormone synthesis. This escape phenomenon from the Wolff-Chaikoff effect helps to safeguard the individual from developing hypothyroidism.

Effect on thyroid hormone metabolism
At the extrathyroidal level, amiodarone has the specific ability to inhibit T4 5’-monodeiodination. The changes in serum thyroxine (T4), triiodothyronine (T3), reverse triiodothyronine (rT3), and thyroid-stimulating hormone (TSH) concentrations are similar to those produced by iodinated radiographic contrast agents, and the magnitude of these alterations is dose dependent. Amiodarone strongly inhibits type I 5’-monodeiodinase activity and thus the fractional conversion of T4 to T3. The decreased 5’-deiodination of T4 into T3 is observed in many tissues but is most pronounced in the thyroid and the liver, the latter being the main extrathyroidal T3 production site. This inhibitory action persists during and for several months after amiodarone treatment, explaining the decreased plasma and tissue T3 concentrations. Alterations in thyroid hormone dynamics occur, as the biological effects are mediated via T3 binding to the nuclear T3 receptors. The inhibition of type I 5’-deiodinase activity also results in the reduced clearance and a consequent rise in serum rT3.
Amiodarone is a highly versatile and effective anti-arrhythmic agent. Its mechanism of action on the heart is in part linked to the complex relationship of its pharmacologic actions with thyroid hormone metabolism. Electrophysiologic changes in the heart induced by chronic amiodarone treatment resemble those induced by hypothyroidism, and these effects may be nullified by concomitant administration of thyroid hormone.\(^{15-17}\) The major active metabolite of amiodarone, desethylamiodarone (DEA), acts as a competitive inhibitor of T3 binding to the \(\alpha\)-thyroid hormone receptor (T3R-\(\alpha\)), and as a non-competitive inhibitor with respect to \(\beta\)-thyroid hormone receptor (T3R-\(\beta\)).\(^{18}\) In animal studies, amiodarone treatment produces a significant decrease in the cardiac \(\beta\)-adrenergic receptor density and heart rate without altering thyroid hormone secretion and serum T3 level.\(^{19}\) The finding that amiodarone treatment decreases the cardiac \(\beta\)-adrenergic receptor density and resting heart rate in euthyroid but not in hypothyroid rats, supports the hypothesis that the cardiac effects of amiodarone are mediated by an antagonistic action to thyroid hormones at the cellular level.\(^{20}\) In addition, it has been hypothesised that cellular or subcellular T3 antagonism induced by amiodarone leads to anti-arrhythmic remodelling of cardiac cells, probably through a modulation of gene expression in ion channels and other functional proteins.\(^{16,17,21}\)

However, the role of the cardiac hypothyroid state in the genesis of anti-arrhythmic activity is still a matter of considerable controversy among investigators. Amiodarone is believed to modulate some myocardial cell functions by direct inhibition of current flow through ion channels in a manner that is independent of its effect on thyroid hormone. Studies performed \textit{in vitro} showed that amiodarone inhibits Na\(^+\)/K\(^+\)-ATPase activity independent of thyroid hormone, and it blocks the sodium, potassium, and calcium channels in the heart.\(^{22,23}\)

\section*{Thyroid hormone profile in patients on amiodarone treatment}

The acute effects of amiodarone administration on thyroid function was studied in 24 patients with cardiac arrhythmias during the first 10 days of treatment.\(^{24}\) In this study, TSH levels were found to increase early and significantly throughout the study, starting from the first day of therapy and reaching a value 2.7-fold higher than the basal value by the 10th day. Total T3 decreased progressively from the second day of study; whereas reverse T3 progressively and significantly increased and paralleled the TSH values, reaching a value of twice the basal value by the 10th day. This was followed by a progressive and significant increase in total and free T4 concentrations starting from the fourth day of treatment. The observed later increase in T4 levels is probably due to both direct thyroid stimulation (by TSH) and a reduction in T4 clearance.\(^{25}\)

After 1–4 months of amiodarone therapy, serum T4 levels increase by an average of 40\% above pretreatment levels. It is important to note that the increase in T4 levels is an expected finding and in itself does not constitute evidence of hyperthyroidism. Likewise, TSH levels often return to normal on chronic amiodarone administration (longer than 3 months). Normalisation of serum TSH occurs as T4 concentrations rise sufficiently to overcome the partial block in T3 production.\(^{26}\) Conversely, a trend to lower plasma TSH concentrations may be observed with prolonged continuation of the drug, which may suggest a partial T3 agonist effect in some circumstances.\(^{27}\) The effects of amiodarone on thyroid hormone profile in euthyroid subjects are summarised in table 1.

\section*{Amiodarone-induced hypothyroidism}

Amiodarone-induced hypothyroidism (AIH) is believed to result from the inability of the thyroid to escape from the Wolff-Chaikoff effect. Thyroid
hormone biosynthesis is impaired because of the persistent block in intrathyroidal iodine organification, as evident by the positive perchlorate discharge test in patients with AIH. This may arise from an underlying thyroid abnormality, such as autoimmune thyroiditis. As many as 40% of patients who develop hypothyroidism after amiodarone administration have positive thyroid antibodies, suggesting that iodide excess could unmask some pre-existent subclinical thyroid disease to produce overt thyroid failure.

The reported incidence of AIH varies widely, ranging from 6% in countries with low iodine intake to 13% in countries with a high dietary iodine intake. The risk of developing hypothyroidism is independent of the daily or cumulative dose of amiodarone. However, the risk is greater in the elderly and in female patients, probably as a result of a higher prevalence of underlying thyroid abnormality. The relative risk of developing AIH was found to be 13-fold higher in female patients with positive thyroid microsomal or thyroglobulin antibodies, as compared with men without thyroid antibodies. AIH may be transient or persistent, the latter is almost always associated with an underlying thyroid disorder. Unlike thyrotoxicosis, which may occur anytime during therapy or even after discontinuation of therapy, hypothyroidism is usually an early event and it is uncommon after the first 18 months of amiodarone treatment.

### Clinical Features and Diagnosis

The clinical features of hypothyroidism are usually vague. Fatigue, lethargy, intolerance of cold, and dry skin are commonly reported; goitre is uncommon. The diagnosis is confirmed by a raised serum TSH concentration (usually > 20 mU/l) in combination with low serum levels of free T4. Serum T3 concentration is an unreliable indicator as it can be low in euthyroid patients, whereas hypothyroid patients may have T3 levels within the normal range. In spite of the large iodine load during amiodarone treatment, the majority of patients with AIH have inappropriately elevated thyroid radioactive iodine uptake (RAIU) results.

### Treatment

AIH may be managed by either discontinuation of amiodarone therapy or thyroid hormone replacement. Discontinuation of amiodarone may not be feasible because of the underlying indication for its use, especially in the treatment of difficult ventricular tachyarrhythmias. A safer and more reliable option is to institute thyroid hormone replacement therapy, starting with 25–50 µg levothyroxine daily and increasing at intervals of 4–6 weeks until the symptoms have resolved and the target serum T4 level is achieved. The goal of treatment is to bring serum T4 levels to the upper end of its normal range, as often seen in euthyroid patients who are receiving amiodarone. It is important to realise that patients on amiodarone can have mildly elevated serum TSH levels despite adequate thyroid hormone replacement. Over-replacement will undermine the anti-arrhythmic effect of amiodarone, believed to be mediated via an intracellular state of hypothyroidism within the cardiac tissues. In general, patients should be monitored at 6 weeks and then every 3 months.

In small studies, perchlorate treatment has been shown to restore normal thyroid function rapidly in patients with AIH. The drug relieves iodine-induced inhibition of thyroid hormone synthesis by its ability to discharge inorganic iodine and to block further entry of iodide into the thyroid. As perchlorate toxicity can result from either prolonged use or high dosages (> 1 g daily), it is generally not recommended, as hypothyroidism can be effectively and safely treated with thyroid hormone substitution.

In the absence of hypothyroid symptoms or thyroid antibodies, patients with moderately raised serum TSH (< 20 mU/l) but high-normal or raised serum free T4 concentrations may reflect amiodarone-induced alteration in thyroid
function parameters or subclinical hypothyroidism. Close monitoring may be all that is necessary in these subjects. A summary of the pathogenesis and clinical features of amiodarone-induced thyroid dysfunction is presented in table 2.

### Amiodarone-induced thyrotoxicosis

Amiodarone-induced thyrotoxicosis (AIT) occurs in 2–12% of patients on chronic amiodarone treatment. Some studies indicate that the incidence varies according to the dietary iodine intake in the population; AIT prevails in areas with low iodine intake (eg, central Europe) and is rather uncommon in iodine replete areas (eg, North America and UK). However, in a Dutch study involving euthyroid subjects living in an area with a moderately sufficient intake of iodine, the incidence of AIT was twice that of AIH.

Like hypothyroidism, there is no relation between the daily or cumulative dose of amiodarone and the incidence of thyrotoxicosis.

In patients with pre-existing thyroid abnormalities, thyrotoxicosis is believed to result from iodine-induced excessive thyroid hormone synthesis (type I AIT). Its pathogenesis is related to the effects of iodine overload on abnormal thyroid glands, such as nodular goitre, autonomous nodule or latent Graves' disease. Due to alterations in the intrinsic autoregulatory mechanisms which regulate the thyroidal iodine handling, hyperthyroidism occurs in the presence of excess iodine in susceptible individuals. This is an example of the Jod-Basedow phenomenon, similar to the occurrence of hyperthyroidism in patients with endemic iodine-deficient goitre upon iodine exposure. Therefore, type I AIT could indicate the unmasking of an underlying thyroid abnormality or iodine deficiency by amiodarone treatment.

In patients with an apparently normal thyroid gland, thyrotoxicosis results from glandular damage with consequent release of preformed thyroid hormones into the circulation (type II AIT). Studies in vitro had shown amiodarone to be cytotoxic to FRTL-5 thyroid cells; this effect was inhibited by treatment with dexamethasone or perchlorate. Similarly, moderate to severe follicular damage and disruption were demonstrated on histopathologic study of thyroid glands obtained from patients with type II AIT. The finding of markedly elevated serum levels of interleukin-6 (IL-6) in type II AIT patients further supports this destructive-cum-inflammatory process, whereas normal or slightly elevated levels of IL-6 are found in type I AIT patients.

Thyrotoxicosis in type II AIT patients is usually self-limiting, which may be explained by the dose-dependent cytotoxic effect of amiodarone. When intrathyroidal amiodarone concentrations exceed a certain threshold, cell damage leads to thyrotoxicosis as the contents of the thyroid leak into the bloodstream. The intrathyroidal concentration of amiodarone would also decrease, allowing repair and the restoration of euthyroidism. Occasionally, hypothyroidism requiring levothyroxine substitution may result from extensive follicular damage.

### Clinical Features and Diagnosis

Thyrotoxicosis is suspected if patients on amiodarone treatment develop unexplained weight loss, sweating, tremor, sinus tachycardia or worsening of the underlying cardiac disorder. Similarly, AIT should be considered if there is new onset of supraventricular arrhythmias such as atrial tachycardia or atrial fibrillation. Features differentiating type I from type II AIT are summarised in table 3; however it should be recognised that both pathologic processes may co-exist in the same gland. Patients with type I AIT normally have underlying multinodu-
Moderate to severe carbimazole or methimazole 40–60 mg/day or addition of lithium (if possible); addition of perchlorate normal or small tender goitre typically transient low to absent extremely high absent

Glucocorticoids (moderate to high dose): prednisone 0.5–1.25 mg/kg bw/day for 3–6 weeks

*A distinct differentiation is not always possible as some patients may have coexistent type I and type II AIT.

TREATMENT
Unlike hypothyroidism, which is relatively easily treated with thyroid hormone replacement, the management of hyperthyroidism can be difficult and treatment strategies must be tailored individually. In patients with mild thyrotoxicosis and a normal underlying thyroid gland or a small goitre, the hyperthyroid state often resolves rapidly after amiodarone is withdrawn. Conversely, patients with underlying thyroid abnormality may have persistent thyrotoxicosis even several months after amiodarone withdrawal. The discontinuation of amiodarone is feasible only if the underlying cardiac arrhythmias are not life-threatening and can be satisfactorily controlled with alternative drugs. In addition to withdrawal of amiodarone, definitive treatment of thyrotoxicosis includes the use of thionamides, high-dose corticosteroids, perchlorate, lithium, plasmapharesis, and surgery.

The medical management of patients with AIT is summarised in box 2. In patients with abnormal thyroid glands and severe thyrotoxicosis (type I AIT), thionamides can be used to block thyroid hormone synthesis. However, high doses are required (eg, carbimazole or methimazole 40–60 mg/day, or propylthiouracil 100–150 mg qid) as thionamides are less effective in the presence of high intrathyroidal iodide concentrations. Although the dose may be reduced in most instances after 6–12 weeks, long-term antithyroid medication is usually required for patients on continued amiodarone treatment. Some investigators prefer to continue antithyroid drugs so as to maintain complete or partial block of thyroid hormone synthesis as long as the patients are on amiodarone treatment, and to use levothyroxine substitution if hypothyroidism develops. Occasionally, treated individuals may remain hypothyroid even after withdrawal of the antithyroid drug.

If thyrotoxicosis is severe or inadequately treated with thionamides, potassium perchlorate (250 mg 6 hourly) can be added for effective control. Perchlorate competitively blocks iodide from entering the thyroid by an effect on the Na⁺/I- symporter, but it has no effect on the iodination process itself. It is concentrated by the thyroid tissue in a manner similar to iodide but is not significantly metabolised in the gland or peripherally. The combination of potassium perchlorate and methimazole treatment appears to be particularly effective in patients with severe thyrotoxicosis, most probably because perchlorate inhibi-
its the active transport of iodide into the thyroid while methimazole blocks the intrathyroidal synthesis of thyroid hormones. The percholate should be tapered-off and stopped after a period of 4–6 weeks, while methimazole is continued until the restoration of euthyroidism. Long-term use of perchlorate is not advocated because of its association with fatal aplastic anaemia.

High-dose glucocorticoid therapy may be useful if thyrotoxicosis is not controlled or if exacerbation occurs. Steroids help by inhibiting 5'-deiodinase activity and perhaps also by affecting the thyroid gland directly. However, the adverse effects associated with high-dose steroids reduce the attractiveness of this option. Moreover, the reduction of steroid dose may be associated with recurrence of thyrotoxicosis.

In patients with apparently normal thyroid glands (type II AIT), thyrotoxicosis is usually transient and resolves upon withdrawal of amiodarone. Occasionally, spontaneous remission may occur despite continued amiodarone use. However, treatment with corticosteroids (eg, prednisone 40–60 mg/day) leads to faster recovery from this inflammatory or destructive form of thyroiditis. In a study of 24 consecutive patients, normal serum free T3 concentrations were achieved after a mean of 8 days in type II AIT patients on prednisone, compared with an average of 4 weeks in type I AIT patients treated with a combination of methimazole and potassium perchlorate.

More recently, the use of lithium carbonate in AIT patients with more severe thyrotoxicosis has been shown to effect more rapid normalisation of thyroid function. In this study, involving 21 AIT patients, the time course to restoration of normal thyroid function in patients treated with a combination of lithium and propylthiouracil was uniformly 4–5 weeks, compared with a mean of greater than 10 weeks in patients on propylthiouracil alone. In addition to inhibiting the release of thyroid hormones, lithium is also believed to influence thyroid hormone production. As amiodarone was withdrawn from all subjects in the above study, further studies are needed to find out whether lithium therapy remains efficacious in those who need continued amiodarone treatment. To avoid the potential complications associated with lithium carbonate therapy, therapeutic drug monitoring should be performed to maintain serum lithium concentrations within the therapeutic range (0.6–1.2 mEq/l).

It is important to realise that the adjuvant use of β-adrenergic antagonists for symptomatic relief of thyrotoxicosis is sometimes contraindicated in patients with compromised myocardial function; furthermore, the combination with amiodarone may give rise to bradycardia and sinus arrest. Under circumstances in which patients fail to improve with medical therapy and discontinuation of amiodarone is impractical, a total or near-total thyroidectomy may be more appropriate. This results in rapid control of thyrotoxicosis and permits continued therapy with amiodarone, although patients must be able to withstand the stress of surgery.

Radioactive iodine is generally not effective in treating patients with AIT, because the prevailing high iodide concentration prevents sufficient thyroidal uptake of the radioisotope. Furthermore, this may lead to an initial exacerbation of the hyperthyroid state due to release of preformed hormones. In areas of borderline iodine deficiency, however, patients with diffuse or nodular goitres may have normal to high RAIU despite the presence of AIT. It appears possible that the thyroid fails to adapt normally to the excess iodide load in these individuals; presumably these patients may respond to radioactive iodine therapy. Plasmapheresis has occasionally been tried, although not always successfully, to ameliorate severe thyrotoxicosis refractory to medical therapy.

Monitoring of thyroid function in amiodarone-treated patients

Baseline thyroid function tests should be performed in all patients to exclude underlying gland dysfunction that may predispose to hypo- or hyperthyroidism after amiodarone therapy is started. Serum levels of TSH, free T4, and T3 may be re-assessed after 3 months of therapy with the drug. In euthyroid subjects, thyroid function results obtained at this stage are used as reference values for future comparisons. Subsequent follow-up involves periodic monitoring of serum TSH concentrations, whereas other thyroid indices are determined only if patients showed abnormal TSH results or clinical suspicion of thyroid dysfunction. Figure 2 represents the suggested algorithm for monitoring thyroid function tests in amiodarone-treated patients.

Conclusion

Amiodarone induces alterations in thyroid hormone levels by actions on thyroidal secretion, on the peripheral tissues, and probably also on the pituitary gland.
Box 3

Summary points

- Amiodarone is a highly effective anti-arrhythmic agent but its use is associated with numerous side-effects.
- Amiodarone is an iodine-rich compound, the drug has many effects on thyroid physiology as well as thyroid hormone metabolism.
- The cardiac effects of amiodarone may be in part mediated by an antagonistic action to thyroid hormone by its metabolite, desethylamiodarone, at the cellular or subcellular level.
- AIT prevails in areas with low iodine intake; it may arise from either iodine-induced excessive thyroid hormone synthesis (type I) or destructive thyroiditis with release of preformed hormones (type II).
- Type IAIT usually occurs in patients with underlying thyroid abnormality and treatment commonly includes the use of thionamides and perchlorate, while surgery is reserved for refractory cases.
- Type II AIT commonly occurs in patients with apparently normal thyroid glands; thyrotoxicosis is often transient and resolves upon withdrawal of amiodarone, recovery is accelerated by glucocorticoid therapy.
- Monitoring of thyroid function should be performed in all amiodarone-treated patients to facilitate early diagnosis and treatment of amiodarone-induced thyroid dysfunction.

Figure 2 Algorithm for monitoring of thyroid function tests in amiodarone-treated patients

These actions result in elevations in serum T4 and rT3 concentrations, transient increases in TSH concentrations, and decreases in T3 concentrations. Both hypothyroidism and hyperthyroidism are prone to occur in patients receiving amiodarone. A proper understanding of the effects of amiodarone on thyroid physiology and thyroid hormone metabolism is thus crucial for the interpretation of thyroid function results in amiodarone-treated individuals. To complicate matters further, the results of standard thyroid function tests are often compounded by non-thyroidal illnesses. Therefore, it remains a challenging task for clinicians to ensure the appropriate diagnosis, monitoring and treatment of patients with amiodarone-induced thyroid dysfunction.
Amiodarone-induced thyrotoxicosis and hypothyroidism. 