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REVIEW ARTICLE

A Compressive Review of Pathophysiology Mechanisms, Diagnosis and Treatment Approaches for Thyroid Disorders in Small Ruminants

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Thyroid disorders of small ruminants are particularly problematic to the health and performance of these animals. The pathogenesis and therapeutic management of thyroid disorders, particularly hypo- and hyperthyroid diseases in sheep and goats, are recent knowledge discussed in this review article. Congenital or acquired hypothyroidism usually causes growth rate impairment, disruption of reproduction, and wool/hair abnormalities due to an excess of iodine or a goitrogen imbalance. Conversely, though rarer, hyperthyroidism is capable of causing metabolic disorders. Because thyroid function varies from species to species, diagnosis needs to be substantiated by a combination of clinical examination and analysis of hormones. Various treatment procedures, ranging from replacement of hormones and supplementation with iodine to remedial treatment of the causative nutritional or environmental defect, are available. In maximizing small ruminant population production and health, this review highlights the importance of proper diagnosis of thyroid disorder, including histopathology, serum thyroid hormone assay, radiographic, and iodine assessment test. It further highlights the therapeutic strategies such as antithyroid medications, beta blockers, iodine, T4, and selenium supplementation. Future research should focus on clarifying the exact causes and enhancing diagnostic and therapeutic methods for these economically important livestock species.

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INTRODUCTION

Thyroxine (T4) and triiodothyronine (T3) play significant roles in the role of the thyroid gland in small ruminant physiology, from metabolism to growth and reproduction (Tosheva and Siderova, 2022). These hormones play a central role in metabolism as regulators, controlling energy expenditure and basal metabolic rate (Sagliocchi *et al*., 2024). Their concentrations are closely related to metabolic activity, particularly during critical phases of growth and adaptation to environmental stresses such as cold (Vincent, 2024). Thyroid hormones are sensitive indicators of the nutritional status of an animal that reflect overall metabolic health as well as basic energy regulation (Kumar, 2023). They control muscle growth and protein synthesis during development, and this directly affects growth rates (Nappi *et al*., 2024). They also play a significant part in fiber production, and this affects quality of wool and hair (Hamadani *et al*., 2023). Levels of thyroid hormone are highly regulated by developmental age, with bursts of rapid growth occurring when activities are highest. Also, since it controls ovulation, pregnancy, lactation, and the estrous cycles, the part played by the thyroid in reproduction cannot be argued against (Petričević *et al*., 2025).

To maintain healthy breeding processes, the thyroid hormones control the expression of genes involved with ovarian and uterine processes (Mugesh *et al*., 2023). More importantly, thyroid hormone also helps control seasonal breeding by regulating the gonadotropin levels, which is an important part in the transition from breeding to anestrus period (Ren *et al*., 2024). The thyroid is critical to the overall health and workability of small ruminants due to its complex interaction with reproductive hormones like estradiol, which enable normal neuroendocrine function as well as feedback mechanisms (Lutterschmidt *et al*., 2024).

The thyroid follicular cells are the locus of the laboriously orchestrated process of thyroid hormone synthesis, crucial to metabolic and physiological regulation in small ruminants (Soundarrajan and Kopp, 2019). T4 and

T3 are generated through active uptake of iodine, a simple building block, which is then converted into thyroglobulin by thyroid peroxidase (Kim *et al*., 2021). Notably, selenium-dependent iodothyronine deiodinases (DIOs) deiodinate the initial product, T4, to yield the more physiologically active T3 (Köhrle, 2023). The hypothalamic-pituitary-thyroid (HPT) axis, a highly developed feedback process in which pituitary thyroid-stimulating hormone (TSH) stimulates thyroid hormone production, controls the whole process (Ortiga-Carvalho *et al*., 2011). The hypothalamus and pituitary receive feedback from plasma levels of T4 and T3, which in turn adjust TSH secretion to maintain hormonal homeostasis (Batistuzzo *et al*., 2023).

In addition, hormone production and release are also regulated by a complex intrathyroidal system of enzymes, transporters, and transcription factors (Gavrila and Hollenberg, 2019). T3 and T4 hormones are synthesized through iodine uptake by the sodium-iodide symporter (NIS), oxidation by thyroid peroxidase (TPO), and coupling of an important globular protein called iodotyrosine on thyroglobulin. Thyroid-stimulating hormone regulates this process while specific enzymes, such as DIO1 and DIO2 (deiodinases), convert T4 into T3 in various peripheral tissues. Mutations at any level of NIS, TPO, TSH receptors, DIO1, and DIO2 inhibit the production or activation and lead to thyroid dysfunction (Damiano *et al*., 2017; Kim *et al*., 2021).

The thyroid hormones are important in metabolism by controlling the metabolism of fat, carbohydrate, and protein (Cicatiello *et al*., 2018). They are also important in thermogenesis, which controls heat production and energy balance. They also influence the growth of neurons and mental functions, being essential for neurodevelopment (Montero-Pedrazuela *et al*., 2021). The need for proper control of hormones and therapeutic potential within the HPT axis and intrathyroidal network is underscored by disruption to this sensitive system, e.g., in hyperthyroidism or hypothyroidism (Jing and Zhang, 2022).

Clinical and pathological investigations, including histopathology and hormone assay in the serum, and imaging studies such as CT and ultrasound scanning, are utilized for establishing the diagnosis (Upadhyay and Kukrele, 2022). Environmental and nutritional control and proper iodine levels, as well as goitrogenic chemicals avoidance, form the main focus of preventive strategies. Congenital hypothyroidism is a serious concern and has to be tackled by selective breeding and genetic analysis in vulnerable breeds (Pearce, 2018). These thyroid conditions cause a wide range of effects on immunity, growth, and reproductive functions (Krassas and Markou, 2019). Although thyroid disease enhances the susceptibility to abortion, stillbirth, and neonatal death, congenital hypothyroidism and iodine deficiency cause growth failure and heightened susceptibility to disease (Sreelatha *et al*., 2018). Immunocompromised animals become more prone to diseases, which is an immediate threat to young animals. These illnesses impact farm profitability through lower productivity and higher cost of treatment (Coelho *et al*., 2024). Beyond continual soil and forage iodine content monitoring, prevention is also dependent on correcting environmental and dietary factors, such as avoidance of goitrogens and proper provision of iodine (Bhardwaj *et al*., 2022). Limiting congenital hypothyroidism in those breeds having inborn susceptibility requires selective breeding and genetic screening (Talebian Masoudi, 2024).

A proper diagnosis technique with a whole plan and exact treatment protocols is required in the treatment of thyroid gland disorders in small ruminants successfully (Dietrich *et al*., 2018). Diagnosis of the main symptoms like goiter, lethargy, and dyspnea, mostly important in congenital cases where myxedema and alopecia can be seen, needs to be done with complete physical examination and rigorous history taking. In order to distinguish between primary and secondary illnesses and in order to diagnose hypothyroidism, testing of hormones and more specifically, T3, T4, and TSH levels cannot be evaded (Alrehaili *et al*., 2018). Imaging methods like radiography, CT scans, and ultrasound also give a total scan of the thyroid gland and hence make it simpler to analyze its shape and size and spot abnormalities like hyperplasia (Iyer, 2020). In rural farm settings, the advanced imaging techniques, including CT and MRI, are not applicable because of their high costs, lack of availability of equipment, and skilled operators. However, ultrasound facilities are somehow affordable and are also available at farm sites. Hormone assays can support thyroid diagnosis if sample transport is possible. To take an accurate image of disorders, animal handling should be stress-free, and methods like ultrasound allow non-invasive evaluation. Mostly in farm settings commonly used method is palpation because it is less expensive, and costly equipment is not required for it (Upadhyay and Kukrele, 2022).

Knowledge of the fundamental pathophysiology is achieved through histopathological examination, which also confirms structural changes in the gland. Histopathological findings in thyroid disorders are often directly linked to the clinical findings. For example, in hypothyroidism, the follicular atrophy is strongly associated with low serum T3 or T4 levels, and clinical signs include poor growth and alopecia (Zhu *et al*., 2023). Similarly, in hyperthyroidism, follicular hyperplasia is associated with increased levels of thyroid hormones, and clinical signs include weight loss and hyperactivity (Sagliocchi *et al*., 2024). Furthermore, in goiter due to iodine deficiency, follicular cell atrophy is associated with neck swelling and reduced metabolism. Identification of causes involves environmental and nutritional assessments that focus on levels of iodine in the diet and in the environment (Knust and Leung, 2017). The cornerstone of therapy is iodine supplementation, which is administered in several forms to correct deficiencies and reduce goiter development (Lisco *et al*., 2023). To re-establish metabolic balance, severe hypothyroidism can be treated with hormone replacement therapy with synthetic thyroxine. Recurrence prevention is achieved through simultaneous management of underlying environmental and dietary factors, e.g., avoidance of goitrogenic medications (Parretti *et al*., 2016). Infrequently, surgery is indicated when large goiters produce marked respiratory distress (Zhu *et al*., 2023). The main focus of this article is on various commonly occurring thyroid gland disorders in small ruminants. This review also focuses on the diagnostic approaches, including histopathology, serum thyroid hormone assay, radiographic assessment, and iodine assessment test. Furthermore, it also discusses treatment strategies such as antithyroid medications, beta blockers, iodine, T4, and selenium supplementation for these disorders. The anatomical and physiological perspectives of the thyroid gland and the pathophysiology of various thyroid gland disorders are also discussed.

Causes of thyroid gland disorders in sheep and goat: Small ruminants, especially sheep and goats, are prone to numerous thyroid gland disorders that can significantly affect their productivity and health. The disorders are often due to genetic predispositions, environmental toxins, and nutritional deficiencies (Davoodi *et al*., 2022). The leading cause is a lack of iodine, which induces goiter, an enlargement of the thyroid gland, and is particularly destructive in congenital cases that induce stillbirth and death. The deficiency impacts development, altering the thyroid hormone levels of the mother and fetus (Olivieri *et al*., 2021). Hyperplastic goiter, also associated with iodine deficiency, is characterized by follicular hyperplasia, enlargement of the neck, and growth retardation. Inflammation and cysts of the thyroid cause complications in embryonic development by altering thyroid hormone (Malinka *et al*., 2024). Congenital hypothyroidism-otherwise under genetic control-produces profound developmental defects, including dwarfed limbs and decreased brain and cerebellar weights, through defective synthesis of thyroglobulin (Tanase-Nakao *et al*., 2024). Ironically, this overdose of iodine can also interfere with thyroid function and raise T4 and TSH levels, which can cause postnatal hypothyroidism (Fan *et al*., 2024). These all impact immunological function, growth, and reproductive success, resulting in reduced production and increased mortality, and financial loss (Velasco and Taylor, 2018). Some of the important thyroid gland disorders and their causes are given in Fig.1.

Anatomy and physiology of the thyroid gland in small ruminants: Anatomically, the thyroid gland, an important endocrine organ, is situated in the neck and consists of two lobes that are joined by a thin isthmus and flank the trachea (Guidoccio *et al*., 2019). The thyroid's structure facilitates its strategic position and protection. It is invested in a layer of connective tissue, divided into outer and inner portions, and often padded by encompassing fatty tissue (Balasubramanian, 2024). It is structured largely in the form of numerous follicles, which are round bodies consisting of colloid, a proteinaceous thyroid hormone storage medium (Al-Suhaimi and Khan, 2022). Simple cuboidal epithelial cells or follicular cells form the lining of these follicles. Its height may vary based on the level of activity of the gland, which is a direct manifestation of its role in hormone production (Mense and Boorman, 2018). Although fewer in number, parafollicular cells or the C-cells are present within these follicular cells and play an important role in the secretion of calcitonin hormone, which is critical for the maintenance of calcium homeostasis (Root, 2021). The synthesis, storage, and release of thyroid hormones are guaranteed by the arrangement of follicles and specific cells within a connective tissue matrix (Brix *et al*., 2019). The anatomical and histological features of the thyroid gland are given in Fig. 2.

By secreting and producing T4 and T3, the thyroid gland plays a physiological function of metabolic regulation. The main cellular elements, these thyrocytes, change shape depending on the functional activity of the gland, indicating an active role to play in the synthesis of hormones (Mugesh *et al*., 2023). The C-cells, invested in a rich capillary bed, also secrete calcitonin, which is accountable for calcium homeostasis. The HPT axis, a sophisticated feedback mechanism that ensures hormonal balance, controls this complex interaction between parafollicular and follicular cells with high accuracy (Root, 2021). Pituitary TSH stimulates the thyroid to secrete T4 and T3, which, in turn, give feedback to the pituitary and the hypothalamus to control the secretion of TSH. This very tightly controlled system indicates the importance of the thyroid to achieve metabolic balance and its connection with the general endocrine system (Gavrila and Hollenberg, 2019).

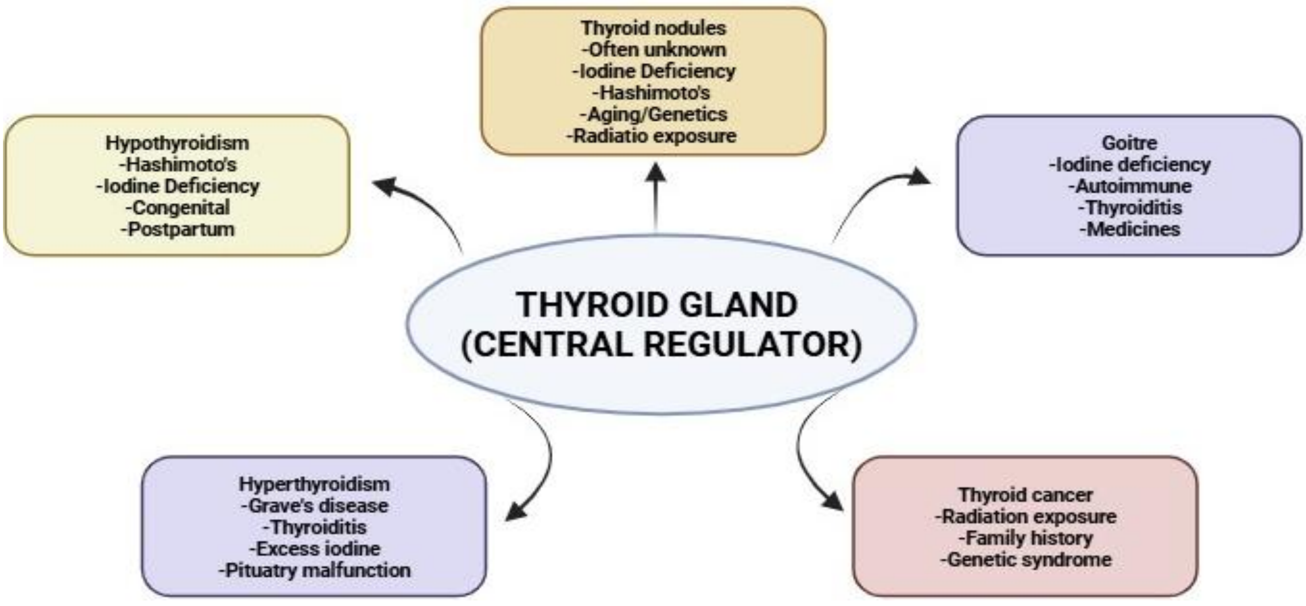

Fig. 1: Some important thyroid gland disorders and their causes in small ruminants. Created in https://BioRender.com.

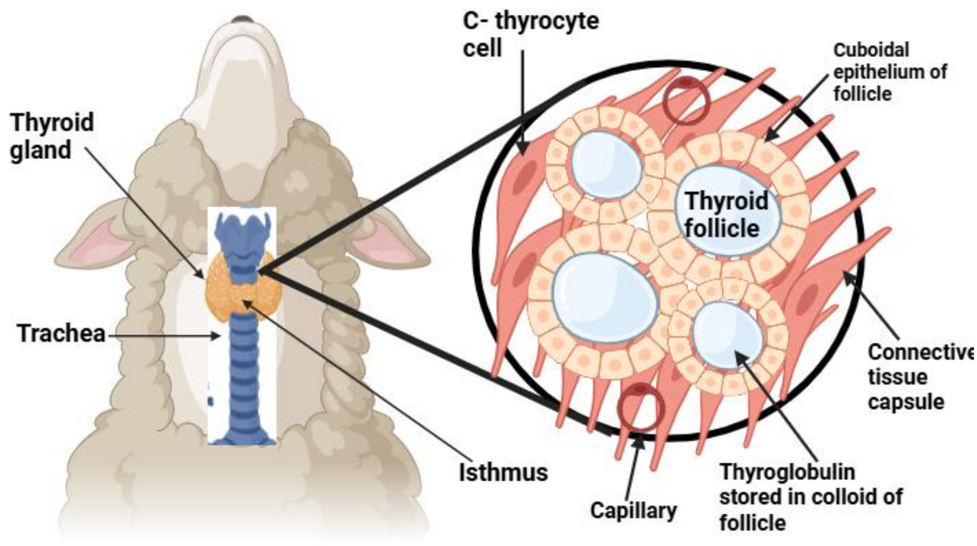

Fig. 2: Anatomical location and histological structure of the thyroid gland, highlighting hormone-producing follicles. Created in https://BioRender.com

The HPT axis, a highly complex system consisting of a cascade of hormonal interplay and inhibitory feedback loops, is directly responsible for most of the complicated control of release of thyroid hormones (Vella, 2018). The thyrotropin-releasing hormone (TRH) of the hypothalamus first acts upon the pituitary gland to cause release of thyrotropin (TSH), which in turn causes the thyroid gland to produce and secrete T3 and T4 (Shahid *et al*., 2018). Such homeostasis in hormone levels is attained through the tight regulation of this delicately controlled process by peripheral T4 and T3 negative feedback (Mancino *et al*., 2021). The operation of the thyroid is also significantly influenced by a range of major factors outside of this primary regulatory loop. Sufficient intake of iodine is necessary as it is part of thyroid hormones; in populations where the supply of iodine is low, the deficiencies can cause goiter and hypothyroidism (Olivieri *et al*., 2021). Selenium consumption is also crucial because it protects thyroid cells against oxidative damage and facilitates the conversion of T4 to the more physiologically active T3 (Wang *et al*., 2023). Thyroid function and disease susceptibility can also be disrupted and increased by environmental factors such as pollution and exposure to endocrine-disrupting chemicals such as bisphenols (Street *et al*., 2024). Climate change and heavy metal exposure are toxic to thyroid health. Inherited predispositions due to genetics also have a major role because they affect the regulation of hormones, environmental stress response, and susceptibility to thyroid disease (Gianì *et al*., 2021). Therefore, while diet and the HPT axis are the mainstays of thyroid health, control of thyroid function is managed holistically due to emerging awareness of environmental and genetic influences (Gavrila and Hollenberg, 2019). The release mechanism of thyroid hormones, along with its stimulating factors, is given in Fig. 3.

Global prevalence and economic impact of thyroid gland disorders: The most common reason for thyroid gland disease in small ruminants is iodine deficiency, and these conditions present a significant health hazard worldwide as well as an economic one. Depending on the environment and diet, incidence levels vary between sites (Bhardwaj, 2018). An excessive rate of goiter has been reported to be typical of the presentation. For instance, according to a study by Davoodi *et al*. (2022) in the Darreh Garm area of Iran, the goats exhibiting the condition displayed clearly lower serum thyroid hormone concentrations than normal goats. In some areas of sub-Saharan Africa, goiter prevalence may startlingly be as high as 64-70%. Congenital goiter and thyroid dysgenesis, which present with ectopic thyroid tissue and are also linked to dwarfism as well as osteoporosis, are further highlighted by Brazilian and Iranian case series by Kaké *et al*. (2019). Iodine deficiency, responsible for impairing the synthesis of thyroid hormones, is the primary etiology behind most of these conditions. Environmental factors are a major concern as highlighted by Zimmermann (2020), such as the low level of iodine in the soil and waters of the earth, seen in the northeastern region of Sicily and the Zhytomyr region in Ukraine. The genetic predispositions and nutritional factors, such as the consumption of goitrogenic medications, which interfere with the secretion of thyroid hormones, are also taken into consideration. With different rates of prevalence, the global distribution presents focal point in South America, Africa, Europe, and Asia. For example, endemic goiter prevalence of 28.6% was found in the Sekota village in Ethiopia (Babiker *et al*., 2020).

Small ruminant thyroid gland disorders are extremely expensive, mainly because of decreased production. Farmers experience significant economic losses through decreased milk production, slower growth rates, and lower reproductive performance caused by iodine deficiency (Pankowski and Bartyzel, 2023). Hypothyroid goats, for instance, have been shown to experience decreased fertility and higher mortality. The economic burden is added to by the cost of prevention and treatment, such as veterinary care, iodine supplements, and testing (Arnold *et al*., 2024). While there are cheap treatments like oil supplementation and iodized salt, it is not always possible to apply them in low-resource situations. Also, the medical ramifications of iodine insufficiency amplify the combined economic impact to pastoral communities in the most serious economic ways in those areas where small ruminants

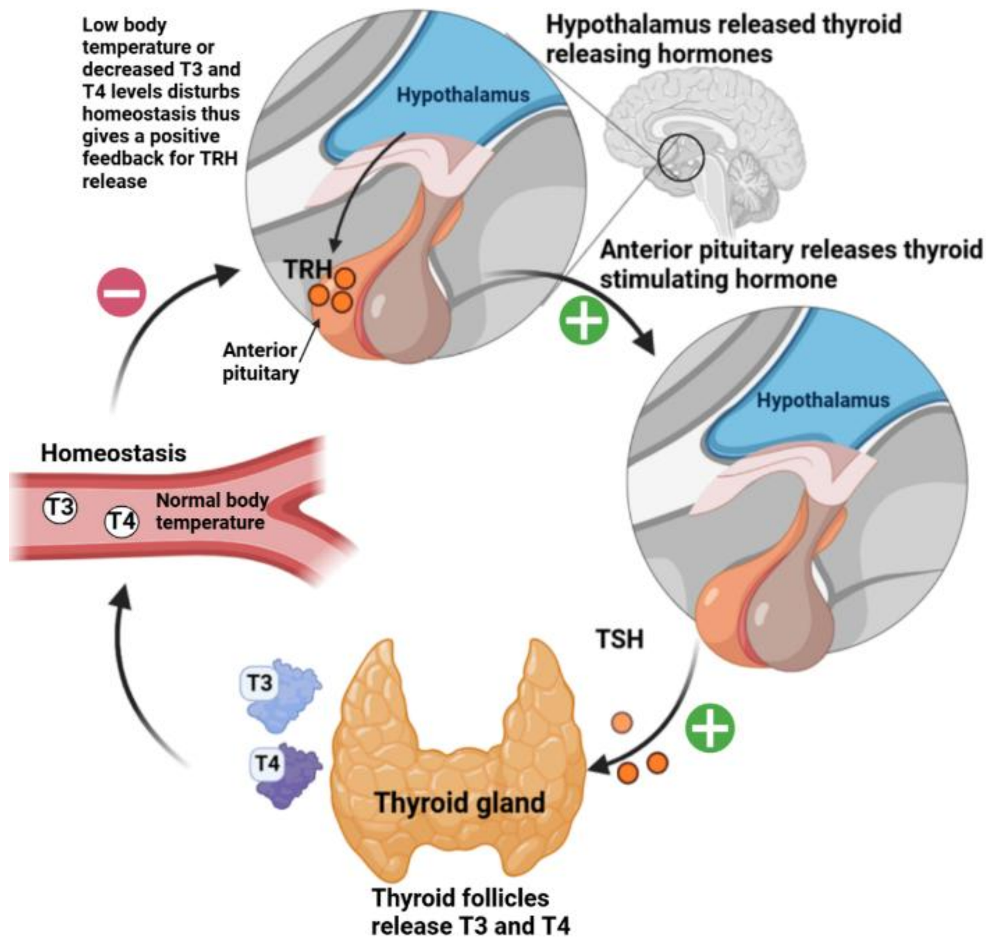

Fig. 3: Pathway illustrating the production and release of thyroid hormones (T3 and T4) via the hypothalamic-pituitary-thyroid axis. Created in https://BioRender.com

constitute a source of staple diet (Lisco *et al*., 2023). Once all the components are incorporated together, an intricate sequence of pressure economics is achieved to stress the necessity of efficacious methods of interventions towards the reduction of the impact of the problem of the thyroid gland on small ruminants around the world (Ligomina *et al*., 2024).

Commonly occurring thyroid gland disorders

Hypothyroidism: A prevalent endocrine disorder called hypothyroidism is caused by a complex interaction of factors leading to an insufficient production of thyroid hormone, and this may manifest with a host of clinical presentations (Zamwar and Muneshwar, 2023). The most prevalent etiology globally is iodine deficiency, which disrupts the T4 and T3 production by the thyroid gland through inhibition of the iodination of thyroglobulin. Such an impact can cause goiter, compromised intellectual development, even cretinism in severe cases (Pretell *et al*., 2017). Alternatively, goitrogenic substances including environmental toxins such as perchlorates and isothiocyanates of cruciferous plants inhibit the activity of thyroid peroxidase (TPO), thereby preventing thyroid hormone synthesis, leading to hyperplasia of the thyroid gland (Serrano-Nascimento and Nunes, 2022). Inadequate selenium, which is necessary to facilitate seleno-protein activities in T4-to-T3 conversion and in antioxidant defense, results in increased oxidative stress and the inhibition of enzymatic activity (Shimada *et al*., 2021). It is further associated with autoimmune thyroiditis as it enhances immunogenicity to thyroglobulin. Congenital hypothyroidism due to dysgenesis of the thyroid or dysfunction in hormone production needs early attention to prevent retardation of growth and intellectual inability (Ghemigian and Dumitru, 2024).

The primary factors for hypothyroidism in small ruminants, such as sheep and goats, include iodine deficiency, environmental stresses, and imbalances in the diet. Insufficiency of essential iodine prevents the thyroid hormones from being synthesized, and endogenous elements such as breed, age, sex, and climatic and seasonal influences also contribute to thyroid functions (Wani *et al*., 2023). Hypothyroidism is defined by a deficiency in the production of thyroid hormone, which is important for metabolic and overall physiological well-being. Clinically, these animals present with weakness, anemia, leg swelling, constipation, hair loss (alopecia), anorexia, lethargy, and dullness (Lokes-Krupka *et al*., 2020). This is supported by hormonal testing, with reduced body temperatures, reduced respiratory and heart rates, reduced levels of T4 and T3, and increased thyroid-stimulating hormone (TSH). Whereas preventative management emphasizes nutricareful monitoring, especially iodine consumption, to ensure the best thyroid function and buffer the condition against affecting animal health and productivity, treatment typically involves iodine supplementation, e.g., potassium iodide, that has proven effective in restoring normal thyroid function within weeks (Opazo *et al*., 2022). This shows the need for ongoing research with the ultimate goal of maximizing management practices. Although prevention management deals with cautious monitoring of nutrition, i.e., iodine intake, to maximize thyroid function and avoid the condition's impact on animal welfare and performance, treatment is mostly based on iodine supplementation, e.g., potassium iodide, which has been shown to restore normal thyroid function within a few weeks. This stresses the need for continuous research aimed at refining managerial practices (Pearce, 2018).

Hyperthyroidism: The primary etiology of hyperthyroidism in small ruminants, although rare, is autonomous thyroid nodules, autonomous hyperfunctioning adenomas, or iatrogenic iodine excess. All these etiologies lead to an overproduction of T4 and T3, disrupting the hypothalamic-pituitary-thyroid axis (Yahya *et al*., 2024). Weight loss despite adequate intake, insulin resistance, and glucose metabolic derangements are induced by this hormonal spurt, creating a hypermetabolic state of increased cellular metabolism and energy use (Vayakkattil and Vayakkattil, 2024). This is followed by certain pathophysiological mechanisms involving enhanced thyroid hormone release, which substantially distorts metabolic homeostasis. The hyperactivity of the deiodinases, the enzymes responsible for facilitating the conversion of T4 to T3, is key to this event and further drives the state of hypermetabolism (Russo *et al*., 2021).

Clinical presentation consists of enhanced hunger, muscle weakness, intolerance to heat, cardiovascular stimulation-induced tachycardia, loss of weight, and anxiety with abnormal behavior. To determine structural or functional thyroid abnormalities, diagnostic methods are thyroid palpation, ultrasound, and perhaps thyroid scans along with laboratory examinations of elevated T4 and T3 (Devaraj and Garnett, 2021). The primary aim of management is to restore normal thyroid function, which involves dietary iodine reduction for supplementation-induced hyperthyroidism, radioactive iodine therapy or surgery for autonomous nodules, and antithyroid drugs such as methimazole for severe cases (Chowdhury *et al*., 2024).

Goiter: The principal cause of goiter in small ruminants, especially in goats, is iodine deficiency, which leads to the hypertrophy of the thyroid glands to capture as much iodine as possible. This affects the normal secretion of thyroid hormones (Olivieri *et al*., 2021). Besides hereditary susceptibilities and other environmental stressors such as selenium deficiency and tobacco smoke, environmental sources such as lower soil and forage iodine concentrations also play a very significant role in this etiology (Hague, 2018). Two forms of goiter are recognized: parenchymatous goiter, which is usually observed at the beginning of a deficit and is characterized by thyroid tissue hyperplasia without obvious accumulation of colloid, and colloid goiter, which is characterized by more follicles containing colloid due to long-standing iodine deficiency (Li *et al*., 2016). Goiter development is strongly determined by iodine status; low environmental iodine reduces thyroid hormone synthesis, which could be effectively managed with iodine supplementation such as sodium thyroxine and preventive strategies such as universal salt iodization (Lisco *et al*., 2023). Due to the etiologic contributions of genetic and more general environmental factors, a combined management program involving dietary supplements and environmental modifications is required to reduce goiter risk, although iodine deficiency is of highest priority (Hague, 2018). Thyroid gland regulation and hormonal activity caused by various factors is illustrated in Fig. 4.

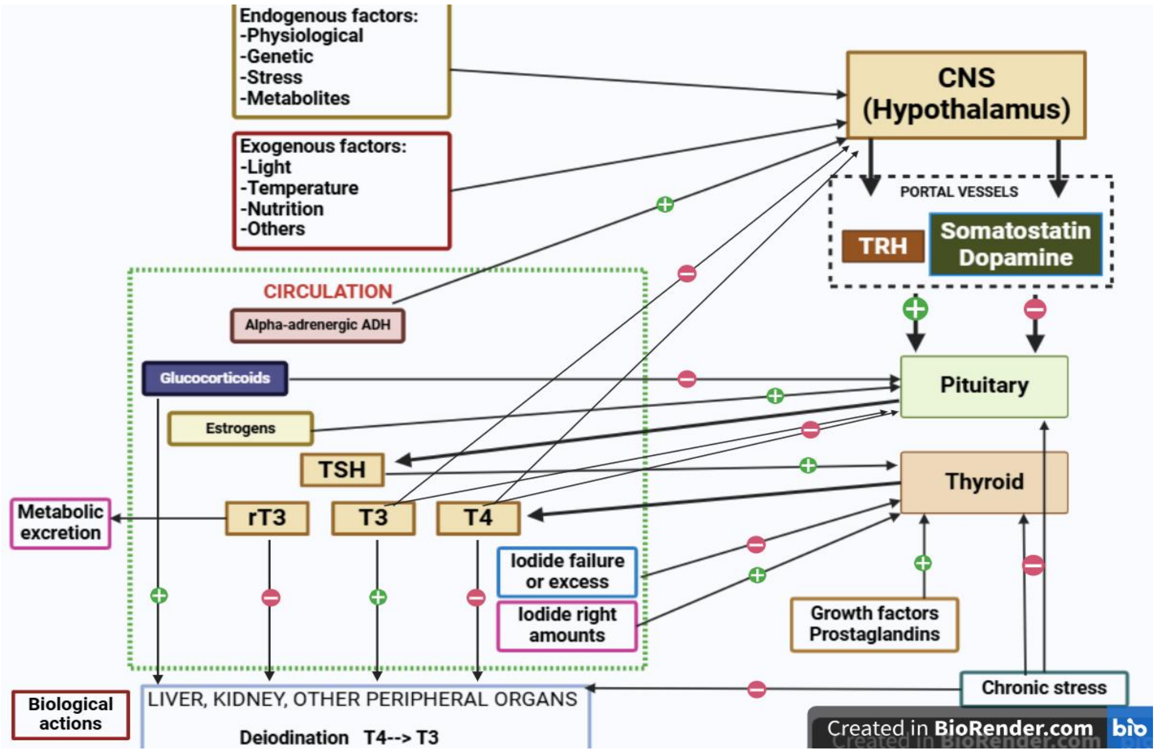

Fig. 4: Schematic representation of thyroid gland regulation and hormonal activity. Created in https://BioRender.com.

Congenital thyroid disorders: Iodine deficiency and inherited defects are primary causes of congenital thyroid disorders in small ruminants like sheep and goats, with a severe influence on the growth of neonates. Inherited factor plays an important role, particularly autosomal recessive mutations influencing thyroglobulin (TG) production (Kostopoulou *et al*., 2021). Exon 8 mutation in the TG gene causes premature termination codons in Dutch goats a resulting of truncated, non-translatable segments of TG developing into congenital hypothyroidism and goiter. The role of genetic defects in TG synthesis is emphasized by comparable rates of inherited goiter in bongo antelopes and Merino sheep (Pathak *et al*., 2024). Fetal thyroid and brain development are profoundly disrupted by iodine deficiency concurrently, primarily in areas of low soil and forage iodine. Iodine deficiency during pregnancy causes congenital goiter and retardation of infant growth, disruption of embryonic neurogenesis, reduction of brain weight and DNA, and inhibition of neuronal migration. The disorders highlight the importance of adequate iodine in embryonic thyroid hormone formation and neurologic development (Nguyen, 2023).

Growth retardation, respiratory distress, and decreased brain development are a few of the significant effects of these congenital thyroid abnormalities on infant growth. Newborns with hypothyroidism have more skin (myxedema), larger thyroid gland, decreased growth, and higher mortality (Makki, 2022). Because iodine deficiency results in late migration of cerebellar granule cells and increased cerebral cortex neuronal density, which are markers of decreased plasma T4 and T3 levels, brain development is specifically sensitive. Clinical examination, biochemical investigations (serum T4, T3), and imaging (ultrasonography, CT) are employed for the diagnosis of these conditions (De Groot *et al*., 2015). Low molecular weight iodinated material (LOMWIOM) in maternal urine can be utilized for the diagnosis of TG synthesis abnormalities in fetuses. Preventive measures include routine thyroid function monitoring in pregnant animals and offspring, universal salt iodization programs, and supplementation of the maternal diet with iodine. To enhance the health and productivity of small ruminant flocks and reduce the adverse effects of congenital thyroid disorders, efficient diagnostic and preventive strategies are needed (Mégier *et al*., 2023). Table 1 gives some of the thyroid gland disorders with their clinical signs, diagnostic approaches, and treatment strategies.

Diagnostic approaches: In ruminant medicine, clinical examination, especially palpation of the thyroid gland, is a basic, simple diagnostic test that is a quick and easy means of detecting potential thyroid malfunction. For the right assessment of the lobes' size, consistency, and mobility, and to detect goiters, which are a typical indicator of thyroid disease, the process should be familiar enough with the anatomy of the thyroid gland (Koshiishi *et al*., 2022). It has been proven through research that when done by experienced professionals, palpation yields quantitative results close to ultrasound values, again demonstrating its diagnostic validity. But recognize that palpation has its own limitations and will likely miss small abnormalities, particularly in the case of early-stage disease or when the gland is not very enlarged (Jacome *et al*., 2024). Furthermore, palpation accuracy significantly relies on the ability of the examiner, as such, emphasizing clinical skill proficiency. Despite the ability to provide critical lead information by means of palpation, the test often succeeds well when supported with other tests in diagnosis (Maan, 2025). Laboratory tests quantifying thyroid hormones provide critical functional information, adding to and reinforcing clinical data, while imaging by ultrasound, for example, provides precise imaging of thyroid architecture, allowing for careful assessment. Reliable management plans are possible through such multi-dimensional diagnosis, providing correct and comprehensive evaluation of thyroid health in small ruminants (Devaraj and Garnett, 2021).

With a focal point of central interest being serum levels of thyroid hormone (T3 and T4), TSH and feed and blood levels of iodine and selenium, biochemical assessment is essential in proper identification of thyroid gland dysfunction in small ruminants. The age, sex, and trace element status all have dramatic impacts on thyroid hormone levels T3 and T4, essential for the control of metabolism, growth, and reproduction (Köhrle, 2023). While T3 levels are quite stable, age-related fluctuation shows that T4 levels are highest in young animals and decrease with advancing age. Selenium deficiency directly impacts the metabolism of thyroid hormones, which may result in decreased T4 to T3 conversion and decreased levels of T3 and T3: T4 ratios (Lin *et al*., 2014). There are also gender differences: young male sheep contain higher T4 than female sheep. The pituitary gland releases TSH that regulates the release of T3 and T4. The test of TSH level is mandatory to diagnose hypothyroidism (Osorio *et al*., 2017). Normal animals have a low level of TSH, but due to diminished negative feedback, they become high in primary hypothyroidism.

Deficiency in iodine and selenium greatly damages the function of the thyroid gland (Wang *et al*., 2023). In the event that iodine, an essential constituent of thyroid hormones, is in short supply, the gland attempts to compensate by secreting increased amounts of TSH, which often results in goiter and fertility issues. When decreased, selenium primarily affects the levels of T3 because it is required for selenoproteins used in the conversion of T4 to T3 (Gorini *et al*., 2021).

The thyroid health is reflected in the levels of iodine and selenium in feed and serum. Iodine deficiency leads to hypothyroidism and needs supplementation to ensure proper thyroxine levels, particularly in nursing animals (Lossow *et al*., 2021). This is particularly necessary where there are shortages in soil and feed. Selenium deficiency affects the synthesis of T3, which has a bearing on the overall function of the thyroid gland (Kazi Tani *et al*., 2020). T3 has been shown to increase after supplementation with selenium, specifically organic forms, pointing to selenium's role in supporting optimal thyroid function, as during lactation. With both iodine and selenium needed for excellent thyroid metabolism of hormones and thyroid production, the interaction is of critical significance (Azorín *et al*., 2024). Thyroid dysfunction is exacerbated by combined selenium and iodine deficits, requiring combined supplements to increase selenium enzyme activity and T3 and T4 levels. Providing sufficient levels of both selenium and iodine is

Table 1: Some thyroid gland disorders along with clinical signs, diagnostic and treatment strategies

Thyroid gland disorders	Species affected	Etiology	Clinical signs and symptoms	Diagnostic approaches	Treatment strategies	Prognosis	References
Congenital hypothyroidism							
Iodine Deficiency-Induced Goiter	Sheep, Goats	Maternal gestational iodine deficiency, soil iodine deficiency	Goiter, weakness, alopecia, stillbirths, neonatal death, delayed skeletal maturation, stunted growth, myxedema (swelling), cretinism (in advanced cases), impaired thermoregulation, decreased fertility	Serum T3/T4 concentration (low), increased TSH, thyroid gland ultrasound, histological assessment of thyroid tissue (if possible)	Iodine supplementation (oral, injectable), iodine-enriched mineral licks for pregnant stock, dietary correction	Variable, depending on duration and severity of deficiency. Early treatment improves prognosis	(Lafta *et al.*, 2023)
Genetic forms	Sheep, Goats (certain breeds could have predispositions)	Genetic mutations of thyroid hormone production or receptor function	Like iodine deficiency, but could have certain breed-related characteristics, congenital goiter, disproportionate dwarfism, neurological impairments	Genetic test, serum T3/T4 concentration, TSH concentration, thyroid gland imaging, histopathology	Hormone replacement therapy (levothyroxine), supportive treatment	Poor prognosis, particularly if severe neurological impairment	(Moran *et al.*, 2022)
Acquired hypothyroidism							
Autoimmune thyroiditis	Sheep, Goats (less common than in other species)	Immune system attacking thyroid gland, genetic predisposition may be a factor	Goiter, progressive thyroid dysfunction, variable clinical signs (can be subtle), weight changes, weakness	Serum T3/T4 concentrations, TSH concentration, presence of thyroid autoantibodies, biopsy of thyroid gland	Hormone replacement therapy, immunosuppressive therapy (less frequent)	Variable, depending on extent and stage of disease	(Kostoglou-Athanassiou *et al.*, 2022)
Nutritional imbalances	Sheep, Goats . .	Consumption of goitrogenic plants (e.g., Brassica spp., soybeans), excessive nitrate consumption, mineral imbalance (e.g., excess calcium)	Goiter, weight gain, lethargy, dry hair and skin coat, decreased milk production, reproductive dysfunction, slowed wool/hair growth	Serum T3/T4 concentrations, TSH concentration, dietary evaluation, determination of goitrogen exposure, thyroid ultrasound	Elimination of goitrogenic sources, iodine supplementation (if concurrent iodine deficiency exists), hormone replacement therapy	Good with early intervention and elimination of goitrogenic factors	(Djuričić *et al.*, 2022)
Iatrogenic (e.g., Post-Surgery, Drug-Induced)	Sheep, Goats	Surgical ablation of thyroid tissue, administration of offending drugs that impact thyroid function (e.g., sulfonamides)	Hypothyroid signs, related to etiology, may appear after surgery, or following administration of drugs	Serum levels of T3/T4, levels of TSH, patient history.	Thyroid hormone replacement therapy, drug withdrawal	Excellent, if appropriately managed	(Economie, 2003)
Environmental Contaminants (e.g., Perchlorate)	Sheep, Goats	Exposure to environmental toxins that disrupt iodine uptake (e.g., perchlorate, thiocyanate)	Goiter, decreased thyroid hormone levels, reproductive disease, changed metabolism	Serum T3/T4 levels, TSH levels, environmental sampling for contaminants, evaluation of exposure history	Elimination of exposure, iodine supplementation, hormone replacement therapy	Variable, depending on contaminant and length of exposure	(Pearce and Braverman, 2017)
Hyperthyroidism (rare in small animals)							
Neoplasia (Thyroid Adenoma/ Carcinoma)	Sheep, Goats (very rare)	Malignant change of thyroid follicular cells	Weight loss, tachycardia, heat intolerance, nervousness, goiter (can be palpable), exophthalmos (rare), elevated metabolic rate	Serum T3/T4 concentration (increased), TSH concentration (decreased), thyroid scintigraphy, ultrasound, fine-needle aspiration, histopathology.	Surgical excision (if possible), radioactive iodine treatment (uncommon), chemotherapy (in case of carcinoma)	Poor, especially with carcinoma and metastasis	(Thapa *et al.*, 2024)
Thyroid neoplasia							
Carcinoma	Sheep, Goats	Thyroid follicular cell malignant tumor	Goiter (can be invasive), loss of weight, anorexia, respiratory distress (if trachea invaded), metastasis to lymph nodes and lungs	Serum T3/T4 levels, ultrasound, CT/MRI (staging), biopsy, histopathology	Surgical excision (if possible), chemotherapy, radiation therapy (rare)	Poor, particularly with metastasis	(Nguyen *et al.*, 2022)
Adenoma	Sheep, Goats	Benign tumor of thyroid follicular cells	Goiter (ordinarily unilateral), can be asymptomatic, mild hyperthyroidism (uncommon)	Serum T3/T4 concentrations, ultrasound, fine-needle aspiration, histopathology	Surgical removal (if symptomatic)	Good, with surgery	(Gupta *et al.*, 2020)

important to the prevention of thyroid disease and the health and productivity of small ruminants. This integrated biochemical screening, combined with the proper supplementation regimens, represents a strong plan for the management of thyroid function in the animals (Rayman and Duntas, 2019).

Both scintigraphy and ultrasound are significant imaging techniques in the diagnostic thyroid disease workup in small ruminants, having strengths and limitations. Chosen for being non-invasive with high resolution anatomy, ultrasound is a strong diagnostic tool which reports conditions such as thyroiditis and nodular disease and documents thyroid morphology fairly accurately (Mohan *et al*., 2023). Advances such as radiomics and incorporation with deep learning enhance the diagnostic accuracy of ultrasound by enhancing image segmentation, classification, and correlation of quantitative image features with clinical pathology. Its performance is operator skill-dependent, however, and it may yield unexpected results that require further studies (Yousefi *et al*., 2024). Radioisotope-based scintigraphy, on the other hand, detects residual or metastatic thyroid tissue after thyroidectomy and discriminates metabolically active from inactive nodules to offer functional assessment (Serpi *et al*., 2021). While scintigraphy is useful for functional assessment, it must be utilized in conjunction with other diagnostic modalities, especially ultrasonography, to obtain an overall image of thyroid pathology in small ruminants due to its low specificity for the discrimination between benign and malignant nodules. With an integration of anatomical and functional knowledge, the complementary approach maximizes diagnostic accuracy and minimizes thyroid complications to contend with (Schenke *et al*., 2023).

Histopathology, a complete microscopic study of the architecture of the thyroid tissue, is critical to the definite diagnosis of thyroid gland issues in small ruminants, particularly where goiter occurs endemically. Biopsy samples representing the tissues may be obtained with ultrasound-guided core biopsies, which have been more sensitive and specific than fine-needle aspiration cytology (Jung, 2024). Iodine-deficiency goiter in goats is characterized by thyroid follicles of various sizes and glandular hyperplasia, according to histopathological findings; in sheep, cysts, follicular hyperplasia, haemorrhage, and inflammation are frequent in the thyroids of dam and foetus. The clinical significance of histopathological findings is also suggested by experiments that show that hormonal replacement in goats following sodium thyroxine treatment emphasizes the intrinsic correlation between these structural defects and alterations in serum levels of thyroid hormones (Davoodi *et al*., 2022). The role of thyroid disease in development is further underscored by correlations between fetal age and sheep plasma T3 and T4 levels. Although histopathology is extremely informative for structural disease and thyroid disease, it is best utilized in a synergistic fashion with clinical data, radiographic imaging, and hormonal studies in a multidisciplinary system. Such a versatile strategy allows us to make more precise diagnosis and helps in preparing individualized and efficient therapeutic courses for thyroid ailments in small ruminants (Veena *et al*., 2018).

Treatment strategies: A multi-disciplinary approach involving thyroid hormone replacement, supplementation with iodine and selenium, and proper dietary control is essential for the treatment of hypothyroidism in small ruminants. Iodine, required for the synthesis of thyroid hormones, may be administered orally as potassium iodide solutions, mixed with feed as iodized salt, or intramuscularly as long-acting iodized oil injections (Mousa *et al*., 2021). The latter has special utility in increasing serum iodine and reducing thyroid enlargement in sheep. As suggested by elevated serum free triiodothyronine (FT3) and glutathione peroxidase activity, selenium, as well as iodine, not only increase thyroid hormone but also increase antioxidant enzyme activity, which is essential to thyroid function and overall well-being (Nóbrega, 2019). Although levothyroxine (LT4) is predominantly studied in human beings but its potential application in small ruminants maybe in combination with selenium needs to be considered to optimize thyroid function and even potentially decrease accompanying symptoms. Levothyroxine alone is rarely used in small ruminant. The research study revealed that minute quantity of it i.e. 10-40µg/kg in sheep and 10-30µg/kg in goats is very effective in treating hyperthyroidism (Divers and Peek, 2014).

Direct hormone replacement therapy treats hormone deficiency directly (Sun *et al*., 2021). Temporally, by eliminating goitrogenic foods, such as in brassica vegetables, that interfere with iodine absorption and increase thyroid enlargement, nutritional control plays a critical role in preventing and alleviating hypothyroidism. This indicates the need for individualized nutritional therapy in stimulating thyroid activity. Thyroid hormone function and iodine and selenium status need to be monitored regularly to facilitate maximum treatment effects and prevent side effects, and that will be to ensure maximum productivity and overall well-being of small ruminant flocks (Muzzaffar *et al*., 2022). In severe cases, when clinical signs become more prominent, then controlled dosage of iodine in the form of potassium iodide and selenium injection may be given (Mousa *et al*., 2021). Whilst uncommon than in hypothyroidism, small ruminant hyperthyroidism requires an earnest management strategy based on attacking the cause, namely autoimmune disorders such as Graves' disease linked with thyroid-stimulating hormone receptor antibodies (TRAb) that lead to overproduction of thyroid hormone.

To achieve euthyroidism, the first line of therapy is usually antithyroid drugs (ATDs), primarily methimazole, which effectively inhibits thyroid hormone production by interfering with iodine oxidation and iodotyrosine coupling (Bhat *et al*., 2022). Side effects like agranulocytosis and hepatotoxicity must be vigilantly watched out for. Although encouraging long-term ATD therapy remission rates exist, patient response, side effect profile, and level of TRAb need to be evaluated in each individual case (Kim *et al*., 2018). A surgical thyroidectomy is a last resort that seeks to cut off the source of excess hormone production, particularly in patients with large goiters, compressive symptoms, or where medical therapy fails. With recent studies pointing to safe surgery in stable hyperthyroid patients, preoperative preparation, which used to focus on achieving euthyroidism to minimize complications such as thyroid storm, is evolving (Uludag *et al*., 2024). To effectively handle hyperthyroidism and sustain maximum health, specially designed treatment plans considering the specific needs and clinical picture of every individual small ruminant are essential, as evident from successful surgeries and the prevention of long-term effects.

In controlling goiter in small ruminants, one has to manage underlying etiologies and, in severe cases, even resort to surgery (Chowdhury *et al*., 2024). Of the primary causes, iodine deficiency can easily be prevented with universal salt iodization, a preventive strategy supported by the WHO. In the absence of this option, administration of iodized oil can be applied, particularly where endemicity is high (Ghareeb *et al*. 2015). Finally, feed or supplements containing iodine can be utilized to overcome iodine-deficient local produce. Aside from iodine supplementation, however, thyroid hypertrophy is primarily brought about by local growth factors that are TSH-regulated, hinting at a complex interaction in goiter development (Duborská *et al*., 2020). Another therapeutic measure is surgical intervention, reserved for cases with obstructive large goiters, possible malignancy, or cases where radioiodine therapy is not indicated. In contrast, for those who prefer not to have surgery or are high-risk candidates for surgery, radioiodine treatment is an available non-surgical alternative, especially for non-toxic multinodular goiter (Riguetto *et al*., 2020). Hence, for optimal management of goiter in small ruminants, a comprehensive strategy involving iodine supplementation, dietary adjustment, and judicious use of surgical or radioiodine treatments must be employed. This method must be tailored to the specific context and severity of the goiter.

In order to prevent irreversible neurodevelopmental problems, of specific importance in high-prevalence areas, early diagnosis by effective screening programs is the starting point of the complete treatment of congenital thyroid disease in neonatal small ruminants (Duntas, 2023). The cornerstone of treatment is the early onset of levothyroxine replacement therapy during the first two weeks of life, with individually adjusted dosing based on TSH and thyroid hormone levels. Careful monitoring of growth and meticulous caregiver education are also important features of management (He *et al*., 2022). Of particular note, intraruminal devices or intramuscular injections of pregnant maternal iodine markedly elevate milk iodine concentrations, reducing neonatal goiter and ensuring optimal thyroid function without injuring either the mother or the fetus. However, close follow-up for the development of thyroid autoantibodies remains necessary (Fuse *et al*., 2023). Through mutation carrier identification and progeny risk assessment, especially in high-risk breeds, genetic counseling improves management further and helps guide breeding decisions to reduce disorders prevalence. Levothyroxine therapy is customized for individual hormonal management based on molecular diagnostics that distinguish between dysembryogenesis and dyshormonogenesis (Figueiredo *et al*., 2018). To reduce the adverse impacts of congenital thyroid disorders on the health of small ruminants, there is a need for early intervention and an integrated approach, despite the important role played by genetic factors. Environmental factors and management practices should also be considered (Persani *et al*., 2024).

Prevention and management: For thyroid gland disease prevention in small ruminants, nutrition control must be dependable. T3 and T4 are iodine production dependent, and they should be supplemented at 0.1–0.3 mg/kg dry matter intake. For preventing both excess and lack, serum total iodine concentration (STIC) should range from 20 to 100 µg/L (Chodkowski, 2024). Selenium potentiates the action of iodine and is required for glutathione peroxidase and selenoprotein-dependent deiodinases. Where selenium is low, supplement with 50–100 µg/day of selenium supplements (Bai *et al*., 2024). Avoid goitrogenic foods such as soybeans and Brassica species, which inhibit the absorption of iodine, particularly in pregnancy and lactation. Early detection is secured through continuous monitoring with pathological examinations, biochemical assays (TSH, T3, and T4), and clinical signs. It is important to apply genetic testing for detecting and preventing mutations in an effort to choose those breeds having the best thyroid function (Gwata *et al*., 2025).

Environmental management is equally important. Thyroid function can be affected by climate and season, and therefore, in bad weather, proper shelter and food are essential. Iodine, selenium, iron, zinc, and vitamins A, C, and E are all essential components of a well-nourished diet (Shulhai *et al*., 2024). Newborn thyroid-weight: birthweight (TW:BW) ratios can be used to determine the iodine status of newborns; the higher the ratio, the more deficient they will be. Sufficient supply of iodine is ensured by supplementing with fortified food, oil injections, or iodized salt. Iodine and selenium interact synergistically and thus both need to be monitored (Jafri *et al*., 2019). Exclude the contaminants that act as goitrogens, such as thiocyanates and isoflavones. In general, for a small ruminant to ensure thyroid function, a multi-modal strategy incorporating environmental, genetic, and nutritional factors is required (Muzzaffar *et al*., 2022).

Future research directions: Future studies of thyroid gland disease in small ruminants must adopt a multistaked holder approach, with a focus on enhanced diagnostics and new interventions. Although genetic research aims at the mapping of loci controlling thyroid mal-function to facilitate breed-based breeding schemes, molecular diagnostics such as qRT-PCR and next-generation sequencing identify exact biomarkers to diagnose early disease. Probiotics (*Lactiplantibacillus plantarum* 299v, *Bifidobacterium longum*) and fecal microbiota transplantation (FMT) are two of the novel therapeutic strategies that have potential for altering the gut microbiota, an essential component of thyroid function influencing neurotransmitters and trace elements throughout the gut-brain and gut-thyroid axes. Since cilia are involved in autoimmune thyroid diseases and thyroid cancer, therapies that are designed to repair primary cilia function in thyroid follicular cells are equally important. Successful management methods depend on knowledge of the long-term consequences of thyroid pathology on productivity, including reduced feed efficiency and reproductive performance in hypothyroidism and augmented metabolic rate and reduced lifespan in hyperthyroidism.

More work must also be done to further define the effect of environmental toxicants and the gut microbiome on thyroid gland function. Identification and prevention research on endocrine-disrupting chemicals such as bisphenols, phthalates, and per- and poly-fluoroalkyl substances is warranted since they are known to disturb thyroid hormone pathways. The mode of action for heavy metals including lead, mercury, and cadmium must also be studied to a large degree since they bind to thyroid-binding proteins and displace iodide from thyroid. Considering the role of the gut microbiota and the link between dysbiosis and thyroid cancer and autoimmune thyroid diseases, investigation of specific bacterial strains (e.g., Lactobacillus and Bifidobacterium) and short-chain fatty acids (SCFAs) as potential therapeutic targets is indicated. Thyroid hormone homeostasis and immunomodulation are imposed directly by changes in the production of bile acid and cytokines that are regulated by gut flora. To improve the productivity and health of small ruminants, it is recommended that future research use these findings to design and implement comprehensive prevention and treatment plans for thyroid gland disorders.

Conclusions: Thyroid gland disease is a significant, though often underdiagnosed, health problem in small ruminants. The pathophysiology of the disease, particularly hypothyroidism, is intimately associated with dietary goitrogens and iodine status, and has a major effect on growth, reproduction, and overall productivity. Treatment strategies must be adapted to the species and etiology, emphasizing hormone replacement, iodine supplementation, and resolution of the underlying environmental or nutritional basis. This review puts forth the need for more knowledge and research into the complexities of sheep and goat thyroid physiology. To enhance economic sustainability and animal welfare in small ruminant production systems, future research has to focus on developing standardized diagnosis techniques and more effective treatment options. Such a comprehensive knowledge of these diseases will enable the producers and the veterinarians to adopt preventive steps, maintaining their health and productivity.

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REFERENCES

Al-Suhaimi EA and Khan FA, 2022. Thyroid glands: Physiology and structure. In: Emerging concepts in endocrine structure and functions. Springer, pp:133-160.

Alrehaili MA, Alharbi AA, Siraj MM, *et al*., 2018. Causes, diagnosis, and management of hypothyroidism. Egypt J Hosp Med 71(1):2250-2252.

Arnold JC, Onono J, Ballesteros C, *et al*., 2024. Modeling the economic performance of small ruminant pastoralist flocks and financial impact of changes in reproductive performance and mortalities in Kajiado county, Kenya. Front Sustain Food Syst 8:1406864.

Azorín I, Madrid J, Martínez-Miró S, *et al*., 2024. Combined supplementation of two selenium forms (organic and inorganic) and iodine in dairy cows' diet to obtain enriched milk, cheese, and yogurt. Animals 14(9):1373.

Babiker A, Alawi A, Al Atawi M, *et al*., 2020. The role of micronutrients in thyroid dysfunction. Sudan J Paediatr 20(1):13.

Bai S, Zhang M, Tang S, *et al*., 2024. Effects and impact of selenium on human health, a review. Molecules 30(1):50.

Balasubramanian SP, 2024. Anatomy of the thyroid, parathyroid, pituitary and adrenal glands. Surgery 38(12):758-762.

Batistuzzo A, Salas-Lucia F, Gereben B, *et al*., 2023. Sustained pituitary T3 production explains the T4-mediated TSH feedback mechanism. Endocrinology 164(12):bqad155.

Bhardwaj A, Jadhao A, Sheetal SK, *et al*., 2022. Thyroid profile of a hypothyroidism affected doe: a case report. Haryana Vet 61(SI): 121-122.

Bhardwaj RK, 2018. Iodine deficiency in goats. Goat Sci 75-84.

Bhat JA, Patto SM, Sharma P, *et al*., 2022. Therapeutic options in Graves' hyperthyroidism. In: Hyperthyroidism–Recent Updates. IntechOpen.

Brix K, Qatato M, Szumska J, *et al*., 2019. Thyroglobulin storage, processing and degradation for thyroid hormone liberation. The Thyroid and Its Diseases: A Comprehensive Guide for the Clinician. pp:25-48.

Chodkowski J, 2024. The role of nutritional supplementation in hypothyroidism: a review. Qual Sport 32:56083-56083.

Chowdhury R, Turkdogan S, Silver JA, *et al*., 2024. Approach to hyperthyroidism. J Otorhinolaryngol Hear Balance Med 5(2):20.

Cicatiello AG, Di Girolamo D, Dentice M, 2018. Metabolic effects of the intracellular regulation of thyroid hormone: old players, new concepts. Front Endocrinol 9:474.

Coelho N, Camarinho R, Garcia P, *et al*., 2024. Histological evidence of hypothyroidism in mice chronically exposed to conventional farming. Environ Toxicol Pharmacol 106:104387.

Damiano F, Rochira A, Gnoni A, *et al*., 2017. Action of thyroid hormones, T3 and T2, on hepatic fatty acids: differences in metabolic effects and molecular mechanisms. Int J Mol Sci 18(4):744.

Davoodi F, Zakian A, Rocky A, *et al*., 2022. Incidence of iodine deficiency and congenital goitre in goats and kids of Darreh Garm region, Khorramabad, Iran. Vet Med Sci 8(1):336-342.

De Groot LJ, Chrousos G and Dungan K, 2015. Thyroid hormones in brain development and function. Endotext-NCBI Bookshelf 2000:1-62.

Devaraj S and Garnett E, 2021. Thyroid disease and laboratory assessment. In: Handbook of Diagnostic Endocrinology. Elsevier, pp:69-101.

Dietrich CF, Müller T, Bojunga J, *et al*., 2018. Statement and recommendations on interventional ultrasound as a thyroid diagnostic and treatment procedure. Ultrasound Med Biol 44:14-36.

Divers TJ, Peek SF, 2014. Endocrine diseases of ruminants. In: Smith BP (Ed), Large Animal Internal Medicine, 5th ed. Elsevier Mosby, St. Louis, MO, pp:1461-1475.

Djuričić I, Todorović V, Dabetić N, *et al*., 2022. Dietary factors and thyroid dysfunction. Arch Pharm 72:455-467.

Duborská E, Urík M, Šeda M, *et al*., 2020. Iodine biofortification of vegetables could improve iodine supplementation status. Agronomy 10(10):1574.

Duntas LH, 2023. Nutrition and thyroid disease. Curr Opin Endocrinol Diabetes Obes 30(6):324-329.

Economie ASP, 2003. Revista a fost înregistrată la Ministerul Justiției al Republicii Moldova la 18:07-2003.

Fan L, Bu Y, Chen S, *et al*., 2024. Iodine nutritional status and its associations with thyroid function of pregnant women and neonatal TSH. Front Endocrinol 15:1394306.

Figueiredo CM, Falcão I, Vilaverde J, *et al*., 2018. Prenatal diagnosis and management of a fetal goiter hypothyroidism due to dyshormonogenesis. Case Rep Endocrinol 2018(1):9564737.

Fuse Y, Ogawa H, Tsukahara Y, *et al*., 2023. Iodine metabolism and thyroid function during the perinatal period: maternal-neonatal correlation and effects of topical povidone-iodine skin disinfectants. Biol Trace Elem Res 201(6):2685-2700.

Gavrila A, Hollenberg AN, 2019. The hypothalamic-pituitary-thyroid axis: physiological regulation and clinical implications. In: The Thyroid and Its Diseases: A Comprehensive Guide for the Clinician. Springer, pp:13-23.

Ghareeb OA, Ali QA, Abed QJ, *et al*., 2015 Iodine: a micronutrient essential for human development and survival. In: Disease and Health: Research Developments. pp:978-993

Ghemigian AM and Dumitru N, 2024. Congenital hypothyroidism. In: Hypothyroidism - Causes, Screening and Therapeutic Approaches. IntechOpen 1005825

Gianì F, Masto R, Trovato MA, *et al*., 2021. Heavy metals in the environment and thyroid cancer. Cancers 13(16):4052.

Gorini F, Sabatino L, Pingitore A, *et al*., 2021. Selenium: an element of life essential for thyroid function. Molecules 26(23):7084.

Guidoccio F, Aghakhanyan G, Grosso M, *et al*., 2019. Hybrid imaging and radionuclide therapy for thyroid disorders. Nucl Med Textb Methodol Clin Appl 42:707-747.

Gupta A, Tyagi S, Yadav ML, *et al.*, 2020. Association of fine needle aspiration cytology with histopathology and thyroid-stimulating hormone in the diagnosis of thyroid lesions. J Mahatma Gandhi Univ Med Sci Technol 5(1):9-15.

Gwata ET, Onipe OO, Naicker O, *et al.*, 2025. A survey of goitrogenic compounds in selected millets and cruciferous vegetables: nutritional downside. In: Food Security and Nutrition. CRC Press, pp:367-381.

Hague A, 2018. Apoptosis and cell death. In: Scott-Brown's Otorhinolaryngology and Head and Neck Surgery. CRC Press, pp: 59-68.

Hamadani A, Ganai NA, Rather MA, *et al.*, 2023. Important genes affecting fibre production in animals: a review. Indian J Anim Sci 93(10):939-945.

He S, Ma X, Yang J, *et al.*, 2022. Levothyroxine treatment for congenital hypothyroidism based on thyroid function: a 10-year clinical retrospective study. BMC Endocr Disord 22(1):142.

Iyer P, 2020. Imaging of the thyroid gland. In: Thyroid and Parathyroid Disorders in Children, CRC Press, pp:13-20.

Jacome CS, Garcia A, Golembiewski E, *et al.*, 2024. Physical examination of the thyroid: accuracy in detecting thyroid nodules and frequency of additional findings. Endocr Pract 30(1):31-35.

Jafri L, Majid H, Ahmed S, *et al.*, 2019. Iodine deficiency in neonates: where do we stand after a quarter century of initiating iodization programs? Lab Med Online 9(4):232-235.

Jing L and Zhang Q, 2022. Intrathyroidal feedforward and feedback network regulating thyroid hormone synthesis and secretion. Front Endocrinol 13:992883.

Jung CK, 2024. Core needle biopsy for the diagnosis of thyroid nodules: Pathologic aspects. In: Thyroid FNA Cytology: Differential Diagnoses and Pitfalls, pp:587-597.

Kaké A, Diallo MM, Sylla D, *et al.*, 2019. Thyroid disease at the University Hospital of Conakry, Guinea. Open J Intern Med 9(4):105-111.

Kazi Tani LS, Dennouni-Medjati N, Toubhans B, *et al.*, 2020. Selenium deficiency—from soil to thyroid cancer. Appl Sci 10(15):5368.

Kim H, Lee J, Ha J, *et al.*, 2018. A case of antithyroid drug-induced agranulocytosis from a second antithyroid drugs (ATD) administration in a relapsed Graves' disease patient who was tolerant to the first ATD treatment. Clin Case Rep 6(9):1701-1703.

Kim K, Kopylov M, Bobe D, *et al.*, 2021. The structure of natively iodinated bovine thyroglobulin. Biol Crystallogr 77(11):1451-1459.

Knust KS and Leung AM, 2017. Iodine: basic nutritional aspects. In: Molecular, Genetic, and Nutritional Aspects of Major and Trace Minerals, Elsevier, pp:133-141.

Köhrle J, 2023. Selenium, iodine and iron–essential trace elements for thyroid hormone synthesis and metabolism. Int J Mol Sci 24(4):3393.

Koshiishi H, Yoshimura T, Takahashi S, *et al.*, 2022. Clinicopathologic examination of the resected cases of thyroid benign tumor diagnosed class Ⅲ by fine needle aspiration cytology. Gan To Kagaku Ryoho 49(13):2022-2024.

Kostoglou-Athanassiou I, Athanassiou L, Athanassiou P, *et al.*, 2022. Autoimmune Hashimoto's thyroiditis and hypothyroidism: novel aspects. In: Hypothyroidism-New Aspects of an Old Disease, IntechOpen.

Kostopoulou E, Miliordos K, Spiliotis B, *et al.*, 2021. Genetics of primary congenital hypothyroidism-a review. Hormones 20:225-236.

Krassas GE and Markou KB, 2019. The impact of thyroid diseases starting from birth on reproductive function. Hormones 18(4):365-381.

Lafta MH, Jarad A, Al Saad KM, *et al.*, 2023. Goiter in cross breed goat kids at Basrah Province, Iraq. Arch Razi Inst 78(2):531.

Li K, Yu J and Kang W, 2016. Iodine intake and thyroid disease. Chin J Endemiol pp:166-169.

Ligomina I, Sokulskyi I, Sokoluk V, *et al.*, 2024. Iodine deficiency as an environmental risk factor for thyroid gland diseases in animals. Ukr J Vet Agric Sci 7(2):36-42.

Lin SL, Wang CW, Tan SR, *et al.*, 2014. Selenium deficiency inhibits the conversion of thyroidal thyroxine (T4) to triiodothyronine (T3) in chicken thyroids. Biol Trace Elem Res 161:263-271.

Lisco G, De Tullio A, Triggiani D, *et al.*, 2023. Iodine deficiency and iodine prophylaxis: an overview and update. Nutrients 15(4):1004.

Lokes-Krupka TP, Tsvilichovsky MI, Zarytskyi SM, *et al.*, 2020. Clinical signs of hypothyroidism in domestic dogs. Sci Mess LNU Vet Med Biotechnol Ser Vet Sci 22(99):80-83.

Lossow K, Renko K, Schwarz M, *et al.*, 2021. The nutritional supply of iodine and selenium affects thyroid hormone axis related endpoints in mice. Nutrients 13(11):3773.

Lutterschmidt DI, Stratton K, Winters TJ, *et al.*, 2024. Neural thyroid hormone metabolism integrates seasonal changes in environmental temperature with the neuroendocrine reproductive axis. Horm Behav 161:105517.

Maan K, 2025. Thyroid biopsy specialist sonographer program. Can J Med Sonogr 16(1):2-7.

Makki KA, 2022. Congenital goitre and respiratory distress as rare presenting features of congenital hypothyroidism in the newborns. Int J Health Sci 6(S9):3543-3550.

Malinka Z, Gmitrzuk J, Wiśniewska K, *et al.*, 2024. The role of iodine in thyroid function and iodine impact on the course of Hashimoto's thyroiditis-review. Qual Sport 16:52639.

Mancino G, Miro C, Di Cicco E, *et al.*, 2021. Thyroid hormone action in epidermal development and homeostasis and its implications in the pathophysiology of the skin. J Endocrinol Investig 44:1571-1579.

Mégier C, Dumery G and Luton D, 2023. Iodine and thyroid maternal and fetal metabolism during pregnancy. Metabolites 13(5):633.

Mense MG and Boorman GA, 2018. Thyroid gland. In: Boorman's Pathology of the Rat, Elsevier, pp:669-686.

Mohan SL, Govindarajalou R, Chakkalakkoombil SV, *et al.*, 2023. Ultrasound imaging of thyroid pathologies: a pictorial review. Indographics 2(2):79-94.

Montero-Pedrazuela A, Grijota-Martínez C, Ausó E, *et al.*, 2021. Endocrine aspects of development. Thyroid hormone actions in neurological processes during brain development. In: Diagnosis, Management and Modeling of Neurodevelopmental Disorders, Elsevier, pp:85-97.

Moran C, Schoenmakers N, Visser WE, *et al.*, 2022. Genetic disorders of thyroid development, hormone biosynthesis and signalling. Clin Endocrinol 97(4):502-514.

Mousa SA, Elmeligy E, Hassan D, *et al.*, 2021. Effect of oral administration of potassium iodide on clinical status and metabolic profile in sheep. Adv Anim Vet Sci 9(6):845-855.

Mugesh G, Giri D, Mondal S, *et al.*, 2023. Chemical biology of thyroid hormones. Asia Chem Mag 3(1):136-145.

Muzzaffar S, Nazir T, Bhat MM, *et al.*, 2022. Goitrogens. In: Handbook of Plant and Animal Toxins in Food, CRC Press, pp:125-154.

Nappi A, Moriello C, Morgante M, *et al.*, 2024. Effects of thyroid hormones in skeletal muscle protein turnover. J Basic Clin Physiol Pharmacol 35(4-5):253-264.

Nguyen CT, 2023. An update: maternal iodine supplementation, thyroid function tests, and child neurodevelopmental outcomes. Curr Opin Endocrinol Diabetes Obes 30(5):265-272.

Nguyen M, He G, Lam AKY, *et al.*, 2022. Clinicopathological and molecular features of secondary cancer (metastasis) to the thyroid and advances in management. Int J Mol Sci 23(6):3242.

Nóbrega AGC, 2019. Micronutrient influence in thyroid function: a review. Int J Nutrol 12(2):52-60.

Olivieri A, De Angelis S, Moleti M, *et al.*, 2021. Iodine deficiency and thyroid function. In: Thyroid, Obesity and Metabolism: Exploring Links Between Thyroid Function, Obesity, Metabolism and Lifestyle. pp:3-20.

Opazo MC, Coronado-Arrázola I, Vallejos OP, *et al.*, 2022. The impact of the micronutrient iodine in health and diseases. Crit Rev Food Sci Nutr 62(6):1466-1479.

Ortiga-Carvalho TM, Chiamolera MI, Pazos-Moura CC, *et al.*, 2011. Hypothalamus-pituitary-thyroid axis. Comp Physiol 6(3):1387-1428.

Osorio JH, Correa Carvajal D and Pérez JE, 2017. Concentraciones de hormona estimulante de la tiroides y tiroxina libre en ovinos jóvenes. Rev Med Vet (33):77-81.

Pankowski F and Bartyzel BJ, 2023. Computed tomographic, ultrasonographic and radiographic features of caprine congenital goiter and normal thyroid gland in 2-month-old goats. Folia Pomer Univ Technol Stetin Agric Aliment Piscaria Zootech 65(1):366.

Parretti H, Okosieme O and Vanderpump M, 2016. Current recommendations in the management of hypothyroidism: developed from a statement by the British Thyroid Association Executive. Br J Gen Pract 66(651):538-540.

Pathak A, Asediya V, Mishra A, *et al.*, 2024. Diseases of the endocrine system of goats. Trends Clin Dis Prod Manag Goats. pp:299-312.

Pearce EN, 2018. Iodine nutrition: recent research and unanswered questions. Eur J Clin Nutr 72(9):1226-1228.

Pearce EN and Braverman LE, 2017. Environmental iodine uptake inhibitors. In: Iodine Deficiency Disorders and Their Elimination, Springer, pp:141-153.

Persani L, Rodien P, Moran C, *et al.*, 2024. 2024 European Thyroid Association guidelines on diagnosis and management of genetic disorders of thyroid hormone transport, metabolism and action. Eur Thyroid J 13(4).

Petričević N, Vugrovečki AS, Tur SM, *et al*., 2025. Thyroid hormones in female and male reproduction with special reference to dogs and cats. Vet Stanica 56(5):1-16.

Pretell EA, Pandav C and Regional Co-ordinator South Asia Iodine Global N, 2017. Severe iodine deficiency. In: Iodine Deficiency Disorders and Their Elimination, pp:45-57.

Rayman MP and Duntas LH, 2019. Selenium deficiency and thyroid disease. In: The Thyroid and Its Diseases: A Comprehensive Guide for the Clinician, Springer, pp:109-126.

Ren Z, Wang W, He X, *et al*., 2024. The response of the miRNA profiles of the thyroid gland to the artificial photoperiod in ovariectomized and estradiol-treated ewes. Animals 15(1):11.

Riguetto CM, Miguel VP, Pavin EJ, *et al*., 2020. Fixed 30 mCi 131I-iodine therapy without recombinant human thyroid-stimulating hormone stimulation as an attractive therapeutic alternative in nontoxic nodular goiter. Nucl Med Commun 41(8):727-732.

Root AW, 2021. Disorders of mineral metabolism: normal homeostasis. In: Sperling Pediatric Endocrinology, Elsevier, pp:220-278.

Russo SC, Salas-Lucia F and Bianco AC, 2021. Deiodinases and the metabolic code for thyroid hormone action. Endocrinology 162(8):bqab059.

Sagliocchi S, Restolfer F, Cossidente A, *et al*., 2024. The key roles of thyroid hormone in mitochondrial regulation, at interface of human health and disease. J Basic Clin Physiol Pharmacol 35(4-5):231-240.

Kumar BAA, 2023. Hormonal regulation of metabolism, water, and minerals. In: Textbook of Veterinary Physiology, Springer, pp:391-415.

Schenke SA, Groener D, Grunert M, *et al*., 2023. Integrated thyroid imaging: ultrasound and scintigraphy. In: Integrated Diagnostics and Theranostics of Thyroid Diseases, Springer, pp:25-62.

Serpi F, Gitto S, Mauri G, *et al*., 2021. Techniques to study thyroid function and morphology. In: Thyroid, Obesity and Metabolism: Exploring Links Between Thyroid Function, Obesity, Metabolism and Lifestyle. pp:37-51.

Serrano-Nascimento C and Nunes MT, 2022. Perchlorate, nitrate, and thiocyanate: environmental relevant NIS-inhibitors pollutants and their impact on thyroid function and human health. Front Endocrinol 13:995503.

Shahid MA, Ashraf MA and Sharma S, 2018. Physiology, thyroid hormone. In: StatPearls. StatPearls Publishing, Treasure Island. 29763182.

Shimada BK, Alfulaij N and Seale LA, 2021. The impact of selenium deficiency on cardiovascular function. Int J Mol Sci 22(19):10713.

Shulhai AM, Rotondo R, Petraroli M, *et al*., 2024. The role of nutrition on thyroid function. Nutrients 16(15):2496.

Soundarrajan M and Kopp PA, 2019. Thyroid hormone biosynthesis and physiology. In: Thyroid Disease and Reproduction: A Clinical Guide to Diagnosis and Management, pp:1-17.

Sreelatha S, Kamala R, Nadagoudar S, *et al*., 2018. A clinical review of obstetric and perinatal outcome in thyroid disorders. Endocrinol Metab Int J 6(4):266-282.

Street ME, Shulhai AM, Petraroli M, *et al*., 2024. The impact of environmental factors and contaminants on thyroid function and disease from fetal to adult life: current evidence and future directions. Front Endocrinol 15:1429884.

Sun C, Zhu M, Li L, *et al*., 2021. [Retracted] Clinical observation of levothyroxine sodium combined with selenium in the treatment of patients with chronic lymphocytic thyroiditis and hypothyroidism and the effects on thyroid function, mood, and inflammatory factors. Evid Based Complement Altern Med 2021(1):5471281.

Talebian Masoudi A, 2024. The effect of iodine or selenium and iodine on thyroid hormone production under selenium deficiency conditions in Farahani sheep. J Rumin Res 12(2):59-76.

Tanase-Nakao K, Iwahashi-Odano M, Sugisawa C, *et al*., 2024. Genotype–phenotype correlations in 30 Japanese patients with congenital hypothyroidism attributable to TG defects. J Clin Endocrinol Metab 109(9):2358-2365.

Thapa P, Kumari S and Adhikari G, 2024. Understanding hyperthyroidism (overactive thyroid gland): causes, symptoms, and treatment options. Am J Patient Health Info 1(1):1-20.

Tosheva G and Siderova MV, 2022. The role of thyroid hormones on the skeletal muscle and the development of sarcopenia. In: Varna Medical Forum pp:124-132.

Uludag M, Cetinoglu I, Unlu MT, *et al*., 2024. Preoperative preparation in hyperthyroidism and surgery in the hyperthyroid state. Med Bull Sisli Etfal Hosp 58(3).

Upadhyay I and Kukrele P, 2022. Study and correlation of clinical, laboratory and radiological findings in the diagnosis of thyroid disorders. J Assoc Physicians India 70(4):11-12.

Vayakkattil AB and Vayakkattil U, 2024. Insulin resistance and cellular metabolism fundamentals: a review. Reprint

Veena MP, Swamy MN, Ramesh PT, *et al*., 2018. Dynamics of thyroid hormones in growth and development of South Indian sheep (Bannur). Int J Curr Microbiol Appl Sci 7(8):4628-4635.

Velasco I and Taylor P, 2018. Identifying and treating subclinical thyroid dysfunction in pregnancy: emerging controversies. Eur J Endocrinol 178(1):D1-D12.

Vella KR, 2018. The thyroid hormone axis: its roles in body weight regulation, obesity, and weight loss. In: Textbook of Energy Balance, Neuropeptide Hormones, and Neuroendocrine Function, pp:255-270.

Vincent L, 2024. The ecological function of thyroid hormones. Philos Trans R Soc B Biol Sci 379.

Wang F, Li C, Li S, *et al*., 2023. Selenium and thyroid diseases. Front Endocrinol 14:1133000.

Wani RA, Singh R, Bhat AM, *et al*., 2023. Iodine level of goats from Shiwalik and middle mountains of north-west Himalayas in relation to soil, fodder, and water status. Indian J Anim Sci 93(2):212-217.

Yahya NA, Nugraha KN, Hardyningrat BID, *et al*., 2024. A complete guide to hyperthyroidism: what you need to know. J Biol Trop 24(1b):115-120.

Yousefi M, Maleki SF, Jafarizadeh A, *et al*., 2024. Advancements in radiomics and artificial intelligence for thyroid cancer diagnosis. arXiv preprint arXiv:2404.07239.

Zamwar UM and Muneshwar KN, 2023. Epidemiology, types, causes, clinical presentation, diagnosis, and treatment of hypothyroidism. Cureus 15(9).

Zhu Q, Zhou H, Ren G, *et al*., 2023. A new treatment strategy for airway obstruction induced by a giant benign goiter: a case report. Exp Ther Med 26(2):376.

Zimmermann MB, 2020. Iodine and the iodine deficiency disorders. In: Present Knowledge in Nutrition, Elsevier, pp:429-441.