**EFFECT OF CONTINUOUS EXPOSURE UNDER HIGH VOLTAGE OVERHEAD POWERLINE ON THYROID FUNCTION**

**ABSTRACT**

Thyroid hormones are essential for regulating metabolism, growth, and development. Exposure to electromagnetic fields (EMF) generated by high voltage overhead powerlines has been suggested to influence thyroid function by inducing oxidative stress and altering hormonal pathways. This study explored the impact of continuous EMF exposure on thyroid function, focusing on the levels of thyroid-stimulating hormone (TSH) and free T4 (fT4). Eighty (80) participants comprised of fifty (50) exposed individuals (test group) residing within 500 meters of the powerlines and control group from low-EMF areas were randomly recruited. Participants were aged between 18-65years and were aged matched. Five millilitre (5 ml) of fasting venous blood samples were collected into plain containers for the determination of TSH and fT4 levels using the Enzyme-Linked Immunosorbent Assay (ELISA) method. Comparative analysis between two and more groups was done using independent sample t-test and one-way analysis of variance. Statistical significance was assumed at p<0.05. The results showed no statistically significant difference in the mean serum levels of TSH and fT4 between the exposed and unexposed groups (p > 0.05). However, a significant increase in fT4 levels (p=0.042) was observed in individuals with prolonged EMF exposure (6-10 years) compared to those with less than one year of exposure. Continuous exposure to EMF from high voltage overhead power lines does not significantly alter TSH levels but may increase FT4 levels with prolonged exposure. Further studies with larger sample sizes and longer follow-up periods are needed to fully understand the health implications of chronic EMF exposure on thyroid function and overall health.

**KEY WORDS:** Electromagnetic fields (EMF), High voltage overhead powerlines, Thyroid function, thyroid-stimulating hormone (TSH), free T4 (fT4), Duration of exposure.

**INTRODUCTION**

The thyroid hormone is crucial for regulating several bodily functions, including development and metabolism (Shahid *et al*., 2023; Marino *et al*., 2025). It is regulated by a self-regulatory process that involves the thyroid gland, anterior pituitary gland and hypothalamus (Jing and Zhang, 2022; Brown *et al*., 2023). Energy usage and body weight are known to be linked to thyroid hormone levels (Iwen *et al.,* 2018). The two primary hormones that the thyroid gland produces are thyroxine (T4) and triiodothyronine (T3). These hormones work in concert with the anterior pituitary glands thyroid-stimulating hormone (TSH) and the brain's thyrotropin-releasing hormone (TRH) to regulate feedback mechanisms and ensure homeostasis (Jing and Zhang, 2022; Shahid *et al.,* 2023).

Thyroid function tests (TFTs) constitute a series of blood analysis designed to assess thyroid gland function. The thyroid gland is a butterfly-shaped organ, located in the lower neck responsible for synthesizing hormones that exert a profound influence on numerous physiological processes, encompassing metabolism, cardiac rate, mood, and digestion (Allen and Fingeret, 2023). TFTs are instrumental in the diagnosis of prevalent thyroid disorders and the subsequent monitoring of implemented treatment regimens.

Typically, TFTs evaluate the concentrations of three critical hormones: thyroid-stimulating hormone (TSH), thyroxine (T4), and triiodothyronine (T3). The pituitary gland secretes TSH, which functions as a regulatory signal for the thyroid gland, stimulating the production of T4, the principal thyroid hormone. A majority of circulating T4 exists in an inactive form, requiring conversion within bodily tissues into the more metabolically active T3. T3 directly modulates a wide range of cellular functions throughout the body (Mullur *et al.,* 2014; Pirahanchi *et al*., 2023).

By quantifying TSH, T4, and T3 levels, TFTs can unveil imbalances in thyroid hormone production. An elevated TSH level in conjunction with a depressed T4 level signifies an underactive thyroid, or hypothyroidism. Conversely, a low TSH level with an elevated T4 level suggests an overactive thyroid, or hyperthyroidism (Edatharayil and Nitin, 2018). It is imperative to acknowledge that for an accurate diagnosis, TFT results must be interpreted in tandem with a patient's clinical presentation and reported symptoms.

TFTs serve as a cornerstone in the diagnostic evaluation of a spectrum of thyroid disorders. Additionally, they are employed to monitor the efficacy of therapeutic interventions for thyroid dysfunction. In patients receiving treatment to regulate an overactive or underactive thyroid, TFTs are performed periodically to ensure the medication is producing the desired effects and that hormone levels are maintained within the targeted range.

Thyroid disorders affect two hundred million people globally, with women particularly vulnerable (Keestra *et al*., 2020). Thyroid nodules are present in 12% of the general population worldwide, with an increased frequency in the elderly. By the age of sixty, at least 50% of people have one thyroid nodule, of which 90–95% are benign. (Ospina and Papaleontiou, 2021). These conditions have been associated with various factors including iodine deficiency, selenium deficiency, and exposure to radiation, both ionizing and non-ionizing (Ferrari *et al.,*2017).

Radiation is categorized into ionizing and non-ionizing. Ionizing radiation (i.e. X-ray or gamma-ray exposure) breaks molecular bonds due to its high frequency, whilst non-ionizing radiation (i.e. infrared, microwave, or radiofrequency waves, electromagnetic fields) damages cells by altering chemical reactions and inducing mechanisms related to heat and electricity. Owing to its frequent use, non-ionizing radiation is likely to cause thyroid abnormalities (Alkayyali *et al*., 2021; El-Benhawy *et al*., 2022; Zufry *et al*., 2024).

Whenever electricity is generated, transmitted, or consumed, electromagnetic fields (EMF) are created. Electric fields are created by differences in voltage: the higher the voltage, the stronger will be the resultant field. Magnetic fields are created when electric current flows: the greater the current, the stronger the magnetic field. An electric field will exist even when there is no current flowing. If current does flow, the strength of the magnetic field will vary with power consumption, but the electric field strength will be constant (Ogunbanjo,2024). The abundant use of high voltage transmission (HVT) lines has resulted in much concern being raised about the impact of EMF exposure from HVT lines on human health (Miller and Green, 2010). Over the last thirty years, the possible relationship between EMF exposure from HVT lines and childhood cancer has been a constant topic of interest since first reported (Wertheimer *et al.,* 1979; Malavolti *et al*., 2024).

EMF is considered a potential endocrine disruptor, capable of interfering with the hormonal functions at multiple levels. Non-ionizing EMF can affect thyroid hormone transporters, alter genomic and non-genomic actions, and disrupt the interaction between thyroid hormones and their receptors (Mughal *et al.,* 2018; Zufry *et al*., 2024). These disruptions can lead to a cascade of hormonal imbalances, affecting not only thyroid function but also other endocrine pathways.

Observational studies have reported associations between EMF exposure and increased incidence of thyroid abnormalities. For instance, increased usage of cell phones has been correlated with higher rates of thyroid cancer in certain populations (Zufry *et al.,* 2024). Furthermore, workers in environments with high EMF exposure, such as those near high-voltage electric transmission lines, might show significant alterations in thyroid hormone levels, there by suggesting a direct link between EMF exposure and thyroid dysfunction. Exposure to non-ionizing EMF can lead to various biochemical and physiological alterations in thyroid cells. EMF exposure affects iodine uptake in the thyroid gland, which is critical for the synthesis of thyroid hormones T3 and T4. Disruption in iodine uptake can consequently lead to thyroid dysfunctions, such as hypothyroidism or hyperthyroidism (Khudair *et al.,*2025).

One of the primary mechanisms through which EMF exerts its effects is the induction of reactive oxygen species (ROS). The increase in ROS due to EMF exposure can cause oxidative stress, leading to cellular damage and apoptosis in thyroid cells. Studies have demonstrated that EMF exposure can result in significant reductions in heat shock proteins (HSP-70 and HSP-90), which are involved in protecting cells from stress. The diminished levels of these proteins can slow down recovery processes and exacerbate cellular damage (Misa Agustiño *et al.,* 2012)

Additionally, EMF exposure has been shown to increase the temperature of the pituitary gland, which can disrupt the regulation of thyroid-stimulating hormone (TSH). This disruption can inhibit the conversion of T4 to the more active T3 hormone, leading to imbalances in thyroid hormone levels and contributing to conditions such as hypothyroidism (Koyu *et al.,* 2005).

Experimental studies have also highlighted various morphological changes in the thyroid gland due to EMF exposure. These changes include increased apoptosis via caspase-dependent pathways, alterations in the follicular epithelium, and increased interfollicular tissue (Eşmekaya *et al.,* 2010).

Histopathological examinations of EMF-exposed thyroid glands reveal significant changes, including a reduction in colloid volume and alterations in follicular structure. These structural changes can impair the gland's ability to produce and secrete thyroid hormones effectively, thereby disrupting overall thyroid function (Zufry *et al.,* 2024).

The thyroid gland plays an important role in the growth process and metabolism; however, it has a high risk of being exposed to non-ionizing radiation (EMF) because of its superficial. The exposure may cause abnormalities in thyroid gland morphology and thyroid hormone functions (Albi *et al.,* 2017). Abnormality of thyroid hormones are associated with some diseases. In addition, it is also suspected to affect thyroid hormone actions, either the transporters or genomic and non-genomic actions, which in turn will disrupt the physiological response (Elsayed *et al.,* 2016). Therefore, this study evaluated the effect of continuous exposure under high voltage overhead power line on thyroid function

**MATERIALS AND METHODS**

### **3.1 Study Design**

**Study Design**

This Cross-sectional study was designed to investigate the effect of continuous exposure to high voltage overhead powerlines on the serum levels of thyroid hormones (Free thyroxine (fT4), thyroid stimulating hormone (TSH).

**Study Area**

The study area was Ugbor road, which is located at Oredo local government area of Edo State in south-south Nigeria. Its coordinate is 6° 16' 0" North, 5° 37' 0" East. The study included individuals who worked under the overhead powerline located at Ugbor road, Benin City, Edo State.

### **Study population and Sample Size**

Eighty (80) volunteers in total were selected at random for the study; the target population consisted of people between the ages of 18 and 65 who lived within a specific radius (e.g., 500 meters) of high voltage overhead powerlines; a control group of people who lived in areas with minimal exposure to electromagnetic fields was included for comparison; the subjects in the test group and the control group were of the same age.

**Inclusion Criteria**

1. Participants fell within the ages of 18-60 years.
2. Participants who provided informed consent to take part in the study.
3. Participants who resided in the study area for at least one year.
4. Participants without pre-existing metabolic conditions and not on drugs which could affect the parameters of analysis.

**Exclusion Criteria**

Subjects who were below the age of 18 or above 60 years, Unwilling candidates, participants with metabolic health issues, cancer patients, Individuals who do not reside in Benin, and sufferers of other chronic systemic conditions were excluded.

### **Ethical Clearance**

Ethical approval was granted from Edo State Ministry of Health Ethics Review Committee (HA/737/24/D/0419270). All objectives and guidelines were adhered to while conducting this research study. The nature and purpose of research was explained to each participant using an informed consent for literate participants and verbal explanation for illiterate participants. Only volunteers became part of this research, their participation was on their own free will. The participants were assured full confidentiality.

**Sample Collection and preparation**

Five millilitre (5 ml) of fasting venous blood samples were collected into plain containers and were allowed to clot, then retracted and centrifuged for 5minutes at 4000rpm to separate the serum from the whole blood and the serum was transferred into another container. The levels of serum free thyroxine (fT4) and thyroid stimulating hormone (TSH) were determined. Samples were stored at –20 °C until analysed.

**Laboratory Methods**

**Quantitative Estimation of fT4 and TSH levels**

Free thyroxine (Bios kit, USA) and thyroid stimulating hormone (PerkinElmer kit, Hayward California) levels were assayed using sandwich enzyme linked immunosorbent assay method.

### **Statistical Analysis**

### Data obtained were expressed as mean and standard error of mean for continuous. Comparative analysis between two and more groups was done using independent sample t-test and one-way analysis of variance. Statistical significance was assumed at p<0.05. All statistics were performed using SPSS for windows (IBM version 26.0)

**Results**

**Table 1** shows the levels of thyroid stimulating (TSH) and free thyroxine (FT4) among subjects exposed to High Voltage Overhead Power Line and the non-unexposed subjects. There was no statistically significant difference in the levels of TSH and FT4 among exposed subjects and the control group (p>0.05).

**Table 2** shows the levels of thyroid stimulating (TSH) and free thyroxine (FT4) among gender of the overall study population. There was no statistical significant difference in the levels of TSH and FT4 among the different gender in overall study population among those exposed to High Voltage Overhead Power Line (p>0.05).

**Table 3** shows the levels of thyroid stimulating (TSH) and free thyroxine (FT4) based on the duration of exposure to High Voltage Overhead Power Line. It was observed that the levels of FT4 was significantly increased (p<0.05) during prolonged exposure of 6-10years compared with <1year of exposure while TSH show no significant difference between of duration of exposure to High Voltage Overhead Power Line (p>0.05).

**Table 4** shows the levels of thyroid stimulating (TSH) and free thyroxine (FT4) among gender exposed to High Voltage Overhead Power Line. It was observed that the levels of TSH and FT4 were not significantly different (p>0.05) among gender.

Table 1: Level of Thyroid Stimulating Hormone and Free Thyroxine Among Overhigh Tension Wire Exposed and Unexposed Subjects

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Parameters | Study Group | N | Mean | Std. Error Mean | T-value | P-value |
| TSH(µIU/ml | Exposed To EMF | 50 | 1.66 | 0.15 | 0.895 | 0.373 |
| Unexposed To EMF | 30 | 1.45 | 0.16 |
| FT4(pmol/L) | Exposed To EMF | 50 | 15.97 | 0.31 | 1.549 | 0.126 |
| Unexposed To EMF | 30 | 15.26 | 0.29 |

\*Statistically significant at P<0.05, EMF- Electromagnetic wave generated by overhead high tension electric wire, TSH-Thyroid stimulating hormone, FT4- Free thyroxine.

Table 2: Level of Thyroid Stimulating Hormone and Free Thyroxine Among Male and Female Study Group

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Parameters | Study Group | Number | Mean | Std. Error Mean | T-value | P-value |
| TSH (µIU/ml | FEMALE | 18 | 1.38 | 0.13 | -0.971 | 0.335 |
| MALE | 62 | 1.64 | 0.14 |
| FT4 (pmol/L) | FEMALE | 18 | 14.92 | 0.65 | -1.490 | 0.151 |
| MALE | 62 | 15.94 | 0.25 |

\*Statistically significant at P<0.05, EMF- Electromagnetic wave generated by overhead high tension electric wire, TSH-Thyroid stimulating hormone, FT4- Free thyroxine

TABLE 3: Level of Thyroid Stimulating Hormone and Free Thyroxine Among Duration of Exposure Exposed Subjects

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Parameters | | Number | Mean | Std. Error | Range | | Statistics | |
| Minimum | Maximum | F-value | P-value |
| TSH  (µIU/ml | <1YRS | 6 | 1.71a | 0.27 | 0.73 | 2.33 | 0.347 | 0.792 |
| 1-5YRS | 37 | 1.70a | 0.19 | 0.68 | 6.32 |
| 6-10YRS | 2 | 0.94a | 0.15 | 0.79 | 1.09 |
| >10YRS | 5 | 1.55a | 0.36 | -0.58 | 2.65 |
| FT4  (pmol/L | <1YRS | 6 | 13.93a | 1.56 | 7.92 | 17.93 | 2.955 | 0.042\* |
| 1-5YRS | 37 | 16.27ab | 0.30 | 12.32 | 20.68 |
| 6-10YRS | 2 | 18.11b | 0.29 | 17.82 | 18.40 |
| >10YRS | 5 | 15.38ab | 0.58 | 14.19 | 17.49 |

Mean values in column with same superscript are not significantly different from each other(p>0.05), Mean values in column with different superscript are significantly different from each other(p<0.05), EMF- Electromagnetic wave generated by overhead high tension electric wire, TSH-Thyroid stimulating hormone, FT4- Free thyroxine

Table 4: Level of Thyroid Stimulating Hormone and Free Thyroxine Among Male and Female Participants Exposed to Overhigh Tension Wire

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Parameters | Study Group | Number | Mean | Std. Error Mean | T-value | P-value |
| TSH(µIU/ml | FEMALE | 11 | 1.48 | 0.21 | -0.632 | 0.531 |
| MALE | 39 | 1.71 | 0.18 |
| FT4(pmol/L) | FEMALE | 11 | 14.96 | 1.05 | -1.207 | 0.256 |
| MALE | 39 | 16.26 | 0.27 |

\*Statistically significant at P<0.05, EMF- Electromagnetic wave generated by overhead high tension electric wire, TSH-Thyroid stimulating hormone, FT4- Free thyroxine.

### **Discussion**

Electromagnetic fields generated by high voltage powerlines are categorized as extremely low frequency (ELF) EMFs. These fields are constant in our environment, produced not only from powerlines but also from various household electrical devices. The strength of these fields diminishes rapidly with distance from the source, yet their omnipresent nature leads to almost continuous exposure for some individuals.

The present study Compared the levels of thyroid-stimulating hormone (TSH) and free thyroxine (fT4) between those exposed to Electromagnetic field generated by Over-head high-tension wire with non-exposed group. This study showed that there were no statistically significant differences in TSH and fT4 levels between the exposed group compared to non-exposed group. This might suggest that short-term EMF exposure from high-tension wires does not interfere with thyroid function, as assessed by these hormonal measures. This agrees with the findings of Fang *et al*. (2022) that notated no significant difference in thyroid function between the exposure and control groups following their study on the Effect of Occupational Extremely Low-Frequency Electromagnetic Field Exposure on the Thyroid Gland of Workers: A Prospective Study.

Also, there were no significant gender-specific differences in TSH and fT4 levels among the study population, which suggests that both women and men are affected by EMF exposure similarly but within the defined limits of parameters examined. Furthermore, the study also observed no significant changes in TSH and fT4 levels between males and females in the exposed group. This gender-to-gender consistency supports the possibility that the responses of men and women to electromagnetic field exposure in terms of thyroid function are comparable, which strengthens the findings' applicability to the population under study. The reason being that thyroid hormones are involved in metabolism, growth and development. There were no marked differences, which imply that EMF factor in ordinary life exposure may not alter the hormonal processes of the thyroid gland at short-term. The study, however, cannot rule out more subtle or long-term effects which would not be registered by this research.

It is however of significance that the duration of EMF exposure had some effects on the levels of fT4 which was significantly higher in those exposed to EMF for duration of six to ten years when compared to shorter exposure periods of less than one year. This is partly in keeping with report of Kim *et al*. (2024) on Effects of 4G Long-Term Evolution Electromagnetic Fields on Thyroid Hormone Dysfunction and Behavioral Changes in Adolescent Male Mice which found T3 levels were significantly elevated in the mice exposed to LTE during adolescence compared to the sham group, while TSH and T4 levels remained unchanged. On the other hand, Zufry *et al*. (2023) found a significant reduction in TSH, T4 following their study on Effects of mobile phone electromagnetic radiation on thyroid glands and hormones in *Rattus norvegicus* brain: An analysis of thyroid function, reactive oxygen species, and monocarboxylate transporter 8 which is in variance with the current findings. Despite the fT4 levels being higher in this study, the results of TSH analysis conducted in those with prolonged exposure > 10 years are within range.  There were no discernible variations in TSH levels based to exposure length. This stability in TSH levels implies that the pituitary-thyroid axis maintains a mostly intact regulatory function over the course of the study, even in the face of fluctuations in FT4, these fluctuations may be as a result of EMF affecting iodine uptake in the thyroid gland, increasing the pituitary gland temperature and trigger a rise in serum cortisol levels, inhibiting the conversion of T4 to T3, there by leading to an increase in FT4 (Zufry *et al.,* 2024). These results highlight the significance of long-term thyroid function monitoring in EMF-exposed populations, since seemingly insignificant early alterations may develop into disorders with practical implications.

The results of this investigation add to our understanding of the effects of high-tension wire EMF exposure on thyroid function. The findings highlight the need for continued research and public health surveillance, even though they do not show any appreciable changes in thyroid function. Additionally, the observed alterations in fT4 with extended exposure, are concerning. Given that electromagnetic fields (EMF) are omnipresent in contemporary settings, particularly in metropolitan regions with substantial electrical infrastructure, public health policies ought to take long-term EMF exposure monitoring and control into account. The results of the present study indicate certain areas of worry that require more research, even though they also offer some comfort regarding the absence of any immediate, major health effects.

**Conclusion**

In conclusion, the study provides valuable insights into the health impacts of EMF exposure from overhead high-tension wires. While the overall thyroid function appears unaffected in the short term, the increase in fT4 with prolonged exposure highlight areas of concern that require further investigation. These findings support the need for continued monitoring and research to ensure public health safety in environments with significant EMF exposure. The study also underscores the importance of considering both short-term and long-term effects in assessing the health risks associated with EMF, guiding future research and public health policies.

**Recommendations**

1. Longitudinal Studies: Future research should focus on long-term, longitudinal studies to track the health impacts of EMF exposure over extended periods. This will help in understanding cumulative effects and potential delayed onset of health issues.
2. Broader Biomarker Analysis: Expanding the range of biomarkers analyzed could provide a more comprehensive understanding of EMF's impact on health. This includes investigating oxidative stress markers, inflammatory cytokines, and other endocrine hormones.
3. Vulnerable Populations: Special attention should be given to vulnerable populations, such as children, pregnant women, and individuals with pre-existing health conditions, to determine if they are more susceptible to EMF exposure.

**REFERENCES**

Albi, E., Cataldi, S., Lazzarini, A., Codini, M., Beccari, T., Ambesi-Impiombato, F. S., & Curcio, F. (2017). Radiation and Thyroid Cancer. *International Journal of Molecular Sciences*, *18*(5), 911. <https://doi.org/10.3390/ijms18050911>

Alkayyali, T., Ochuba, O., Srivastava, K., Sandhu, J. K., Joseph, C., Ruo, S. W., Jain, A., Waqar, A., & Poudel, S. (2021). An Exploration of the Effects of Radiofrequency Radiation Emitted by Mobile Phones and Extremely Low Frequency Radiation on Thyroid Hormones and Thyroid Gland Histopathology. *Cureus*, *13*(8), e17329. https://doi.org/10.7759/cureus.17329

Allen, E., & Fingeret, A. (2023). Anatomy, Head and Neck, Thyroid. In *StatPearls*. StatPearls Publishing. Available online: https://pubmed.ncbi.nlm.nih.gov/29262169/

Brown, E. D. L., Obeng-Gyasi, B., Hall, J. E., & Shekhar, S. (2023). The Thyroid Hormone Axis and Female Reproduction. International Journal of Molecular Sciences, 24(12), 9815. <https://doi.org/10.3390/ijms24129815>

El-Benhawy, S. A., Fahmy, E. I., Mahdy, S. M., Khedr, G. H., Sarhan, A. S., Nafady, M. H., Yousef Selim, Y. A., Salem, T. M., Abu-Samra, N., & El Khadry, H. A. (2022). Assessment of thyroid gland hormones and ultrasonographic abnormalities in medical staff occupationally exposed to ionizing radiation. *BMC Endocrine Disorders*, *22*(1), 287. https://doi.org/10.1186/s12902-022-01196-z

Elsayed, N.M., & Jastaniah, S.D. (2016). Mobile phone use and risk of thyroid gland lesions detected by ultrasonography, *Open Journal of Radiology (Online)*, 06(02), 140–146.

Eşmekaya, M. A., Seyhan, N., & Ömeroğlu, S. (2010). Pulse modulated 900 MHz radiation induces hypothyroidism and apoptosis in thyroid cells: a light, electron microscopy and immunohistochemical study. *International Journal of Radiation Biology*, *86*(12), 1106–1116. https://doi.org/10.3109/09553002.2010.502960

Fang, Y. Y., Tu, Q., Zhang, Y. T., Liu, J., Liu, H. G., Zhao, Z. H., Wu, H., & Yin, T. J. (2022). Effect of Occupational Extremely Low-Frequency Electromagnetic Field Exposure on the Thyroid Gland of Workers: A Prospective Study. *Current Medical Science*, *42*(4), 817–823. https://doi.org/10.1007/s11596-022-2610-8

Ferrari, S.M., Fallahi, P., Antonelli, A., & Benvenga, S. (2017). Environmental Issues in Thyroid Diseases. *Frontiers in Endocrinology*, *8*, 50. <https://doi.org/10.3389/fendo.2017.00050>

Iwen, K. A., Oelkrug, R., & Brabant, G. (2018). Effects of thyroid hormones on thermogenesis and energy partitioning. Journal of Molecular Endocrinology, 60(3), R157-R170. Retrieved May 9, 2025, from <https://doi.org/10.1530/JME-17-0319>

Jing, L., & Zhang, Q. (2022). Intrathyroidal feedforward and feedback network regulating thyroid hormone synthesis and secretion. *Frontiers in Endocrinology*, *13*, 992883. https://doi.org/10.3389/fendo.2022.992883

Keestra, S., Högqvist Tabor, V., & Alvergne, A. (2020). Reinterpreting patterns of variation in human thyroid function: An evolutionary ecology perspective. *Evolution, Medicine, and Public Health*, *9*(1), 93–112. <https://doi.org/10.1093/emph/eoaa043>

Khudair, A., Khudair, A., Niinuma, S. A., Habib, H., & Butler, A. E. (2025). Beyond thyroid dysfunction: the systemic impact of iodine excess. *Frontiers in Endocrinology*, *16*, 1568807. https://doi.org/10.3389/fendo.2025.1568807

Kim, H.-Y., Son, Y., Jeong, Y. J., Lee, S.-H., Kim, N., Ahn, Y. H., Jeon, S. B., Choi, H.-D., & Lee, H.-J. (2024). Effects of 4G Long-Term Evolution Electromagnetic Fields on Thyroid Hormone Dysfunction and Behavioral Changes in Adolescent Male Mice. International Journal of Molecular Sciences, 25(20), 10875. <https://doi.org/10.3390/ijms252010875>

Koyu, A., Cesur, G., Ozguner, F., Akdogan, M., Mollaoglu, H., & Ozen, S. (2005). Effects of 900 MHz electromagnetic field on TSH and thyroid hormones in rats. [Toxicology Letters](https://www.sciencedirect.com/journal/toxicology-letters), 157 (3), 257-262. <https://doi.org/10.1016/j.toxlet.2005.03.006>.

Kurian, M.E., & Kapoor, N. (2018). Interpretation of Thyroid Function Tests. *Current Medical Issues,* 16(2), 34-38. <https://doi.org/10.4103/cmi.cmi_17_18>

Malavolti, M., Malagoli, C., Wise, L. A., Poli, M., Notari, B., Taddei, I., Fabbi, S., Teggi, S., Balboni, E., Pancaldi, A., Palazzi, G., Vinceti, M., & Filippini, T. (2024). Residential exposure to magnetic fields from transformer stations and risk of childhood leukemia. *Environmental Research*, *245*, 118043. https://doi.org/10.1016/j.envres.2023.118043

Marino, L., Kim, A., Ni, B., & Celi, F. S. (2025). Thyroid hormone action and liver disease, a complex interplay. *Hepatology (Baltimore, Md.)*, *81*(2), 651–669. <https://doi.org/10.1097/HEP.0000000000000551>

Miller, A. B., & Green, L. M. (2010). Electric and magnetic fields at power frequencies. *Chronic Diseases in Canada*, *29 Suppl 1*, 69–83.

Misa Agustiño, M. J., Leiro, J. M., Jorge Mora, M. T., Rodríguez-González, J. A., Jorge Barreiro, F. J., Ares-Pena, F. J., & López-Martín, E. (2012). Electromagnetic fields at 2.45 GHz trigger changes in heat shock proteins 90 and 70 without altering apoptotic activity in rat thyroid gland. *Biology open*, *1*(9), 831–838. <https://doi.org/10.1242/bio.20121297>

Mughal, B. B., Fini, J. B., & Demeneix, B. A. (2018). Thyroid-disrupting chemicals and brain development: an update. *Endocrine Connections*, *7*(4), R160–R186. https://doi.org/10.1530/EC-18-0029

Mullur, R., Liu, Y. Y., & Brent, G. A. (2014). Thyroid hormone regulation of metabolism. *Physiological Reviews*, *94*(2), 355–382. <https://doi.org/10.1152/physrev.00030.2013>

Ogunbanjo, D. (2024). EMF Exposure And Health:The Consumer Perspective; National President, National Association Of Telecommunications Subscribers (Natcoms) On The Occasion Of NCC’s First West African Conference On Electromagnetic Fields Exposure And Health At Victoria Crown Plaza Hotel, Victoria Island, Lagos, Nigeria, On Wednesday, 27th And Thursday, 28th June, 2012.

Available online at <https://ncc.gov.ng/sites/default/files/2024-11/Documents/EMF-20120628_Exposure_And_Health_President_NATCOMS.pdf>

Ospina, N. S., & Papaleontiou, M. (2021). Thyroid Nodule Evaluation and Management in Older Adults: A Review of Practical Considerations for Clinical Endocrinologists. *Endocrine Practice: official journal of the American College of Endocrinology and the American Association of Clinical Endocrinologists*, *27*(3), 261–268. <https://doi.org/10.1016/j.eprac.2021.02.003>

Pirahanchi Y, Toro F, Jialal I. Physiology, Thyroid Stimulating Hormone. [Updated 2023 May 1]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025 Jan-. Available online from: <https://www.ncbi.nlm.nih.gov/books/NBK499850/>

Shahid MA, Ashraf MA, Sharma S. Physiology, Thyroid Hormone. [Updated 2023 Jun 5]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025 Jan-. Available from: <https://www.ncbi.nlm.nih.gov/books/NBK500006/>

Wertheimer, N., & Leeper, E. (1979). Electrical wiring configurations and childhood cancer. *American Journal of Epidemiology*, *109*(3), 273–284. https://doi.org/10.1093/oxfordjournals.aje.a112681

Zufry, H., Rudijanto, A., Soeatmadji, D.W.,Sakti, S.P., Munadi K., Sujuti, H., & Mintaroen, K. (2024). Do electromagnetic fields significantly affect thyroid cells and their functions? – A systematic review [version 1; peer review: awaiting peer review]. *F1000Research*, *13*, 12. <https://doi.org/10.12688/f1000research.128740.1>

Zufry, H., Rudijanto, A., Soeatmadji, D. W., Sakti, S. P., Munadi, K., Sujuti, H., & Mintaroem, K. (2023). Effects of mobile phone electromagnetic radiation on thyroid glands and hormones in Rattus norvegicus brain: An analysis of thyroid function, reactive oxygen species, and monocarboxylate transporter 8. *Journal of advanced pharmaceutical technology & Research*, 14(2), 63–68. https://doi.org/10.4103/japtr.japtr\_680\_22