Open Access https://www.jparathyroid.com

Journal of Parathyroid Disease

Journal of Parathyroid Disease 2025,13, e13289

DOI:10.34172/jpd.2025.13289

Review

Mobile radiation's impact on thyroid health-focused on pediatric population; a review of literature

Mojtaba Lotfi[1], Fatemeh Khaleghi[2], Fatemeh Etemadi Nia[3], Ameneh Sheikh[4], Mahsa Asadollahi Hamedani[5], Amirhossein Khoshghadam[6], Siavash Assar[7], Baharak Maddahi[8*]

Abstract

Since evidence suggesting a direct link between mobile phone radiation and thyroid cancer is not conclusive, emerging studies indicate its biological effects on thyroid function among heavy users. The impact of mobile radiation on pediatric thyroid health warrants serious consideration as mobile technology becomes increasingly pervasive in children's lives. The unique anatomical and physiological vulnerabilities present in children make them particularly susceptible to potential adverse effects from radio frequency electromagnetic radiation. Studies indicate a possible association between mobile radiation exposure and thyroid dysfunction. The complexity of interactions between mobile radiation, individual genetic backgrounds, and persistent health outcomes still needs several studies.

Keywords: Mobile radiation, Thyroid gland, Thyroid dysfunction, Thyroid health, Metabolic function, Pediatric thyroid health, Radio frequency, Electromagnetic radiation

Please cite this paper as: Lotfi M, Khaleghi F, Etemadi Nia F, Sheikh A, Asadollahi Hamedani M, Khoshghadam A, Assar S, Maddahi B. Mobile radiation's impact on thyroid health-focused on pediatric population; a review of literature. J Parathyr Dis. 2025;13:e13289. doi:10.34172/jpd.2025.13289.

Introduction

Several epidemiological studies have reported an increase in thyroid disorders, which coincides with the rapid increase in mobile phone usage. Although the causal link remains unclear, the simultaneous rise suggests a need for further exploration of the underlying mechanisms (1). As mobile phone adoption surged, studies indicated rising incidences of hypothyroidism and goiter, raising questions about whether electromagnetic radiation might contribute to these trends (2). While some studies predominantly focused on cancer risks. However, other investigations began to consider the electromagnetic fields as a possible contributor to non-cancerous disorders, particularly thyroid dysfunction, sleep disorders, and metabolic irregularities (3). Mobile phones emit radiofrequency radiation, which falls within the nonionizing range of the electromagnetic spectrum. This form of radiation is considerably weaker than ionizing radiation, such as X-rays, which can cause DNA damage and subsequently lead to cancer (4). Therefore, concerns raised on the proximity of mobile phones to the thyroid gland, which is across with an enhanced exposure level. The increasing adoption of second-, third-, fourth-, and fifth-generation mobile technologies, which operate across a range of frequencies from 0.7 to 80 GHz, has sparked concerns regarding their potential biological effects (5).

Children exhibit unique anatomical and physiological characteristics that render them particularly vulnerable to the effects of mobile radiation. Due to their smaller head size and thinner cranial bones, children can absorb a higher dose of radio frequency electromagnetic radiation compared to adults (6). Moreover, the water content in children's bodies is higher, which facilitates increased absorption of radio frequency electromagnetic radiation. Research has demonstrated that a child's brain can absorb radio frequency electromagnetic radiation two to three times more than that of an adult under similar exposure conditions (7). The thyroid gland plays a crucial role in

Received: 26 Feb. 2025, Revised: 4 Apr. 2025, Accepted: 6 Apr. 2025, ePublished: 15 Apr. 2025

[1]Clinical Research Development Unit of Akbar Hospital, Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran. [2]Department of Radiology, Shahid Sadoughi University of Medical Sciences, Yazd, Iran. [3]Development of Nursing, Student Research Committee, Faculty of Nursing and Midwifery, Zahedan University of Medical Sciences, Zahedan, Iran. [4]Research Committee of the Nursing and Midwifery, Zabol University of Medical Sciences, Zabol, Iran. [5]Department of Nursing, School of Nursing and Midwifery, Hormozgan University of Medical Sciences, Bandar Abbas, Iran. [6]Department of Occupational Health, Tehran Islamic Azad University of Medical Sciences, Tehran, Iran. [7]Department of Anesthesiology, Kerman University of Medical Sciences, Kerman, Iran. [8]Pediatric Health Research Center, Tabriz University of Medical Sciences, Tabriz, Iran.

***Corresponding author:** Baharak Maddahi, Email: bahar_68421@yahoo.com

Implication for health policy/practice/research/ medical education

The rapid proliferation of mobile technology has transformed the landscape of communication and entertainment, especially among children. As mobile devices have become integral to daily life, concerns about the health impacts of mobile radiation have emerged. Among the various health implications, the thyroid gland, vital for regulating metabolism and growth through hormone production, has arisen as a focal point of research.

growth and development, making it potentially more vulnerable to disruptions during childhood. Since the thyroid gland is located near the head and neck area, children are subjected to more intense radiation exposure while using mobile devices, Likewise, the thyroid gland's proximity to commonly used mobile devices increases the radiation absorption and potential disruption of thyroid function (8). Moreover, the developing endocrine systems of children, including the thyroid gland, may respond differently to environmental stressors such as electromagnetic radiation. This exposure during crucial growth periods raises concerns about long-term implications for thyroid health, metabolic function, and overall development (9). In this review, we aimed to explore the current research findings, underscore the biological mechanisms explaining the interaction of mobile radiation and thyroid function and structure, and specific studies that illuminate the biological vulnerabilities of pediatric patients.

Search strategy

For this study, we searched PubMed, Web of Science, EBSCO, Scopus, Google Scholar, Directory of Open Access Journals (DOAJ), and Embase, using different keywords such as mobile radiation, thyroid gland, thyroid dysfunction, thyroid health, metabolic function, pediatric thyroid health, radio frequency and electromagnetic radiation.

Mobile radiation and thyroid: a short look

Numerous epidemiological studies have investigated the association between cell phone usage and thyroid cancer risk, yielding mixed results. A case-control study by Lue et al in Connecticut found no significant correlation between cell phone use and thyroid cancer (10). This assumption is echoed in other investigations, including a review conducted by the National Cancer Institute that examined cancer incidence in relation to the increased use of mobile phones over several decades. These studies found that thyroid cancer rates remained stable during a time of significant mobile phone adoption (11). These findings suggest a potential regulatory disruption in the hypothalamic-pituitary-thyroid axis, even if definitive cancer links remain unproven. Likewise, the study by Alkayyali et al focused on the association between radiofrequency radiation emitted by mobile devices and thyroid function tests. This study indicated that prolonged exposure to mobile phone radiation might lead to alterations in hormone levels, including TSH (thyroid-stimulating hormone), T3, and T4. This finding implies that radiofrequency energy may impact the hypothalamic-pituitary-thyroid axis, disrupting normal hormonal regulation, although the mechanisms are not fully understood (3). Also, the study by Elsayed and Jastaniah who intended to determine the direct relationship between mobile phone usage and thyroid hormone levels in a broader population context in Saudi Arabia. This study highlighted that over 29.4% of smartphone users experienced thyroid hormone abnormalities, in contrast to only 13.3% of non-smartphone users. The findings of this investigation indicated a strong association between mobile phone usage duration and potential disruptions to thyroid function, emphasizing its health concerns (1).

Children's thyroid glands are generally more sensitive to radiation than those of adults, including non-ionizing radiation from mobile phones. However, most studies on thyroid sensitivity to radiation have focused on ionizing radiation rather than specifically on mobile phone radiation (12). The increased sensitivity of children's thyroids to radiation can be attributed to several factors. Children's thyroid cells have a higher proliferative activity compared to adults. a study by Saad et al found that the rate of Ki-67 labeling, which indicates cell proliferation, was significantly higher in fetal and childhood thyroids compared to adult thyroids (13). There is a strong inverse relationship between age at exposure and the risk of thyroid cancer. Children exposed to radiation before age 10 have a higher risk of developing thyroid cancer compared to those exposed at older ages. Since children are likely to use mobile phones for many years, their cumulative exposure over a lifetime could be greater than that of adults who started using mobile phones later in life (14).

The age at which children are exposed to radiation significantly affects their thyroid cancer risk, with younger children being more vulnerable. Children exposed to radiation before the age of 4 years have a fivefold greater risk per Gy of developing thyroid cancer compared to those exposed at ages 10-14 years (15). The risk of thyroid cancer is maximal for radiation exposure during the first years of life and decreases with increasing age at exposure. A study on thyroid cancer after external radiation therapy for childhood cancer found a 10-fold higher excess relative risk per Gy for those treated at age 0-1 year compared to those aged 15-20 years (16). The highest rates of thyroid cancer following the Chernobyl accident were observed among children who were 5 years of age or less at the time of exposure (17). The increasing dose-response trend for thyroid cancer risk was found to be greater at younger age at exposure and younger attained age. These findings consistently demonstrate that younger children, particularly those under five years old, are at the highest risk for radiation-induced thyroid cancer. The risk decreases progressively with increasing age at exposure, becoming relatively low for individuals exposed after age 15 (18). Several studies have highlighted the differential impacts of mobile radiation on thyroid hormone levels in children compared to adults. Children have a greater susceptibility to hormonal disruptions due to their developing endocrine system. The thyroid gland in children is smaller in size but operates under dynamic conditions as it regulates growth and metabolic processes (19). Children exposed to radiofrequency electromagnetic radiation from mobile phones have demonstrated statistically significant changes in their thyroid hormone profiles compared to adult counterparts, who possess more stable white matter and mature neural pathways (9). For instance, the study by Reiners et al highlighted that excessive mobile radiation exposure raised TSH levels while simultaneously decreasing T4 in children, potentially contributing to a hypothyroid state (20). In adult populations, while radiofrequency exposure has been implicated in thyroid dysfunction, the hormonal perturbations tend to be less severe, possibly due to the thyroid gland's maturity and adaptability (21). One significant investigation conducted a systematic review of the literature addressing the effects of radiofrequency electromagnetic radiation (RF-EMR) on thyroid hormones. The findings indicated that children exposed to mobile radiation demonstrated altered serum levels of thyroid hormones, which may suggest an underactive thyroid or thyroid dysfunction (22). Additionally, histopathological changes have been documented in animal studies involving radio frequency electromagnetic radiation exposure, revealing alterations in thyroid follicular cells and apoptosis, which could have parallels in human pediatric outcomes (23). The interphone study also contributed to the discourse by examining the risk of brain tumors in adolescents, where findings suggested elevated risks for those who began mobile phone usage at an early age. While the primary focus was brain health, the implications for surrounding organs, including the thyroid, cannot be dismissed. Given the thyroid's susceptibility to radiation, similar risks may be inferred (24).

Molecular mechanism of thyroid involvement by mobile radiation

The thyroid gland is sensitive to external stimuli, including electromagnetic radiation. Although radiofrequency radiation does not capable sufficient energy to induce direct DNA damage, however its thermal effects, causing localized heating near the tissues where the mobile phone is held, could lead to physiological changes (25). Such heating effects may influence thyroid hormone release, thus disrupting normal hormone signaling. This effect suggests that mobile radiation per self may not universally cause thyroid dysfunction or cancer, since genetic factors could interplay uniquely with radiofrequency radiation exposure, demanding further investigation (12). Several studies showed that, mobile phones emit non-ionizing electromagnetic radiation, is much weaker than ionizing radiation, such as X-rays. In addition to the above effects, ionizing radiation is known to cause direct DNA damage and non-ionizing radiation's effects too (14,26). Following the use of cellphones, a localize heating of thyroid tissues, may alter metabolic processes, potentially affecting hormone release and function (27). Across with above findings, genetic susceptibility has a role in moderating the effects of mobile phone radiation on thyroid health, since, certain individuals may have inherent genetic predispositions that render them more susceptible to thyroid dysfunction when exposed to mobile phone radiation (12).

Numerous studies found that mobile phone radiation affects thyroid hormones is through inducing oxidative stress (28). Oxidative stress occurs when there's an imbalance between the production of ROS (reactive oxygen species) and the body's ability to detoxify these reactive products. Elevated ROS levels can damage cellular structures, including DNA, lipids, and proteins, in thyroid cells, influencing their ability to synthesize and release hormones properly (29). This link between oxidative stress and thyroid dysfunction has been supported by studies that correlate increased oxidative markers with reduced thyroid hormone levels (30).

Long-term effects of thyroid dysfunction after radiation exposure

One significant long-term effect of radiation exposure is the increased risk of developing thyroid cancer. Studies have demonstrated a well-established link between exposure to ionizing radiation and the incidence of thyroid malignancies, particularly in children and adolescents (31). Epidemiological evidence indicates that the risk of thyroid cancer is significantly elevated following radiation doses as low as 50 mGy, notably when exposure happens throughout childhood (32). The types of thyroid cancers that have been most frequently associated with radiation exposure include papillary thyroid carcinoma (PTC), which have a prolonged latency period before symptoms manifest. This long latency period, typically ranging from 5 to 10 years, means that individuals exposed to radiation as children may develop cancer many years later, complicating the timeline for monitoring and treatment (15). Additionally, recent studies indicated that radiation-induced thyroid cancers often exhibit specific genetic alterations, such as mutations in the RET proto-oncogene and rearrangements leading to RET/PTC fusion genes, which are associated with heightened malignancy (33). Another significant long-term effect of radiation exposure is the development of hypothyroidism. Following radiation therapy, particularly for cancers involving the head and neck, thyroid damage can lead to a gradual decline in thyroid function over time (34). It has been established that the incidence of hypothyroidism increases significantly among individuals treated with external beam radiation, with estimations suggesting that around 26% of patients treated for head and neck cancers experience hypothyroidism within five years' post-treatment (35). Another important concern on radiation exposure can also predispose individuals to autoimmune thyroid disorders, such as Hashimoto's thyroiditis and Graves' disease. These conditions can emerge as a result of the immune system's strengthened response following thyroid irradiation, leading to pathological changes in thyroid function (36).

The developing endocrine systems in children suggest that chronic exposure could have significant effects on growth, metabolism, and cognitive functioning, which may not be as pronounced in adults (37). Research indicates that children exposed to mobile phone radiation may exhibit behavioral symptoms associated with thyroid dysfunction, such as attention deficits and increased anxiety levels (38). Adults, while still at risk, may present with symptoms more directly related to metabolic changes and thyroid disease, such as weight changes or fatigue (39). Evidence from research highlights that children experiencing thyroid dysfunction due to mobile radiation exposure may be at risk for developing symptoms of attention deficit hyperactivity disorder and other behavioral issues (38). A longitudinal study indicated that children with altered thyroid hormone levels exhibited higher rates of behavioral problems, which could persist into adolescence and adulthood, affecting academic performance and social interactions (40). As thyroid hormones are essential for normal growth and development during childhood, disruptions in thyroid function due to mobile radiation exposure can impair growth patterns, potentially leading to stunted physical growth and delayed developmental milestones (41). Research has found that children diagnosed with hypothyroidism early in life often face challenges related to both physical and cognitive growth, a concern that may be exacerbated by mobile radiation (42). Moreover, Studies have shown that children exposed to maternal hypothyroxinemia during pregnancy may demonstrate significant deficits in cognitive abilities, highlighting the potential long-term implications associated with thyroid dysfunction stemming from environmental factors, including mobile radiation exposure (43). Long-term thyroid dysfunction can increase the risk of metabolic disorders in children. Conditions such as obesity, insulin resistance, and metabolic syndrome have been associated with hypothyroidism and thyroid dysfunction (44). The interplay between thyroid hormones and metabolism underscores the significance of maintaining thyroid health, particularly in the face of mobile radiation exposure (45). Studies have indicated that thyroid dysfunction may lead to alterations in lipid profiles and glucose metabolism, raising the risk of metabolic syndrome in children who have experienced prolonged exposure to Radio Frequency Electromagnetic Radiation (46).

Thyroid symptoms following radiation exposure

Thyroid dysfunction in children can manifest through a variety of physical, cognitive, and behavioral symptoms. physical signs of thyroid dysfunction in children can vary significantly depending on whether the child is experiencing hypothyroidism or hyperthyroidism (47). in instances of hypothyroidism, the following signs are commonly slowed growth rate, fatigue and low energy, weight gain, dry skin and hair changes, sensitivity to cold (48). Conversely, hyperthyroidism can present with other symptoms, such as accelerated growth, increased appetite, heat intolerance and sweating, tremors and elevated heart rate (49). Given the serious implications of these symptoms, monitoring thyroid function in individuals exposed to high levels of radiation is crucial to delivering appropriate interventions and improving outcomes. Awareness of these signs can lead to earlier diagnosis and effective management, addressing potential complications stemming from thyroid dysfunction due to radiation exposure.

Conclusion

Various studies indicate a potential link between mobile phone use and thyroid dysfunction, suggesting that excessive usage may contribute to minor alterations in thyroid hormone levels. While direct causal relationships remain inconclusive, the evidence points to the necessity of further investigation into this pressing area of public health.

Authors' contribution

Conceptualization: Mojtaba Lotfi and Baharak Maddahi.
Data curation: Ameneh Sheikh and Mahsa Asadollahi Hamedani
Investigation: Fatemeh Khaleghi and Baharak Maddahi.
Resources: Siavash Assar and Amirhossein Khoshghadam.
Supervision: Mojtaba Lotfi.
Validation: Fatemeh Khaleghi and Fatemeh Etemadi Nia.
Visualization: Mahsa Asadollahi Hamedani.
Writing–original draft: All authors.
Writing–review and editing: All authors.

Conflicts of interest

The authors declare that they have no competing interests.

Declaration of generative artificial intelligence (AI) and AI-assisted technologies in the writing process

During the preparation of this work, the authors utilized Perplexity AI to refine grammar points and language style in writing. Subsequently, the authors thoroughly reviewed and edited the content as necessary, assuming full responsibility for the publication's content.

Ethical issues

The authors have completely observed ethical issues (including plagiarism, data fabrication, and double publication).

Funding/Support

None.

References

1. Elsayed NM, Jastaniah SD. Mobile Phone Use and Risk of Thyroid Gland Lesions Detected by Ultrasonography. Open J Radiol. 2016;6:140-146. doi: 10.4236/ojrad.2016.62021.
2. Baby NM, Koshy G, Mathew A. The Effect of Electromagnetic Radiation due to Mobile Phone Use on Thyroid Function in Medical Students Studying in a Medical College in South India. Indian J Endocrinol Metab. 2017;21:797-802. doi: 10.4103/ijem.IJEM_12_17.
3. Alkayyali T, Ochuba O, Srivastava K, Sandhu JK, Joseph C, Ruo SW, et al. 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. 2021;13:e17329. doi: 10.7759/cureus.17329.
4. Grimes DR. Radiofrequency Radiation and Cancer: A Review. JAMA Oncol. 2022;8:456. doi: 10.1001/jamaoncol.2021.5964.
5. Karipidis K, Mate R, Urban D, Tinker R, Wood A. 5G mobile networks and health—a state-of-the-science review of the research into low-level RF fields above 6 GHz. J Expo Sci Environ Epidemiol. 2021;31:585-605. doi: 10.1038/s41370-021-00297-6.
6. Gandhi OP. Yes the Children Are More Exposed to Radiofrequency Energy From Mobile Telephones Than Adults. IEEE Access. 2015;3:985-8. doi: 10.1109/ACCESS.2015.2438782.
7. Fernández C, de Salles AA, Sears ME, Morris RD, Davis DL. Absorption of wireless radiation in the child versus adult brain and eye from cell phone conversation or virtual reality. Environ Res. 2018;167:694-9. doi: 10.1016/j.envres.2018.05.013.
8. Morris RD, Morgan LL, Davis D. Children Absorb Higher Doses of Radio Frequency Electromagnetic Radiation From Mobile Phones Than Adults. IEEE Access. 2015;3:2379-87. doi: 10.1109/ACCESS.2015.2478701.
9. Kim HY, Son Y, Jeong YJ, Lee SH, Kim N, Ahn YH, et al. Effects of 4G Long-Term Evolution Electromagnetic Fields on Thyroid Hormone Dysfunction and Behavioral Changes in Adolescent Male Mice. Int J Mol Sci. 2024;25:10875. doi: 10.3390/ijms252010875.
10. Luo J, Deziel NC, Huang H, Chen Y, Ni X, Ma S, et al. Cell phone use and risk of thyroid cancer: a population-based case-control study in Connecticut. Ann Epidemiol. 2019;29:39-45. doi: 10.1016/j.annepidem.2018.10.004.
11. De Vocht F. Interpretation of Timetrends (1996–2017) of the Incidence of Selected Cancers in England in Relation to Mobile Phone Use as a Possible Risk Factor. Bioelectromagnetics. 2021;42:609-15. doi: 10.1002/bem.22375
12. Luo J, Li H, Deziel NC, et al. Genetic susceptibility may modify the association between cell phone use and thyroid cancer: A population-based case-control study in Connecticut. Environ Res. 2020;182:109013. doi: 10.1016/j.envres.2019.109013
13. Saad AG, Kumar S, Ron E, et al. Proliferative Activity of Human Thyroid Cells in Various Age Groups and Its Correlation with the Risk of Thyroid Cancer after Radiation Exposure. J Clin Endocrinol Metab. 2006;91:2672-7. doi: 10.1210/jc.2006-0417
14. Kutanzi KR, Lumen A, Koturbash I, Miousse IR. Pediatric Exposures to Ionizing Radiation: Carcinogenic Considerations. Int J Environ Res Public Health. 2016;13:1057. doi: 10.3390/ijerph13111057.
15. Iglesias ML, Schmidt A, Ghuzlan AA, Lacroix L, Vathaire F, Chevillard S, et al. Radiation exposure and thyroid cancer: a review. Arch Endocrinol Metab. 2017;61:180-7. doi: 10.1590/2359-3997000000257.
16. Veiga LH, Holmberg E, Anderson H, Pottern L, Sadetzki S, Adams MJ, et al. Thyroid Cancer after Childhood Exposure to External Radiation: An Updated Pooled Analysis of 12 Studies. Radiat Res. 2016;185:473-84. doi: 10.1667/RR14213.1.
17. Suzuki K, Mitsutake N, Saenko V, Yamashita S. Radiation signatures in childhood thyroid cancers after the Chernobyl accident: Possible roles of radiation in carcinogenesis. Cancer Sci. 2015;106:127-33. doi: 10.1111/cas.12583.
18. Rogers C, Bush N. Heart Failure: Pathophysiology, Diagnosis, Medical Treatment Guidelines, and Nursing Management. Nurs Clin North Am. 2015;50:787-99. doi: 10.1016/j.cnur.2015.07.012.
19. Gebauer J, Higham C, Langer T, Denzer C, Brabant G. Long-Term Endocrine and Metabolic Consequences of Cancer Treatment: A Systematic Review. Endocr Rev. 2019;40:711-67. doi: 10.1210/er.2018-00092
20. Reiners C, Drozd V, Yamashita S. Hypothyroidism after radiation exposure: brief narrative review. J Neural Transm. 2020;127:1455-66. doi: 10.1007/s00702-020-02260-5.
21. Zufry H, Rudijanto A, Soeatmadji DW, Sakti SP, Munadi K, Sujuti H, et al. 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. J Adv Pharm Technol Res. 2023;14:63-68. doi: 10.4103/japtr.japtr_680_22.
22. Zufry H, Rudijanto A, Soeatmadji DW, Sakti SP, Munadi K, Sujuti H, et al. Do electromagnetic fields significantly affect thyroid cells and their functions? – A systematic review. F1000Research. 2024;13:12. doi: 10.12688/f1000research.128740.1.
23. Silva V, Hilly O, Strenov Y, Tzabari C, Hauptman Y, Feinmesser R. Effect of cell phone-like electromagnetic radiation on primary human thyroid cells. Int J Radiat Biol. 2016;92:107-115. doi: 10.3109/09553002.2016.1117678.
24. Swerdlow AJ, Feychting M, Green AC, Kheifets L, Savitz DA. Mobile Phones, Brain Tumors, and the Interphone Study: Where Are We Now? Environ Health Perspect. 2011;119:1534-8. doi: 10.1289/ehp.1103693.
25. Miller AB, Sears ME, Morgan LL, Davis DL, Hardell L, Oremus M, et al. Risks to Health and Well-Being From Radio-Frequency Radiation Emitted by Cell Phones and Other Wireless Devices. Front Public Health. 2019;7:223. doi: 10.3389/fpubh.2019.00223.
26. Sinnott B, Ron E, Schneider AB. Exposing the Thyroid to Radiation: A Review of Its Current Extent, Risks, and Implications. Endocr Rev. 2010;31:756-773. doi: 10.1210/er.2010-0003.
27. Mullur R, Liu YY, Brent GA. Thyroid Hormone Regulation of Metabolism. Physiol Rev. 2014;94:355-382. doi: 10.1152/physrev.00030.2013.
28. Zufry H, Rudijanto A, Soeatmadji DW, Sakti SP, Munadi K, Sujuti H, et al. A study protocol for investigating the effects of mobile phone-originated electromagnetic waves on thyroid gland and thyroid hormone activities in the brain. F1000Research. 2023;12:132. doi: 10.12688/f1000research.129735.2.
29. Pizzino G, Irrera N, Cucinotta M, et al. Oxidative Stress: Harms and Benefits for Human Health. Oxid Med Cell Longev. 2017;2017:8416763. doi: 10.1155/2017/8416763.
30. Cheserek MJ, Wu GR, Ntazinda A, Shi YH, Shen LY, Le GW. Association Between Thyroid Hormones, Lipids and Oxidative Stress Markers in Subclinical Hypothyroidism. J Med Biochem. 2015;34:323-331. doi: 10.2478/jomb-2014-0044.
31. Ho WLC, Zacharin MR. Thyroid carcinoma in children, adolescents and adults, both spontaneous and after childhood radiation exposure. Eur J Pediatr. 2016;175:677-683. doi: 10.1007/s00431-016-2692-z.
32. Mirkatouli NB, Hirota S, Yoshinaga S. Thyroid cancer risk

after radiation exposure in adults—systematic review and meta-analysis. J Radiat Res (Tokyo). 2023;64:893-903. doi: 10.1093/jrr/rrad073.
33. Bulanova Pekova B, Sykorova V, Mastnikova K, Vaclavikova E, Moravcova J, Vlcek P, et al. RET fusion genes in pediatric and adult thyroid carcinomas: cohort characteristics and prognosis. Endocr Relat Cancer. 2023;30:e230117. doi: 10.1530/ERC-23-0117.
34. Rooney MK, Andring LM, Corrigan KL, Bernard V, Williamson TD, Fuller CD, et al. Hypothyroidism following Radiotherapy for Head and Neck Cancer: A Systematic Review of the Literature and Opportunities to Improve the Therapeutic Ratio. Cancers. 2023;15:4321. doi: 10.3390/cancers15174321.
35. Liening DA, Duncan NO, Blakeslee DB, Smith DB. Hypothyroidism following radiotherapy for head and neck cancer. Otolaryngol Head Neck Surg. 1990;103:10-3. doi: 10.1177/019459989010300102.
36. Antonelli A, Ferrari SM, Corrado A, Di Domenicantonio A, Fallahi P. Autoimmune thyroid disorders. Autoimmun Rev. 2015;14:174-180. doi: 10.1016/j.autrev.2014.10.016.
37. Di Pietro G, Forcucci F, Chiarelli F. Endocrine Disruptor Chemicals and Children's Health. Int J Mol Sci. 2023;24:2671. doi: 10.3390/ijms24032671.
38. Byun YH, Ha M, Kwon HJ, et al. Mobile Phone Use, Blood Lead Levels, and Attention Deficit Hyperactivity Symptoms in Children: A Longitudinal Study. PLoS One. 2013;8:e59742. doi: 10.1371/journal.pone.0059742.
39. Geronikolou SA, Chamakou A, Mantzou A, Chrousos G, KanakaGantenbein C. Frequent cellular phone use modifies hypothalamic–pituitary–adrenal axis response to a cellular phone call after mental stress in healthy children and adolescents: A pilot study. Sci Total Environ. 2015;536:182-188. doi: 10.1016/j.scitotenv.2015.07.052.
40. Hamed SA, Attiah FA, Abdulhamid SK, Fawzy M. Behavioral assessment of children and adolescents with Graves' disease: A prospective study. PLoS One. 2021;16:e0248937. doi: 10.1371/journal.pone.0248937.
41. Tarım Ö. Thyroid Hormones and Growth in Health and Disease. J Clin Res Pediatr Endocrinol. 2011;3:51-55. doi: 10.4274/jcrpe.v3i2.11
42. Rastogi MV, LaFranchi SH. Congenital hypothyroidism. Orphanet J Rare Dis. 2010;5:17. doi: 10.1186/1750-1172-5-17.
43. Grossklaus R, Liesenkötter KP, Doubek K, Völzke H, Gaertner R. Iodine Deficiency, Maternal Hypothyroxinemia and Endocrine Disrupters Affecting Fetal Brain Development: A Scoping Review. Nutrients. 2023;15:2249. doi: 10.3390/nu15102249.
44. Calcaterra V, Biganzoli G, Ferraro S, et al. Thyroid Function and Metabolic Syndrome in Children and Adolescents with Neuromotor Disability. Children. 2022;9:1531. doi: 10.3390/children9101531.
45. Ramouzi E, Sveroni K, Manou M, Papagiannopoulos C, Genitsaridi SM, Tragomalou A, et al. The Impact of Thyroid Hormones on Cardiometabolic Risk in Children and Adolescents with Obesity, Overweight and Normal Body Mass Index (BMI): A One-Year Intervention Study. Nutrients. 2024;16:2650. doi: 10.3390/nu16162650.
46. Di Ciaula A, Bonfrate L, Noviello M, Portincasa P. Thyroid Function: A Target for Endocrine Disruptors, Air Pollution and Radiofrequencies. Endocr Metab Immune Disord - Drug Targets. 2023;23:1032-40. doi: 10.2174/1871530321666210909115040.
47. Hanley P, Lord K, Bauer AJ. Thyroid Disorders in Children and Adolescents: A Review. JAMA Pediatr. 2016;170:1008. doi: 10.1001/jamapediatrics.2016.0486.
48. Chaker L, Bianco AC, Jonklaas J, Peeters RP. Hypothyroidism. Lancet Lond Engl. 2017;390:1550-62. doi: 10.1016/S0140-6736(17)30703-1.
49. Lee SY, Pearce EN. Hyperthyroidism. JAMA. 2023;330:1472-83. doi: 10.1001/jama.2023.19052.