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The Use of Technetium-99m Radioactive Isotope in The Diagnosis and Treatment of Thyroid Diseases: A Review

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Keywords: Technetium-99m, Radioactive Isotope, Thyroid, Radiation Exposure, Scanning Protocols.

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Abstract:

A Tc-99m thyroid scanning is one of the most common diagnostic modalities in nuclear medicine for the evaluation of various thyroid dysfunctions and anomalies. Therefore, this review study will delve into the various dimensions related to patient exposure during Tc-99m thyroid scanning. Various subjects are covered, such as radiation risks from the procedure, methods for reducing patient exposures, imaging technology developments, and the importance of an effective radiation safety program. In this review, some new developments in and possible ways toward better safety for the patient and diagnostic accuracy of the thyroid imaging methods are also discussed.

Keywords: Technetium-99m, Radioactive Isotope, Thyroid, Radiation Exposure, Scanning Protocols.

(Immediately after the abstract, provide 5-7 keywords and arrange them alphabetically, using American spelling and avoiding general and plural terms and multiple concepts (avoid, for example, 'and', 'of'). Be sparing with abbreviations: only abbreviations firmly established in the field may be eligible. These keywords will be used for indexing purposes).

أستخدام النظائر المشعة التكنيتيوم-m ٩٩ في تشخيص وعلاج أمراض الغدة الدرقية: مراجعة

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الخلاصة:

في الطب النووي، يعد مسح الغدة الدرقية بالتكنيتيوم-*99m* (*Tc-99m*) تقنية تشخيصية شائعة الاستخدام لتقييم وظيفة الغدة الدرقية وتحديد الحالات الشاذة. تبحث دراسة المراجعة هذه في المشاكل التي يتعرض المريض أثناء عمليات فحص الغدة الدرقية Tc-99*m*. وهو يغطي المخاطر الإشعاعية لهذا الإجراء، وطرق تقليل تعرض لهذه المخاطر، والتطورات في تكنولوجيا التصوير، وأهمية بروتوكولات السلامة الإشعاعية القوية. وتناقش المراجعة أيضًا التطورات الجديدة والمسارات المحتملة لطرق تصوير الغدة الدرقية لتحسين سلامة المرضى ودقة التشخيص.

الكلمات المفتاحية: التكنيشيوم-٩٩m، النظائر المشعة، الغدة الدرقية، التعرض للإشعاع، تحسين بروتوكولات المسح.

1. Introduction:

The thyroid is a relatively large endocrine organ in the body that plays a very important role in body growth, metabolism, and maturation **[1, 2],** the thyroid gland regulates numerous biological processes by constantly releasing many thyroid hormones into the bloodstream. When a woman is pregnant, when it's chilly outside, or when her body requires more energy, it releases more hormones **[3].** This organ produces two hormones: triiodothyronine (T3) and thyroxin (T4) **[4, 5, 6].** There are several stages to thyroid disorders, from early to late stages. Individuals suffering from thyroid diseases are classified as having either "hypothyroidism" (low T4 levels) or "hyperthyroidism" (high T4 or T3 and low TSH) based on the function parameters **[7, 8].** Hypothyroidism is regarded as one of the most prevalent illnesses in endocrine therapy **[9],** it refers to a reduction in thyroid hormone **[10, 11].** Hypothyroidism symptoms include weariness, muscle swelling or cramping, loss of balance, weight gain, hair loss, and cold intolerance. Ultrasound, computed tomography (CT), and magnetic resonance imaging (MRI) are three common imaging modalities used to diagnose thyroid problems. Ultrasound is the first-line imaging modality because it is good at evaluating thyroid nodules and determining their features, such as size and content, which can signal malignancy risk **[12].** CT scans are highly effective for determining the severity of thyroid illness, particularly in cases of suspected malignancy or when evaluating adjacent structures **[13].** While MRI is less widely used than ultrasound and CT, it can produce comprehensive images of the thyroid and adjacent tissues, making it useful in certain clinical settings, such as assessing big goiters or invasive thyroid malignancies **[14].** Besides that, nuclear medicine methods that include thyroid scintigraphy are used to assess thyroid function and detect hyperfunctioning nodules **[15].**

Other than medical applications, radioactive isotopes are used in countless other applications within soil science, wastewater treatment, and industry. In the medical profession, lasers abound in therapeutic procedures as external radiation sources, and injections are performed for hyperthyroidism and malignancies **[16, 17]**. Thyroid scanning by technetium-99m radioactive isotope is now a very common diagnostics technique of nuclear medicine **[18].**

Patient exposure in such scans should be kept in mind for potential risks and precautions **[19].** One major precaution to be taken needs to find the right quantity and potential radio isotopic nature which can be used in a human body safely. It can be calculated by giving an appropriate dose to a particular individual according to their body weight and medical history. The whole-body doses that reach the patient make it necessary to use lead or lead glass shields when performing the procedure. Besides, it is important to inform the patient beforehand and get their consent before proceeding with the thyroid scan. Such a consent form should point at the advantages a given process has on the health of the subject, the potential risk of radiation exposure, and alternative measures. In general, the technetium-99m radioactive isotope scans of the thyroid are of great importance for diagnostic purposes in the field of nuclear medicine. Adequate precautions should be taken and informed consent by the patient is to be ensured for patient safety **[18].** On every occasion during the use of radioisotopes, some precautions should be taken to ensure the safety of the scientist **[20].** Some of the considerations, relative to isotopes used most frequently in biological research, include proper shielding and protective gear, proper safe-handling procedures, and reduction of manual handling procedures of the radioisotopes **[21].** Furthermore, it becomes essential to ensure regular radiation level monitoring within the laboratories alongside very strict procedures on storage and disposal of radioactive materials with a view of reducing the possible risks of exposure to healthcare workers and patients. The last year marked the beginning of a period with computer technology advances in the actual development of imaging techniques without using ionizing radiation. These techniques, applied in the diagnoses, are costly conventional procedures but are also rich sources of functional and morphological information. Informed consent from the patients should be routinely obtained prior to any radiography procedure, including thyroid scanning with technetium-99m radioactive isotope [18]. Imaging of thyroid nodules remains important in the evaluation of thyroid scintigraphy because it helps in determining benign from malignant lesions [22, 23].

Initial results for the use of 99mTc in thyroid scintigraphy following inconclusive results of the exact-needle biopsy, especially ultrasound EU-TIRADS, are highly promising [24]. Consecutive pertechnetate- and MIBI scans have also been described as useful methods to display hypofunctional thyroid tissue and, therefore, allow the diagnosis of dystopic tissue or metastases [25]. Establishing diagnostic reference levels for thyroid scans with 99mTc is a step required for the optimization of nuclear medicine investigations in connection with the radiation safety requirements [26]. Thyroid scintigraphy can be helpful in providing information in difficult cases. The results show that it makes a significant contribution to the thyroid nodule detection process. Radiation dose rates were recorded at different distances after treatment with Technetium (Tc-99m) for thyroid scintigraphy.

The present article intends to provide an overview of the application of Technetium (Tc-99m) in thyroid scans looking into the risks of radiation exposure methods, for improving scanning processes and new developments, in thyroid imaging technology. Through discussing these points the review aims to support the endeavors to improve the safety and efficiency of Tc 99m related thyroid imaging tests.

2. Material and methods:

2.1. Role of Technetium-99m for thyroid scintigraphy: One of the two elements lacking stable isotopes with an atomic number less than 83 is technetium. 99Tc was found in a sample in 1937 by Perrier and Segré using the Berkeley Radiation Laboratory's 37-inch cyclotron to blast a Mo sample with deuterons [27]. They questioned Lawrence, who in 1929 created the cyclotron [28], to make the bombardment. Segré and Seaborg found the 99Tc metastable state in 1938 [29]. Technetium (Tc-99m) is, due to its concentrating nature in the thyroid, an important isotope for diagnosing thyroid disorders [30, 31]. It has a significant contribution to many diagnostic tests for thyroid diseases with benefits over other imaging modalities [30]. Technetium-99m is unique in nuclear medicine due to the versatility of applications and its most favored properties. This has been recently obtained from a 99Mo/99mTc generator, which offers easy accessibility of the isotope to medical applications [32]. The 99mTc being employed decays by gamma emission and has a physical six-hour half-life, and is thus perfect for soft tissue imaging like the thyroid and brain and bones [33]. Its electron configuration makes it apt for the formation of complexes with various ligands, helping materialize the concept of mainly targeting imaging and therapy at different parts of the body through SPECT [34]. Moreover, 99mTc has been utilized in examinations of pediatric nuclear medicine with a high rate of residual radioactivity; it is hence quite vital in the diagnosis of many ailments in children [35]. In summary, the ability to produce 99mTc, its property for imaging, and the eventual residual behavior have collectively made the radionuclide an important substance in nuclear medicine applications.

Tc-99m pertechnetate thyroid scintigraphy is very useful in assessing thyroid function and estimating thyroid uptake percentage as well as for the diagnosis of hyperthyroidism and hypothyroidism [36, 37]. The Tc-99m scan is indicated for the diagnosis of congenital hypothyroidism and the differentiation of agenesis from thyroid versus reduced uptake. The Tc-99m pertechnetate scintigraphy is also useful for the diagnosis of cold nodules of the thyroid, which determines the possibility of malignancy and aids in treatment decisions.

Of the isotopes in use in medicine, technetium-99m occupies a very special niche in nuclear medicine diagnosis, whose metastable isotope is greatly utilized. On the other hand, 99mTc finds wide applications for all types of diagnostic procedures, including SPECT imaging, which it has made a workhorse compared to other isotopes [32-34]. Also, new ways of implementing nanodiamonds as 99mTc carriers have been investigated, showing the versatility of this radionuclide and an expectation of further development in medical diagnostics [35]. What has made the isotope 99mTc special for nuclear medicine, compared with other isotopes applied for similar purposes in diagnosis, is the good storage properties of Tc-99m and its use in clinical routines, in addition to the specific features of 99mTc.

Scanning with Tc-99m in nuclear medicine is an important tool that allows for the noninvasive assessment of thyroid morphology, function, and pathology [38]. Gamma radiation emissions combined with excellent imaging characteristics make Tc-99m thyroid scanning useful in the management and diagnosis of various thyroid disorders [39]. Common indications for Tc-99m thyroid scanning include assessing thyroid- nodules and evaluating thyroid function in hyperthyroidism and hypothyroidism, other than detecting the relapse of thyroid cancer after treatment [40]. Techniques like the Tc-99m MIBI scintigraphy can, therefore, clearly discriminate thyroid from parathyroid tissue. This feature makes the diagnosis more accurate

[41]. Secondly, Tc-99m thyroid uptake is a good alternative to radioiodine in thyrotoxicosis, where it provides an accurate diagnosis for many thyroid diseases [42].

However, on the downside, despite being diagnostic, Tc-99m thyroid scanning involves radiation exposure and its associated health Hazards. Although the radiation doses for thyroid scans are generally relatively low compared with other nuclear medicine examinations, meticulous concerns for radiation safety principles that directly contribute to the reduction of patient radiation exposure and reduction of risks associated with it become paramount. This paper reviews the dosimetry of Tc-99m thyroid scanning, comparative radiation doses from other imaging modalities for the diagnosis of similar pathologies, and strategies for the optimization of imaging protocols to achieve diagnostic efficacy at the lowest possible radiation exposures, Pertechnetate Tc99m is a radiopharmaceutical that finds utilization in diagnosing thyroid diseases primarily due to its sodium iodide symporter (NIS) facilitated uptake mechanism [43]. This glycoprotein aids the transportation of iodide ions into the thyroid follicular cells through active means which allows for a concentration of Tc99m within the thyroid gland thus enabling visualization using gamma cameras or single photon emission tomography (SPECT) imaging techniques [44]. In this process, localization of the radiopharmaceutical as well as biodistribution can be confirmed by demonstrating where NIS-expressing tissues such as salivary glands and thyroid are located [44]. Additionally, mechanisms underlying the action of thyroid hormones should be understood since they inform the interpretation of imaging findings and clinical implications of thyroid disorders [45]. By leveraging machine learning models in the classification of thyroid diseases, diagnostic accuracy is further improved especially with challenges related to data imbalance and model interpretability [43]. Altogether, Tc99m-pertechnetate is an essential tool for the diagnosis of various types of thyroid conditions characterized by efficient imaging obtained from its specific uptake mechanism

2.2. Radiation Exposure Risks: Radiation dangers have become an issue with the growing usage of computed tomography (CT) scans in the medical industry [46]. Radiation dose levels — even low ones — through ionizing radiation can lead to cancer development risk increase especially in pediatric patients because their developing tissues and organs are increasingly radiation-sensitive. Maximizing diagnostic value while minimizing harm is dependent on a keen consideration of radiation dosimetry, as well as the implementation of strategies for imaging protocol optimization. While the use of Tc-99m for thyroid imaging is an established diagnostic modality, it's important that one knows the associated radiation doses so one can be able to compare them with alternative imaging techniques: The effective doses typically delivered by Tc-99m thyroid scans range from 1-5 mSv which generally is lower than other nuclear medicine procedures like radioiodine thyroid uptake studies **[47].** However, the amount of radiation from repeat Tc-99m thyroid scans can add up: in cases where multiple scans are done or when other imaging modalities are used along with it, especially in children. Among the Tc-99m thyroid technique, especially with 99mTc-MIBI, it seems to have an edge over the others in risk assessment and diagnostic accuracy. A major multicenter study recorded that 99mTc-MIBI imaging had a high negative predictive value—sensitivity of 96% for excluding malignancy in hyperfunctioning thyroid nodules—but poor specificity, 21%, because of frequent false positives, hence requiring careful pre-test selection of nodules **[48].** In contrast, 99mTc scintigraphy showed better accuracy in diagnosing Graves' disease compared to thyroid ultrasonography with a sensitivity of 96.1% versus 23.5%, respectively, for ultrasound **[49].** Additionally, the gamma camera measurement of 99mTc pertechnetate uptake showed better diagnostic accuracy than that of the gamma probe method with a sensitivity of 93.4% and specificity of 94.8% **[50].** These results indicate that, although the Tc-99m techniques seem to have some limitations in terms of specificity, their high sensitivity and diagnostic accuracy render them, when taken together, good tools for thyroid assessment, particularly for the differential diagnosis among thyroid diseases. Tc-99m thyroid technique provide an advantages many grounds when compared with the traditional techniques, more specifically I-131. First, Tc-99m pertechnetate presents better image quality due to its low radiation dose of about 10,000 times less compared to that of I-131, and at the same time, it emits no beta radiation, reducing exposure to the patient. Besides, Tc-99m has a rather short half-life time and a biological retention time, allowing faster procedures and less discomfort to the patient. This technique is also relatively inexpensive and very accessible, hence its availability for clinical use **[51].** Besides, the Tc-99m scintigraphy can even differentiate between amiodarone-induced thyrotoxicosis types of thyroid disorders, which helps in appropriate diagnosis and treatment planning **[52].** On the whole, these factors create an increasing preference for the use of Tc-99m in thyroid imaging, hence making it a very valuable tool in clinical practice **[51, 52].**

2.3. Optimizing Protocols for Tc-99m Thyroid Scanning: Several techniques can be used to reduce radiation exposure during Tc-99m thyroid scanning. Patient selection and justification for imaging should be Entailed primarily. Where Tc-99m thyroid scanning is indicated, optimization of the scanning protocol by altering parameters such as administered radiotracer activity, imaging time, collimator selection, etc., should be done. [47, 53]. In addition, it can be seen that new modalities of imaging, in particular, SPECT and combined SPECT/CT, are capable of providing better diagnostic information while presumably keeping at the lowest level the radiation doses applied compared to conventional planar imaging [54]. Patient factors, especially age- and body habitus-dependent variables, are another strong determinant of clinical indications that may also guide protocol optimization. In particular, pediatric patients require special consideration since they are more radiosensitive and could benefit from additional procedures in terms of dose reduction, such as low-dose CT for hybrid imaging modalities' attenuation correction [47, 53].

2.4. Emerging Trends in Thyroid Imaging Technology: Investigation, in the domain of nuclear medicine imaging, is currently focused on enhancing the safety and effectiveness of thyroid scans utilizing Tc- 99m. Technetium 99m plays a role in nuclear medicine especially for thyroid imaging [55]. Scientists are exploring imaging techniques like Computed Tomography (CT) combined with Single-Photon Emission Computed Tomography (SPECT) to improve the accuracy and specificity of thyroid scans [56, 57]. Additionally, studies are being conducted on radioisotopes and radiopharmaceuticals such as Thallium 199. Gallium 68, for thyroid imaging, shows potential in diagnosing various conditions, including cancer [58, 59]. These developments aim to not only enhance the capabilities of nuclear medicine but also prioritize patient safety and optimize treatment outcomes for thyroid-related disorders.

3. Results:

According to the literature review, there are a few studies that have looked into the patient radiation exposure in Technetium-99m based thyroid scans. Several techniques were used by these studies including phantom-based measurements, Monte Carlo simulations, and patient-specific dose assessments to quantify radiation exposure to various organs as well as the effective doses of patients.

Reported effective doses ranged between about 1-5 mSv from technetium-99m thyroid scans and varied depending on factors like imaging protocol, patients' characteristics and specific radiopharmaceutical formulation used. In some cases, the organ-specific doses were calculated with the thyroid gland experiencing relatively high radiation compared to other organs examined.

Some factors such as Technetium-99m administered activity, imaging protocol parameters (for example acquisition time or number of views), body habitus of patients, and particular radiopharmaceutical formulation were found during the review to affect patient radiation dose during thyroid scans.

4. Discussion

This review has found that it is important for one to know how much radiation a patient gets during a Technetium-99m based thyroid scan as shown in **Figure 1**, which gives a good and clear image of the thyroid with different doses **[60]**. Although the diagnostic benefits of these scans are well known, health risks associated with radiation exposure cannot be ignored.

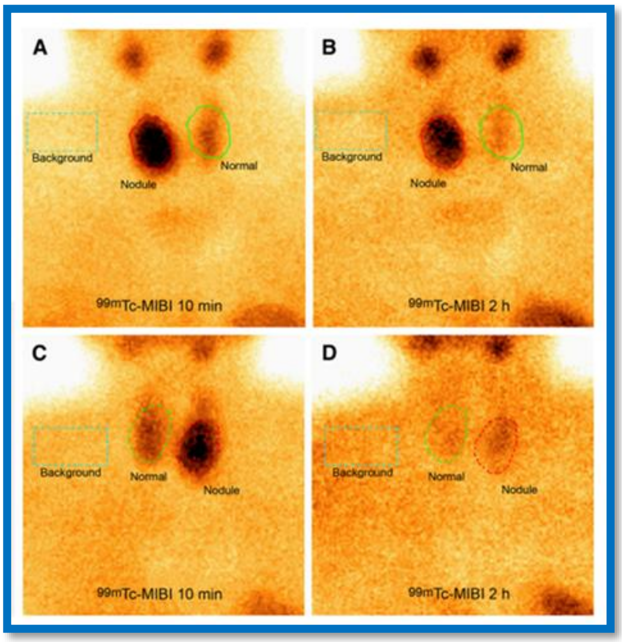

Figure 1: 99mTc-MIBI Thyroid scan. A&B A single chilly thyroid nodule in the right lobe that was histologically identified as non-oncocytic solid/trabecular poorly differentiated carcinoma is a representative positive case (RI, 71.76). (A) An early image shows tracer buildup in a nodule (ER, 2.62). (B) Tracer retention in the lesion with delayed imaging (DR, 4.50). (C & D) Representative nugatory case (RI, 240.64) A solitary chilly thyroid nodule in the left lobe was diagnosed as a micro follicular goiter. (C) early picture with Tracer raised uptake in nodules (ER, 2.81). (D) A delayed picture with a complete tracer fiasco from the nodule (DR = 1.67).

The reported effective dose range of 1-5 mSv is generally within the recommended limits for medical imaging procedures. However, this does not account for cumulative radiation doses from multiple diagnostic tests, especially in patients with chronic thyroid conditions and who may require regular follow-up scans.

Efforts towards optimizing radiation protection should therefore emphasize establishing appropriate imaging protocols, utilizing advanced imaging techniques (e.g., low-dose protocols), and taking into consideration patient-specific factors (e.g., body habitus) that can minimize unnecessary irradiation.

Also, the review revealed that Technetium-99m administered activity, imaging protocol parameters, patient body habitus, and specific radiopharmaceutical formulation were some of the factors affecting patient’s radiation dose in thyroid scans. The present findings also highlight proper dosimetry strategies as well as optimization of imaging protocols to guarantee patients’ safety during thyroid scans.

5. Recommendations

This requires health workers to maintain at least one meter's distance from the patient after injection because of radiation safety reasons **[61].** Finally, it was put into consideration that members of the public should keep their distance from proximity to the patient for at least 3 hours after injection to avoid risks associated with radiation exposure **[62].** These precautions are therefore very important, with nuclear radiation being hazardous material in nature, and thus any exposure should be reduced to ensure minimum medical effects on medic workers and public protection from potential harm **[63].** Safety distances and lengths of time should, therefore, be observed both before and after injection to minimize risks related to exposure to radiation of all persons involved or around nuclear medicines procedures.

6. Conclusions

This review explores Technetium-99m thyroid scans; and how much patients are exposed to radiation from the procedure. The results show that nuclear medicine imaging must continue being optimized as far as the protection and safety of patients against radiation are concerned.

The dose received during Tc-99m thyroid scanning should be evaluated carefully and adjusted to achieve appropriate diagnostic efficacy and to minimize radiation exposure, particularly in vulnerable populations like children. By implementing appropriate radiation protection strategies, including justification of imaging, optimization of scanning protocols, and the use of alternative modalities when feasible, healthcare providers can ensure the safe and effective use of Tc-99m thyroid imaging.

It was established that the high sensitivity and diagnostic accuracy of the TC-99 m technique makes it a good tool for thyroid assessment, particularly in the differential diagnosis of thyroid diseases. When compared to traditional methods, including I-131, the Tc-99m thyroid technique offers several advantages. To begin with, better quality images are produced by Tc-99m pertechnetate because its radiation dose is approximately 10,000 times less than that of I-131 and it does not emit beta radiation; thus reducing patient exposure. Further still, Tc-99m has a relatively short half-life time as well as a biological retention period such that procedures can be done more quickly and comfortably for patients. The other reason why this procedure is advantageous includes its low cost implying that it is affordable to many people and hence used in clinical practice. Additionally, even the Tc-99m scintigraphy can differentiate between amiodarone-induced thyrotoxicosis types of thyroid disorders which helps in appropriate diagnosis and treatment planning. Therefore, an increasing preference towards using Tc-99m for thyroid imaging due to these factors makes it a very important tool in clinical practice.

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