RESEARCH PAPER

Thyroid Dose Measurement and Radiation Protection in Computed Tomography: A Narrative Review of Current Evidence and Emerging Strategies

***Running Title:** Thyroid Dose and Protection in CT*

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Abstract

Background: Computed tomography (CT) is an essential diagnostic imaging modality, but its increasing utilization has raised concerns regarding radiation exposure to the thyroid gland, one of the most radiosensitive organs. Owing to its superficial anatomical location, the thyroid is frequently exposed during CT examinations of the head, neck, chest, and upper thorax, highlighting the importance of accurate dose assessment and effective radiation protection. **Objective:** To critically review current evidence on thyroid dose measurement techniques, radiation protection strategies, conventional and emerging thyroid shielding technologies, and future approaches for minimizing thyroid radiation exposure during CT imaging. **Methods:** A narrative review of peer-reviewed literature, clinical and phantom studies, review articles, and international radiation protection guidelines was conducted. Current evidence regarding thyroid dosimetry, CT dose optimization, shielding devices, advanced imaging technologies, and artificial intelligence (AI)-assisted radiation protection was synthesized. **Results:** Thermoluminescent dosimeters, optically stimulated luminescence dosimeters, MOSFET detectors, anthropomorphic phantoms, and computational dosimetry remain the principal methods for thyroid dose assessment. Current evidence demonstrates that protocol optimization, automatic exposure control, iterative and deep-learning reconstruction, scan range optimization, and appropriate thyroid shielding can substantially reduce radiation exposure while maintaining diagnostic image quality. Emerging approaches, including patient-specific shielding, 3D-printed devices, composite shielding materials, and AI-guided dose optimization, show considerable potential for enhancing radiation safety. However, variability in dosimetry methods and shielding protocols limits comparison across studies. **Conclusion:** Standardized dosimetry, optimized CT protocols, evidence-based shielding, and continued development of affordable, innovative protection technologies are essential to minimize thyroid radiation exposure and improve patient safety during CT imaging.

Keywords: *Computed tomography; Thyroid radiation dose; Radiation protection; Thyroid shielding; Thermoluminescent dosimeter; Artificial intelligence; Indigenous thyroid shield.*

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1. Introduction

Computation Tomography (CT) scanning technique has become one of the most commonly used techniques because of its fast scanning speed, high resolution, and high diagnostic accuracy.(1) Multidetector Computed Tomography, Automatic Exposure Control, Iterative Reconstruction, Image Reconstruction by Deep Learning, and Spectral Imaging are some of the innovations that have made huge improvements in the image quality and broadened the application of CT in evaluating trauma, oncology, cardiology, pulmonology, and emergency medicine.(2) Nevertheless, even with the huge advances in technology, CT has been found to be accountable for the largest share of the patient's accumulated radiation dose compared to any other diagnostic imaging procedure.(3)

In radiosensitive organs, the thyroid gland is regarded to be one of the most radiosensitive due to its superficial location and radiosensitive tissues. As per the computed tomography of the head, neck, cervical spine, chest and upper thorax region, the thyroid gland can be subjected to ionizing radiations coming from the direct X-ray beam as well as scattered radiation, even though it is not the organ of concern. (4) Many epidemiological studies conducted on the population who were exposed to atomic bombings, medically exposed individuals and individuals exposed during nuclear incidents have proved the association between ionizing radiation exposure and thyroid cancers, more so in young individuals who are radiosensitive to the development of radiation induced tumors. (5)

The recommendations for radiation protection in CT scans, which have been provided by the ICRP, along with the principles of justification and optimization, recommend that CT scan should be performed in such a manner that information obtained from this examination is maximal with the lowest dose reasonably achievable (ALARA). (6) Over the last ten years, many developments in dose reduction in CT scans have taken place due to the use of automatic tube current modulation, organ specific tube current modulation, optimized scan range determination, low-dose CT scanning, and advanced image processing. The dose to patients has been reduced significantly due to advancements in technology without deteriorating the image quality.(7)

It is very important to find out the dose of the thyroid gland in order to estimate the efficacy of the CT protocols and dose reduction techniques.(8) The dose of the thyroid gland has been evaluated using different dosimetry procedures like TLD, OSLD, MOSFET detection procedure, anthropomorphic phantom and Monte Carlo method.(9) Apart from that, there are some defined CT dosimetry quantities like CTDIvol, DLP, SSDE, organ dose and effective dose which could be helpful in optimization of the protocols and evaluation of radiation risks.(10)

Several approaches were assessed for the reduction of the thyroid gland dose in CT scans. Traditional approaches are associated with optimization of scan parameters, patient positioning, and application of lead or bismuth collars; however, recently there were suggestions to use light composite collars, 3D-printed personalized shields, and reduction of radiation doses by means of artificial intelligence (AI) technology. (11) Although many investigations reported significant reduction of the dose to the thyroid gland with the strategies, the differences in design of experiments, dosimetric assessment, CT scanners and shielding protocols resulted in discrepancies of the obtained data. (12) In addition, some concerns regarding image artifacting, incompatibility with automated exposure control systems, and lack of standardized recommendations limit the application of some of the proposed approaches.

This narrative review aims to present a critical synthesis of existing knowledge regarding radiation doses to the thyroid gland in computed tomography, emphasizing the following aspects: dosimetry, CT dose index values, radiation protection, standard and novel shielding methods for the thyroid gland, as well as personalized radiation protection.

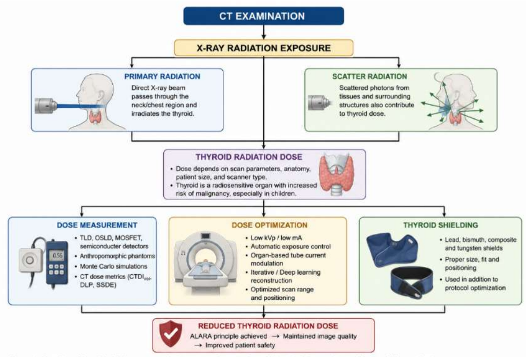

Figure 1. Overview of thyroid radiation exposure during computed tomography and the principal strategies used for thyroid dose reduction.

2. Search Strategy

The narrative literature review approach was applied for locating and summarizing the current literature about radiation dose measurement in thyroid in CT and radiation protection in CT. The literature search was extensively done in PubMed/MEDLINE, Scopus, Web of Science, Google Scholar, and IEEE Xplore for the articles published from January 2005 to June 2026. The search terms involved the MeSH terms and free text terms including computed tomography, CT radiation dose, thyroid gland, thyroid radiation dose, radiation protection, thyroid shielding, thermoluminescent dosimeter (TLD), optically stimulated luminescence dosimeter (OSLD), MOSFET dosimeter, Monte Carlo simulation, artificial intelligence, dose optimization, 3D printing, and patient-specific shielding. Boolean operators (AND, OR) were used for effective search.

Literature resources eligible for use included primary research papers, phantom and clinical studies, systematic reviews, narrative reviews, technical reports, and international guidelines in the English language. International guidelines from agencies such as ICRP, IAEA, and AAPM were considered in the search because of their significance in CT radiation protection. The exclusion criteria consisted of conference abstracts, editorials, letters to the editor, non-English publications, and insufficient methodological and outcome details in studies.

The selected literature has been filtered out depending upon its title, abstract, and full-text information. Literature which has been focusing on thyroid dosimetry, dosing techniques for CT, radiation dosing optimization, radiation shielding, radiation imaging, and innovative techniques such as artificial intelligence and personalized protection of patients from radiation has been given priority. More literature has been selected manually by reviewing the references section of the selected articles. Evidence selected has been reviewed and organized in themes such as radiation exposure of thyroid gland, radiation dosing techniques, radiation protection, novel shielding techniques, problems encountered, and future research direction.

As a narrative review, this study did not follow a systematic review methodology or perform a formal risk-of-bias assessment. Consequently, study selection and synthesis may be influenced by publication bias and methodological heterogeneity.

3. Radiation Exposure to the Thyroid During CT Imaging

The thyroid gland is one of the radiosensitive glands as it is situated superficially in the anterior neck area, well-vascularized and has a fast cellular turnover rate.(13) In the scanning process of the head, neck, cervical spine, chest, and upper thorax, there will be exposure to radiation of the thyroid gland either directly or through scatter radiation in X-rays, even if this is not the main area being examined.(14) Although the amount of radiation used in each scanning procedure may not be too high, repeated scanning procedures can increase the total amount of radiation that the thyroid gland receives.(15)

The biological effects of radiation exposure can be categorized into deterministic and stochastic. Deterministic effect will occur only when the doses exceed a certain threshold and is rarely observed in diagnostic CT scan since the radiation doses utilized during CT scans are less than the dose needed to cause any significant damage to the thyroid. (16) On the other hand, stochastic effect does not have a known threshold; its probability of occurrence increases as the dose of radiation increases. Radiation-induced thyroid cancer becomes the primary long-term effect of thyroid irradiation. (17) Epidemiologic studies show that there is a high incidence of thyroid cancer in atomic bomb survivors, in addition to those who have been medically exposed to radiation and nuclear accidents. (18)

Various technical and patient factors influence the thyroid dose received during CT examinations. These factors include kVp that influences the energy of X-ray produced by X-ray tube; mA that influences the intensity of X-ray and, in conjunction with kVp, increases the dose absorbed by the thyroid gland.(19) The other factor is the scan length, because the longer the scan, the more the thyroid gland gets exposed to radiation without the need of it. Other factors that influence exposure of the gland to radiation are pitch, gantry rotation time, field of view, and patient's position.(20) Multi detector CT machines with AEC, organ-specific tube current modulation, and optimal reconstruction techniques can be useful in decreasing thyroid dose to a significant extent.(21)

In accordance with international radioprotection organizations like ICRP, all CT examinations must be done in compliance with the principles of justification, optimization and ALARA, in order to obtain the lowest level of radiation exposure possible. Patient selection, optimization of scanning parameters, restricted scope of scanning and application of dose reduction techniques are still the key to thyroid radiation protection in CT examination. (22)

Despite the tremendous advances that have been made in CT imaging technology, protection of patients from excessive radiation exposure to thyroid gland remains to be a significant clinical problem. Evaluation of the dose of radiation exposure to thyroid gland is crucial to maintain the right balance between benefits of diagnosis and patient's safety.

Table 1. Summary of Major Studies on Thyroid Radiation Dose and Protection During CT Imaging

Author (Year)	**Study Type**	**Study Focus**	**Dose Measurement / Protection Method**	**Key Findings**
Derbew et al. (2023)	Retrospective clinical study	Inadvertent thyroid exposure during chest CT	Clinical dose assessment	Demonstrated that the thyroid receives substantial radiation exposure during chest CT even when outside the primary imaging field.
Jeyasugiththan et al. (2022)	Phantom study	Effectiveness of thyroid shielding during abdominal CT	TLD dosimetry with thyroid shield	Thyroid shielding significantly reduced absorbed thyroid dose without compromising diagnostic image quality.
Hoang et al. (2012)	Phantom study	Organ-based tube current modulation and thyroid shielding	TLD dosimetry	Combined organ-based tube current modulation and thyroid shielding reduced thyroid radiation dose while maintaining image quality.
Maziar et al. (2019)	Clinical dosimetry study	Thyroid dose estimation during head CT	TLD measurements and ImPACT software	Demonstrated good agreement between measured thyroid dose and computational dose estimation methods.
Yamashita et al. (2021)	Experimental study	Direct organ dose measurement during CT	Direct organ dosimetry	Validated direct measurement as an accurate approa

				ch for assessing organ-specific radiation dose.
Khoramian et al. (2024)	Multicenter clinical study	Thyroid dose and radiation risk during head CT	Effective dose and thyroid cancer risk estimation	Reported measurable thyroid radiation exposure and emphasized optimization of CT protocols to reduce lifetime radiation risk.
McCollough & Yu (2026)	Review	Advances in CT dose reduction	Modern CT dose optimization techniques	Summarized technological advances including iterative reconstruction, automatic exposure control, and optimized acquisition parameters for reducing radiation dose.
Patil et al. (2026)	Scoping review	Pediatric CT dose optimization	Low-dose CT strategies	Highlighted age-specific CT protocols, dose optimization techniques, and emerging technologies for reducing radiation exposure in children.
Clement David-Olawade et al. (2025)	Review	AI-driven low-dose CT imaging	Artificial intelligence-based dose optimization	Demonstrated the growing role of AI in optimizing CT protocols while preserving diagnostic image quality.
Schürmann et al. (2026)	Review	Modern patient shielding recommendations	Evidence-based shielding practice	Recommended selective patient shielding integrated with optimized CT protocols rather

				than routine shieldi ng alone.

4. Thyroid Dose Measurement Techniques

The determination of the dose to the thyroid is crucial for evaluating the radiation dose exposure, as well as the effectiveness of the dose reduction measures in computerized tomography (CT).(23) Correct dose determination enables optimization of the scan process, testing of the effectiveness of shielding equipment, evaluation of various dose reduction techniques and the risk assessment associated with the radiation exposure. There are various techniques for thyroid dose measurement, such as direct dosimetry, phantom dosimetry, simulation and CT dose index measurements.(24)

4.1 Direct Dosimetry

Direct dosimetry suggests measurement of absorbed dose with detectors positioned at the patient's skin surface or anthropomorphic phantoms simulating the thyroid gland. In this way, one can get quantitative dose estimation of an organ and thus, these methods serve as the reference for assessment of CT protocols and radiation protection devices. (25)

Popular thyroid dosimeters include thermoluminescent dosimeters (TLDs). TLDs represent detectors made of tissue equivalent materials, e.g. lithium fluoride. These detectors capture energy of irradiation and convert it into light by means of heating. (26) High sensitivity, precision, compactness and low effect on image quality make these dosimeters optimal for phantom and clinical studies. However, special device is necessary for data interpretation, TLDs must be annealed after each measurement and they do not allow real-time dosimetry. (27)

The optical stimulated luminescence dosimeters operate on similar principles, but they trigger the release of energy storage through light stimulus. As compared to TLD dosimeters, OSLD dosimeters have faster readings and multiple readings with higher reproducibility. However, the issue of fading signal and need for calibration is another challenge. (28)

MOSFET dosimeters give instant readings and can be used for optimization and quality control of CT protocols. Its small size allows it to be placed close to the thyroid gland while not affecting image quality. Limited lifespan of the detector, calibration, and relatively high cost are some of the limitations of using MOSFET dosimeters. Another way of measuring radiation is through the use of semiconductor detectors with high resolution in real time. (29)

4.2 Phantom-Based Dosimetry

The Phantom-based dosimetry method allows evaluating the dose of radiation received by the thyroid gland in a reproducible manner without exposing patients to additional radiation.(30) The use of phantoms makes it possible to simulate human anatomy, and to assess parameters of acquisition, shields, and radiation dose reduction techniques. Thus, phantom-based studies form the basis of the research and testing in radiation protection area.(31)

Anthropomorphic phantoms, such as Alderson RANDO phantom, are used to simulate human anatomy, and to provide cavities to place the dosimeters. This type of phantoms is considered a standard for measuring doses in organs due to its ability to reproduce realistic simulation of tissue attenuation and anatomical relations.(32) Recently 3D thyroid phantoms were developed as low cost platforms for testing of new shielding materials and personalized radiation protection measures. Moreover, pediatric phantoms became more widespread, because they allow assessment of age-specific CT scanning protocols, due to increased sensitivity of children to radiation compared to adults.(33)

Despite highly reproducibility of the results obtained using phantom-based methods, it is impossible to fully simulate patient variability in anatomical characteristics, physiological motion, and body habitus.

4.3 Computational Dosimetry

The computation of dosimetry determines the radiation absorbed by the thyroid using calculations and modeling via the computer without the need for any physical measurement. This method does not require any additional radiation exposure to be done, making it easy to test multiple scan techniques and anatomy rapidly. (34)

The Monte Carlo simulation is one of the most widely used reference methods because of the accuracy of modeling the interaction of photons in tissues and accurate calculation of organ doses. However, it has strict requirements for data related to scanner parameters, anatomical models, and computing resources which may be a limitation for its use in practice. (35)

Computer programs such as NCICT and VirtualDose have been created to perform dose calculations of organs based on specific cases of patients through the use of computational phantoms. The software combines parameters of the scanners and anatomical models to quickly determine the dose in the thyroid. Artificial intelligence (AI) is a relatively new technology that has great potential for predicting the dose absorbed by organs, optimizing acquisition parameters and individualizing radiation protection. (36)

4.4 CT Dose Metrics

Several standardized dose metrics are routinely used to evaluate radiation output during CT examinations. CT dose index volume (CTDI_{vol}) represents the average scanner radiation output, whereas dose-length product (DLP) reflects the total radiation output for a complete examination.(37) Size-specific dose estimate (SSDE) incorporates patient size to provide a more individualized estimate of radiation exposure, particularly in pediatric imaging. Organ dose, expressed in milligray (mGy), remains the most clinically relevant parameter because it reflects the absorbed radiation dose to the thyroid.(38) Effective dose, expressed in millisievert (mSv), estimates overall radiation risk by incorporating tissue weighting factors and is primarily intended for population-based comparisons rather than individual patient assessment.(39)

4.5 Comparison of Dosimetry Methods

No single dosimetry technique is suitable for every application. Direct dosimetry provides the highest measurement accuracy and remains the preferred method for validating shielding devices and experimental protocols.(40) Phantom-based studies offer standardized and reproducible conditions for comparative research, whereas computational methods facilitate rapid, non-invasive organ dose estimation and protocol optimization. Standardized CT dose metrics complement these approaches by enabling comparison of scanner performance and examination protocols.(31) Integrating direct measurements, phantom experiments, and computational modeling provides the most comprehensive assessment of thyroid radiation exposure and supports the development of effective radiation protection strategies in CT imaging.(25)

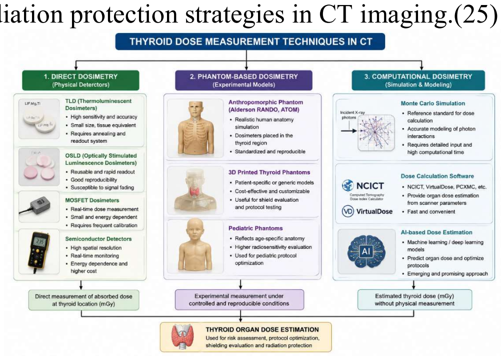

Figure 2. Classification and overview of thyroid dose measurement techniques used in computed tomography.

Table 2. Comparison of Thyroid Dose Measurement Techniques

Method	**Advantages**	**Limitations**	**Typical Application**
Thermoluminescent Dosimeter (TLD)	High accuracy, tissue equivalent, inexpensive	No real-time reading, requires annealing	Phantom and clinical dosimetry
Optically Stimulated Luminescence Dosimeter (OSLD)	High sensitivity, repeatable readout	Higher cost, signal fading	Clinical quality assurance
MOSFET Dosimeter	Real-time measurement, compact	Limited lifespan, calibration required	Interventional procedures
Semiconductor Detector	High spatial resolution, rapid response	Energy dependence	Equipment quality control
Monte Carlo-based Computational Dosimetry	Highest computational accuracy	Time-consuming, software dependent	Organ dose estimation
Computational Organ Dose Software (VirtualDose®, NCICT)	Fast patient-specific dose estimation	Dependent on scanner input parameters	Research and protocol optimization
Anthropomorphic Phantom	Realistic anatomy	Cannot simulate physiology	Shield evaluation and protocol optimization

5. Current Strategies for Thyroid Radiation Protection

Radiation protection during computed tomography (CT) aims to achieve the maximum diagnostic benefit while minimizing unnecessary radiation exposure to radiosensitive organs. The thyroid gland is particularly susceptible to ionizing radiation because of its superficial anatomical location and high radiosensitivity.(20) Consequently, reducing thyroid dose has become a major focus of CT protocol optimization, especially in pediatric patients and individuals requiring repeated imaging.(41) Current thyroid radiation protection strategies combine protocol optimization, advanced scanner technologies, patient positioning, and shielding techniques to reduce radiation exposure without compromising diagnostic image quality.(42)

5.1 CT Protocol Optimization

Optimization of CT acquisition parameters remains the most effective and universally applicable approach for reducing thyroid radiation exposure. Appropriate selection of tube voltage (kVp), tube current (mA), pitch, rotation time, and scan length directly influences radiation dose delivered to the patient.(23) Lower tube voltage and tube current settings can substantially decrease thyroid dose when diagnostic image quality is preserved. Similarly, restricting the scan range to the region of clinical interest prevents unnecessary irradiation of the thyroid gland, particularly during head, neck, and chest examinations. Individualized protocols based on patient age, body size, and clinical indication further improve dose efficiency while maintaining diagnostic accuracy.(43)

5.2 Automatic Exposure Control and Organ-Based Tube Current Modulation

Modern multidetector CT scanners incorporate Automatic Exposure Control (AEC) systems that automatically adjust tube current according to patient attenuation characteristics. By delivering only the radiation required for adequate image quality, AEC reduces unnecessary exposure compared with fixed tube current techniques.(44) In addition, Organ-Based Tube Current Modulation (OBTCM) selectively lowers X-ray tube output when the beam passes over radiosensitive anterior organs, including the thyroid, while maintaining image quality in deeper anatomical structures. Numerous phantom and clinical studies have demonstrated that these technologies can achieve meaningful reductions in thyroid radiation dose without significantly affecting diagnostic performance.(45)

5.3 Advanced Image Reconstruction Techniques

Recent developments in image reconstruction have enabled further dose reduction by improving image quality at lower radiation exposures. Iterative reconstruction (IR) algorithms reduce image noise and enhance spatial resolution, allowing CT examinations to be performed using lower acquisition parameters than conventional filtered back projection.(46) More recently, deep-learning image reconstruction (DLIR) has demonstrated superior noise reduction and image quality, enabled additional dose reductions while preserving diagnostic confidence. These reconstruction methods have become integral components of modern low-dose CT protocols and contribute significantly to thyroid radiation protection.(47)

5.4 Patient Positioning and Scan Planning

Appropriate patient positioning is a simple yet effective strategy for minimizing thyroid radiation exposure. Correct alignment of the patient within the scanner isocenter ensures optimal functioning of automatic exposure control systems and prevents unnecessary increases in radiation output.(48) Whenever clinically feasible, extending the neck or positioning the thyroid outside the primary X-ray beam reduces direct thyroid irradiation. Careful selection of scan boundaries and avoidance of unnecessarily long scan ranges also contribute to lowering thyroid dose while preserving diagnostic information.(49)

5.5 Thyroid Shielding

Thyroid shielding remains one of the most widely investigated methods for protecting the gland during CT examinations. Conventional shields are typically fabricated from lead or bismuth and are placed over the anterior neck to attenuate scattered and, in selected situations, primary radiation. Numerous phantom and clinical studies have reported significant reductions in thyroid dose with these devices.(50) However, inappropriate placement may introduce beam-hardening artifacts, interfere with automatic exposure control systems, and degrade image quality if positioned within the scan field. Consequently, current professional recommendations emphasize that thyroid shielding should be used selectively and only when it does not compromise diagnostic accuracy or interfere with optimized scanner technology.(51)

5.6 Pediatric Radiation Protection

Children are considerably more radiosensitive than adults because of their rapidly dividing tissues and longer expected lifetime during which radiation-induced effects may develop. Therefore, pediatric CT examinations require dedicated dose optimization strategies. Age- and size-specific imaging protocols, reduced tube voltage, lower tube current, shortened scan coverage, and advanced reconstruction techniques should be routinely implemented.(52) When clinically appropriate, carefully positioned thyroid shields may provide additional protection, although protocol optimization remains the primary method of dose reduction. Adherence to pediatric imaging initiatives such as Image Gently further promotes safe CT practice in children.(53)

5.7 Emerging Patient-Centered Protection Strategies

Recent advances in radiation protection extend beyond conventional shielding. Patient-specific shielding designed using three-dimensional (3D) printing, lightweight composite shielding materials, and artificial intelligence (AI)-based optimization systems are emerging as promising approaches for individualized radiation protection.(54) AI algorithms can assist in selecting patient-specific acquisition parameters, predicting organ dose, and improving image quality at lower radiation exposures. Although these technologies require further clinical validation, they represent important developments toward precision radiation protection in CT imaging.(55)

Current thyroid radiation protection relies on a combination of optimized CT protocols, automatic exposure control, organ-based tube current modulation, advanced image reconstruction, appropriate patient positioning, and selective use of thyroid shielding. Rather than relying on a single intervention, integrating these complementary strategies provides the greatest reduction in thyroid radiation dose while preserving diagnostic image quality.(21) Continued advancements in patient-specific shielding, AI-assisted optimization, and personalized imaging protocols are expected to further enhance thyroid radiation safety in future CT practice.

Table 3. Comparison of Thyroid Radiation Protection Strategies During CT

Strategy	**Dose Reduction**	**Advantages**	**Limitations**
Scan range optimization	Moderate	No additional equipment	Operator dependent
Automatic exposure control	Moderate	Automatic dose reduction	Scanner dependent
Organ-based tube current modulation	Moderate–High	Protects superficial organs	Limited availability
Iterative reconstruction	Moderate	Maintains image quality	Vendor specific
Deep-learning reconstruction	High	Enables ultra-low-dose CT	Expensive technology
Lead thyroid collar	Moderate–High	Widely available, inexpensive	Beam-hardening artifacts if improperly positioned
Bismuth shield	Moderate	Lightweight	Increased image noise near shield
Tungsten/composite shield	High	Lightweight, flexible	Higher cost
Patient positioning	Low–Moderate	No cost	Requires proper training
AI-assisted protocol optimization	High	Personalized scanning	Limited clinical validation
Patient-specific 3D shielding	Moderate–High	Customized protection	Experimental

Among the various radiation protection strategies discussed above, thyroid shielding remains one of the most extensively investigated approaches. Commercial shielding devices have therefore been developed using different materials and designs to maximize thyroid dose reduction while preserving image quality.

6. Commercial Thyroid Shielding Devices

Commercial thyroid shielding devices have been widely adopted as an additional radiation protection measure during computed tomography (CT) examinations, particularly when the thyroid gland lies within or adjacent to the primary X-ray beam.(57) These devices are designed to attenuate primary and scattered radiation reaching the thyroid while maintaining diagnostic image quality. Although advances in CT technology have shifted emphasis toward protocol optimization and automated dose reduction techniques, thyroid shields continue to play an important role in selected clinical situations, especially in pediatric imaging and for patients undergoing repeated CT examinations. Their effectiveness depends on shielding material, design, positioning, and compatibility with modern CT systems.(57)

6.1 Lead Thyroid Collars

Lead thyroid collars remain the most used commercial shielding devices because of the excellent radiation attenuation properties of lead. These collars typically contain lead-equivalent thicknesses ranging from 0.25 to 0.50 mm Pb, which effectively reduce low- and medium-energy X-ray photons commonly encountered in diagnostic CT.(53) Properly positioned lead collars have demonstrated significant reductions in thyroid dose during head, neck, and chest CT examinations. Their widespread availability, relatively low cost, and durability have made them the standard shielding option in many radiology departments.(57) However, lead collars are relatively heavy and inflexible, which may reduce patient comfort and make accurate positioning difficult. In addition, placement within the primary imaging field can introduce beam-hardening artifacts and interfere with automatic exposure control (AEC), potentially increasing radiation output rather than reducing it. Consequently, careful placement outside the scan volume is essential for maximizing their protective benefit.(58)

6.2 Bismuth Thyroid Shields

Bismuth shielding was introduced as a lightweight alternative to conventional lead collars. Bismuth-impregnated latex or flexible polymer materials provide effective attenuation of superficial radiation while offering greater flexibility and improved patient comfort.(59) Several phantom and clinical studies have reported meaningful reductions in thyroid dose with bismuth shields, particularly during chest and cervical CT examinations. However, concerns have been raised regarding increased image noise, streak artifacts, and inaccuracies in CT number measurements when shields are positioned directly within the imaging field.(60) Furthermore, the interaction between bismuth shielding and AEC systems may result in unintended increases in tube current if the shield is applied before scout image acquisition. Current recommendations therefore advise careful patient selection and correct shield placement to minimize image degradation while preserving dose reduction benefits.(61)

6.3 Tungsten and Composite Shielding Materials

Recent commercial developments have focused on replacing traditional lead with lighter and environmentally safer materials. Tungsten-based and composite shielding devices incorporate high atomic number elements within flexible polymer matrices to provide radiation attenuation comparable to lead while reducing weight and improving flexibility.(62) Composite materials containing tungsten, barium sulfate, bismuth oxide, or other heavy-metal compounds have demonstrated favorable attenuation characteristics and improved ergonomics. These shields are more comfortable for patients, easier to position, and eliminate many of the environmental concerns associated with lead disposal. Although early studies report promising dosimetric performance, long-term clinical validation and standardized testing across different CT systems remain limited.(63)

6.4 Ergonomic and Adjustable Shield Designs

Commercial manufacturers have also introduced ergonomic thyroid shields designed to improve patient comfort and positioning accuracy. Adjustable collars with Velcro fasteners, contoured neck supports, and flexible multilayer constructions allow better adaptation to different patient body sizes and reduce the likelihood of shield displacement during scanning. Such improvements are particularly valuable in pediatric imaging, where maintaining correct shield position can be challenging. Enhanced ergonomics also facilitate routine clinical use without substantially increasing examination time.

6.5 Clinical Effectiveness and Limitations

Numerous phantom and clinical investigations have demonstrated that commercially available thyroid shields can substantially reduce thyroid radiation exposure when used appropriately. Reported dose reductions vary widely depending on CT scanner model, acquisition parameters, scan region, shielding material, and measurement methodology.(11) Despite these benefits, commercial shielding should not be regarded as a substitute for optimized CT protocols. Incorrect shield placement may produce beam-hardening artifacts, interfere with automatic exposure control, obscure anatomical structures, and adversely affect diagnostic image quality. For these reasons, several professional organizations recommend prioritizing protocol optimization, scan range limitation, automatic exposure control, and advanced reconstruction techniques, while reserving thyroid shielding for carefully selected clinical situations where it provides additional benefit without compromising image quality.(51)

6.6 Future Directions for Commercial Shielding

Commercial thyroid shielding devices continue to play an important role as adjunctive radiation protection measures during selected CT examinations.(64) Conventional lead collars remain the most widely used because of their excellent radiation attenuation, whereas bismuth, tungsten, and composite-material shields provide lighter and more flexible alternatives with improved patient comfort. The clinical effectiveness of these devices depends not only on the shielding material but also on appropriate patient selection, correct positioning, and compatibility with modern CT technologies, including automatic exposure control and advanced image reconstruction algorithms.(33) When improperly positioned within the scan field, shields may introduce beam-hardening artifacts or interfere with scanner dose modulation, potentially reducing their overall benefit. Consequently, current evidence supports the selective use of thyroid shielding as a complementary strategy rather than a substitute for optimized CT protocols. Integrating commercial shielding with protocol optimization, scan range limitation, and advanced reconstruction techniques provides the greatest opportunity to minimize thyroid radiation exposure while maintaining diagnostic image quality.(57)

Table 4. Comparison of Current and Emerging Thyroid Shielding Technologies

Shield Type	Material	Advantages	Limitations	Current Status
Commercial lead collar	Lead (0.25–0.5 mm Pb)	Excellent attenuation, reusable	Heavy, artifact risk	Widely used
Bismuth shield	Bismuth	Lightweight,	May alter CT	Selective use

		flexible	numbers	
Tungsten shield	Tungsten	Higher attenuation, thinner	Costly	Emerging
Composite shield	Tungsten/ Bismuth polymer composites	Lightweight, flexible	Limited clinical validation	Emerging
Indigenous shield	Locally available materials	Low cost, customizable	Limited multicenter evidence	Experimental
3D-printed shield	Tungsten composite filament	Patient-specific, lightweight	Manufacturing expertise required	Emerging
Patient-specific shield	Customized composite	Excellent anatomical fit	Expensive production	Under development

Although commercially available shielding devices have demonstrated satisfactory performance, recent advances in materials science and artificial intelligence have stimulated the development of next-generation thyroid protection technologies.

7. Emerging Thyroid Shielding Technologies

Recent advances in material science, additive manufacturing, and artificial intelligence (AI) have driven the development of next-generation thyroid shielding technologies aimed at overcoming the limitations of conventional lead and bismuth collars. While traditional shielding remains effective for reducing thyroid radiation exposure, concerns regarding weight, patient comfort, image artifacts, environmental safety, and compatibility with modern CT scanners have stimulated research into lightweight, patient-specific, and intelligent shielding systems. These emerging technologies seek to enhance radiation protection while maintaining diagnostic image quality and improving clinical usability.(65)

7.1 Three-Dimensional (3D)-Printed Thyroid Shields

Three-dimensional (3D) printing has emerged as a promising technology for developing customized thyroid shields tailored to individual patient anatomy. Unlike commercially available collars of fixed dimensions, 3D-printed shields can be designed using patient-specific anatomical data obtained from CT or surface scanning, ensuring improved conformity and coverage of the thyroid gland.(66) Such customization enhances patient comfort and minimizes shield displacement during imaging. Furthermore, additive manufacturing enables rapid fabrication of lightweight devices using composite materials with high radiation attenuation properties. Although preliminary phantom studies have demonstrated encouraging reductions in thyroid dose, further clinical validation is required before widespread implementation.(67)

7.2 Composite and Nanocomposite Shielding Materials

Novel shielding materials incorporating tungsten, bismuth oxide, barium sulfate, tungsten oxide, and other high atomic number compounds have attracted considerable attention as environmentally friendly alternatives to lead. These materials are embedded within flexible polymer matrices to produce lightweight, non-toxic, and mechanically durable shields capable of providing effective attenuation of diagnostic X-rays. More recently, nanotechnology has enabled the development of nanocomposite shielding materials with improved attenuation efficiency, flexibility, and reduced thickness. Although these materials demonstrate favorable experimental performance, large-scale clinical studies evaluating their long-term durability, cost-effectiveness, and compatibility with different CT systems remain limited.(68)

7.3 Artificial Intelligence and Personalized Dose Optimization

Artificial intelligence is increasingly being integrated into CT imaging to support personalized radiation protection. Machine learning algorithms can analyze patient characteristics, anatomical features, and examination protocols to recommend individualized acquisition parameters that minimize radiation exposure while preserving diagnostic image quality. AI-based organ segmentation also enables estimation of patient-specific thyroid dose and facilitates optimized scan planning. In addition, deep-learning reconstruction algorithms reduce image noise at lower radiation doses, complementing conventional dose optimization strategies. Although these technologies remain under active investigation, they have significant potential to improve precision radiation protection in clinical practice.(2)

7.4 Indigenous and Low-Cost Thyroid Shielding Devices

Affordable indigenous thyroid shielding devices have emerged as an attractive alternative for healthcare facilities with limited resources. Locally manufactured shields using readily available radiation-attenuating materials can substantially reduce costs while providing radiation protection comparable to commercially available products. These devices are particularly relevant in low- and middle-income countries where access to imported shielding equipment may be limited. However, standardized testing of attenuation efficiency, mechanical durability, patient comfort, and image quality remains essential before routine clinical implementation. Comparative studies evaluating indigenous and commercial shields are needed to establish evidence-based recommendations for their clinical use.(69)

Emerging thyroid shielding technologies emphasize lightweight materials, patient-specific design, and intelligent dose optimization rather than reliance on conventional shielding alone. Integration of 3D printing, advanced composite materials, AI-assisted imaging, and validated indigenous shielding devices has the potential to improve radiation protection while enhancing patient comfort and maintaining diagnostic image quality. Continued multidisciplinary research is required to translate these innovations into routine clinical practice.(33)

8. Challenges, Limitations, and Future Directions

Despite significant advances in CT technology and radiation protection, several challenges continue to limit effective thyroid dose reduction. Considerable variability exists among published studies regarding scanner models, acquisition parameters, dosimetry techniques, phantom designs, shielding materials, and outcome measures. This methodological heterogeneity complicates comparison across studies and limits the development of standardized clinical recommendations.

One of the major challenges involves balancing radiation dose reduction with diagnostic image quality. While lowering tube current or tube voltage can substantially decrease radiation exposure, excessive dose reduction may increase image noise and reduce diagnostic confidence. Similarly, although thyroid shields effectively attenuate radiation, incorrect positioning or inappropriate use within the scan field may introduce beam-hardening artifacts and interfere with automatic exposure control systems. Consequently, protocol optimization should remain the primary approach to radiation reduction, with shielding used selectively when clinically appropriate.

Accurate thyroid dosimetry also remains an area requiring further standardization. Thermoluminescent dosimeters, optically stimulated luminescence dosimeters, MOSFET detectors, and Monte Carlo simulations each provide valuable information but differ in measurement principles, accuracy, calibration requirements, and clinical applicability. The absence of standardized protocols for organ dose measurement limits reproducibility and comparison of research findings across institutions. Development of internationally accepted dosimetry guidelines would improve consistency and facilitate multicenter studies.

Emerging technologies offer promising opportunities for improving thyroid radiation protection. AI-assisted protocol optimization, automated organ segmentation, patient-specific shielding, and advanced reconstruction algorithms have the potential to achieve further dose reductions while maintaining image quality. Similarly, 3D printing and composite shielding materials may improve patient comfort and reduce environmental concerns associated with lead-based devices. However, these technologies require prospective multicenter validation before routine clinical adoption.

Future research should prioritize standardized dosimetry methodologies, pediatric-specific optimization protocols, multicenter clinical trials evaluating emerging shielding technologies, and development of affordable patient-specific protective devices. Comparative evaluation of commercial and indigenous thyroid shields, together with cost-effectiveness analyses, will be particularly valuable for expanding access to effective radiation protection in resource-limited healthcare settings. Integration of technological innovation with evidence-based clinical practice will be essential for achieving safer and more personalized CT imaging.

Table 5. Current Challenges and Future Research Priorities

Current Challenge	**Clinical Impact**	**Recommended Future Direction**
Lack of standardized shielding guidelines	Variable clinical practice	International consensus guidelines
Heterogeneous dosimetry methods	Difficult comparison among studies	Standardized reporting protocols
Limited pediatric evidence	Uncertain dose optimization	Dedicated pediatric multicenter studies
Shield-induced image artifacts	Reduced diagnostic confidence	Development of artifact-free materials
High cost of advanced shields	Limited accessibility	Low-cost indigenous shielding devices
Limited clinical validation of emerging technologies	Slow implementation	Large multicentre clinical trials

Limited AI integration	Inconsistent protocol optimization	AI-guided personalized CT protocols
Variability among CT scanners	Different radiation outputs	Vendor-independent optimization strategies
Lack of standardized reporting	Difficult evidence synthesis	Development of international reporting guidelines

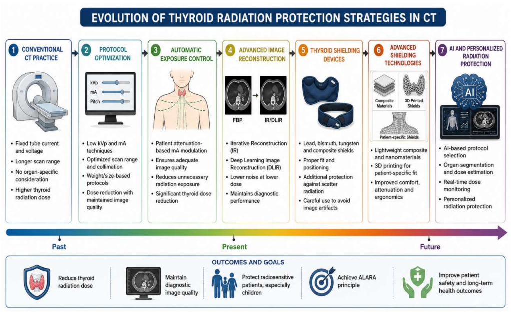

Figure 3. Evolution of thyroid radiation protection strategies in computed tomography—from conventional practice to future AI-based personalized radiation protection.

9. Conclusion

Computed tomography has transformed diagnostic imaging by providing rapid and accurate visualization of a wide range of pathological conditions; however, concerns regarding radiation exposure to radiosensitive organs such as the thyroid remain clinically important. Accurate thyroid dose assessment using direct dosimetry, phantom studies, computational modeling, and standardized CT dose metrics provides the foundation for evaluating radiation exposure and optimizing imaging protocols. Current evidence indicates that protocol optimization, automatic exposure control, organ-based tube current modulation, advanced image reconstruction, and appropriate patient positioning are the most effective strategies for reducing thyroid radiation dose while maintaining diagnostic image quality. Commercial thyroid shielding devices continue to provide additional protection in selected clinical situations, whereas emerging technologies including lightweight composite materials, 3D-printed patient-specific shields, artificial intelligence, and indigenous shielding devices offer promising opportunities for further improvement. Nevertheless, standardized dosimetry methods, high-quality clinical evidence, and multicenter validation studies remain necessary to establish best practices. Future research should focus on personalized radiation protection strategies that integrate technological innovation with evidence-based imaging protocols to enhance patient safety while preserving the diagnostic benefits of CT imaging. As CT utilization continues to increase worldwide, integrating standardized dosimetry, optimized imaging protocols, innovative shielding technologies, and AI-driven personalized dose optimization will be essential to achieving safer, patient-centered CT imaging works well and does not require further modification.

10. References

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