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Applications of Radioactive Isotopes in Nuclear Medicine: Diagnosis and Cancer Treatment

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Abstract

Radioactive isotopes are used in nuclear medicine for both diagnostic imaging and targeted treatment. This article reviews their main applications with emphasis on cancer diagnosis and therapy, the functional roles of SPECT and PET, radioactive iodine treatment, treatment-related safety, and recent developments in precision nuclear medicine. The review also examines the use of advanced imaging, targeted radiopharmaceuticals, artificial intelligence, and medical robotics as supporting technologies for tumor localization, treatment planning, and dose delivery. SPECT and PET provide complementary functional and metabolic information, while therapeutic radionuclides extend the same targeting principle to disease treatment. Iodine-131 remains a clear example of tissue-selective therapy, whereas newer radionuclide and carrier systems broaden the range of potential targets. The reviewed literature further indicates that clinical benefit depends on isotope selection, biological uptake, dosimetry, radiation safety, and patient-specific treatment planning. The article concludes that the future development of nuclear medicine will depend on closer integration of radiopharmaceutical science, imaging, computational analysis, and controlled dose delivery, together with clinically validated workflows and appropriate infrastructure.

Keywords: Radioisotopes, Nuclear Medicine, Cancer Diagnosis, Cancer Treatment, Therapeutic Radioisotopes, Medical Imaging

1. Introduction

Nuclear medicine uses radioactive isotopes and radiopharmaceuticals to examine physiological processes and to deliver radiation to selected tissues. Diagnostic applications are mainly based on the detection of emitted radiation after administration of a tracer,

whereas therapeutic applications use the radiation itself to damage or control diseased tissue. Technetium-based imaging and iodine radioisotopes remain established examples of these two roles (Abubakr et al., 2024; Qaim, 2017).

The clinical value of nuclear medicine is closely linked to its ability to provide functional and metabolic information that is not available from anatomical imaging alone. Single-photon emission computed tomography (SPECT) and positron emission tomography (PET) are widely used for functional imaging, while targeted radionuclide therapies extend the same principle to treatment. Recent work has also expanded the field toward theranostic approaches that combine diagnosis, treatment selection, and response assessment (Filippi et al., 2020; Sproull et al., 2023).

At the same time, the use of radioactive materials requires attention to isotope selection, radiation dose, exposure of healthy tissue, and patient-specific factors. These considerations are increasingly addressed through improved imaging, targeted radiopharmaceuticals, computational analysis, and precision treatment planning. Artificial intelligence and advanced image analysis are therefore becoming relevant to tumor delineation, treatment planning, and response assessment within modern nuclear medicine workflows (O'Brien & Mankoff, 2024).

This article provides a narrative review of the diagnostic and therapeutic applications of radioisotopes, with emphasis on cancer diagnosis and treatment. It compares SPECT and PET, discusses radioactive iodine therapy and treatment-related safety considerations, and reviews developments in personalized medicine, artificial intelligence, medical robotics, and precision targeting. The final sections use selected clinical application examples to connect these concepts with practice. The article synthesizes the cited literature and does not report a new clinical trial or patient cohort.

2. Background and Related Work

Nuclear medicine has developed from the early use of radioactive tracers into a clinical field that combines radionuclide production, radiopharmaceutical chemistry, functional imaging, and targeted therapy. Historical and technical reviews describe continuing improvements in isotope production, detector technology, tracer design, and clinical application (Anderson et al., 2019; Braghirolli et al., 2014; Schmor, 2011).

Recent literature places greater emphasis on radiopharmaceuticals that can support both disease characterization and treatment. Reviews of modern radioisotope applications describe a shift from general tracer use toward target-specific diagnostic and therapeutic systems, particularly in oncology (Abubakr et al., 2024; Varghese et al., 2024). This shift has also increased the importance of nuclear data, isotope availability, quality control, and traceable activity standards (Qaim, 2017; Judge et al., 2023).

Within this literature, the present article focuses on the relationship between diagnostic imaging, targeted radionuclide therapy, safety, and smart technologies. The aim is not to

compare individual clinical trials, but to organize the main technical and clinical concepts that determine how radioisotopes are selected, imaged, delivered, and monitored.

2.1 Radioisotopes and Mechanism of Action

Isotopes are forms of the same chemical element that contain the same number of protons but different numbers of neutrons. Radioisotopes are unstable isotopes that undergo radioactive decay and emit particles or photons. Their physical half-life, emission type, and energy determine whether a radionuclide is more suitable for imaging, therapy, or both (Anderson et al., 2019; Qaim, 2017).

In diagnostic applications, the emitted radiation is detected outside the body and reconstructed into images that represent tracer distribution and biological function. In therapeutic applications, the emitted energy is deposited in or near the target tissue. Nuclear medicine therefore depends on matching the physical characteristics of the radionuclide with the biological behavior of the carrier molecule and the clinical objective.

2.2 Medical Applications of Radioisotopes

Medical radioisotopes are used as diagnostic tracers, therapeutic sources, and components of targeted radiopharmaceuticals. Technetium-based compounds remain important for gamma-camera and SPECT imaging, while radioiodine is an established example of a radionuclide with both diagnostic and therapeutic relevance (Lengacher & Alberto, 2021; Ferris et al., 2020).

A radiopharmaceutical combines a radioactive component with a carrier that determines its biological distribution. Depending on the application, carriers may include small molecules, receptor-targeting ligands, antibodies, or engineered nanomaterials. This design determines where the radioactive signal or dose accumulates and therefore affects image quality, treatment selectivity, and exposure of non-target tissue (Ge et al., 2020).

Modern nuclear medicine increasingly links imaging and therapy through theranostic strategies. In this model, diagnostic information is used to identify or characterize a target and to support treatment selection or response assessment, while a related therapeutic agent delivers radiation to the same biological pathway (Filippi et al., 2020; Zoi et al., 2023).

2.3 Risks and Environmental Considerations

The use of ionizing radiation requires controlled handling, dose optimization, and protection of patients, staff, and the public. Risk is not determined by the presence of a radioisotope alone; it depends on administered activity, radiation type, tissue distribution, exposure time, and the sensitivity of the organs involved. Clinical nuclear-medicine departments therefore rely on standardized procedures for preparation, administration, monitoring, and disposal (Hung et al., 2023).

At the system level, safe practice also depends on reliable calibration, traceable radioactivity standards, trained personnel, and appropriate infrastructure (Judge et al., 2023; Singh et al., 2023). Environmental considerations mainly concern the controlled

management of radioactive materials and waste so that medical use does not create unnecessary occupational or environmental exposure.

3. Diagnostic Imaging Techniques

3.1 Scintigraphy (SPECT)

Single-photon emission computed tomography (SPECT) is a nuclear-imaging technique that detects gamma photons emitted by an administered radiotracer. Rotating detector systems acquire projections around the patient, and computational reconstruction produces cross-sectional or three-dimensional representations of tracer distribution (Filippi et al., 2020).

The main value of SPECT is functional assessment. Depending on the tracer, it can be used to evaluate perfusion, organ function, bone turnover, and other physiological processes. Technetium-99m remains widely used because its physical characteristics are compatible with gamma-camera imaging and a broad range of radiopharmaceutical preparations (Lengacher & Alberto, 2021).

SPECT is generally more accessible than PET and can support a wide range of routine studies. Its limitations include lower spatial resolution and sensitivity compared with modern PET systems, which can reduce its ability to characterize small or low-contrast abnormalities.

3.2 Positron Emission Tomography (PET)

Positron emission tomography (PET) detects pairs of photons produced after positron annihilation. Because the method measures tracer distribution associated with biochemical or metabolic processes, PET is widely used in oncology and also has applications in neurology and cardiology (Sproull et al., 2023).

A common PET strategy uses fluorine-18-labelled compounds such as fluorodeoxyglucose to visualize glucose-related metabolic activity. Regions with increased tracer uptake may support tumor detection, staging, treatment assessment, or identification of other metabolically active tissue. PET is frequently combined with CT, and in selected settings with MRI, to connect functional information with detailed anatomy.

Compared with SPECT, PET generally provides higher sensitivity and spatial resolution but requires more specialized infrastructure and access to short-lived radionuclides. These requirements can limit availability despite the clinical value of high-resolution metabolic imaging (Aluicio-Sarduy et al., 2019; Sproull et al., 2023).

3.3 Comparison of SPECT and PET

SPECT and PET provide complementary forms of functional imaging. Table 1 summarizes the main differences discussed in this review, including radiation type, image resolution, cost, common applications, isotope characteristics, and the ability to visualize metabolic activity.

Table 1: *Comparison of SPECT and PET imaging characteristics in nuclear medicine.*

Feature	SPECT	PET
Type of Radiation	Gamma photons	Positrons that interact to produce gamma photons
Resolution	Lower resolution	High resolution, especially for tumor imaging
Cost	Relatively lower	Higher cost
Applications	Heart imaging, brain imaging, bone imaging	Cancer diagnosis, brain activity, cardiac function assessment
Type of Isotopes Used	Long-lived isotopes like Technetium-99m	Short-lived isotopes like Fluorine-18
Metabolic Activity Visualization	Limited visualization	Excellent for metabolic activity and functional imaging

As shown in Table 1, SPECT remains useful for functional imaging in a broad range of organs and is generally less resource-intensive, whereas PET provides stronger metabolic characterization and higher image resolution for applications such as tumor assessment and neurologic imaging. Selection between the two modalities therefore depends on the clinical question, tracer availability, required resolution, and local infrastructure (Parrilha et al., 2022).

4. Therapeutic Applications of Radioisotopes

Radioactive iodine (RAI), particularly iodine-131 (I-131), is an established radionuclide therapy for selected thyroid disorders. It can be administered orally and is used because iodine is preferentially taken up by thyroid tissue, allowing radiation to be concentrated at the therapeutic target (Ferris et al., 2020).

After systemic administration, I-131 is concentrated by iodine-avid thyroid tissue and can therefore be used to ablate residual thyroid tissue or treat selected differentiated thyroid cancers. This targeted uptake is central to the clinical value of radioiodine because it concentrates the therapeutic effect in tissue that retains iodine-handling capacity (Ferris et al., 2020; Esposito et al., 2019).

4.1 Preparation for Radioactive Iodine Therapy

Radioactive iodine therapy is generally administered under controlled clinical and radiation-safety procedures. Although thyroid uptake concentrates the dose in the target tissue, patients may temporarily emit measurable radiation after treatment; consequently, post-treatment precautions are used to reduce unnecessary exposure to other people.

The biological basis of RAI therapy is the normal requirement of thyroid cells for iodine. The gland therefore concentrates administered radioiodine, and the emitted radiation can be used to damage targeted thyroid tissue while limiting exposure outside the main uptake sites (Xiao et al., 2019).

Iodine-131 can be delivered using clinically appropriate formulations, with oral administration commonly used in thyroid-directed treatment.

4.2 Radioactive Iodine Therapy for Hyperthyroidism

Radioactive iodine is also used in selected cases of hyperthyroidism, including diffuse thyroid overactivity and autonomously functioning nodules. Treatment selection depends on the clinical condition, previous therapy, and suitability of alternative approaches (Dyer et al., 2024).

Alternative management options include antithyroid medication and thyroid surgery. Radioactive iodine may be considered when medication is ineffective or unsuitable, or when surgery is not the preferred option.

Because thyroid-directed radiation can reduce functional thyroid tissue, long-term endocrine follow-up is required and thyroid-hormone replacement may be needed after treatment.

4.3 Radioactive Iodine Therapy for Thyroid Cancer

Radioactive iodine may form part of the treatment plan for selected differentiated thyroid cancers, particularly papillary and follicular disease that retains iodine uptake.

Following surgery, RAI may be used to ablate residual thyroid tissue or to treat iodine-avid metastatic disease in selected patients (Hung et al., 2023).

The method is not applicable to thyroid tumors that do not retain clinically useful iodine uptake, which limits its role in non-iodine-avid thyroid cancer subtypes.

5. Safety, Side Effects, and Patient Considerations

5.1 Dose-Related Side Effects

Adverse effects from diagnostic or therapeutic radioisotopes depend on absorbed dose, tissue sensitivity, treatment geometry, radionuclide distribution, and the biological clearance of the radiopharmaceutical. Diagnostic studies generally use lower activities than therapeutic procedures, whereas treatment may require substantially higher absorbed doses in order to damage diseased tissue (Reissig et al., 2021).

The practical objective is therefore to maximize target dose while reducing exposure of healthy organs. This balance is particularly important when radionuclides circulate systemically or when treatment is repeated. Dose optimization, image-based planning, and organ-specific monitoring are used to reduce avoidable toxicity and to maintain an acceptable relationship between therapeutic benefit and radiation risk (Bourgeois et al., 2017).

5.2 Short- and Long-Term Effects on Healthy Tissue

Short-term effects vary with the treatment and may include transient fatigue, nausea, local inflammation, or other symptoms related to the irradiated tissue. These effects should be

interpreted in relation to the specific radionuclide, administered activity, and target organ rather than as uniform consequences of all nuclear-medicine procedures (Zhao et al., 2017).

Long-term considerations include cumulative tissue injury and the possibility of delayed radiation effects. The magnitude of these risks depends on the organs exposed and the total absorbed dose. Consequently, treatment protocols emphasize dose limitation outside the target and follow-up of organs that may receive clinically relevant exposure (Singh et al., 2023).

5.3 Psychosocial Impact on Patients

Patient experience is also relevant to treatment quality. Concerns about radiation, isolation precautions, uncertainty about treatment response, and visible treatment-related changes can contribute to anxiety or stress. Clear communication is therefore required so that patients understand the purpose of the procedure, the duration of any precautions, and the expected follow-up.

Psychosocial support may be particularly important when radionuclide therapy is delivered as part of cancer care. Counseling, family support, and access to appropriate clinical information can help patients manage treatment-related uncertainty and maintain participation in follow-up and supportive care (Pyrzynska et al., 2022).

6. Advanced and Smart Technologies in Nuclear Medicine

Current nuclear medicine increasingly combines radiopharmaceutical science with advanced imaging, computational analysis, and precision delivery. These developments are relevant to both diagnosis and treatment because they support better localization of disease, selection of therapeutic targets, and adaptation of treatment to patient-specific characteristics.

6.1 Personalized Treatment Based on Tumor Characteristics

Personalized radionuclide treatment requires matching the radiopharmaceutical to the biological characteristics and anatomical distribution of the disease. Relevant factors include target expression, tumor location, disease burden, prior treatment, expected organ exposure, and the ability of imaging to confirm uptake before or during therapy.

Theranostic approaches are particularly suited to this model because diagnostic imaging can provide evidence about target localization and may support patient selection or treatment adaptation. In prostate cancer and other oncologic settings, this integration of imaging and targeted therapy is an important direction of current nuclear-medicine practice (Lima et al., 2024; O'Brien & Mankoff, 2024; Zoi et al., 2023).

6.2 Developments in 3D Tumor Imaging

Three-dimensional imaging improves treatment planning by combining functional information with anatomical localization. PET/CT links tracer uptake with cross-sectional anatomy, while PET/MRI can provide complementary soft-tissue contrast in selected applications. These hybrid approaches are useful when accurate definition of tumor extent

and adjacent organs is required for treatment planning (Stora et al., 2022; Oliveira et al., 2016).

Repeated imaging can also support response assessment by showing changes in tracer distribution or metabolic activity over time. The value of three-dimensional imaging is therefore not limited to detection; it can contribute to target definition, dose planning, and longitudinal evaluation of treatment.

6.3 Novel Targeted Radioisotopes

Research on targeted nuclear medicine includes both new radionuclides and new carrier systems. Candidate radionuclides differ in half-life, emission type, production route, and chemical behavior, and these properties influence whether they can be paired with a suitable targeting molecule and delivered at clinically practical activity levels (Sun, 2021; Ioannidis et al., 2024).

The literature reviewed here illustrates the breadth of this development. Examples include radiolanthanum chemistry, barium isotopes, rhenium and ruthenium radioisotopes, and radiometal complexes intended for diagnostic or therapeutic use (Aluicio-Sarduy et al., 2019; Reissig et al., 2021; Uccelli et al., 2022; Zuba et al., 2020). Research on porphyrins, dendrimers, and other nanomaterial platforms further shows how carrier design can be used to modify biological distribution and support molecular imaging or targeted delivery (Pyrzynska et al., 2022; Xiao et al., 2019; Zhao et al., 2017; Ge et al., 2020; Kazakov et al., 2020).

These developments should be evaluated in terms of target specificity, production feasibility, dosimetry, stability, toxicity, and reproducibility. A technically attractive radionuclide is clinically useful only when the complete radiopharmaceutical system can be produced, administered, imaged, and monitored safely.

6.4 Modern Techniques for Precision Tumor Targeting

6.4.1 Advanced Imaging for Therapeutic Dose Guidance

Advanced imaging provides the spatial information needed to connect radiopharmaceutical uptake with treatment geometry. PET/CT can combine metabolic or receptor-related information with anatomical localization, while MRI can add soft-tissue contrast in selected tumors. These data can be used to define targets, identify organs at risk, and support treatment planning (Ioannidis et al., 2024; Oliveira et al., 2016).

In prostate and other cancers, the integration of imaging with radionuclide therapy also supports patient selection and response assessment. The main advantage of image guidance is therefore improved localization and quantification rather than imaging alone (Lima et al., 2024).

6.4.2 Artificial Intelligence for Targeting and Treatment Planning

Artificial intelligence (AI), including machine-learning and deep-learning methods, is increasingly used to support medical-image interpretation, tumor segmentation, and

treatment planning. In nuclear medicine, these methods can assist with the analysis of complex imaging data and with the identification of spatial patterns relevant to target definition (O'Brien & Mankoff, 2024).

AI-based segmentation can reduce the manual workload associated with contouring and can improve consistency when models are properly validated. Computational planning tools can also integrate tumor size, location, imaging characteristics, and proximity to sensitive structures to support dose-distribution analysis and candidate treatment strategies.

Predictive models may additionally be used to examine imaging and outcome patterns and estimate likely treatment response. Such systems are most appropriately used as decision-support tools. Their clinical value depends on data quality, external validation, interpretable outputs, and integration with specialist review rather than on model performance alone.

6.4.3 Medical Robotics for Accurate Dose Delivery

Robotic systems can support procedures that require controlled placement of needles, catheters, or radioactive sources. Their main contribution is mechanical precision and repeatability, particularly when treatment must be delivered to anatomically constrained targets.

In localized radiation procedures such as brachytherapy, robotic or image-guided assistance may support source positioning and treatment geometry. These systems should be considered as delivery tools within a broader workflow that still depends on imaging, treatment planning, radiation measurement, and clinical supervision (Lima et al., 2024).

6.4.4 Precision Targeting and Reduced Side Effects

The common objective of advanced imaging, AI-assisted planning, targeted radiopharmaceuticals, and precision delivery is to improve the ratio between radiation deposited in the target and radiation received by healthy tissue. Better localization can reduce off-target exposure and can support more consistent treatment planning (Bourgeois et al., 2017; Varghese et al., 2024).

This objective does not eliminate treatment risk. Clinical benefit still depends on target biology, absorbed dose, organ sensitivity, and patient-specific factors. Precision technologies are therefore most useful when they improve measurement and control of these variables rather than when they are treated as independent indicators of treatment quality.

7. Illustrative Clinical Applications

The following examples summarize representative ways in which the radionuclides discussed in this review are applied in cancer diagnosis or treatment. They are presented as literature-based illustrations of clinical use and should not be interpreted as results from a new experimental patient cohort.

7.1 Iodine-131 in Thyroid Cancer

Iodine-131 provides a clear example of a radionuclide with both diagnostic and therapeutic relevance in thyroid disease. Its uptake by thyroid tissue allows disease localization and, when administered at therapeutic activity, targeted irradiation of residual or malignant iodine-avid tissue (Ferris et al., 2020).

Figure 1 illustrates the thyroid-focused use of I-131. The example emphasizes the same principle discussed earlier in the article: selective biological uptake can concentrate radiation at the intended tissue while reducing unnecessary exposure elsewhere.

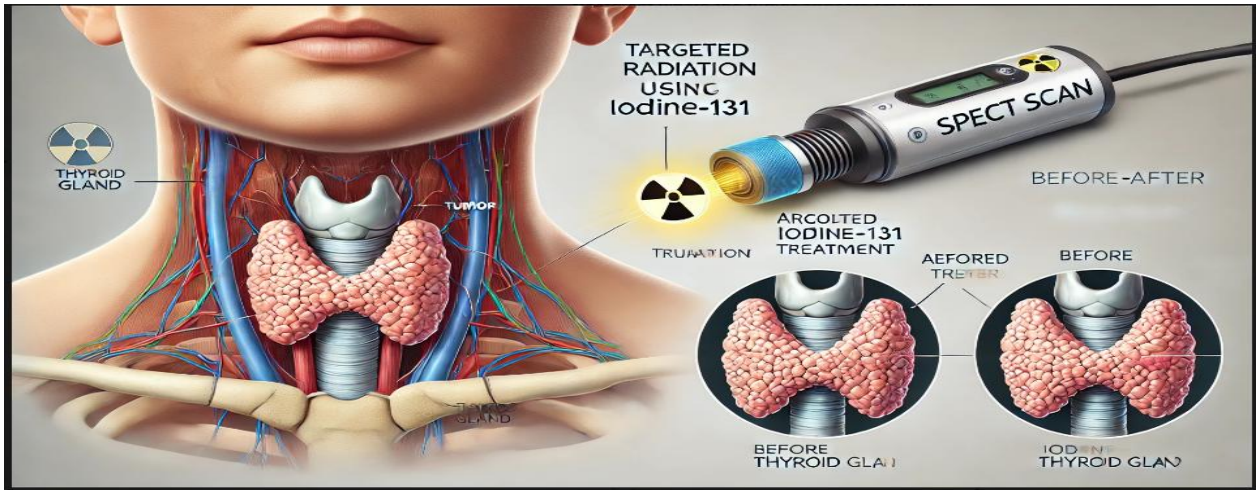

Figure 1: *Illustrative use of iodine-131 in thyroid-focused diagnosis and treatment.*

This application demonstrates why radionuclide selection must be linked to tissue biology. The usefulness of I-131 depends on retained iodine uptake, and treatment therefore requires patient selection, dose planning, and post-treatment radiation-safety procedures (Hung et al., 2023).

7.2 Iridium-192 in Prostate Cancer (Brachytherapy)

Iridium-192 is used here as an example of localized brachytherapy, in which a radiation source is positioned close to the tumor rather than delivered as external-beam radiation. The clinical rationale is to concentrate dose within the treatment region and limit exposure of surrounding tissue.

Figure 2 provides an illustrative representation of prostate brachytherapy. In this application, treatment quality depends on accurate source placement, treatment geometry, and dose distribution, which explains the relevance of imaging guidance and precision-delivery systems discussed in Section 6.

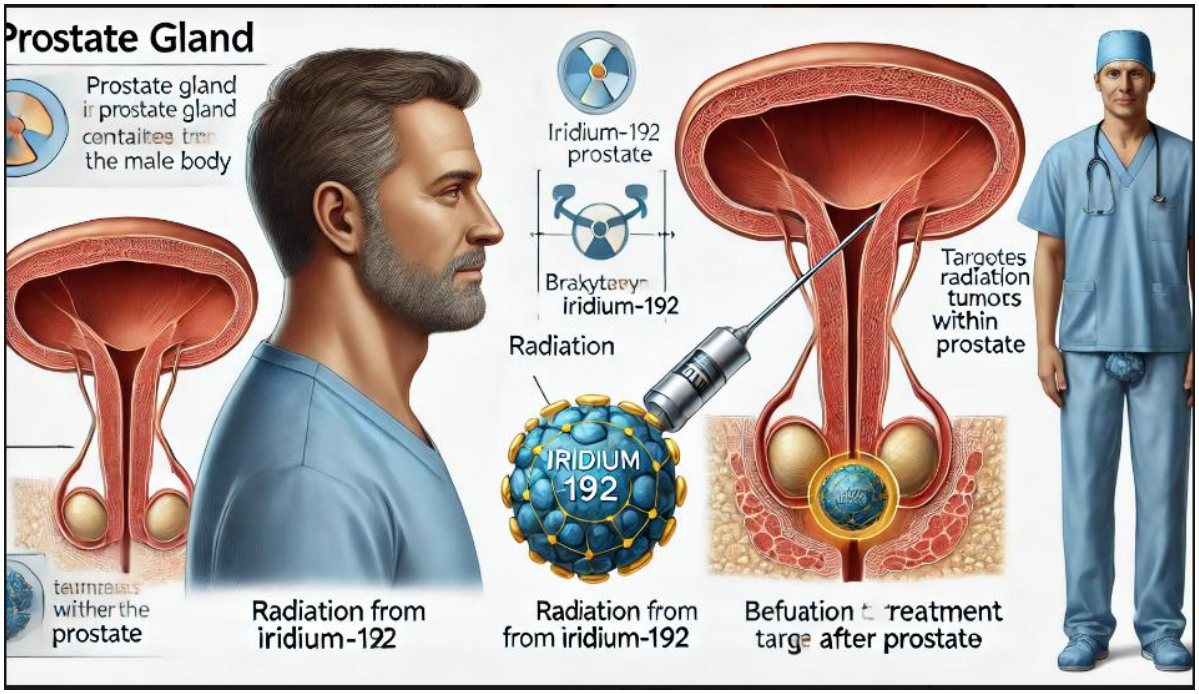

Figure 2: *Illustrative representation of Iridium-192 brachytherapy for localized prostate cancer treatment.*

The example also shows the broader role of precision treatment in nuclear and radiation medicine: therapeutic benefit depends not only on the radioactive source itself, but also on controlled placement and protection of adjacent healthy structures.

7.3 Lutetium-177 in Lymphatic Cancer

Lutetium-177 represents the targeted-radionuclide-therapy model in which a therapeutic isotope is linked to a carrier with affinity for selected disease targets. The manuscript uses this approach as an example of how radionuclide therapy can be directed beyond thyroid tissue and combined with molecular targeting concepts (Zoi et al., 2023).

Figure 3 illustrates the targeted-delivery concept associated with lutetium-177. The clinical objective is to increase radiation deposition in tumor tissue while reducing exposure of non-target structures.

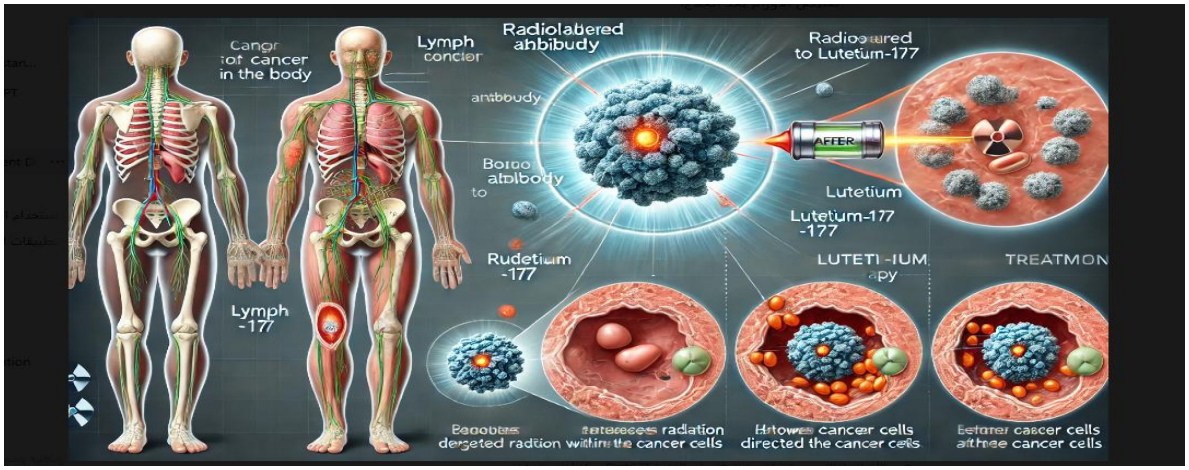

Figure 3: *Conceptual illustration of lutetium-177 targeted radionuclide therapy.*

This example is consistent with the broader theranostic direction of nuclear medicine, where molecular targeting, imaging, and therapy are increasingly considered within the same treatment pathway (O'Brien & Mankoff, 2024).

8. Discussion

The literature reviewed in this article shows that radioisotopes occupy two closely related roles in nuclear medicine: they provide functional or metabolic information for diagnosis, and they deliver radiation for targeted treatment. SPECT and PET illustrate the diagnostic side of this relationship, whereas iodine-131 and other therapeutic radionuclides illustrate the treatment side. The main clinical advantage is therefore not radioactivity alone, but the ability to link a radioactive signal or dose to a biological target (Filippi et al., 2020; Zoi et al., 2023).

The comparison of SPECT and PET also demonstrates that modality selection is context dependent. SPECT is widely applicable to organ function and perfusion assessment, while PET provides stronger metabolic characterization and can support detailed tumor assessment. Neither modality is universally preferable; the required information, tracer availability, resolution, cost, and clinical infrastructure determine the appropriate choice (Parrilha et al., 2022).

Therapeutic applications follow the same principle of target selectivity. Radioiodine treatment is effective only when the relevant tissue retains iodine uptake, and other targeted radionuclide strategies depend on the interaction between a radionuclide-bearing compound and a molecular or anatomical target. This dependence explains why dose optimization, imaging guidance, and patient selection remain central to both treatment effectiveness and safety (Ferris et al., 2020; O'Brien & Mankoff, 2024).

The role of smart technologies is mainly supportive rather than independent. AI can assist with image segmentation, pattern analysis, and treatment planning; advanced imaging improves target definition; and robotic systems can support accurate placement or delivery.

These technologies do not replace the radiopharmaceutical mechanism or clinical judgment, but they can improve the consistency and precision of the workflow when appropriately validated.

This review has limitations. It is a narrative synthesis of the cited literature rather than a systematic review or meta-analysis, and the clinical examples in Section 7 are illustrative rather than outcomes from a new patient cohort. Consequently, quantitative statements should be interpreted within the context of their cited sources. Future evidence should place greater emphasis on standardized comparative evaluation, clinically validated AI models, and patient-level outcome studies.

9. Future Directions

Future work in nuclear medicine is expected to focus on more selective radiopharmaceuticals, improved image-guided treatment planning, and closer integration between diagnostic imaging and targeted therapy. Development of new radionuclides and carrier molecules may expand the range of disease targets while improving dose localization and reducing unnecessary exposure (Ioannidis et al., 2024; Stora et al., 2022).

AI and deep-learning methods are also likely to play a larger role in image analysis, target delineation, treatment planning, and response assessment. The main research requirement is not only higher model accuracy, but also reproducible validation, interpretable outputs, and integration with clinical workflows. These requirements are particularly important when automated analysis affects treatment selection or radiation delivery.

A second direction concerns accessibility and infrastructure. Wider clinical use depends on reliable isotope production, traceable activity standards, trained personnel, and appropriate radiation-safety systems. Strengthening local production and technical capacity may be especially important in regions where access to advanced nuclear-medicine services remains limited (Judge et al., 2023; Singh et al., 2023).

10. Conclusion

This article reviewed the role of radioactive isotopes in nuclear medicine with emphasis on cancer diagnosis, targeted treatment, and the technologies that support precision delivery. SPECT and PET provide complementary functional and metabolic information, while therapeutic radionuclides extend the same targeting principle to disease treatment. Radioiodine remains a clear example of tissue-selective therapy, and newer targeted approaches broaden the use of radionuclides beyond thyroid disease.

The reviewed evidence also shows that future progress will depend on the integration of radiopharmaceutical science with imaging, dosimetry, AI-assisted analysis, and precise delivery systems. These technologies can improve target definition and treatment planning, but their value depends on clinical validation, radiation safety, and appropriate patient selection. The central conclusion is therefore that radioisotope-based medicine is most

effective when biological targeting, imaging information, and controlled dose delivery are treated as one coordinated clinical process rather than as separate technical components.

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