EJPMR, 2026, 13(1), 309-313 **Research Article** **Impact Factor 7.065**

EUROPEAN JOURNAL OF PHARMACEUTICAL AND MEDICAL RESEARCH

www.ejpmr.com

ISSN (O): 2394-3211
ISSN (P): 3051-2573
Coden USA: EJPMAG

THE ROLE OF NUCLEAR MEDICINE IN HEMATO-ONCOLOGY IN YEMEN: CURRENT DEFICITS AND A CALL FOR STRATEGIC DEVELOPMENT

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DOI: https://doi.org/10.5281/zenodo.18093881

How to cite this Article: Prof. Dr. Gamal Abdul Hamid*. (2026). THE ROLE OF NUCLEAR MEDICINE IN HEMATO-ONCOLOGY IN YEMEN: CURRENT DEFICITS AND A CALL FOR STRATEGIC DEVELOPMENT. European Journal of Biomedical and Pharmaceutical Sciences, 13(1), 309–313.

Article Received on 02/12/2025 **Article Revised on 23/12/2025** **Article Published on 01/01/2026**

ABSTRACT

Nuclear Medicine (NM) is a cornerstone in the modern management of hematologic malignancies, providing essential diagnostic, prognostic, and emerging therapeutic capabilities. This review outlines the established global role of techniques like FDG-PET/CT and the promising paradigm of theranostics. However, it specifically contextualizes this knowledge within the critical healthcare challenges of Yemen, where a complete absence of NM services forces patients into costly and life-threatening medical travel. The resulting delays in diagnosis, staging, and response assessment directly contribute to poorer outcomes and increased mortality. This article synthesizes the clinical evidence for NM's impact and uses it to frame an urgent call to action. We propose a phased, collaborative strategy involving the Yemeni Ministry of Public Health and Population, the Atomic Energy Commission, and international partners like the International Atomic Energy Agency (IAEA) to develop sustainable NM infrastructure. The goal is to translate global advancements into tangible, life-saving solutions for Yemeni patients, moving from a state of critical deficit toward integrated, precise hemato-oncologic care.

KEYWORDS: Nuclear Medicine, Hemato-Oncology, Yemen, PET/CT, Theranostics, Healthcare Access, Medical Travel, Resource-Limited Settings.

INTRODUCTION

Hematological malignancies, encompassing leukemias, lymphomas, and multiple myeloma, represent a heterogeneous group of cancers requiring precise diagnostic and therapeutic strategies for optimal management.[1-4] Globally, nuclear medicine has emerged as a pivotal discipline in this field. By leveraging radiopharmaceuticals, NM enables functional and molecular imaging that transcends the limitations of conventional anatomical modalities.[5-9] The integration of PET/CT, for instance, has revolutionized staging and response assessment in lymphomas, altering clinical management in 10–30% of cases.[10] Furthermore, the rise of theranostics—using the same molecule for both imaging and targeted radiotherapy—promises to transform NM into a direct therapeutic modality, particularly with potent alpha-emitting radionuclides.[11,12]

The Yemeni Context: A Critical Deficit in Cancer Care

In stark contrast to this global progress, the Republic of Yemen faces a profound healthcare crisis, severely exacerbated by the complete lack of nuclear medicine and advanced radiological scanning centers. For patients with hematologic malignancies—diseases where timely and accurate staging and response evaluation are paramount—this deficit is catastrophic. The standard of care, as defined by international guidelines[8], is unavailable domestically.

Consequently, patients who can afford it are forced to seek treatment abroad, primarily in Egypt, India, or Jordan. This medical travel imposes an insurmountable financial burden on most families, involving costs for travel, accommodation, and foreign medical services. More critically, it introduces devastating delays in diagnosis, interim response assessment, and follow-up. For aggressive lymphomas or acute leukemias, these

delays can directly translate to disease progression, reduced treatment efficacy, and increased mortality rates. For those unable to travel, care is limited to basic chemotherapy without the precision imaging needed to guide it effectively, leading to suboptimal outcomes and unnecessary toxicity.[13-16]

This situation places a major responsibility on national bodies, including the **Ministry of Public Health and Population (MOPHP)** and the **National Atomic Energy Commission (NATEC)**, in collaboration with international agencies like the **International Atomic Energy Agency (IAEA)**, to develop urgent, strategic solutions. This review, therefore, aims to achieve two objectives: 1) to summarize the indispensable role of NM in hemato-oncology as evidenced globally, and 2) to utilize this evidence as a foundation for advocating and outlining a realistic pathway toward establishing these vital services in Yemen, thereby alleviating the suffering of patients and improving national cancer care outcomes.

MATERIALS AND METHODS

A narrative review was conducted based on the presentation content, supported by a literature search using PubMed, Scopus, and Google Scholar for articles published between 2000 and 2023. Key search terms included "PET/CT in lymphoma," "FDG-PET in hematology," "theranostics in hematologic malignancies," and "resource-limited settings." Clinical guidelines from the National Comprehensive Cancer Network (NCCN) and the Lugano Classification were referenced. Data on healthcare access challenges in Yemen were drawn from reports by the World Health Organization (WHO) and the MOPHP. Data from landmark trials and meta-analyses were synthesized to illustrate the diagnostic and prognostic utility of NM and to build the case for its development in Yemen.

RESULTS

1. Global Evidence: The Promise of Theranostics

Emerging radiotheranostic agents, particularly those employing alpha emitters (e.g., ^{225}Ac), allow precise targeting of malignant cells while sparing healthy tissue. These represent a paradigm shift from diagnostic imaging to integrated "see-and-treat" strategies, showing promise in refractory diseases.[17-19]

2. Global Evidence: The Impact of FDG-PET/CT

FDG-PET/CT is the gold standard for initial staging of Hodgkin lymphoma and aggressive B-cell lymphomas. It detects extranodal involvement in 30–40% of cases and provides a metabolic baseline. Interim PET after 2–4 cycles in diffuse large B-cell lymphoma (DLBCL) is a strong predictor of outcome. The Deauville 5-point scale standardizes response assessment, guiding critical therapy decisions.[8-9,20-28]

3. The Yemeni Reality: Consequences of Absence

The absence of the above technologies in Yemen results in:

- **Management based on incomplete staging,** leading to potential under- or over-treatment.
- **No standardized response assessment,** making it impossible to tailor therapy effectively or early identify refractory disease.
- **No access to targeted radionuclide therapy** for relapsed/refractory patients.
- **Financial catastrophe and care delays** due to mandatory medical travel, negatively impacting survival.

DISCUSSION

Nuclear Medicine has fundamentally transformed the diagnostic and therapeutic landscape of hematologic malignancies globally. For Yemen, the established evidence of NM's impact—changing management in up to 30% of cases and offering new therapeutic avenues—highlights not just a technological gap, but a critical quality-of-care chasm that directly affects patient survival.

The Diagnostic Imperative and the Theranostic Horizon

The superiority of ^{18}F-FDG PET/CT over anatomic imaging in lymphomas is unequivocal.[1,2] In a Yemeni setting, establishing even a single PET/CT center, strategically located and supported by a reliable supply chain for ^{18}F-FDG, would revolutionize the management of the most common FDG-avid hematologic cancers. It would eliminate the need for travel for staging and response evaluation for many patients, ensuring faster, more accurate decisions. While theranostics with alpha-emitters represent a longer-term goal, the logistical lessons from global experiences are crucial for Yemen's planning phase.[17-18,29-35]

The Yemeni Context: A Case Study in Resource Limitations

The challenges to establishing NM in Yemen are significant but not insurmountable. They require a phased, pragmatic approach:

1. **Infrastructure and Expertise:** The highest priority is building a specialized facility (radiation shielding, pharmacy) and cultivating human capital. This begins with **targeted training** of physicians (hematologists, radiologists) and technologists through IAEA fellowships and partnerships with centers in neighboring Arab countries (e.g., Jordan, Saudi Arabia, Egypt).
2. **Radiopharmaceutical Supply:** Establishing a reliable supply of ^{18}F-FDG is the first logistical hurdle. Solutions could include a partnership with a regional cyclotron center for regular deliveries or, as a long-term vision, exploring compact cyclotron options supported by the IAEA's technical cooperation program.

3. **Funding and Sustainability:** Initial capital investment must be secured through government commitment, grants from international donors, and partnerships with global health initiatives focused on non-communicable diseases. A sustainable business model must be developed to ensure ongoing operations.
4. **Regulatory and Safety Framework:** The Yemeni AEC must work with the MOPHP to develop and enforce robust regulations for radiation safety, waste management, and radiopharmacy practice, aligned with IAEA safety standards.

A Path Forward: Integration and Advocacy

The integration of NM into Yemen's cancer care pathway must be championed by a multidisciplinary coalition. Hematologists must advocate for its necessity based on clinical evidence. The MOPHP must prioritize cancer care infrastructure in its health sector planning. The AEC must provide the technical and regulatory backbone. Ultimately, the journey must start with a **feasibility study and a national strategic plan**, developed with the direct assistance of the IAEA, to create a roadmap from zero to a functional, sustainable NM service.

CONCLUSIONS

Nuclear medicine is not a luxury but a necessity for modern hemato-oncology care. In Yemen, its absence constitutes a significant barrier to achieving optimal cancer outcomes, perpetuating health inequity and patient suffering. The global evidence for NM's efficacy in staging, response assessment, and therapy provides a compelling rationale for action. While the challenges are substantial, a coordinated, phased approach led by national authorities (MOPHP, AEC) and strongly supported by international partners like the IAEA can turn this deficit into an opportunity. Investing in nuclear medicine infrastructure and expertise is an investment in saving the lives of Yemeni cancer patients, reducing the burden of medical travel, and building a more resilient and precise national healthcare system for the future.

Recommendations for Yemen

Based on the clinical evidence and the specific context of Yemen, the following actionable recommendations are proposed:

1. **Immediate Advocacy and Planning**

✓ The **MOPHP** and the **Yemeni NATEC** should jointly commission a feasibility study, supported by the **IAEA**, to analyze sites, costs, and infrastructure needs for establishing a national Nuclear Medicine centers in Aden, Taiz and Hadramout.

- Form a **National Multidisciplinary Committee** for Nuclear Medicine Development, including hematologists, oncologists, radiologists, medical physicists, and hospital administrators.

2. **Human Resource Development (Short-Term)**

- Prioritize the training of personnel. Utilize **IAEA fellowship programs** to send Yemeni physicians and technologists for training in PET/CT and general NM in regional centers.
- Invite **IAEA experts** to conduct in-country training missions and workshops to build foundational knowledge.

3. **Phased Infrastructure Implementation**

- **Phase 1:** Establish a basic NM department with a SPECT/CT camera, which is less complex and costly than PET/CT, to provide bone scintigraphy and other essential services. This builds local expertise.
- **Phase 2:** Plan for a **PET/CT unit** as the central goal. Explore models like **mobile PET/CT units** (used in other resource-limited settings) or a fixed center established through an international public-private partnership.

4. **Secure Supply and Logistics**

- Negotiate **regional agreements** with cyclotron hubs in Jordan or Egypt for the regular supply of ^{18}F-FDG generators.
- The **IAEA** can facilitate technical support for establishing a radiopharmacy and quality control protocols.

5. **Integration into National Cancer Care**

- Develop **Yemen-specific clinical guidelines** for hemato-oncology that incorporate NM, defining clear indications for PET/CT based on available international standards.
- Ensure NM physicians are core members of tumor boards at major teaching hospitals.

6. **International Collaboration and Funding**

- Actively seek **grants and partnerships** from international bodies (IAEA, WHO, World Bank), Gulf cooperation councils, and non-governmental organizations focused on cancer care.
- Partner with academic institutions in Arab countries for long-term mentorship and telemedicine support in image interpretation.

7. ACKNOWLEDGE AND STRENGTHEN INTERNATIONAL PARTNERSHIP

We extend our sincere gratitude to the **International Atomic Energy Agency (IAEA)** for its ongoing support to Yemen through specialized training programs and initiatives aimed at providing nuclear medicine instrumentation. The IAEA's stated commitment to assist in establishing nuclear medicine centers in Yemen during the 2026-2029 period is a beacon of hope. We strongly urge continued and deepened collaboration with the IAEA to translate this commitment into a concrete, sustainable reality, ensuring that international expertise and resources are effectively channeled to build a lasting nuclear medicine capacity for the benefit of all Yemeni patients.

CONSENT AND ETHICAL APPROVAL: It is not applicable.

DISCLAIMER (ARTICIAL INTELLIGENCE) Author(s) hereby declares that no generative AI technologies and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS: Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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