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Nuclear Medicine: A Key Driver for Sustainable Healthcare in India

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Abstract

Nuclear medicine is very well-equipped to make an important contribution to both the SDG and the betterment of the country's healthcare. Health and happiness as the nation works toward "Viksit Bharat" by 2047. Nuclear medicine's sophisticated diagnostic and therapeutic capabilities stand ready to transform healthcare through improved health for all, enhanced disease diagnosis accuracy, and extended treatment options. Nuclear medicine techniques such

as SPECT and PET diagnose cancer, heart diseases, and neurological problems earlier, non-invasively, and enable early treatment. The early diagnosis and targeted treatment of millions will bring about health and quality of life improvement through nuclear medicine. It is under the SDG3 goal of healthy lives.

Nuclear medicine is an important element in the health care system of India in dealing with issues of non-communicable diseases such as cancer and heart disease, which demand new forms of treatment. Nuclear medicine involves radiation and imaging in tailoring treatment so that side effects are reduced and procedures not needed are avoided. This makes healthcare more sustainable and accessible and enhances effectiveness and efficiency. India has also upgraded significantly its nuclear medical facilities. The two premier training institutions in terms of nuclear medicine are INMAS and RMC.INMAS promotes innovation, and research while providing quality healthcare services to individuals. Nuclear medicine will be the agent for long-term development in Viksit Bharat by developing an effective healthcare system, high-quality care to all, and equitable access. Its inclusion in our health care system can bring SDG3.

Keywords: Theranostics, Sustainable Development Goals (SDG), Nuclear Medicine, Single Positron Emission Computer Tomography (SPECT), Positron Emission Tomography (PET), and Sustainable Healthcare

Introduction

India's healthcare system is fast changing because to nuclear medicine, which is becoming an essential part of the country's plan to create a Viksit Bharat by 2047. Nuclear medicine's potential to transform diagnostic and therapeutic approaches makes it a perfect fit with India's efforts to fulfil Sustainable Development Goal (SDG) 3: Good Health and Well-Being. This cutting-edge discipline, which employs radioactive materials for both diagnosis and treatment, is essential to tackling the healthcare issues brought on by an ageing population and an increase in non-communicable diseases (NCDs) (Singh et al., 2023).

Nuclear medicine is at the forefront of contemporary medical developments, from the early diagnosis of cardiovascular illnesses and tumours to the provision of highly focused medicines. India is in a position to use its expanding infrastructure and technical advancements to improve public health outcomes and secure the long-term viability of its healthcare system (Singh et al., 2023). Better health outcomes, lower treatment costs, and a generally healthier populace are all possible as long as the nation keeps developing its nuclear medical skills. This article examines how nuclear medicine is boosting cancer treatment, developing a competent healthcare staff, and improving diagnostics in order to support India's sustainable growth (Lee et al., 2019).

Harnessing Nuclear Medicine for a Healthier and Sustainable India

Particularly in India's healthcare industry, nuclear medicine is becoming a vital driver of sustainable growth. Nuclear medicine presents a priceless chance to address current healthcare issues and greatly enhance public health outcomes as the nation works to realise its goal of Viksit Bharat by 2047. It supports early diagnosis, efficient treatment, and the improvement of healthcare services, all of which are in line with Sustainable Development Goal (SDG) 3, which is centred on good health and well-being. A better and more wealthy future for the country is largely dependent on nuclear medicine. One of nuclear medicine's most important contributions to sustainable development is its ability to provide early diagnosis through the use of state-of-the-art imaging techniques like Positron Emission Tomography (PET) and Single Photon Emission Computed Tomography (SPECT) (Lee et al., 2019). With the use of these technologies, medical professionals may identify conditions like cancer, heart disease, and neurological illnesses early on, frequently before symptoms manifest. Early diagnosis results in early intervention, which lowers the long-term healthcare burden by greatly increasing the likelihood of effective treatment and recovery (Almansouri et al., 2024). Furthermore, nuclear medicine is crucial for improving the efficacy of treatment, especially for the treatment of cancer and other chronic conditions (Barbet et al., 2020). Compared to traditional medicines like chemotherapy, radionuclide therapy is a type of focused treatment that reduces side effects by directly delivering radiation to damaged areas. Radionuclide therapy improves treatment results and reduces harm to surrounding healthy tissues by selectively targeting cancer cells, improving patients' quality of life (Gudkov et al., 2015). With more than 442 nuclear medicine

institutes functioning nationwide, India's nuclear medicine infrastructure has grown. For precise diagnosis and treatment, these centres are outfitted with cutting-edge equipment such as PET-CT scanners, medical cyclotrons, and radionuclide therapy facilities (Singh et al., 2023). In terms of the number of PET-CT scanners per million people, the nation remains trails affluent countries like the USA and Japan despite these improvements. India must keep developing its nuclear medical infrastructure in order to create a sustainable healthcare system, especially in underprivileged areas (Gallach et al., 2020).

Transforming Healthcare with Advanced Diagnostics through Nuclear Medicine

By providing innovative molecular imaging tools that are essential for the early diagnosis of illnesses like cancer, heart disease, and neurological problems, nuclear medicine has completely transformed the healthcare industry. In terms of long-term results, therapeutic effectiveness, and overall healthcare efficiency, the capacity to identify illnesses in their early stages is revolutionary (Dhoundiyal et al., 2024). Medical professionals can now observe the complex functioning of organs and tissues in a non-invasive manner thanks to technologies like Positron Emission Tomography (PET) and Single Photon Emission Computed Tomography (SPECT), which are at the forefront of this shift in advanced diagnostic tools (Crișan et al., 2022).

Early Detection: The Key to Better Health Outcomes

The ability of nuclear medicine to give early diagnosis, which is essential for managing disease, is one of its most impressive accomplishments. Nuclear medicine provides a window into the body's interior workings through PET and SPECT imaging, enabling medical professionals to identify anomalies before they become clinical symptoms. In the treatment of cancer, this skill is very important (Crișan et al., 2022). Physicians are able to customise less intrusive, more effective, and more patient-specific treatment plans when cancer is detected early. For instance, physicians can develop targeted medicines that improve treatment outcomes and lower the risk of metastasis by using PET scans to detect tumour activity even before the tumour is physically detectable (Griffeth L et al., 2005).

Nuclear medicine methods like SPECT are used to assess blood flow to the heart muscle in the setting of cardiovascular illnesses. This enables the detection of any blockages or other problems that may result in heart attacks. Preventing more serious consequences, such as cardiac failure or myocardial infarctions, requires early detection of such disorders (Netala et al., 2024). The study of brain metabolism and function in neurological illnesses is made possible by nuclear medicine methods, which provide insight into conditions including epilepsy, Parkinson's disease, and Alzheimer's disease (Hughes S et al., 2012).

Early illness detection is particularly crucial in a country like India, where the prevalence of non-communicable diseases (NCDs) is fast increasing. Since NCDs including cancer, diabetes, and heart disease cause about 60% of all deaths in India, the World Health Organisation (WHO) has made early identification a top goal in the country's healthcare plan (WHO, 2020) (Siegel et al., 2014).

Cost-Effective Treatment: Preventing Expensive Interventions

Nuclear medicine's ability to enable early detection not only enhances health outcomes but also lowers treatment costs. Early illness detection allows physicians to treat patients with less aggressive approaches, which frequently leads to fewer problems, shorter hospital stays, and lower total healthcare expenses. For instance, localized therapies like surgery or targeted radiation therapy are frequently used in oncology to treat early-stage cancers because they are less expensive and disruptive than more extensive treatments like chemotherapy or full-body radiation therapy, which are usually needed in advanced stages of the disease (Hyatt et al., 2009).

Nuclear medicine helps to ensure the sustainability of healthcare systems by averting costly treatments at later stages of illness progression. It lessens patients' and families' indirect financial burden in addition to direct medical expenses (Bajwah et al., 2020). According to American Cancer Society research, by preventing needless treatments and hospital stays, the utilisation of modern imaging methods, like as PET scans, can dramatically save total healthcare expenditures (American Cancer Society, 2021) (Raghavan et al., 2022). In low- and middle-income nations like India, where healthcare resources are frequently scarce and

expensive treatments can put a heavy burden on both people and the healthcare system, the financial benefit of early identification and intervention is especially crucial (Pantoja et al., 2017).

Additionally, nuclear medicine lessens the need for more intrusive and expensive treatments like biopsies or exploratory operations by providing non-invasive diagnostic instruments. This results in better patient satisfaction, quicker healing periods, and reduced treatment costs (Hacker et al., 2015).

Advancing Cancer Treatment and Care through Nuclear Medicine

By facilitating access to cutting-edge diagnostics and customised treatments, nuclear medicine has become a vital component in the battle against cancer and has made a substantial contribution to the objective of sustainable development. Nuclear medicine is revolutionising cancer care and improving patient outcomes with its ability to provide accurate imaging and focused treatment. Assuring everyone's health and well-being is a key component of sustainable development, which is in line with this (Echavidre et al., 2023).

Revolutionizing Cancer Treatment with Targeted Therapies

One of nuclear medicine's most significant advances to the treatment of cancer is targeted radionuclide therapy (RNT). Unlike conventional treatments like chemotherapy and external beam radiation, which can damage both sick and healthy tissues, RNT delivers radiation specifically to cancer cells with minimal impact on surrounding healthy tissues. This targeted approach is particularly effective in treating conditions like neuroendocrine tumours and metastatic prostate cancer that don't respond to standard therapies (Dash et al., 2013).

Lutetium-177-DOTATATE for neuroendocrine tumours and Lutetium-177-PSMA for advanced prostate cancer are two examples of treatments that have demonstrated impressive effectiveness in India in enhancing patient survival and quality of life. Research at the All India Institute of Medical Sciences (AIIMS), New Delhi, has shown that these treatments improve patients' general health in addition to lowering the burden of tumours (AIIMS, 2021) (Choudhury et al., 2019).

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Enhancing Diagnosis and Treatment Monitoring with PET-CT Scans

Additionally, nuclear medicine is essential for early cancer diagnosis and therapy response monitoring using sophisticated imaging methods such as Positron Emission Tomography-Computerized Tomography (PET-CT). Healthcare practitioners may identify cancer early on, when it is more likely to be treatable, thanks to PET-CT scans, which offer comprehensive insights into the metabolic activities of cancer cells. Furthermore, oncologists can provide individualised and efficient care by using PET-CT imaging to track the efficacy of ongoing therapies and make real-time modifications to therapy plans (Vijayakumar, et al., 2022). For example, PET-CT imaging is essential for evaluating how well treatments like immunotherapy or chemotherapy are working. It lowers the risk of cancer progression or recurrence by detecting residual or recurring illness and enabling prompt therapies. Incorporating PET-CT into regular cancer care has improved overall treatment results and survival rates for Indian patients, according to the Indian Council of Medical Research (ICMR, 2022) (Eary J. F. (2008)).

Addressing India's Cancer Burden

An estimated 1.39 million new instances of cancer are recorded in India each year, contributing to the country's rising cancer burden (National Cancer Registry Program, 2021). The nation's healthcare system is under a lot of strain as a result of the increase in cancer incidence. By facilitating early detection, increasing treatment accuracy, and lowering death rates, nuclear medicine offers a solution to address these issues (Sathishkumar et al.,2025).

To increase the affordability and accessibility of cancer care, nuclear medicine services must be expanded. By expanding the number of nuclear medicine facilities and PET-CT scanners, the Indian government has achieved progress in this area. In comparison to international standards, India currently lacks appropriate nuclear medicine facilities, despite having more than 442 operating nuclear medicine centres and 359 PET-CT scanners nationwide (Department of Atomic Energy, 2023) (Singhet al., 23). For example, India has just around 0.3 PET-CT scanners per million, compared to about 4 PET-CT scanners per million in the United States, underscoring the need for significant investment to close this gap (Gallach et al., 2020).

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Supporting Healthcare Sustainability

In addition to improving patient results individually, using nuclear therapy in cancer treatment keeps the healthcare system fiscally sustainable. Patients' and the healthcare system's financial burden is lessened when early identification and individualised treatment programs eliminate the need for expensive late-stage procedures. The sustainability of the healthcare industry is further supported by nuclear medicine's assistance for the training of a qualified workforce, which includes nuclear medicine doctors and technologists (Ringborg et al., 23).

Increasing access to nuclear medicine infrastructure, such as imaging centres, cyclotrons, and radionuclide treatment facilities, will be essential to reducing cancer care inequities, especially in underprivileged areas. India has the potential to create a more robust healthcare system, lower death rates, and greatly improve the quality of life for its cancer patients by guaranteeing fair access to these life-saving technologies (Hricak et al., 2021).

Infrastructure Expansion: Bridging the Gap

As the need for nuclear medicine services grows, India's nuclear medicine infrastructure must expand to serve the diverse population of the nation. There are now 442 nuclear medicine centres in the country, along with 359 PET-CT scanners and a growing number of high-dose radionuclide treatment facilities. To provide equitable access to these life-saving technologies, India must significantly increase the number of PET-CT scanners and other diagnostic tools, particularly in rural and disadvantaged regions (Singh et al., 2023).

The establishment of new nuclear medicine centres and the renovation of current ones would necessitate a significant investment from the public and commercial sectors. These efforts will be spearheaded by the Department of Atomic Energy (DAE) and the Union Ministry of Health, which will make sure that the funds are available to deliver high-quality, reasonably priced, and easily accessible nuclear medical services throughout the nation (Singh et al., 2023).

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Molecular Imaging: Enhancing Cancer Survival Rates

Positron Emission Tomography (PET) in particular has made molecular imaging a game-changer for early cancer identification and successful treatment. PET imaging greatly increases diagnostic accuracy by enabling physicians to see metabolic processes and identify malignant tissues in their early stages, sometimes before symptoms appear. This makes it possible to implement individualised therapy plans that improve patients' overall quality of life and progression-free survival (Jin et al., 2022).

The Role of PET Imaging in Cancer Detection and Addressing India's Rising Cancer Burden

Radiotracers are used in PET imaging to show the metabolic activity in tissues, which is frequently higher in malignant cells. In addition to detecting cancers, this non-invasive method offers vital details regarding their size, location, and risk for spread. In order to optimise patient care, PET scans are especially useful for identifying aggressive tumours, evaluating how well they respond to treatment, and tracking recurrence (Zhu et al., 2011). The capacity of PET imaging to aid in early detection, which is essential for raising survival rates, is among its most important advantages. Cancers that are discovered in their early stages have a far better chance of being successfully treated, with survival rates for some cancer types increasing by up to 90%, according to the Indian Council of Medical Research (ICMR). By allowing physicians to respond quickly and precisely, PET imaging has emerged as a key component in doing this (Griffeth L et al., 2005).

The National Cancer Registry Program (NCRP) reports that over 1.5 million new instances of cancer are registered in India each year, contributing to the country's escalating cancer pandemic. Late-stage diagnoses continue to be a major problem, increasing treatment expenses and decreasing survival rates. By enabling early diagnosis and therapies when they are most effective, PET imaging can alter this course (Sathishkumar et al.,2025). With a disproportionately high number of PET-CT scanners in metropolitan areas, access to PET imaging is still unequal. India now only has 359 PET-CT scanners in use, much fewer than what is needed to satisfy the country's population's needs. In contrast, India has less than 0.3

PET-CT scanners per million, whereas nations like the US and Japan have four per million. Over the next ten years, at least 1,000 PET-CT scanners would need to be added in order to reach the realistic goal of one scanner per million (Khan S et al., 2016).

PET imaging growth in India might make a substantial contribution to the nation's healthcare objectives and long-term economic viability. The financial impact on families and the healthcare system is lessened when early identification with PET imaging eliminates the need for costly and time-consuming late-stage cancer therapies (Hricak et al., 2021). PET imaging reduces productivity losses linked to advanced cancer stages, where patients frequently need long-term care, by identifying cancer earlyThis aligns with India's broader goal of achieving Sustainable Development Goal 3 (SDG 3), which emphasises ensuring healthy lives and improving everyone's well-being (Chan et al., 2020). Infrastructure investments in PET-CT are essential for expanding the advantages of molecular imaging. In order to produce radiotracers, the Department of Atomic Energy (DAE) and the Union Health Ministry have been attempting to expand the number of PET-CT scanners and medical cyclotrons that are already in use. Furthermore, funding the construction of PET imaging facilities, particularly in underprivileged areas, might be greatly aided by public-private partnerships (Duclos et al., 2021).

India's Ascent in Advanced Radio-Theranostics: Clinical and Research Aspects

Theranostic processes have been greatly enhanced by a number of Indian studies that have gained international recognition. Among these are the remarkable disease control attained by using locally generated 177Lu-DOTATATE and 177Lu-PSMA-617 to treat metastatic neuroendocrine tumours and prostate cancer (Sitani et al., 2021; Yadav et al., 2021). 225Ac-DOTATATE and 225Ac-PSMA have demonstrated good therapeutic effectiveness in patients with neuroendocrine tumours (NET) and prostate cancer, respectively, who had disease progression after therapy with 177Lu-based radioligand therapies (Bal et al., 2022). (Yadav et al., 2020). This groundbreaking work from AIIMS, New Delhi, garnered significant international recognition after winning the Best Abstract Award at the 2022 SNMMI summit.

Fortis, Gurgaon, has gained recognition in the field of radionuclide treatment as the first clinical centre to use alpha (225Ac/213Bi) therapy for prostate cancer (Sen et al., 2021).

68Ga-Pentixa for in vivo PET-CT imaging has demonstrated a high density of CXCR4 receptors, which are overexpressed in a number of neoplasms, including lung cancer and multiple myeloma (Shekhawat et al., 2022), (Watts et al., 2017), (Watts et al., 2022), (Watts et al., 2023).These studies, carried out at PGIMER (the first facility in Asia) and funded by the Government of India's DST-FIST, have provided a guide for choosing patients who could benefit from CXCR4-targeted alpha/beta radionuclide treatment. CXCR4-based (alpha/beta) therapeutics show great potential to treat advanced-stage cancers when conventional medications have failed. In conjunction with its counterparts 177Lu/225Ac/213Bi, 68Ga-Pentixa for PET-CT is shown significant potential as a theranostic combination for the treatment of advanced-stage haematological malignancies and solid tumours. The ongoing advancements in precision-based radiomolecular oncology are putting more and more strain on traditional, statistical evidence-based therapy (Singh et al., 2022).

India has made great strides in nuclear medicine. The National Institute of Mental Health and Neurosciences (NIMHANS) in Bengaluru showcased the country's first simultaneous PET-MR system and cyclotron facility. A leading neuro-focused centre, NIMHANS has developed radiotracers such as fluorine-18-[18F] flumazenil for imaging benzodiazepine receptors and [18F]-AVT-011 for measuring P-glycoprotein expression. It has also initiated carbon-11-PBR28 TSPO PET imaging for amyotrophic lateral sclerosis (Kumar et al., 2021).

Organisations such as INMAS and the Advanced Centre for Treatment, Research, and Education in Cancer (ACTREC) have made great strides in translational research. These institutions have worked with leading pharmaceutical companies to build preclinical SPECT/PET-CT systems and conduct clinical research for a range of new anticancer medications employing state-of-the-art radiopharmaceuticals. Following thorough preclinical imaging testing, new radiotracers created by scientists at BARC and ACTREC-TMH in Mumbai have been successfully transitioned into clinical applications (Das et al., 2023).

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Strengthening India's Healthcare Ecosystem Through Nuclear Medicine

Nuclear medicine has the ability to completely change how diseases are managed and support the overall growth of the country when it is included in India's healthcare system. Nuclear medicine offers a chance to build a strong and sustainable healthcare ecosystem that is suited to the requirements of a large and varied population by filling important gaps in diagnosis, treatment, and healthcare accessible. With its innovative uses, this sector has the potential to revolutionise the country's healthcare system by spurring improvements in medical research, infrastructure, and service delivery (Cutler et al., 2021).

The capacity of nuclear medicine to promote cooperative healthcare networks is one of its main accomplishments. It may support multi-institutional research initiatives that find and optimise solutions suited to India's particular healthcare concerns by bridging the gap between public institutions, commercial businesses, and academic institutions. In order to ensure that patients in underprivileged and rural regions may receive these cutting-edge therapies, public-private partnerships can also be crucial in funding and operationalising nuclear medicine facilities. This cooperative strategy guarantees that the advantages of nuclear medicine are dispersed fairly throughout the nation (Singh et al., 2023).

The development of a strong medical isotope supply chain is essential to the effective implementation of nuclear medicine. Technetium-99m and other isotopes that are necessary for diagnostic imaging are frequently imported, which raises prices and creates supply chain risks. In addition to guaranteeing a steady supply, investing in local isotope manufacturing facilities and streamlining distribution networks will help lessen reliance on imports, cut treatment expenses, and improve accessibility. This freedom is in line with India's overarching objectives of economic resiliency and healthcare independence (OECD/NEA (2019).

Another essential component of incorporating nuclear medicine into the healthcare system is empowering medical practitioners. Comprehensive training programs for radiologists, technicians, and oncologists are crucial since advanced technology require specialised expertise (Dhoundiyal et al., 2024). India can provide certification programs and fellowship opportunities to develop a workforce capable of using nuclear medicine efficiently.

Furthermore, encouraging an atmosphere of ongoing education and creativity will guarantee that the nation stays at the forefront of international developments, advancing both domestically and the medical community internationally.

Global Difficulties in Standardising Radiopharmaceutical Treatment Methods

Radiotheranostic techniques are rapidly evolving in India (Kumar et al., 2022). The human genome project and the omics of diseases, particularly cancer, have shown a previously unheard-of level of molecular targeting potential for diagnosis and therapy, which has led to the use of unsealed radioactive chemicals in medicine today. However, according to a thorough white paper document on radiotheranotic practices that was complied with by global leaders in nuclear medicine, it has become very challenging for nuclear medicine professionals worldwide to understand and eventually learn a vast amount of specialised and advanced information on various types of cancers and their cognate diagnostic and therapeutic radiopharmaceutical probes that have been or are currently being developed (Urbain et al., 2023). India has produced a number of exceptional leaders who are carrying on the heritage of teaching theranostics. Many Indian research fellows are now in the news across the world and are actively trying to create a curriculum for educating "Nuclear Oncologists." Similarly, certain internationally recognised therapy institutions in the West have produced a number of these individuals. India is a leader in radiopharmaceutical treatments, according to international organisations like the International Centre for Precision Oncology (ICPO), which also plans to designate a few public and private nuclear medicine facilities that actively treat cancer patients as "Centres of Excellence" (CoE). These facilities will train individuals from various countries in addition to Indians (Sharma A et al., 2018).

Conclusion

Nuclear medicine is a catalyst for sustainable growth as well as a means of enhancing healthcare results. India can create a healthcare system that sustainably and fairly serves its people by improving diagnostic technology, boosting cancer treatment choices, building a qualified staff, and improving infrastructure across (Lee et al., 2019).

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Nuclear medicine will be an essential component of the plan to improve public health, lower healthcare costs, and raise quality of life as India strives to become a Viksit Bharat by 2047. Nuclear medicine can assist India in achieving SDG 3—Good Health and Well-Being—for all of its population by means of investments in education, infrastructure development, and technical breakthroughs, guaranteeing that the nation's healthcare system is both robust and sustainable for future generations.

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