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RESEARCH ARTICLE

Cost-Effective and Strategic Planning for Cancer Management in India: A Comparative Study of PET/CT and CT Imaging

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Aim: The aim of the study is to analyze the cost-effectiveness of positron emission tomography/computed tomography (PET/CT) and computed tomography(CT) for cancer management in India, offering an economic evaluation to address healthcare disparities and inform strategic planning. A cost-effectiveness model was developed to compare PET/CT and CT in cancer management, providing policymakers and healthcare providers with data to support informed decisions, optimize resource allocation, and enhance cancer care efficiency in India.

Methods: We used a probabilistic and deterministic Markov model which will assess the cost-effectiveness of PET/CT from a societal perspective over 5, 10 years, and a lifetime. Direct medical, non-medical, and indirect costs were calculated and reported with means, standard errors, and distribution types. Costs and quality-adjusted life-years (QALYs) were discounted at 3% annually. PET/CT unit data across Indian states were mapped against the cancer burden.

Results: Over periods of 5, 10 years, and a lifetime, the model demonstrated PET/CT gains of 4.19, 6.42, and 6.99 QALYs, respectively. The incremental cost-effectiveness ratio (ICER) for PET/CT in comparison to CT was 617, 1,783, and 2,337 for these respective time frames. The probability sensitivity analysis (PSA) results were similar to the base-case lifetime ICER.

Conclusion: This is the first Indian study on PET/CT capacity planning, utilizing evidence-based data, which indicates the need for one cyclotron for every 67 million individuals and one PET/CT unit for every 3.562 million individuals. Setting up a PET/CT facility without a cyclotron incurs a cost of INR 17.08 Cr (USD 2,339,048.75), whereas the expense for a cyclotron is INR 58.63 Cr (USD 8,026,734.1).

Keywords: Evidence-based planning, PET/CT, CT, Cost-effectiveness, Markov model, India

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INTRODUCTION

In India, more than 2.25 million individuals are living with cancer, with 11,57,294 new cases reported each year. By the age of 75, the likelihood of developing cancer was 9.81% for men and 9.42% for women. Every eight minutes, cervical cancer results in the death of a woman. Additionally, for every two women diagnosed with breast cancer, one succumbs to the disease. Tobacco use is responsible for around 3500 deaths daily. In 2018, cancer led to 7,84,821 fatalities in India, with the probability of dying from cancer by age 75 being 7.34% for men and 6.28% for women. The five most common cancers among men and women account for nearly half of all cancer cases in India and can be effectively prevented, screened, and treated if identified early.(1)

In India, nuclear medicine imaging, such as PET/CT and PET-MRI, has made remarkable progress. In the past forty years, PET imaging has evolved into the most advanced medical imaging technology, predominantly utilized in the field of oncology.(2) The medical device sector in India, with a valuation of USD 5.2 billion, is experiencing a compound annual growth rate of 15.8%. Nevertheless, the growth of PET imaging in the nation encounters obstacles due to the expensive nature of scanners, the scarcity of crucial biomolecules, and a shortage of trained technicians.(3,4) Positron imaging

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has transformed cancer care by facilitating early detection, accurate staging, and evaluation of treatment effectiveness, which in turn helps lower expenses by eliminating the need for unnecessary surgeries and chemotherapy.(5) Innovative biomolecules generated by self-shielded medical cyclotrons and PET generators enable precise imaging and early cancer detection at the metabolic dysregulation stage, prior to any anatomical alterations. Nonetheless, these technological advancements have posed a challenge for healthcare providers to create accessible and cost-effective PET/CT and PET-MRI facilities for populations in underserved and remote areas.(6) Achieving this goal necessitates a robust national commitment and a team of dedicated experts from the start of the project through to its completion. Neglecting this could result in considerable healthcare inequalities and hinder the effectiveness of comprehensive cancer care and control initiatives.(7)

The diagnostic imaging landscape in healthcare has advanced significantly and multiple modalities are now essential for accurate oncology diagnoses. The six primary imaging technologies are gamma cameras, positron emission tomography (PET), computed tomography (CT), single-photon emission computed tomography (SPECT), magnetic resonance imaging (MRI), and other systems, such as PET/MRI, and SPECT-CT, which combine multiple modalities for precise diagnostics.(8) The increasing importance of cyclotrons, which generate the proton-rich radioisotopes essential for these methods, is evident. The growing global incidence of cancer has led to a heightened need for precise diagnostic imaging, thereby boosting the cyclotron market.(9) Cyclotrons provide an economical way to produce radioactive tracers on-site, thereby facilitating the extensive application of PET/CT and SPECT. The integration of these cutting-edge technologies is anticipated to increase significantly from 2020 to 2030, driven by the demand for enhanced diagnostic tools and treatment planning in the field of oncology.(6,9) In India, where cancer rates are rising rapidly, the adoption of advanced diagnostic tools such as PET/CT is essential for effective cancer management.(10) Nevertheless, the availability of these technologies is inconsistent, and the expense of establishing such infrastructure poses a major obstacle. Consequently, conducting a cost-effectiveness analysis that compares PET/CT with traditional CT is essential to guide healthcare policymakers in making the most efficient and fair decisions regarding resource distribution in cancer treatment. This research aimed to perform a cost-effectiveness analysis of PET/CT *vs.* computed tomography (CT) for the management of cancer in India, offering an economic assessment to address disparities and support strategic healthcare planning. The goal is to create a cost-effectiveness model for PET/CT and CT in cancer management, providing policymakers and healthcare providers with evidence-based data for strategic planning and resource allocation, as well as mapping nuclear medicine infrastructure in India in relation to cancer incidence. Meeting these goals will offer insights into developing fair and cost-effective cancer care in India.

METHODS

Using cancer incidence data at the state and district levels, the mapping of nuclear medicine infrastructure in India has been conducted for the five most common cancers: breast, lung, oral, gastric, and cervical. This data was sourced from the Global Cancer Observatory and the International Agency for Research on Cancer.(11) Descriptive statistics have been used to summarize the distribution of infrastructure in relation to the cancer burden, while a comparative analysis has pinpointed areas with notable disparities. Data on nuclear medicine infrastructure, such as the locations and capacities of PET/CT centers, gamma cameras, and cyclotrons, were collected from government health databases, the Atomic Energy Regulatory Board, and professional societies. Geographic information system (GIS) software was employed to map cancer incidence rates and overlay them with the distribution of nuclear medicine facilities, identifying spatial alignments and gaps. An accessibility analysis measured the travel distance or time from high-incidence regions to the nearest facility, highlighting areas with insufficient access. For the economic evaluation, cost-effectiveness analysis (CEA) was utilized to assess the economic impact and health outcomes of PET/CT compared to CT for diagnosing high-risk cancers (breast, lung, oral, gastric, and cervical) in India. A cost-effectiveness model was created and executed in Microsoft Excel, calculating transition probabilities, costs, and health outcomes (QALYs) for each diagnostic method. The outcome of the model includes incremental QALYs, incremental costs, and the ICER, which were used to assess the effectiveness of PET/CT *vs.* CT. Sensitivity analyses, including probabilistic sensitivity analysis and one-way sensitivity analysis, were conducted to test the uncertainties in model parameters against the results. Cost-effectiveness acceptability curve (CEAC) was generated to demonstrate the probability that PET/CT is effective at the monetary terms at different thresholds. Costs were presented in INR, and the results were interpreted to inform evidence-based decision-making and resource allocation for cancer diagnosis and management in India.

Markov Model

Recognizing cancer as a non-communicable disease, we developed a cohort-based Markov model to replicate the

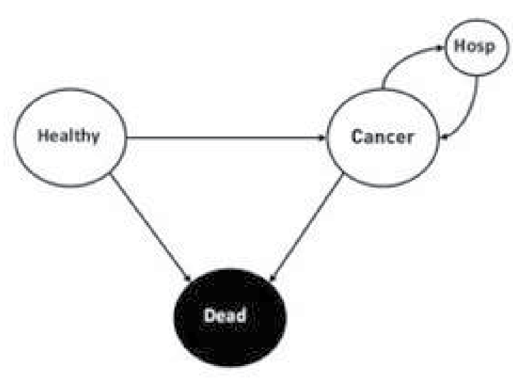

Figure 1: Markov Model

natural course and treatment of cancer (Figure 1). This model comprises three main health states: being healthy, experiencing cancer with hospitalization, and death. The model outlines three main health states—Healthy, cancer (with hospitalization), and dead—depicting the progression of individuals undergoing diagnostic testing and treatment. Individuals start in a healthy state, where they are susceptible to a cancer diagnosis, and may move to a cancer state (with hospitalization) or directly to death. The dead state is terminal, representing mortality from cancer-related or other causes. Transitions between these states are determined by diagnostic results and treatment pathways. Diagnostic testing, such as CT or PET/CT scans, plays a crucial role in the model, with PET/CT providing more detailed images of organs, soft tissues and bones than traditional X-rays, aiding in better visualization of cancer's extent. The cohort included individuals aged 30 to 80 years at high risk for one of the five cancers studied. The model was executed with 1000 patients and a length of cycle considered as 1 year over a lifetime horizon (50 years), applying a 3% annual discount rate to both costs and QALYs. The analysis was performed in a view of societal perspective, including all the direct costs including medical and non-medical, and indirect costs (e.g., productivity losses due to illness). Data inputs for the model were sourced from primary data collected from published literature, healthcare providers in India, and expert opinions where data were unavailable.

Model Assumptions and Data

Table 1 outlines the assumptions and data used in this study. All probability figures were sourced from existing literature. In cases where published data or datasets were unavailable, expert opinions were considered. Our model includes both direct and indirect costs related to diagnostic testing, hospitalization, and productivity losses, all expressed in 2020 Indian Rupees (INR). We applied a gamma distribution to model all cost parameters. Foreign currency was exchanged into INR at the prevailing rate, and domestic expenses were adjusted to account for inflation. For the natural history component of the model, we relied on incidence and mortality data from existing literature.

The utility values for health states in the cost-effectiveness analysis comparing PET/CT to CT were obtained from literature and expert opinions. These values were modelled using a beta distribution to account for uncertainty in health state utilities, a standard method for quality-of-life data in cost-effectiveness studies. In cases where specific utility values were unavailable, we turned to clinical guidelines, consulted with healthcare professionals, and sought expert opinions. These were based on the QALY of cancer patients in comparable healthcare environments, derived from incidence and mortality rates integrated into this model.

We collected data on age-specific cancer incidence for the five most prevalent cancers in India : lung, breast, oral, cervical and gastric cancers. We determined the percentage of cancer incidence by age and calculated cumulative probabilities based on these age-specific incidence percentages. Cancer mortality probabilities were obtained using age-specific cancer death rates from the World Health Organization (WHO). The likelihood of hospitalization for cancer was estimated by assuming hospitalization would occur if the cancer had advanced to stage III or IV, or if the patient was 50 years or older. We computed the probabilities for each type of cancer and combined them into a single probability using a weighted average approach. Various statistical distributions were applied to the input parameters according to the data type: gamma distribution for

Table 1: Probabilities, Utilities and Cost used in the study

	Parameter	*Mean*	*Standard error*	*Distribution Type*	*Reference*
Direct Cost					
Diagnostic Cost					
	Total diagnostic cost PET/CT	11305	1130.5	Gamma	(18,19)
	Total diagnostic cost CT	2551	255.1	Gamma	(18,19)
Hospitalization Cost					
	Total hosp for LOS PET/CT	4150	415	Gamma	(18,19)
	Total hosp for LOS PET/CT	4150	415	Gamma	(18,19)
Indirect Cost					
Productivity lost due to premature death					
	Total Indirect cost for PET/CT	460	23	Gamma	(20)
	Total Indirect cost for CT	460	23	Gamma	(20)
Utilities Value					
	Healthy State PET/CT	0.95	0.095	Beta	Calculated
	Disease State PET/CT	0.60	0.06	Beta	Calculated
	Hospitalization PET/CT	0.20	0.02	Beta	Calculated
	Healthy State CT	0.85	0.085	Beta	Calculated
	Disease State CT	0.50	0.05	Beta	Calculated
	Hospitalization CT	0.20	0.02	Beta	Calculated

cost parameters and length of stay [LOS]; beta distributions for utility weights and normal distribution for hazard ratios. QALYs calculated to reflect both quantity and quality of life, with utility values ranging from 0 [death] to 1 [perfect health]. The ICER was determined by cost difference and QALYs. We used the GDP per capita as the cost-effectiveness threshold to evaluate the cost-effectiveness of PET/CT compared to CT. Additionally, we included different willingness-to-pay thresholds in the model in estimating the probability of PET/CT, a cost-effective screening tool under various conditions.

Sensitivity Analysis

Sensitivity analysis was conducted to evaluate the model's robustness and the impact of uncertainty on the input parameters. In the probabilistic sensitivity analysis (PSA), a range of values was randomly sampled for each parameter to create different scenarios for costs and health outcomes. To capture variation and account for heterogeneity, a Monte Carlo simulation with 1000 iterations was performed. Furthermore, a CEAC was developed to demonstrate the cost-effectiveness of PET/CT at different willingness-to-pay thresholds. PSA results were presented by a scatter plot of the incremental cost-effectiveness and cost-effectiveness acceptability curves.

RESULTS

The cancer rate per 100,000 people was determined, revealing a higher rate in Kerala at 135.3% per 100,000, while Jharkhand and Manipur had a lower rate of 61.3% (figure 2). Maharashtra

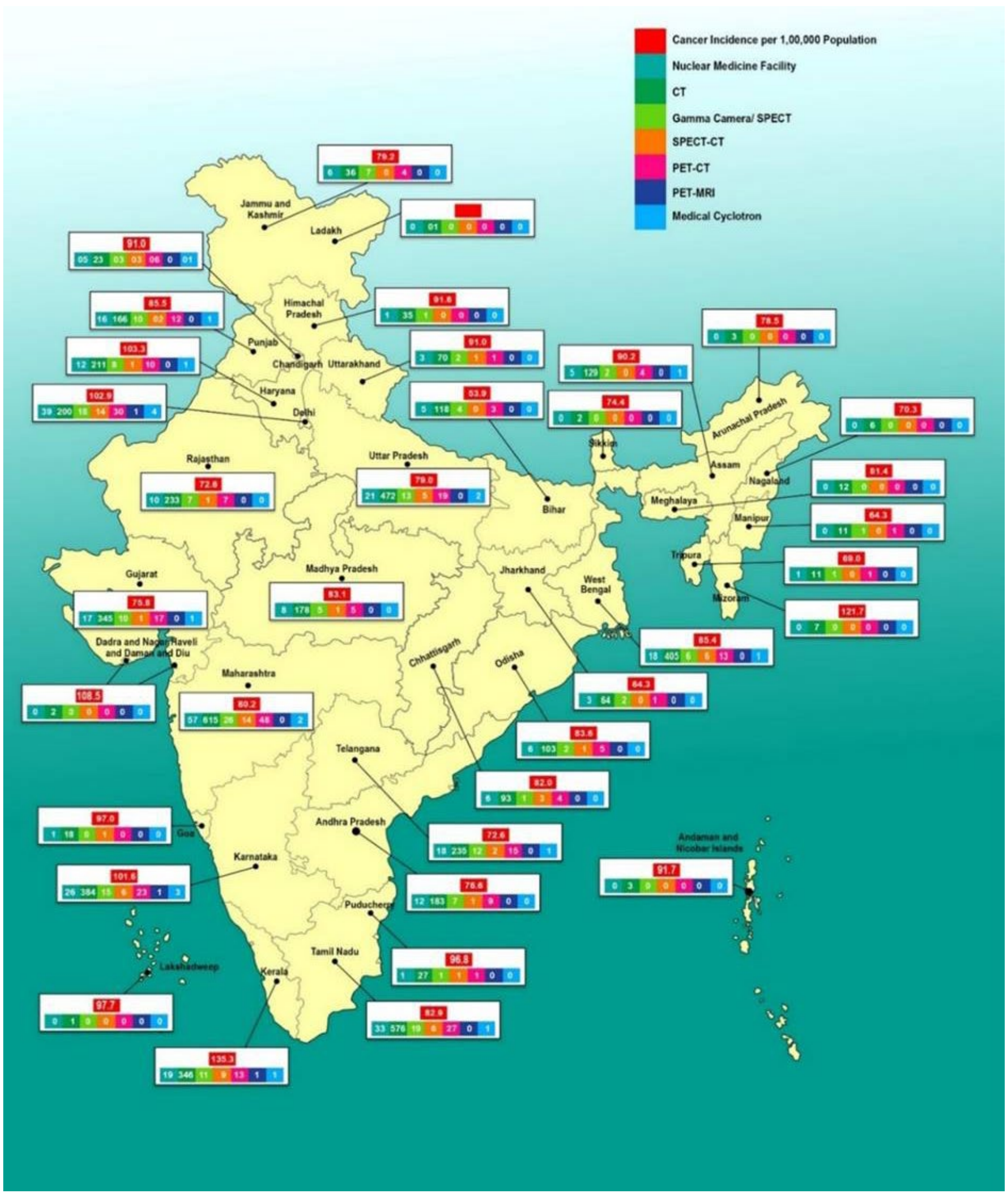

Figure 2: Distribution of nuclear medicine facilities in india in relation to cancer rates

has the highest number of PET/CT units, totaling 48, whereas Manipur, Tripura, Uttarakhand, Jharkhand, and Puducherry each have only one PET/CT unit. Several states and union territories, including Arunachal Pradesh, Himachal Pradesh, Mizoram, Goa, Nagaland, Meghalaya, Sikkim, Andaman & Nicobar Islands, Dadra & Nagar Haveli, Ladakh and Lakshadweep do not have any PET/CT units. In contrast, Kerala alone has 13 PET/CT units.

Base case results

Table 2 presents the base-case outcomes of model analysis, indicating that PET/CT as a diagnostic tool achieves 4.19, 6.42, and 6.99 QALYs over 5 years, 10 years, and a lifetime, respectively. The ICER for PET/CT in comparison to CT were 617, 1,783, and 2,337 for the respective time frames.

PSA Results

Figure 3 illustrates the findings derived from the probabilistic model. To tackle the uncertainty of the variables influencing the results, a Monte Carlo simulation with 1000 iterations was conducted. The ICER values obtained from the PSA closely aligned with the base case lifetime horizon ICER value. The graph clearly indicates that the QALY gained from PET/CT diagnostics is significantly higher compared to CT.

Figure 3 also demonstrates that the probability of PET/CT diagnosis being cost-effective is high concerning the willingness to pay. The threshold for India was determined to be 1,46,000, while CT remains cost-effective up to a willingness to pay of ₹ 9,000. When the willingness to pay

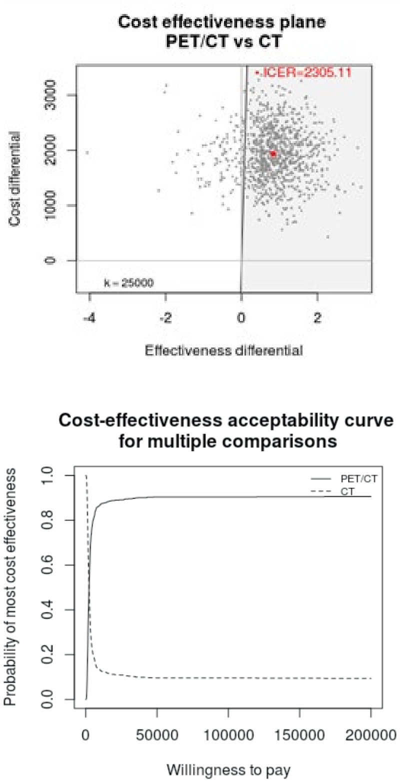

Figure 3: ICER scatter plot and CEAC

Table 2: Base-case results for QALYs and ICERs

Time Horizon	Diagnostic Techniques	QALYs	Cost	ICER
5 years	PET/CT	4.19	₹ 8,36,904	617
	CT	3.74	₹ 8,36,625	
10 years	PET/CT	6.42	₹ 59,30,657	1,783
	CT	5.69	₹ 59,29,359	
Lifetime	PET/CT	6.99	₹ 3,03,89,268	2,337
	CT	6.18	₹ 3,03,87,377	

is substantial, patients tend to choose superior interventions that yield better outcomes. In our study, when the WTP exceeded 9,000, PET/CT was nearly 80% cost-effective. As WTP increases, so does the likelihood of PET/CT being cost-effective. The net monetary benefit of using PET/CT for lung cancer diagnosis surpassed that of CT.

The primary finding of this research was that using PET/CT for cancer diagnosis is more cost-effective than CT for patients at high risk. The ICER values derived from PSA were nearly identical to the base-case lifetime horizon ICER value. The graph clearly shows that the QALY obtained from PET/CT diagnostics is significantly higher compared to CT. Since the incremental net monetary benefit is greater when diagnosing cancer with PET/CT, it proves to be a cost-effective option for high-risk patients.

OWSA Results

One-way sensitivity analysis indicated that the greatest influence on the ICER came from the uncertainty in the utility of patients with the disease, the total hospitalization cost and length of stay for PET/CT and CT, the overall diagnostic cost for PET/CT and CT, and the utility of the healthy population (Figure 4).

DISCUSSION

Delays in cancer treatment represent a prevalent issue on a global scale. Assessing the impact of these delays on mortality is essential for establishing priorities and developing predictive models. Research indicates that a delay of merely four weeks in cancer treatment can lead to increased mortality rates among patients receiving surgery, systemic therapy, or radiotherapy. Therefore, implementing policies aimed at minimizing delays in the initiation of cancer treatment at the system level can improve overall survival outcomes for the population.(12)

Overcoming disparities in the availability and accessibility of nuclear medicine and diagnostic imaging continues to be a significant issue for the nation. If the standard is set at one PET/CT scanner for every 500,000 people, we are currently striving to fulfill this requirement. At present, there are 279 PET/CT units, and an additional 2,224 units are needed to meet these criteria. For a standard of one PET/CT scanner per 1,000,000 individuals, an extra 972 units would be necessary to comply with the norms.(13) In situations where there is one PET/CT scanner available for every 10 million people, there are excess units currently in operation. Suggesting the

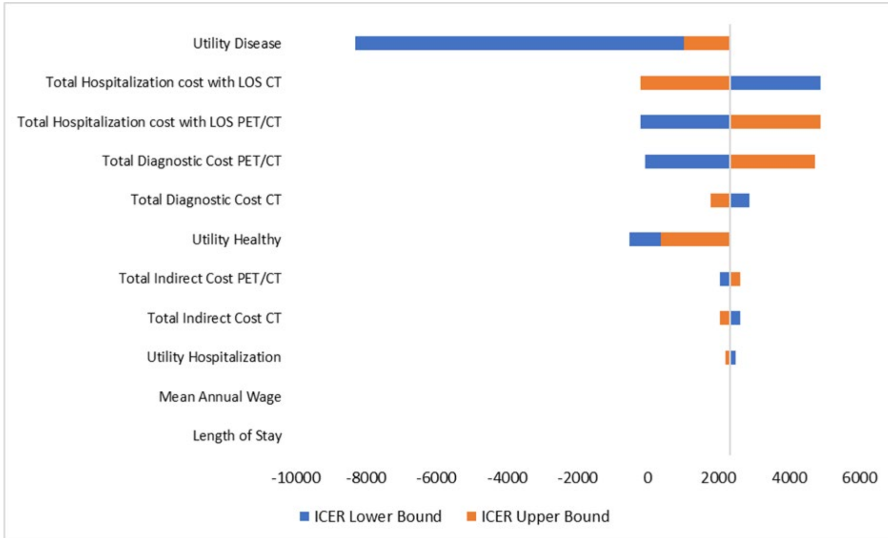

Figure 4: Tornado plot

addition of over 1000 units would result in significant expenses for the government, especially given the lack of data on how much the existing units are being used. To address the present demand, 13 more PET/CT units and four cyclotron units could be established, although this number still falls short of what is necessary.(14)

Our study underscores that adopting a public-private partnership (PPP) model for PET/CT diagnostic services, in line with the National Free Diagnostic Scheme, has the potential to greatly improve the availability of high-quality and cost-effective cancer diagnostic services throughout India. (15) The PPP model could enhance the availability of PET/CT services at district hospitals, lower out-of-pocket costs for individuals, and utilize the capabilities of private service providers to bolster the PET/CT diagnostic network. Given that PET/CT scans in the private sector range from Rs 11,000 to 15,000, offering these services for free under the PMJAY scheme could significantly improve healthcare affordability. To ensure sustainable cost management, it is recommended that cyclotron facilities remain within the public sector, as this would help stabilize the price of FDG, the radiotracer used in PET/CT scans. Due to FDG's short shelf life, an even distribution of cyclotron units is necessary, and a public sector approach would prevent market-driven price variations and ensure cyclotrons are strategically placed across the country to support PET/CT services.

In India, the growth of PET technology faces challenges due to high operational and capital costs, insufficient infrastructure, and limited availability of FDG, which is a result of the few cyclotrons available.(13) The expense and scarcity of FDG, along with transportation issues and its rapid decay, further hinder the affordability of PET services. Furthermore, the adoption of PET is limited by educational and training deficiencies. There is a lack of skilled nuclear medicine professionals, including radiopharmaceutical formulators, imaging specialists, and cyclotron operators, as well as inadequate regulatory and maintenance support.(16) Additionally, both healthcare providers and the public have limited awareness of the clinical advantages of PET, often considering it a last-resort diagnostic tool, despite evidence showing it can change treatment plans in up to 50% of cases and reduce unnecessary procedures. Addressing these challenges through comprehensive policy initiatives, investment in training, and educational programs could facilitate the widespread adoption of PET technology, improve cancer care, and enhance clinical outcomes in India.

Recommendations

Currently, the early detection of cancer and its precursor lesions offers considerable untapped potential to decrease the morbidity and mortality linked to malignancies. It is crucial to highlight the importance of cancer awareness, early detection, diagnosis, and ensuring that treatment for all cancer types is both accessible and affordable. The introduction of PET–CT has brought about a new method for simultaneously assessing physiology and morphology, while the new PET–MR class, which operates without radiation, has broadened the scope of healthcare applications. Integrated PET/CT has been found to improve image interpretation in 49% of patients and 30% of sites. (16) Although PET/CT has made a significant impact in the difficult area of identifying unknown primary tumors, no single imaging technique has been completely successful. Presently, 194 SPECT facilities in India have the capability to be converted into PET by replacing the detector. This conversion could lead to considerable cost savings, making the intervention more economical. Additionally, in India, the public sector accounts for only about 20% of the total healthcare expenditure, which is roughly 1% of GDP.(17)

Limitations

There were concerns about the potential overuse of PET imaging due to the growing reliance on other diagnostic techniques. In the private sector, CT and MRI are often seen as being excessively utilized, frequently without substantial evidence to justify their necessity. This apprehension also applies to PET scans, despite their more limited applications. While this report does not delve into the evaluation of CT and MRI usage, the prevailing perception indicates that governments should conduct a systematic review of CT and MRI practices instead of limiting the development and clinical application of PET technology. It is important for governments to assess PET technology based on its own advantages, rather than the excessive use of other diagnostic tools.

CONCLUSION

Setting up a PET/CT scan center without a cyclotron involves an expenditure of INR 17.08 Cr (USD 2,339,048.75). Introducing more units would be a financial burden for the government, particularly in the absence of data on the usage of current units. The expense of PET/CT can be minimized by increasing the frequency of examinations over time. Several approaches can be adopted to reduce both the capital and operational expenses of these centers, thus lowering the per-unit cost of PET/CT. Establishing a cyclotron facility requires INR 58.63 Cr (USD 8,026,734.1). This plan suggests the gradual addition of four cyclotron units to address the existing demand, although this would still be inadequate.

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AUTHORS CONTRIBUTION

KK, JS contributed to the implementation of the research. ANVJ, SAKM, and KJ contributed to the writing of the manuscript. ANVJ edited and critically reviewed the final draft of the manuscript for submission.

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