(RESEARCH ARTICLE)

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Positron Emission Tomography (PET) Performance Measurements using the NEMA NU 2-2018 Standard: A Systematic Review

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Abstract

The use of many types of imaging (such as Positron Emission Tomography (PET), X-ray, and Computed Tomography (CT)) has been used in therapeutic settings over the past few decades to quantify the body's physiological and metabolic processes. Among them, PET is primarily relevant to provide detailed data regarding molecular and cellular processes. PET systems have played a key role in precise and confident functionality as far as efficient diagnosis and treatment design, and observation, mainly cancer, brain and heart disorders. In order to evaluate the performance of PET systems, the National Electrical Manufacturers Association (NEMA) developed the NU 2-2018 standard, which specifies the requirements. Certain steps of quantification of the major performance measures, such as image quality, Spatial Resolution (SR), sensitivity, noise, and Count Rate (CR), are described in this work, thereby providing an objective way of comparing and validating the quality of the PET scanners across manufacturers and applications. To achieve high-quality images and diagnostic accuracy, PET systems can follow the following protocols, enabling clinicians to make informed decisions. Therefore, it is obvious what the objective of the current review paper is. The NEMA-NU2 2018 standard of PET performance measurement has been explored, and the issues associated with the use of PET performance measurements have been analyzed in this review article using the NEMA-NU2 2018 standard.

Keywords: Positron Emission Tomography; National Electrical Manufacturers Association; Spatial Resolutions; Sensitivity; Timely Resolutions; Performance Measurements; Noise Equivalent Count Rate

1. Introduction

The healthcare industry has undergone a significant transformation in recent years, marked by numerous innovations that enhance patient care, streamline medical processes, and facilitate the adoption of new technologies.[1] In healthcare, proper diagnosis and effective treatment are essential in order to ensure the best possible patient outcomes and well-being. Different disorders can be diagnosed and treated with the aid of imaging technology. Since it enables doctors to identify and treat illnesses without the need for intrusive procedures, medical imaging is a crucial component of the healthcare system. Moreover, the non-invasive techniques and procedures used to create visual representations of the internal organs and tissues of the body are referred to as medical imaging. Naturally, medical imaging and its various variations are used extensively to provide accurate impressions of the body's interior structure and functions, particularly in the case of diagnostic imaging.[2] A few examples of diagnostic imaging modalities used to identify and diagnose illnesses, as well as assess their severity, include X-ray radiography, CT, ultrasound (US), magnetic resonance imaging (MRI), and PET.[3] PET is an important diagnostic imaging modality relative to others, e.g., X-ray radiography, CT, MRI, and ultrasound, because it has the potential to provide detailed metabolic and functional data.[4] The introduction of PET has played a vital role in the field of oncology, cardiology, neurology, and other clinical specialties to provide quantitative perceptions of disease processes, treatment outcomes, and patient outcomes.[5] The fundamental idea of PET imaging is shown in Figure 1

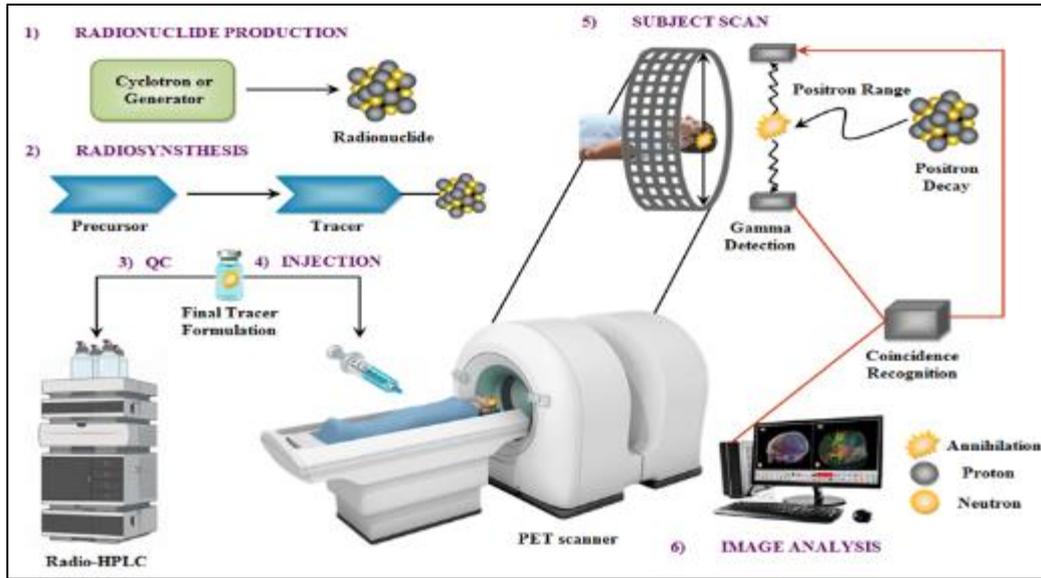* Corresponding author: Rahul P. Mahajan

Figure 1 Principle of PET imaging

Similar to any imaging technology, the accuracy and usefulness of imaging technologies have a significant impact on PET's clinical performance. So the quality and reliability of the images produced by PET systems depends on the assessment and verification of their performance.6 NEMA-NU2 2018 is a standard that NEMA has developed to ensure photographs remain reliable and of quality. Additionally, by offering a common method for measuring and reporting significant characteristics, the standard is used to compare the performance of PET scanners with one another.7 One standard to measure the performance of the PET systems and report on it fairly consistently has been created by NEMA,8 this standard is called NEMA-NU2 2018 standard (Recent update). Furthermore, this standard offers comprehensive methods of determining multiple important PET scanner performance characteristics, which guarantee that the performance of different equipment and manufacturers can be uniform and reproducible.9 Additionally, NEMA-NU2 2018 standard,10 helps to facilitate more comparisons between different PET systems across different manufacturers and technology advancements. Hence, to highlight the importance of standardized measurements in the improvement of the quality and reliability of PET imaging in research and clinical settings, the study addresses information on the performance criteria. Figure 2 provides an explanation of the review paper's remaining headings.
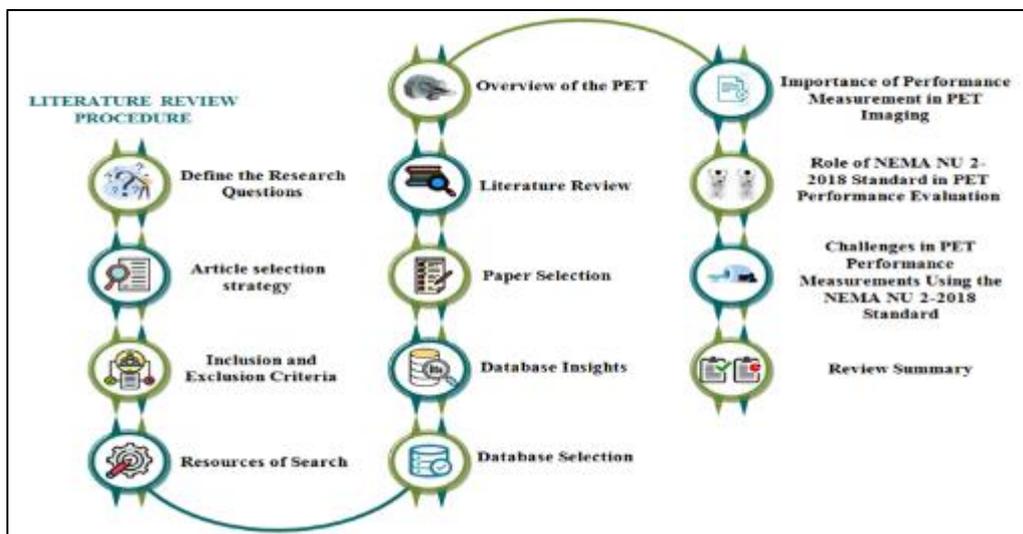

Figure 2 Rest of the sections' headings in the review paper

2. Research Question and Article Selection Strategy

2.1. Research Questions

Research Questions (RQs) are significant when designing a literature review because they facilitate the review and they are the basis of the whole study. To analyze the literature review, RQs are needed as they help not only facilitate the analysis of the review but help clearly define the main points of the review. RQ also assists in determining which topic and subheadings should be clearly focused on and ensures that the analysis is fully aligned with the study's goals.

2.2. Establishment of RQs

The RQs' purpose is to systematically examine and assess the performance parameters of PET systems, confirming the criteria attained by the NEMA-NU2 2018 standard. These questions guide the research to validate factors such as sensitivity, resolution, and accuracy, ultimately aiming to enhance the reliability and quality of PET imaging for improved diagnostic outcomes. The developed RQs are explained in Figure 3.
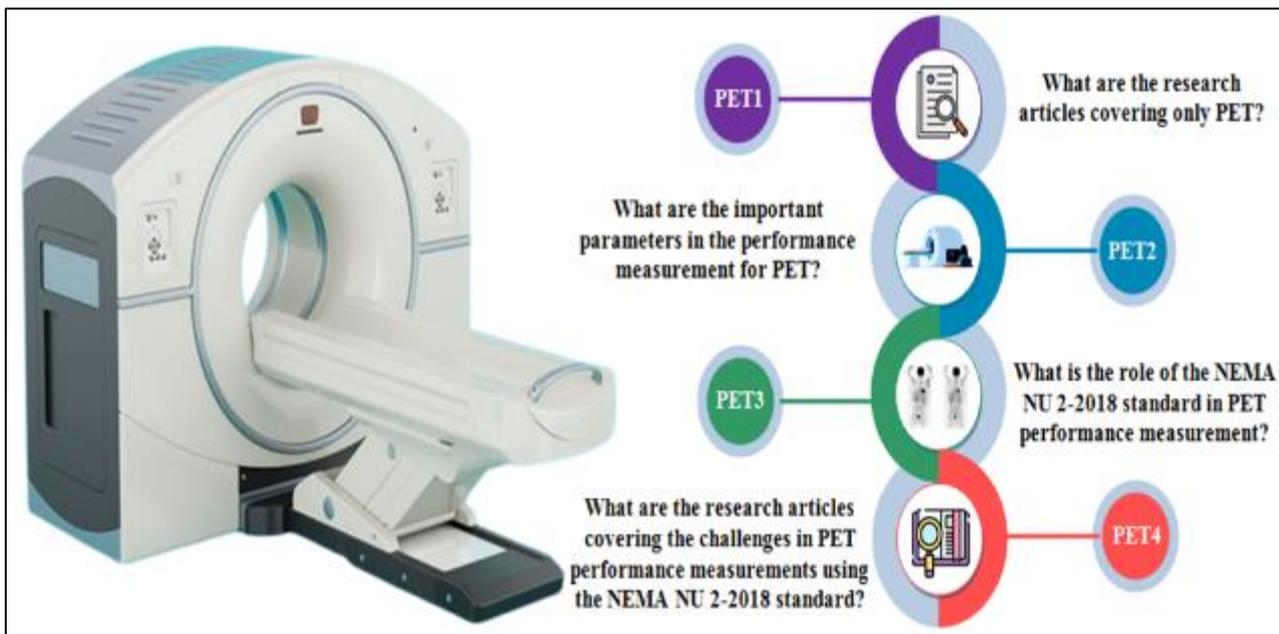

Figure 3 Developed RQs

By answering these queries, scientists can detect the merits and demerits of the PET system's operation, recommend improvements, and ensure the imaging technology satisfies the exact requirements necessitated for precise diagnosis and patient care. Finally, in this study, PET imaging technology is advanced, thereby elevating its efficacy and dependability in medical applications.

2.3. Article selection strategy

It is a process of choosing the papers that are necessitated for a research systematic review. To pick similar articles to review and ensure that the goal is related to the evaluation under consideration, a systematic approach is needed. The aim of the article selection technique of the study is to present a comprehensive and systemized analysis of the relevant literature. This framework has helped to make the evaluation is thorough, accurate, and current as it has helped to identify high-quality studies that provide meaningful information regarding PET performance characteristics.

2.4. Inclusion and Exclusion Criteria

As it is thought that the English language is unique and can be understood by a large audience, the research incorporates research articles in English only. The focus of the analysis is on the studies released not earlier than 2015 and not later than 2023.

- Inclusion criteria: The research was conducted by testing the NEMA-NU2 2018 standard of PET performance. The literature review was based on research studies published from 2014 to 2024.

- Exclusion criteria: The articles that covered the NEMA-NU2 2018 standard alone were filtered out. The literature evaluation eliminated the research articles that only defined the problems related to the PET performance evaluation based on NEMA-NU2 2018 standard.

2.5. Resources of search and selection strategy

In this section, an account of the resources used to conduct a literature search and review is given.

- Resources: As per the original analysis, a set of academic search engines, that is, Google Scholar, Springer, Elsevier, and IEEE Xplore, was used to select the articles. To protect information about the matching target, the research search engines mentioned above were created.
- Database selection: Web of Science (WOS), Scopus, and Science Citation Index Expanded (SCIE) were key databases that were employed for finding and choosing articles for the literature review.
- Database Insights: The vast abstract and citation databases of peer-reviewed content published in scientific publications made journal-centered databases stand out from the other databases. The chosen databases rendered substantial benefits with regard to evaluating appearance and content.

To implement an article selection technique, the Prisma methodology has been used in this work. Systematic reviewers developed PRISMA for transparently recording the procedures involved in conducting a review-based study. It confirms that the authors provide a comprehensive and intelligible description of the review's goals, methodology, and conclusions, comprising the characteristics of the contributing papers and the meta-analyses' findings. The quantity of records discovered, the information that was included and excluded, and the explanations for the exclusion were all listed. Figure 4 shows the Prisma framework.

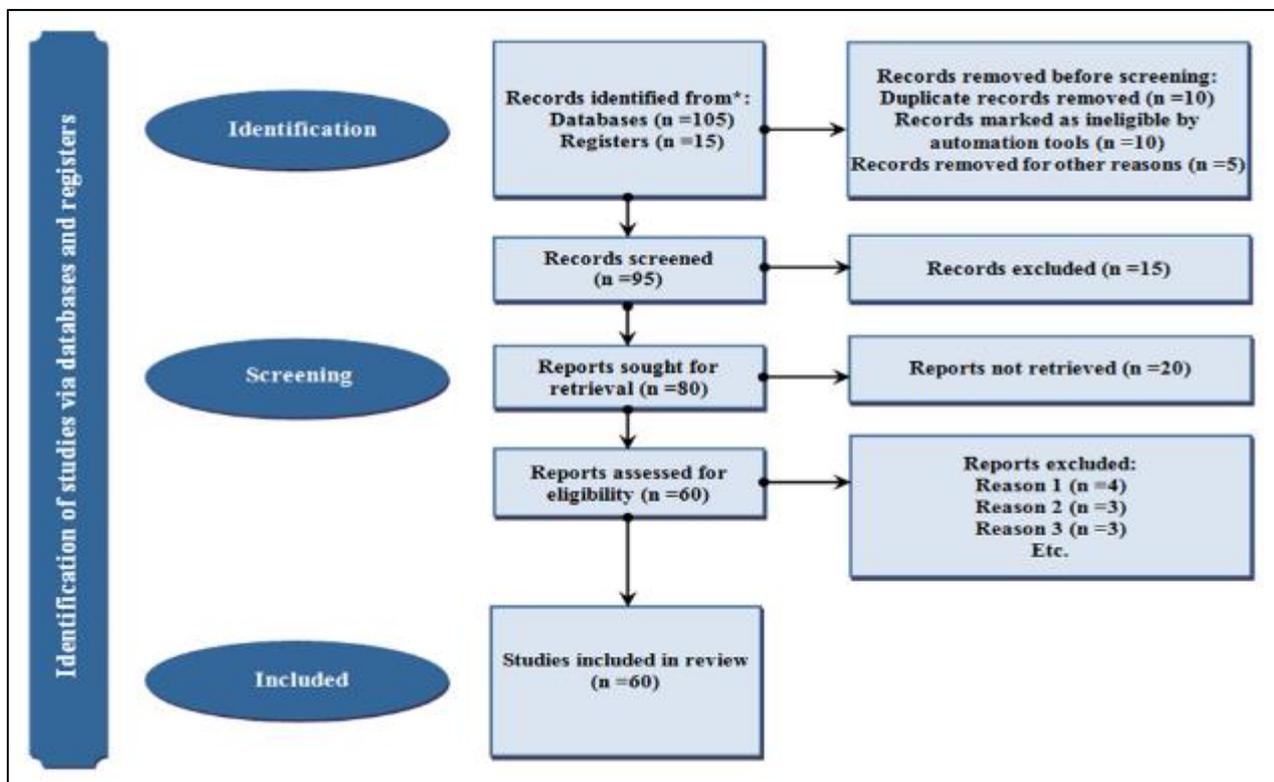**Figure 4** PRISMA Framework

2.6. Paper Selection

60 papers in total were chosen for analysis after determining the exact number of journals that were pertinent to the main keywords. The papers' selection was grounded on preset criteria. Figure 5 shows the search results for this review-based investigation graphically, and Figure 6 explains the pie chart representation for the publication % analysis.
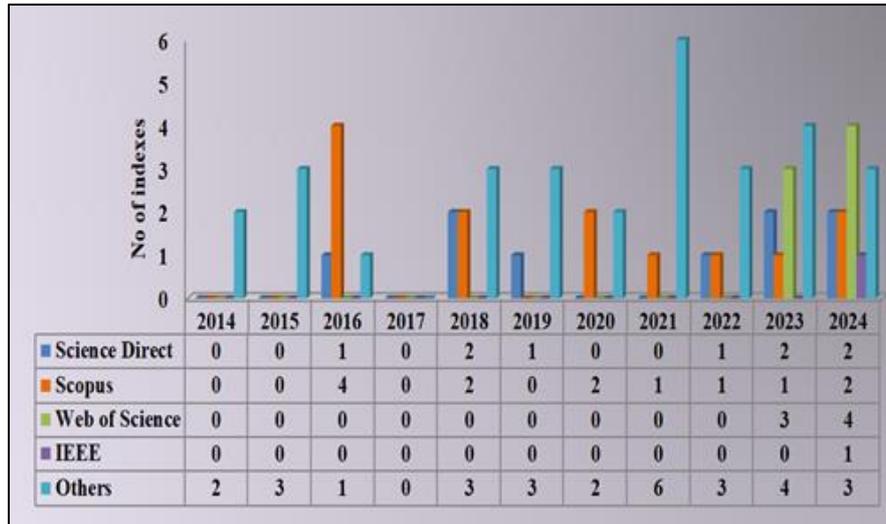
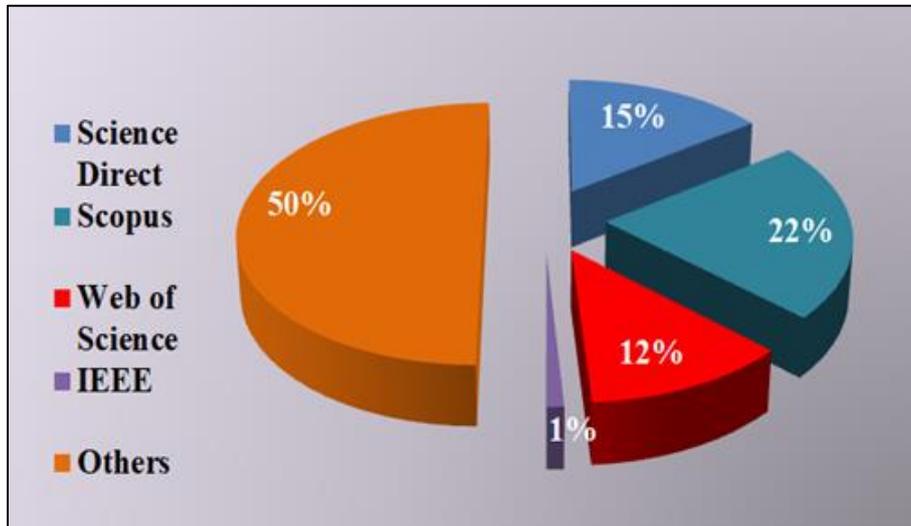**Figure 5** Graphical representation of search results of the article

Figure 6 Pie chart of the percentage of databases related to the objective

3. Literature Review

A vital imaging technology that visualizes the body's metabolic processes is called PET. It is also utilized to diagnose and track numerous medical disorders. By rendering a consistent approach to measure and report significant performance metrics, the NEMA-NU2 2018 standard ensures consistency and dependability across numerous PET systems, which are needed for PET performance evaluation. The performance metrics, i.e., sensitivity, SR, scatter fraction, CR performance, and image uniformity are critically evaluated as per the NEMA-NU2 2018 standard. The actions are necessary to assess the precision and calibre of PET scans, which have a direct influence on clinical judgement and patient outcomes. A few of the challenges of measuring performance based on the NEMA-NU2 2018 standard are recording complex measurements with accuracy, managing variances in clinical scenarios, and ensuring the PET systems are of the quality required to capture accurate imaging. These have to be addressed and make the PET imaging and salvage the best out of the PET diagnosis. Altogether, additional cooperation has a positive impact on the work and the validity of PET as a diagnostic instrument within a modern medical environment in terms of fulfilling the demands, as well as, handling the corresponding task.

3.1. Overview of the PET

A non-invasive procedure of imaging applied in the process of monitoring metabolic activities in the body during medical diagnosis is called PET. During the scanning procedure, the patient's body is injected with a small quantity of a radioactive tracer, usually a positron-emitting isotope.11 As the tracer passes through tissues, it releases positrons, and these positrons clash with electrons to produce gamma rays.12 PET scans offer significant information into the physiological functioning of the body. PET is often employed to diagnose cancer, monitor brain activity, assess neurological illnesses like Alzheimer's, and investigate cardiac issues.13

Serena et al14 explained the patient's outcomes with positive interim PET that continued ABVD in the clinical setting. Every patient treated with frontline ABVD for modified diagnosed advanced-stage Hodgkin lymphoma at the assessment of the Memorial Sloan Kettering Cancer Centre was conducted from 2008 to 2017. Among the 227 individuals identified, 25% (57) had qPET2+ status, while only 14% (31) had dvPET2+ status. For qPET2+ and dvPET2+, the three-year PFS was 70% and 64%, respectively, for 48 patients (84%) who maintained ABVD.

Charlotte et al15 described the fragile X patient's brain's GABAA receptors were measured using PET. This study looked at the regional availability of GABAA receptors in 10 healthy people and 10 fragile X patients. That analysis stated that the GABAA receptor's binding ability was significantly mitigated in fragile X individuals' brains by an average of 10%. The thalamus, which was a part of the brain, saw the biggest change, and the availability of GABAA receptors was dramatically reduced by 17%.

Mouaz et al16 explained the cardiac PET, along with other methods for assessing coronary artery disease, as a snapshot of Medicare data. The proportion of PET/CT and Myocardial Blood Flow (MBF) computations, the median number of investigations read per physician, and the number of PET Myocardial Perfusion Imaging (MPI) procedures were assessed. As per the data, the cardiologists assessed 86% of PET scans and 23% interpreted 25 tests a year with a median of 58 researches per reader. The median number of SPECT scans per reader was 63, compared to the medians of 27, 20, and 24 for stress MRI, stress echocardiography, and CCTA, respectively.

Shorena et al17 investigated Alzheimer's disease and the correlation between tau PET and plasma phospho-tau217 levels. Participants in the BioFINDER-2 experiment who had moderate cognitive impairment (n = 176) or subjective cognitive decline (n = 89) were included in the cohort study along with cognitively healthy control individuals (n = 225). Tau-PET in the entorhinal cortex increased more throughout time in individuals with abnormal plasma P-tau217 at baseline than in those with normal baseline tau-PET.

Tomas et al18 explained the efficacy of cardiac MRI and PET/CT in conjunction for evaluating cardiac sarcoidosis. In this retrospective analysis, 107 consecutive individuals were included and were referred for CS evaluation utilizing both CMR and PET. Out of the 91 people who had positive late gadolinium enhancement, 60 people (66%) showed aberrant absorption of F18-fluorodeoxyglucose. The probability of CS was reclassified for 48 (45%) individuals when PET data were added to CMR. In addition, the majority of these patients (80%) had their final diagnosis accurately reclassified.

Rahul et al19 described the variation in the absorption of the prostate-specific membrane antigen PET tracer when metastatic prostate cancer begins to obstruct the androgen pathway. Prospective single-institution investigation of patients having castration-resistant prostate cancer (n = 4) and metastatic castration-sensitive (n = 4) started treatment with enzalutamide and ADT, accordingly. Before and after the start of therapy, Additionally, they got 68Ga-PSMA-11 PET imaging in serial. Significant intra- and inter-patient variations were exhibited by the PSMA uptake's temporal pattern on initiation of treatment.

Mina et al20 explained that the release of transcranial direct-current activation of endogenous dopamine regulated enhanced attention in a PET. After tDCS to the DLPFC, one scan was performed. The remaining one was executed subsequent to sham stimulation (control). [11C]-raclopride PET data illustrated that the right ventral striatum experienced the release of dopamine as a result of tDCS to the DLPFC. Following the stimulation, only a brief period of time was spent assessing cognitive functions.

3.2. Importance of Performance Measurement in PET Imaging

To guarantee the precision, dependability, and coherence of diagnostic findings, performance measurement in PET imaging is crucial.21 Performance measurements help assess how well a PET scanner captures and represents physiological data by systematically evaluating key performance metrics, such as SR, sensitivity, image quality, and CR.22 The point source's position in the capillary tube for SR measurement is explained in Figure 7.

Figure 7 Position of the point source in the capillary tube for measurement of spatial resolution

These metrics are significant for accurate disease detection, treatment planning, and monitoring, specifically in complex conditions like cancer, neurological disorders, and cardiovascular diseases.23 For comparing numerous PET systems and making sure they satisfy clinical and safety standards, standardized performance measurement protocols like those described in the NEMA standard render a baseline. Regular performance reviews also make it possible to spot possible issues with the system, which encourages ongoing technological advancements and enhances patient outcomes.24

NEMA standards are essential for guaranteeing the quality, uniformity, and dependability of PET systems.25 These standards define the technical specifications for PET scanners, namely performance metrics like image resolution, sensitivity, and calibration procedures that are necessary for generating accurate and reproducible imaging outcomes.26

Jeffrey et al27 explained the Ingenuity TF PET/CT scanner's performance assessment with a concentration on higher CR situations. To evaluate picture quality, CR characteristics, SR, and sensitivity, ACR phantom certification processes were used. In comparison, SR (4.8–5.1 mm FWHM), peak Noise Equivalent CR (NECR) (124 kcps), peak trues rate (365 kcps), and sensitivity (7.3 cps kBq−1) were all displayed by the Gemini TF PET/CT. A 2 mm body reconstruction had a higher contrast recovery than a 4 mm body reconstruction, even if the latter had a lower accuracy. The peak NECR was extensive, falling within 10% of the 241–609 MBq peak.

David et al28 described the preclinical insert PET's performance measurement for digital SiPM technology in PET/MRI. In this study, digital silicon photomultipliers were deployed. The measured energy resolution range was betwixt 12.4%–12.9% for lower activity, reducing to ~13.6% at approximately 100 MBq activity. Also, it didn't exhibit a larger reliance on the chosen parameters.

Melissa et al29 explained the performance as well as limitations of PET scanners to identify reasons for decreased activity. The counting rate performance of the Siemens Biograph Reveal 16 scanner and 2 clinical PET/CT scanners was assessed. Temperature and the counting rate of intrinsic background singles were found to be linearly correlated in a stronger way. After a CT scan, minor temperature variations were found right away. As there was a sudden shift in the recorded singles rates, an exponential recovery period with a time constant of 6–8 minutes was associated with this.

Jun et al30 described the performance assessment of the future solid-state DPC PET/CT system. The gauged energy resolution was 11.2%. The SR (mm in FWHM) for axial, radial, and tangential NEMA tests ranged from 3.96, 4.01, and 4.01 at 1 cm to 5.81, 5.83, and 4.95 at 20 cm, correspondingly. Both Peak real CR and peak NECR implied augmenting values up to the maximal activity detected (~ 1100 MBq), thus making them impossible to differentiate.

3.3. Role of Nema-Nu2 2018 Standard in PET Performance Evaluation

NEMA standards assist manufacturers in designing equipment that meets higher safety, efficiency, and performance benchmarks by establishing uniform guidelines.31 This consistency across PET systems ensures that while facilitating

interoperability between different devices and technologies, healthcare providers can rely on imaging data for diagnosis and treatment planning.32,33

The NEMA-NU2 2018 standard is found to be more appropriate and broadly utilized for evaluating PET system performance although various NEMA standards exist for PET.34,35 Manufacturers can guarantee the quality and reliability of their PET systems by following this standard, and healthcare providers can ensure that the imaging technology meets the highest standards requisite for accurate diagnosis and patient care.36

Some of the parameters used in the analyzed research articles are SR, Sensitivity, NECR, and Timing Resolutions (TRs). The research articles associated with the NEMA-NU2 2018 standard role in PET performance evaluation, with its aims, findings, and limitations, are explained in Table 1.

Table 1 Research articles associated with the NEMA-NU2 2018 standard role in PET performance evaluation with its aims, findings, and limitations

Authors	Aims	Findings				Limitations
		SR	*Sensitivity*	*NECR*	*TR*	
Shuguang et al[37]	To execute a physical performance assessment on the uMI550 whole-body PET/CT system utilizing NEMA NU2-2018	2.91 mm (tangential), 2.98 mm (radial), and 2.97 mm (axial)	10.24 cps/kBq to line source	124.4 kcps at 18.85 kBq/mL	372 ps at a low CR	Challenges in certain clinical scenarios might be presented by the system's sensitivity to small lesions and TR.
Pasawang et al[38]	To analyze the performance measurements of PET with NEMA NU2 – 2018	6.1 mm (radial) and 8.3 mm (axial) FWHM for 20 cm radial distance	Center (0cm) (%Diff): 5.72% and Offset (10 cm) (%Diff): 3.6%	278 kBq/cc	RT measured < 1.05 RT expected	The standard might not fully account for all real-world clinical scenarios, which could impact the generalizability.
Konstantinos et al[39]	To explore the performance validation Field-of-View (FOV) Discovery MI PET/CT utilizing NEMA NU 2–2018	The 5-ring and 6-ring configurations' SR were the same.	32.76 cps/kBq	3-ring system:100 kcps at 20.6 kBq/mL and 4-ring system: 181.3 at 20.6 kBq/mL	Similar values among the 4 distinct ring configurations	Performance consistency was affected by the challenges in accurately measuring complex metrics like scatter fraction.
Manoj et al[40]	To assess the Performance validation of Time-of-Flight-incorporated Digital PET-CT System by employing the NEMA-NU2 2018	5.79 mm (tangential), 5.57 mm (radial), and 5.69 mm (transaxial) at 10 mm	12.053 cps/kBq.	452.98 (kcps) @ 29.95 (kBq/cc)	302 ps	TR presented challenges in certain clinical scenarios.
				1,524 kcps	Nil	

Benjamin et al[41]	To evaluate the uEXPLORER Total-body PET/CT scanner centered on NEMA NU 2-2018	4.4 mm (tangential), 4.6 mm (radial), and 3.3 mm (transaxial) at 10 mm	174 kcps/MBq			Because of variations in phantoms, possible differences were found in the evaluation of image quality.
George et al[42]	To explore the performance characteristics of the biograph vision quadra PET/CT system by employing the NEMA-NU2 2018 standard	3.3 mm (tangential), 3.4 mm (radial), and 3.8 mm (transaxial)	83 cps/kBq for MRD 85 and 176 cps/kBq for MRD 322	1,613 kcps for MRD 85 and 2,956 kcps for MRD 322	228 ps for MRD 85 and 230 ps for MRD 322	Longer FOV could cause higher noise levels, especially in the peripheral regions.
Tahereh et al[43]	To analyze the performance assessment of SiPM centered on a high-resolution PET Scanner	3.74 mm (tangential) and 3.18 mm (radial)	5.7 kBq/mL	18.85 at 5 kBq/mL	500 to 250 ps	Simulations often failed to fully capture the complex noise and other irregularities that occurred in real-world clinical environments

Rhodri et al44 explained the performance assessment of Omni Legend PET-CT, a cutting-edge digital 32-cm axial FOV. The performance of 2 additional commercial GE scanners with a broader FOV was analogized. The corresponding FWHMs for the tangential, radial approach at Axial SR and a 1 cm radial offset were found to be 3.76, 3.73, and 4.25 mm. Overall, the system was 44.36 cps/kBq sensitive to line sources at the centre. The peak NECR was 17.8 kBq/mL at 501 kcps. The scatter percentage was 35.48% and the maximum CR inaccuracy was 5.5% at the peak NECR.

Joyce, et al45 described the capabilities of the computerized Biograph vision CT/PET system. The outcomes from the Biograph mCT Flow were directly analogized with measurements. As per the Biograph vision, NEMA sensitivity, a NEMA peak NECR, 306 kcps at 32 kBq/mL, 3.6 mm, 3.5 mm, and 16.4 kcps/MBq were obtained in full width at half-maximal at a distance of 1 cm from the FOV centre, as well as a transverse SR, respectively (gauged with a point source of 22Na 0.25-mm).

Hadi et al46 explained the performance validation of a PET scanner that uses Monte-Carlo simulations for the entire body based on the 2018 NEMA-NU2 guidelines. The simulated and experiential total sensitivity differed by 2.3% and 0.0%, correspondingly, for the NEMA as well as extended phantoms in the middle of the FOV. For the extended and NEMA phantoms, the peak NECR differences were 1.0% and 9.9%, respectively. The NECR for the 252-ring difference (2.11 Mcps) was more than the NECR for the 336-ring difference.

Matic et al47 described the design optimization of a limited-angle, flat-panel. As a simulation study focused on NEMA-NU2 2018 specifications, TOF-PET Scanner. Moreover, point sources were simulated. Then, a technique was introduced for assessing SR more appropriately for flat-panel geometry. As per the outcomes, while employing a significant reduction in scintillator material, a flat-panel scanner might generate image quality when analogized to a reference clinical scanner with a CTR below 100 ps.

Gabriel et al48 explained the simulation investigation of clinical PET scanners with diverse geometries, comprising TOF as well as Depth-Of-Interaction (DOI) abilities, utilizing NEMA-NU2 2018 standards. By deploying the DOI data, the SR was kept uniform to account for the parallax inaccuracy. The sensitivity was 58 and 115 cps/kBq for the 5 and 7-ring arrangements, correspondingly. Also, the NECR was found to be 563 kcps/mL.

Akamatsu et al49 explained the evaluation of VRAIN's performance as a brain-specific PET that conforms with NEMA-NU2 2018 requirements and uses a hemispherical detector setup. VRAIN used 54 detectors to generate the main hemispherical unit and an additional half-ring behind the neck. A 19% scatter fraction, 229 ps TOF resolution, and good resolution for isolating 2.2 mm rods were demonstrated by the VRAIN. Here,25 kcps MBq−1 was the sensitivity. For the TOF gain, the maximum NECR for an object with a 20 cm diameter was 144 kcps at 9.8 kBq ml−1.

Refaat et al50 described Performance characteristics of the 5-ring PET/CT scanner from GE Discovery MI based on NEMA-NU2 2018 requirements. The clinical protocol's image-registration accuracy betwixt PET and CT generated good outcomes of ≤1 mm. NEMA and TG-126 sensitivity were 20.73 cps/kBq and 19.43 cps/kBq, respectively. SUV values, which signified the correction accuracy for count losses of TG-126, were determined to be within 10% of the anticipated SUV.

4. Challenges in PET Performance Measurements Using the NEMA NU 2-2018 Standard

Knowing the challenges associated with the performance measurement while utilizing the NEMA-NU2 2018 standard is essential.51 For ensuring that PET systems deliver precise and trustworthy diagnostic data, PET first aids in identifying possible areas for enhancement in system performance and design.52 Secondly, these difficulties are recognized to create more reliable and consistent testing procedures that may enhance the comparability of numerous PET systems.53 Lastly, resolving these issues can improve patient safety and clinical results by reducing radiation exposure and improving image quality.54,55 Scientists and producers can try to enhance PET technology and its use in medical diagnosis via a thorough comprehension of these obstacles. When utilizing the NEMA-NU2 2018 standards, variability across Manufacturers, Longer Axial Field of View (LAFOV) Systems, Difficulties in Quantitative Accuracy, and Impact of Noise and Artifacts are the challenges in PET performance measurements.56

Gary et al57 explained the influence of LAFOV PET on oncologic imaging based NEME 2018 standard. The greatest advancement in PET imaging might be the formation of LAFOV PET combined with CT (PET/CT) scanners. A key advancement in molecular imaging, TB-PET and LAFOV PET offered notable sensitivity improvements that allowed for the quicker and simultaneous collection of images of all essential organs.

Challenges: When applying the NEMA-NU2 2018 standard tests, PET scanners with extended axial FOVs, such as those utilized for whole-body imaging, present difficulties.

Delphine et al58 described the use of the NEMA image quality analysis to evaluate the accuracy of PET quantitation across many discoveries IQ CT/PET systems. Although there was more data dispersion with OSEM than with BSREM, the data from the 68Ge solid phantom data didn't illustrate statistic variations betwixt sites, thus signifying better repeatability amongst the PET center models.

Challenges: For applications, accurately estimating tracer uptake is crucial in PET imaging, particularly for fields such as brain research and cancer detection. Nevertheless, achieving consistent and accurate quantification across diverse PET systems and under varying clinical conditions can be difficult.

Thomas et al59 explained the use of the NEMA standard for the computational noise measurement in PET that is fully automated. Regardless of There was no significant difference in the distribution of absolute noise levels between the GNI and manual liver measurements (p=0.84 for Q.Clear 450 and p=0.51 for Q.Clear 600). In the liver parenchyma, a reasonable to moderately significant association was exhibited by the GNI and manual noise measures.

Challenges: The existence of noise, particularly in lower-activity regions or peripheral areas of the FOV, can degrade the image quality and affect performance measurements.

Rukiah et al60 described the customized positron range correction in post-reconstruction 68Ga PET imaging. The image noise locations of uniform uptake in a patient study were importantly augmented by ∼2%. The lesion contrast was augmented by 20% and a maximum uptake value was enhanced by 45 % with statistical significance (P⬚0.05).

Challenges: Similar technologies may be implemented by different manufacturers in varying ways, causing differences in system design, detector configurations, and calibration methodologies.

5. Summary of the Study

An effective imaging technique that shows the body's physiological and metabolic functions is called PET, which offers significant information for the diagnosis and ongoing monitoring of a number of illnesses. Higher-quality imaging performance across numerous devices is made possible by the NEMA-NU2 2018 standard, which renders a uniform as well as a consistent way to test and report the PET systems' performance characteristics. The paper explains how the NEMA-NU2 2018 standard renders detailed methodologies for measuring key parameters like SR, sensitivity, scatter fraction, NECR, and tomographic uniformity. For assessing a PET scanner's image quality and operational efficiency, the abovementioned parameters are crucial. Nevertheless, difficulties in performance measurement, such as precisely recording intricate variables and handling differences in clinical settings, may impact the accuracy and generalizability of the results. These problems must be resolved for PET technology to advance its usage in medical diagnostics for enhancing patient care. Moreover, the RQs are classified into 4 categories, namely PET1, PET2, PET3, and PET4, to make the stated RQs more creative. Table 2 tabulates the RQs and related responses.

Table 2 RQs and responses

Numbers	RQs	Responses
PET_1	What are the research articles covering only PET?	The research articles that cover only the PET were from the reference number 14th to 20th in Section 3.1.
PET_2	What are the important parameters in the performance measurement for PET?	Some of the significant parameters in the performance measurement for PET were sensitivity, SR, scatter fraction, CR performance, image uniformity, and so on. These parameters were mentioned in Section 3.1.1.
PET_3	What is the role of the NEMA-NU2 2018 standard in PET performance measurement?	NEMA-NU2 2018 standard role in PET performance measurement was detailed in Section 3.2.
PET_4	What are the research articles covering the challenges in PET performance measurements using the NEMA-NU2 2018 standard?	The references from 57 to 60 were the research articles covering the challenges in PET performance measurements by employing the NEMA-NU2 2018 standard.

NEMA-NU2 2018 standard's usage confirms consistent image quality, reliability, and comparability across devices, thus making it an indispensable resource for manufacturers, healthcare providers, and researchers in the medical imaging field. The PET technology's continuous evolution is guided by standardized performance measurements, and It is anticipated to significantly enhance this imaging modality's diagnostic capabilities and efficacy in clinical practice.

6. Conclusion

Consequently, it was found from the literature survey that the NEMA-NU2 2018 standard played an indispensable part in defining the PET systems' performance characteristics, thereby confirming that the rigorous requirements of clinical applications are attained by the applied standard. The standard offered a way to compare and evaluate PET systems from various manufacturers independently through the formation of precise and uniform techniques for evaluating important performance indicators, including SR, sensitivity, uniformity, and image quality. System sensitivity, resolution, and overall imaging capabilities were optimized by employing the NEMA-NU2 2018 standard. Although there were distinct advantages, there was a significant limitation to be noted when analyzing the existing research articles. The limitation was that the NEMA-NU2 2018 standard might not sufficiently consider the technological developments in contemporary PET systems like Time-of-Flight imaging and hybrid imaging methodologies (for instance, PET/CT and PET/MRI). These developments could enhance the resolution, sensitivity, and quantification; however, the special performance characteristics of these new technologies might not be adequately addressed or considered by the standard. Future researchers will deem this limitation and find solutions to fully account for the performance characteristics of PET by employing the NEMA-NU2 2018 standard.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Use of Artificial Intelligence (AI)-Assisted Technology for Manuscript Preparation

The authors confirm that there was no use of AI-assisted technology for assisting in the writing of the manuscript and no images were manipulated using AI.

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