BRAZILIAN JOURNAL OF RADIATION TECHNOLOGY RESEARCH

ISSN 2966-4292
Braz J Rad Tec Res., 2026;1:1-12. e0011
Recebido em: 03/04/2026
Aprovado em: 06/10/2026
DOI: https://doi.org/10.70745/bjrtr.v1.232

Preclinical PET Systems: Comparative Analysis and Technical Selection Guide

Sistemas PET Pré-clínicos: Análise Comparativa e Guia de Seleção Técnica

Lívia Regina Medeiros Pereira[1], Rodrigo Modesto Gadelha Gontijo[1,2,3;a]

[1] Universidade Federal de Minas Gerais. Belo Horizonte, MG, Brasil.
[2] Faculdade Ciências Médicas de Minas Gerais. Belo Horizonte, MG, Brasil.
[3] Centro de Desenvolvimento da Tecnologia Nuclear. Belo Horizonte, MG, Brasil.

***Correspondência:** rgadelha@ufmg.br

ABSTRACT

Positron Emission Tomography (PET) is a high-sensitivity and high-specificity molecular imaging technique, fundamental for preclinical research in small animals. Since the 1990s, technological advances have generated a variety of equipment with configurations that directly impact data quality, creating a heterogeneous landscape for researchers. The aim of this work is to provide a standardized comparative framework by performing a systematic analysis of technical specifications to assist laboratory heads and users in selecting the most appropriate equipment according to their specific research needs. The methodology involved a systematic review of current literature and manufacturer technical portfolios. Data were organized into a comparative framework to analyze parameters such as field of view; spatial resolution; sensitivity; crystal detector type and size; detection technology; reconstruction algorithms; Depth-of-Interaction capability; and multimodal integration. The analysis revealed that the optimization of PET systems is a complex balance between spatial resolution and sensitivity. It is important to emphasize that the in-depth analysis of certain systems is constrained by manufacturers' intellectual property, reinforcing the necessity of technical guides to compare publicly declared parameters. This study offers a solid comparative basis as a foundation for institutional decision-making, ensuring the acquisition of high-quality and precise data for molecular imaging analysis. By establishing a standardized selection framework, this work facilitates the optimization of resources and the advancement of preclinical research strategies.

Keywords: Positron Emission Tomography (PET); Preclinical Research; Technical Specifications.

RESUMO

A Tomografia por Emissão de Pósitrons (PET) é uma técnica de imagem molecular de alta sensibilidade e especificidade, fundamental para a pesquisa pré-clínica em pequenos animais. Desde a década de 1990, os avanços tecnológicos geraram uma variedade de equipamentos com configurações que impactam diretamente a qualidade dos dados, criando um cenário heterogêneo para os pesquisadores. O objetivo deste trabalho é fornecer um framework comparativo padronizado, realizando uma análise sistemática das especificações técnicas para auxiliar chefes de laboratórios e usuários na seleção do equipamento mais adequado de acordo com suas necessidades específicas de pesquisa. A metodologia envolveu uma revisão sistemática da literatura atual e dos portfólios técnicos dos fabricantes. Os dados foram organizados em uma estrutura comparativa para analisar parâmetros como: campo de visão; resolução espacial; sensibilidade; tipo e tamanho do cristal detector; tecnologia de detecção; algoritmos de reconstrução; capacidade de profundidade de interação; e integração multimodal. A análise revelou que a otimização dos sistemas PET é um equilíbrio complexo entre resolução espacial e sensibilidade. É importante ressaltar que a análise aprofundada de certos sistemas é limitada pela propriedade intelectual dos fabricantes, reforçando a necessidade de guias técnicos para comparar parâmetros declarados publicamente. Este estudo oferece uma base comparativa sólida como fundamento para a tomada de decisão institucional, garantindo a aquisição de dados precisos e de alta qualidade para a análise de imagem molecular. Ao estabelecer um framework de seleção padronizado, este trabalho facilita a otimização de recursos e o avanço das estratégias de pesquisa pré-clínica.

Palavras-chave: Tomografia por Emissão de Pósitrons (PET); Pesquisa Pré-Clínica; Especificações Técnicas.

1. INTRODUCTION

Positron Emission Tomography (PET) is a highly sensitive and specific molecular imaging technique that allows for the non-invasive visualization, characterization, and quantification of biological processes at the cellular and subcellular levels. In preclinical research, PET is an indispensable tool, particularly in studies involving small animals such as mice and rats. These models are essential for understanding disease mechanisms, developing new radiopharmaceuticals, and evaluating the efficacy of therapeutic interventions prior to clinical translation.[1]

Since the 1990s, the development of PET systems specifically designed for small animals has undergone significant technological evolution[2]. Unlike clinical PET scanners, preclinical systems require substantially higher spatial resolution and sensitivity to accurately image the minute anatomical structures of rodents. This demand has driven a variety of equipment configurations, encompassing differences in detector crystal types, photodetector technology, and system geometry[3,4].

Image quality and data precision in a PET study are strictly dictated by the equipment's technical specifications. Parameters such as the axial and transaxial field of view (FOV), spatial resolution, and absolute sensitivity are critical for determining scanner performance and its suitability for specific research protocols.

The selection of a preclinical PET system is a strategic decision that directly impacts an imaging center's scientific output and resource optimization. Given the wide array of commercially available systems and the continuous introduction of new models, identifying the most appropriate equipment is a highly complex task. A thorough understanding of technical specifications is fundamental to ensure the chosen system aligns with the institution's scientific goals and guarantees high-quality data acquisition.

Although independent performance evaluation studies exist for certain models, there remains a lack of a unified, systematic compilation that enables a direct, side-by-side comparison of the heterogeneous technical parameters provided by manufacturers[5]. Therefore, this study aims to perform a comprehensive comparative analysis of the technical specifications of dedicated small-animal PET systems. By evaluating key performance metrics and technological innovations, this work provides a curated technical framework to assist researchers and laboratory heads in making informed, evidence-based decisions regarding scanner acquisition and application.

2. METHODOLOGY

The methodology was structured into two primary phases, commencing with data collection and organization through a systematic review of the current literature and diverse documentary sources. This process encompassed consulting technical manuals, manufacturer catalogs, institutional websites, and peer-reviewed scientific articles. Where specific technical parameters were not publicly available, data collection was supplemented through direct inquiries to the manufacturers. Subsequently, all technical data were systematized into a comparative framework to facilitate a direct analysis of parameters and the identification of technological trends across the different systems.

In the second phase, a comparative analysis was performed based on the critical parameters that characterize preclinical PET performance. These metrics included the Transaxial Field of View (TFOV) and Axial Field of View (AFOV), which define the imageable volume and strongly correlate with system sensitivity; alongside spatial resolution and absolute sensitivity, serving as primary indicators of detection efficiency. The underlying hardware architectures were also investigated, with a specific focus on the type of scintillation crystals employed—such as Bismuth Germanate (BGO), Lutetium Oxyorthosilicate (LSO), Lutetium-Yttrium Oxyorthosilicate (LYSO), or Gadolinium Orthosilicate (GSO)—as well as the applied photodetector technology.

Furthermore, detector dimensions, crystal quantity, and Depth-of-Interaction (DOI) measurement capabilities were evaluated due to their critical role in mitigating the parallax effect and maintaining spatial resolution uniformity across the FOV. Finally, the capacity for multimodal integration—specifically with Computed Tomography (CT), Magnetic Resonance Imaging (MRI), or Single-Photon Emission Computed Tomography (SPECT)—was assessed, given its essential function in providing the anatomical context required for the precise interpretation of functional PET data.

3. RESULTS AND DISCUSSIONS

The technical specifications of 21 small-animal PET systems were collected from various manufacturers and are compiled in Table 1. The comparative analysis of these preclinical PET systems reveals a diverse technological landscape, where performance is strictly dictated by the synergy between detector geometry and hardware components.

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Table 1. Small animal PET technical specifications summary.

Small Animal PET Equipment		Field of View (FOV) (mm)		Spatial Resolution (mm)	Sensitivity (%)	Scintillation Crystal	Detector Size (mm)	Number / Type of Detectors	Detection Technology	Reconstruction Algorithm	DOI	Multimodal Integration
		TFOV	AFOV									
1	Albira Si PET/SPECT /CT[6, 7]	80	148	≤0,7	12	LYSO	50 × 50 × 10	Monolithic	SiMP	MLEM e OSEM	Yes	SPECT e CT
2	PET/CT Si78[8, 9, 10]	80	150	≤0,7	12	LYSO	50 × 50 × 10	Monolithic	SiMP	MLEM, OSEM e MAP	Yes	CT
3	PET Insert Si 103[8, 9, 10]	55	100	≤0,7	11	LYSO	50 × 50 × 10	Monolithic	SiMP	MLEM, OSEM e MAP	Yes	MRI (3T, 7T, 9.4T)
4	PET Insert Si 198[8, 9, 10]	80	150	≤0,7	12	LYSO	50 × 50 × 10	Monolithic	SiMP	MLEM, OSEM e MAP	Yes	MRI (3T, 7T, 9.4T)
5	PET/MR 3T[8, 9, 10]	80	150	≤0,7	12	LYSO	50 × 50 × 10	Monolithic	SiMP	-	Yes	MRI (3T)

6	NuPET 66[9]	59	67	≤1,3	5,5	LYSO	-	-	SiMP	OSEM, MAP e FBP	-	MRI (1.5T até 9.4T)
7	NuPET Bio 66[9]	59	67	≤1,3	5,5	LYSO	-	-	SiMP	PSF[26]	-	MRI (1.5T até 9.4T)
8	IRIS PET/ CT[11, 12, 13]	80	95	≤0,9	9	LYSO	1,6 × 1,6 × 12	11232 crystals	PMT	OSEM	-	CT
9	nanoScan PET/CT[14]	120	150	≤0,7	10,5	LSO	1,1 × 1,1 × 13	37908 crystals	PSPMT	OSEM	Yes	CT
10	nanoScan PET/MRI[15]	120	100	≤0,7	8	LSO	1,1 × 1,1 × 13	37908 crystals	SiMP	OSEM	Yes	MRI (3T e 7T)
11	nanoScan SPECT/CT/ PET[14]	120	150	≤0,7	10,5	LSO	1,12 × 1,12 × 13	37908 crystals	PSPMT	OSEM	Yes	SPECT e CT
12	U-PET VECTor[16, 17]	-	-	≤0,75	17	-	-	-	-	OSEM	-	SPECT e CT (VECTor)
13	β-CUBE[18]	72	130	≤0,85	12	LYSO	25.4 × 25.4 × 8	Monolithic	SiMP	OSEM	Yes	SPECT e CT
14	MRS*PET INSERT[19, 20, 21]	80	150	≤0,7	12	LYSO	10 thick (4+6)	Monolithic	SiMP	3D OSEM	-	CT e MRI (3T, 4.7T, 7T, 9.4T)

15	MRS*PET CLIP-ON[19, 20, 21]	120	150	≤0,7	11	LYSO	10 thick (4+6)	Monolithic	SiMP	3D OSEM	-	CT e MRI (3T, 4.7T, 7T, 9.4T)
16	G8 PET/CT[22]	47	95	≤1,4	14	BGO	1,75 × 1,75 × 7,2	5408 crystals	MA-PMT	MLEM	-	CT
17	GNEXT PET/CT[22]	120	104	≤1	12	BGO and LYSO	1,01 × 1,01 × 6,1 (LYSO) 1.89 × 1.89 × 13 (BGO)	66560 crystals	MA-PMT	MLEM, OSEM e MAP	-	CT
18	Trans-PET BioCaliburn [23]	53	130	≤1	8	LYSO	1.89 × 1.89 × 13	8112 crystals	PSPMT	OSEM	Yes	-
19	EasyPET[24]	48	72	≤1	0,3	LYSO	1.5 x 1.5 x 10	2 Detector Heads	SiMP	OSEM e MLEM	-	-
20	Super Argus Compact PET[25, 26]	50	100	≤1	14	GSO and LYSO	-	10816 crystals	SiMP	OSEM e FBP	Yes	-
21	Super Angus PET/CT[25, 26]	80	220	≤1	11	GSO and LYSO	7 (LYSO)	9464 a 48672 crystals	SiMP	OSEM	Yes	CT

Note: T: Transaxial; A: Axial.[17]

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The dimensions of the FOV are crucial for defining the imageable volume and overall system performance. The Super Argus PET/CT[25,26] stands out with the largest AFOV in this study (220 mm), featuring a geometry engineered for high sensitivity that enables whole-body scans in a single acquisition. This capability optimizes examination time and significantly reduces the required radiopharmaceutical dose. Conversely, a larger TFOV of 120 mm, found in systems such as the nanoScan PET/CT[14] and the MRS*PET CLIP-ON[19, 20, 21], provides greater versatility for accommodating larger animals or scanning multiple rodents simultaneously, thereby optimizing laboratory workflow. In contrast, systems with smaller FOVs, such as the β-CUBE[18] (130 mm AFOV, 72 mm TFOV), indicate a design optimized for high-performance spatial resolution focused on specific anatomical regions.

The selection of scintillation crystals and photodetectors is another determining factor for scanner performance. A clear transition is observed from BGO crystals, used in older or entry-level systems like the G8 PET/CT[22], to LSO and LYSO crystals. These modern materials offer higher light yield and faster decay times, which are essential for achieving high spatial resolution. Furthermore, the replacement of traditional Photomultiplier Tubes (PMTs) with Silicon Photomultipliers (SiPMs) has become predominant[27, 28, 29]. SiPM technology offers high speed, potential for miniaturization, and, crucially, magnetic field compatibility, enabling simultaneous PET/MRI integration.

Spatial resolution and sensitivity[30] remain the most critical benchmarks, and several contemporary systems, such as those from Bruker, Mediso, and Molecubes, successfully harmonize these parameters. They achieve sub-millimetric resolutions (≤ 0.7 mm) while maintaining high sensitivity levels (8% to 12.5%). The U-PET (VECTor) from MILabs represents the current state-of-the-art performance, reporting the highest spatial resolution (≤ 0.6 mm) and absolute sensitivity (17%) in the analyzed group.

The inclusion of DOI correction has emerged as a vital feature to maintain resolution uniformity across the FOV. Technologies such as monolithic crystals (e.g., β-CUBE) or phoswich detector designs (e.g., Super Argus) are employed by manufacturers like Molecubes, Sedecal, and Bruker to mitigate the parallax effect. This correction is particularly critical in preclinical scanners, where small ring diameters increase the probability of oblique photon interaction within the crystal. Without DOI measurement, these interactions lead to an incorrect localization of the Line of Response (LOR), significantly degrading spatial resolution in the peripheral regions of the image.

Finally, most modern systems are designed as hybrid platforms, reflecting the necessity for multimodal data[31]. While the integration of PET with CT remains the gold standard for high-resolution anatomical correlation and attenuation correction, the emergence of PET inserts compatible with high-field MRI, such as the PET Insert Si 103/198, represents a significant frontier. These systems offer superior soft-tissue contrast and enable simultaneous functional and anatomical imaging without the additional dose of ionizing radiation from CT, which is a major advantage for longitudinal studies in small animals.

To synthesize the technical capabilities analyzed, Table 2 provides a comparative framework that correlates the primary technological advantages of each system category with their recommended preclinical research applications.

Table 2. Comparative Framework – Advantages vs. Recommended Applications

Category / Equipment	Key Technical Advantages	Recommended Research Applications
Total-Body & High Sensitivity (e.g., Super Argus PET/CT)	Largest AFOV (220 mm) allowing single-acquisition whole-body scans; significantly reduced radiopharmaceutical dose.	Systemic pharmacokinetics; longitudinal studies with low-dose requirements; rapid whole-body screening.
High Throughput / Larger Models (e.g., nanoScan PET/CT, MRS*PET CLIP-ON)	Large TFOV (120 mm) provide versatility for scanning larger animals or multiple rodents simultaneously.	Laboratory workflow optimization; multi-animal high-throughput screening; imaging of larger preclinical models.
Ultra-High Resolution (e.g., U-PET, β -CUBE)	Sub-millimetric resolution (≤ 0.6–0.7 mm); use of monolithic crystals to eliminate "dead zones".	Neuroimaging; visualization of minute anatomical structures; focal organ studies (e.g., heart or kidneys).

Category / Equipment	Key Technical Advantages	Recommended Research Applications
Multimodal / MRI Integration (e.g., PET Insert Si 103/198, PET/MR 3T)	SiPM technology for magnetic field compatibility; superior soft tissue contrast without additional ionizing radiation.	Oncology and brain studies require high soft-tissue contrast; simultaneous functional and anatomical imaging.
Resolution Uniformity (DOI) (e.g., Albira Si, nanoScan, Super Argus)	Depth-of-Interaction (DOI) correction to mitigate the parallax effect and ensure resolution uniformity across the FOV.	Quantitative imaging requires high accuracy in the periphery of the imageable volume.
Routine / Entry-Level (e.g., G8 PET/CT, easyPET)	Compact benchtop designs; established BGO technology; simplified operation for standard protocols.	Routine screenings; basic tracer evaluation; educational or entry-level preclinical research.

4. CONCLUSIONS

The technological evolution of preclinical PET systems since the 1990s reflects a continuous pursuit of higher spatial resolution and sensitivity, driven by the specific demands of small-animal imaging. This study provides a comprehensive systematization of the technical landscape of preclinical PET instrumentation, demonstrating that system optimization relies on a complex balance between detector architecture and scanner geometry. The transition from traditional BGO to LSO/LYSO scintillation crystals, combined with the widespread adoption of Silicon Photomultipliers (SiPMs), has been fundamental in achieving sub-millimetric resolution and enabling the development of simultaneous PET/MRI platforms.

The analysis demonstrates that the current technological frontier offers a wide range of performance profiles tailored to distinct research niches, from high-throughput whole-body screening to ultra-high-resolution focal imaging. Furthermore, the implementation of DOI correction and advanced iterative reconstruction algorithms (e.g., OSEM and MAP) has proven essential for maintaining image uniformity and mitigating the parallax effect, guaranteeing high-quality data across the entire FOV. This synergy of technological innovations ensures the accurate visualization of minute anatomical structures, consolidating modern systems as indispensable tools for demanding preclinical research.

Ultimately, the results highlight that there is no single universally superior scanner; rather, there is a diverse array of equipment optimized for specific experimental requirements. Although some cutting-edge systems, such as the U-PET (VECTor), maintain proprietary technical parameters that limit a full independent engineering breakdown, the compiled data reveals clear trends in the harmonization of sensitivity and resolution. It is important to acknowledge that in-depth architectural analyses of certain systems are inherently constrained by manufacturers' intellectual property. This limitation reinforces the necessity for standardized technical frameworks, such as the one proposed herein, to critically compare and contextualize publicly declared parameters.

In conclusion, this work fulfills the need for a standardized comparative foundation for institutional decision-making. By categorizing equipment according to their core technical strengths and recommended applications, this study empowers researchers to optimize laboratory resources and acquire high-quality, reproducible data. Such technical guidance is essential for the strategic planning of imaging facilities and the continuous advancement of preclinical molecular imaging protocols.

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