European Journal of Nuclear Medicine and Molecular Imaging (2023) 50:3809–3816
https://doi.org/10.1007/s00259-023-06386-y

EDITORIAL

Inside Brazilian nuclear medicine: numbers, projections and behaviors

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Published online: 11 August 2023

In Brazil, nuclear medicine services are provided mainly by the public Unified Health System (*Sistema Único de Saúde*-SUS), with the private sector have an important complementary role. The establishment of the SUS was an important social reform considering the socioeconomic inequality in the country. Annual health expenditure in Brazil amounts to 9% of the gross domestic product (GDP), yet less than half of that total is allocated to the SUS. In comparison with other Latin America countries, the *per capita* expenditure of the SUS is lower than that of the public health systems of Argentina, Chile, Colombia, and Uruguay [1].

This report involved data collection from national databases and reports published by institutions. The data organization involved the following steps:

1. Key documents issued by regulatory agencies, including the National Nuclear Energy Commission (CNEN), National Health Surveillance Agency (ANVISA), and the Ministry of Labor, were consulted regarding norms, laws, edicts, and collegial board resolutions (RDC) related to radiopharmacy, nuclear medicine, and related professions.
2. Data on the country's technological infrastructure were collected by accessing the platforms of facilities authorized by the CNEN, equipment available identified at the National Registry of Health Establishments (CNES) website, and data from the IBGE, which were compared with publications from the World Health Organization (WHO).
3. Data on the national workforce in nuclear medicine were investigated.
4. The database of the Department of Informatics of the Unified Health System (DATASUS), which provides data on procedures and treatments performed by the SUS, was accessed. Additionally, reports from the National Supplementary Health Agency (ANS), which contains information on treatments performed by private services, were consulted.

We report on several characteristics of Brazilian nuclear medicine: the national population and its distribution, regulation and legislation in the field of nuclear medicine in Brazil, distribution of nuclear medicine services, the technological infrastructure of nuclear medicine equipment, national consumption of radioisotopes, nuclear medicine examinations performed by nuclear medicine services, systems developed for establishing reference levels in nuclear medicine, and reporting of accidents and incidents.

- **Regulation and legislation in the field of nuclear medicine in the country**

Nuclear medicine in Brazil is regulated by three major national authorities: CNEN (Nuclear Energy Commission), ANVISA (National Health Surveillance Agency), and MTE (Ministry of Labor and Employment). Despite sharing responsibilities in some areas, each of the authorities is responsible for specific areas in radiation protection and control of occupationally exposed individuals (OEI), the general public, patients, and medical equipment (Table 1).

- **Distribution of nuclear medicine services in Brazil and technological infrastructure of equipment**

Brazilian nuclear medicine services are regulated by various organizations, with the main authority responsible for licensing being the CNEN, which has a regularly updated online database including information such as registration, institution name, city, state, and authorization validity of

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Table 1 Regulatory authorities in the Brazilian nuclear medicine field and their respective responsibilities for specific areas

Authorities	Responsibilities for specific areas
National Health Surveillance Agency (ANVISA)	Promote the protection of the health of the population through the sanitary control of the production and consumption of products and services subject to sanitary surveillance [2]
Nuclear Energy Commission (CNEN)	Monitor, regulate and supervise nuclear safety and radiological protection of nuclear activities and facilities, nuclear materials and radiation sources in the country [3, 4]
Ministry of Labor and Employment (MTE)	Decide on matters of labor relations, remuneration, employment, professional and union organization and health and safety at work [5–7]

nuclear medicine services throughout the country, as shown in Table 2. Additionally, the database includes data on the radioisotopes used, consumption, and authorized activity.

The data regarding the number of services are reported in Table 2 along with the population data obtained from the IBGE website. Based on this, the number of services per million people was calculated for each region. The data on available equipment were acquired by consulting the website of the CNES (National Registry of Health Establishments) and organized according to the publication "Global Atlas of Medical Devices" from the World Health Organization (WHO) [13].

The data were organized considering the respective medical diagnostic technology: positron emission tomography/computed tomography (PET/CT) and gamma camera analysis.

Table 2 Distribution of nuclear medicine service providers and density per million inhabitants [8–12]

State	Service Providers	Dens. *	PET/CT	Dens. *	Gamma Camera	Dens. *	Population*
Acre (AC)	2	2.21	—*	—*	—*	—*	906,876
Alagoas (AL)	6	1.78	3	0.89	16	4.75	3,365,351
Amapá (AP)	2	2.28	—*	—*	5	5.70	877,613
Amazonas (AM)	6	1.41	1	0.23	10	2.34	4,269,995
Bahia (BA)	20	1.33	3	0.20	38	2.54	14,985,284
Ceará (CE)	9	0.97	—*	—*	17	1.84	9,240,580
Distrito Federal (DF)	23	7.43	—*	—*	—*	—*	3,094,325
Espírito Santo (ES)	14	3.41	1	0.24	23	5.60	4,108,508
Goiás (GO)	14	1.94	—*	—*	21	2.91	7,206,589
Maranhão (MA)	4	0.56	4	0.56	14	1.96	7,153,262
Mato Grosso (MT)	5	1.40	2	0.56	16	4.49	3,567,234
Mato Grosso do Sul (MS)	5	1.76	—*	—*	12	4.23	2,839,188
Minas Gerais (MG)	60	2.80	13	0.61	91	4.25	21,411,923
Pará (PA)	9	1.03	4	0.46	23	2.62	8,777,124
Paraíba (PB)	5	1.23	3	0.74	13	3.20	4,059,905
Paraná (PR)	25	2.16	7	0.6	47	4.05	11,597,484
Pernambuco (PE)	13	1.34	6	0.62	25	2.58	9,674,793
Piauí (PI)	5	1.52	—*	—*	11	3.34	3,289,290
Rio de Janeiro (RJ)	53	3.03	19	1.09	86	4.92	17,463,349
Rio Grande do Norte (RN)	3	0.84	2	0.56	6	1.68	3,560,903
Rio Grande do Sul (RS)	35	3.05	6	0.52	60	5.23	11,466,630
Rondônia (RO)	3	1.65	—*	—*	9	4.96	1,815,278
Roraima (RR)	1	1.53	—*	—*	2	3.06	652,713
Santa Catarina (SC)	19	2.59	5	0.68	31	4.22	7,338,473
São Paulo (SP)	131	2.81	30	0.64	219	4.69	46,649,132
Sergipe (SE)	4	1.71	3	1.28	5	2.14	2,338,474
Tocantins (TO)	2	1.24	—*	—*	8	4.98	1,607,363
TOTAL	478	2.24	112	0.53	808	3.79	213,317,639

*Dens.**, Density per million population; —*, data unavailable or missing

Table 3 Number of nuclear medicine service providers by Brazilian region

Brazilian Region	Percentage of the Brazilian Population	Total number of service providers	Percentage of service providers
Midwest	7,83	47	9,83
Northeast	27,03	69	14,44
North	8,86	25	5,23
Southeast	42	258	54
South	14,25	79	16,53

Brazil has 27 “federative units” (26 states and the Federal District, location of the capital Brasília), organized into five macro-regions [14]. The number of nuclear medicine service providers by Brazilian region is represented in the Table 3.

Although the population percentages and the number of authorized NM service providers are very close, their availability and distribution vary significantly, with several Brazilian states having a service provider-to-population ratio well below the national average of 2.24, such as the Maranhão with a density of 0.56 service provider per million inhabitants. These data demonstrate a significant inequality in the location and distribution of available service providers in the country, with places like the Federal District having a density of 7.43. Another important point to consider is that the density of equipment per million inhabitants is more relevant than mere quantity. For example, the state of São Paulo has the highest number of service providers (131) but a density of 2.81, while the state of Roraima, with only 1 service provider, has a density of 1.53.

As for the technological infrastructure, the density of equipment per million inhabitants was compared with the data published by the WHO in its document "Global Atlas of Medical Devices" [13]. Brazil has densities equivalent to those of developed countries in various equipment categories. For nuclear magnetic resonance, the density is 14.73, which is comparable to that of countries like Australia, Canada, France, Netherlands, New Zealand, and Spain. For computed tomography, the density is 29.23, which is equivalent to or even higher than countries like Austria, Canada, Finland, France, New Zealand, Portugal, and Spain. However, for PET/CT, Brazil has a density of 0.53, which is significantly lower than most of the listed countries, comparable only to Mexico, Portugal, and Uruguay. As for gamma cameras, the density is 3.79, which is also below the majority of countries, with densities closest to those of New Zealand and Uruguay. For mammography, a density of 285.16 was observed, inferior only to countries like Monaco, South Korea, and United States. It is important to note that even the lowest state density is 200, in Roraima, which is still higher than some developed countries, like Austria, Canada, New Zealand, and Spain [13].

The data displayed in Table 4 reveals that in several areas, the differences in equipment and service provider densities in the country are significant, with some differences being even 12 times higher for nuclear medicine service providers compared to the lowest observed value. These data are strong indicators of regional disparities, which are related to socioeconomic factors, income distribution, low government investments in healthcare in certain areas, unequal resource distribution, and a higher concentration of service providers and equipment in states that have large urban centers.

- **National production and consumption of radioisotopes**

The consumption and production of radiopharmaceuticals in Brazil are experiencing significant growth, with over 2 million patients being served in clinics and hospitals with nuclear medicine services. The Institute for Energy and Nuclear Research (IPEN) caters to 85% of the national demand for nuclear medicine. However, the country imports inputs for production from countries such as South Africa, Russia, and the Netherlands, resulting in an annual expenditure of around US$15 million on radioisotope imports. Radioisotopes for use in PET equipment account for 15% of the national demand [15].

In 2022, a constitutional amendment (E.C.no.118/2022) was approved to allow the production and sale of radiopharmaceuticals produced in cyclotrons by the private sector, ending the government monopoly [15, 16]. The producers, distributors, and consumers of radioisotopes in the country are listed in Table 5.

Even though Brazil has domestic reactors, cyclotrons, radiopharmacy centers, and radiopharmaceutical distributors, the current quantities fall far short of meeting the demand for procedures. However, considering the recent constitutional amendment ending the government monopoly, an increase in the number of radioisotope production and sale entities is expected. Other areas related to nuclear medicine include research centers working on new applications of radioisotopes and radioimmunoassay services, which have medical purposes.

The consumption of radioisotopes in Brazil undergoes annual changes, as new service providers are authorized and others are deactivated. In a previous study conducted in 2019

Table 4 The ranges of maximum and minimum equipment and service densities in Brazil

Equipment / Service Provider	Minimum density	Maximum density	National density
Nuclear Medicine Services	0.56	7.43	2.24
PET / CT	0.2	1.28	0.53
Gamma Camera	1.68	5.7	3.79

Table 5 Producers, distributors and consumers of radioisotopes in Brazil related to nuclear medicine in 2022 [14, 16–21]

Designation	Authorized Installations
Radiopharmacy Center	3
Research Center	190
Cyclotrons	10
Radioisotope Distributors	5
Sources distributors	3
Radioimmunoassay	7
Reactors	4

as part the third author's dissertation entitled "Development of a Model for Registering and Reporting Accidents and Incidents in Nuclear Medicine," as shown in Table 6, even during the pandemic period, when a decrease in radioisotope consumption in the country was expected, an increase was observed. This confirms the growth rate and the market strength.

Table 6 Consumption of radioisotopes in Brazil and difference in total activity (MBq) in 2019 and 2022 [22]

Radionuclide	Total activity (MBq) in 2019	Total activity (MBq) in 2022	Difference in total activity (MBq)
[225Ac]Ac	0	78	78
[11C]C	44,400	48,100	3,700
[14C]C	250	250	0
[64Cu]Cu	0	16,650	16,650
[51Cr]Cr	2.932	3,608	676
[18F]F	5,692,339	6,000,586	308,247
[67Ga]Ga	347,125	368,405	21,280
[68Ga]Ga	280,318	522,371	242,053
[123I]I	296,124	338,142	42,018
[123I]I-MIBG	0	574	574
[124I]I	1,110	0	0
[125I]I	0	3,586	3,86
[131I]I	5,163,868	5,535,959	372,091
[131I]I-MIBG	3,443	190,754	187,311
[111In]In	91,930	1,955,037	1,863,107
[177Lu]Lu	1,454,285	2,715,937	1,261,652
[13N]N	0	3,700	3,700
[15O]O	37,000	37,000	0
[32P]P	1,110	1,110	0
[223Ra]Ra	29,889	26,790	-3,099
[153Sm]Sm	1,648,289	1,860,788	212,499
[99mTc]Tc	30,234,698	33,282,111	3,047,413
[201Tl]Tl	457,824	452,493	-5,331
[90Y]Y	255,790	495,822	240,032
[89Zr]Zr	0	370	370
Total number of radioisotopes	19	24	5
Total activity	46 TBq	≈ 54TBq	≈ 8TBq

According to the estimate presented here, over the past three years, there has been an increase from 19 to 24 radioisotopes being used in the country ([225Ac]Ac, [51Cr]Cr, [125I]I, [13N]N, [89Zr]Zr). However, radioisotope [124I]I, which was used by only one facility in the country, has been discontinued this year. As for the weekly activity consumption, there was a 17.4% increase in 2022 compared to 2019. These data are important for logistical planning and control carried out by regulatory authorities, since increased consumption indicates an increase in procedures performed, a greater need for nuclear medicine professionals, an increase in the volume of radioisotopes transported, more research and applications, and also a potential increase in the number of accidents and incidents.

The radioisotopes with the highest and lowest consumption are presented in Table 7.

It can be observed that the radioisotopes with the highest consumption are predominantly used for diagnosis ([99mTc]Tc, [18F]F, [131I]I, [111In]In, [68Ga]Ga, [201Tl]Tl, [67Ga]Ga, [123I]I, [131I]I-MIBG) and therapy ([131I]I, [177Lu]Lu, [153Sm]Sm, [90Y]Y, [131I]I-MIBG), with 9 used for diagnosis and 5 used for therapy, including 2 radioisotopes used in theranostics and 2 used in PET equipment. As for the radioisotopes with lowest usage, new procedures in the country are present, such as [225Ac]Ac, [89Zr]Zr and [13N]N, and among the lower-used radioisotopes are 8 used in diagnosis ([14C]C, [89Zr]Zr, [123I]I-MIBG, [51Cr]Cr, [13N]N, [64Cu]Cu, [15O]O, [11C]C) and 4 used in therapy ([225Ac]Ac, [32P]P, [125I]I, [223Ra]Ra), with 4 used

Table 7 Radioisotopes grouped by higher and lower usage [8]

12 with the highest consumption		12 with the lowest consumption	
Radionuclide	Total activity (MBq)	Radionuclide	Total activity (MBq)
[99mTc]Tc	33,282,111	[225Ac]Ac	78
[18F]F	60,00,586	[14C]C	250
[131I]I	5,535,959	[89Zr]Zr	370
[177Lu]Lu	2,715,937	[123I]I-MIBG	574
[111In]In	1,955,037	[32P]P	1,110
[153Sm]Sm	1,860,788	[125I]I	3,586
[68Ga]Ga	522,371	[51Cr]Cr	3,608
[90Y]Y	495,822	[13N]N	3,700
[201Tl]Tl	452,493	[64Cu]Cu	16,650
[67Ga]Ga	368,405	[223Ra]Ra	26,790
[123I]I	338,142	[15O]O	37,000
[131I]I - MIBG	190,754	[11C]C	48,100

in PET. Is important to notice that due the specificity and origin of the emission (alpha, beta, gamma, Meitner-Auger electrons, and positrons) values and activities cannot be intercompared.

[99mTc]Tc is the most consumed radiopharmaceutical for gamma cameras in the country, while [18F]F is the most consumed PET radiopharmaceutical, and [177Lu]Lu is the most consumed radiopharmaceutical for therapy.

- **Nuclear medicine professionals in the country**

Another crucial aspect for the growth of nuclear medicine in the country is the training of professionals. This includes nuclear physicians, radiologists and diagnostic imaging physicians (ultrasound, MRI) medical physicists specialized in nuclear medicine and radiodiagnostics, nursing professionals,radiology technicians/technologists specialized in nuclear medicine and radiopharmacist [10]. All of these professionals directly contribute to the execution of diagnostic and therapeutic procedures, ranging from prescription and procedure execution to equipment quality control, dosimetry planning, and applied activity calculation.

Before these professionals can practice, they undergo specialized training, which includes postgraduate courses and professional development programs for individuals from various fields. Multiprofessional residencies are an important tool for training medical, nursing, and medical physics professionals.

Another professional involved in nuclear medicine and radiology is the radiation protection supervisor (RPS), who is responsible for planning and executing radiation protection plans, training of occupationally exposed individuals (OEI), and plays a role in nuclear and radiological emergencies. This professional has different specialties as certified by the ANSN (Table 8) [23]. From 2010 to 2019, there was an increase of 40% in nuclear medicine residents and an annual growth rate of 3.3% in the number of physicians entering nuclear medicine residencies in Brazil. As for residents in radiology and diagnostic imaging during the same period, there was an increase of 84.5% and an annual growth rate of 6.3% [24].

Another important point is that the distribution of professionals follows the same pattern as the distribution of equipment in the country, with a higher concentration of these persons in the states of the Southeast region and a lower concentration in states in the North region. In some states, there are even reports of only one or no professionals practicing in the field. This raises significant concerns since various procedures are not offered, leaving patients without coverage.

- **Procedures and nuclear medicine exams performed in SMNs**

Brazil has a database managed by the Department of Informatics of the Unified Health System (DATASUS) that provides information on laboratory and hospital production, including nuclear medicine exams performed in the country through the Unified Health System (SUS). The data include statistics on the procedure, age group, gender, municipality, state and year, among other aspects. Data from private health providers are published by the National Supplementary Health Agency (ANS) in annual reports on procedures,

Table 8 Professionals working in nuclear medicine and radiodiagnostics in Brazil, categorized by specialty and gender [24–32]

Radiation Protection Supervisors (SPRs)	
Type of activity/facility	Number
Transport of radioactive waste	27
Management of radioactive waste	Unavailable
Intermediate storage facilities or final disposal facilities for radioactive waste	5
Nuclear research reactors and critical/subcritical units	2
Industrial radiopharmacy facilities	28
Facilities with particle accelerators for radioisotope production	23
Nuclear medicine facilities	339
Higher-level professionals, nuclear medicine physicians, and radiologists	
Higher-level professionals qualified for the preparation, use, and handling of radioactive materials for in vivo diagnosis and therapy with radiopharmaceuticals	539
Specialists in nuclear medicine	1,009
Nuclear medicine physicians	894
Specialists in radiology and diagnostic imaging	14,225
Radiologists	12,756
Residents in radiology and diagnostic imaging	1,879

Residents in nuclear medicine and radiology* - Residents of all periods in 2019 but the information is presented in a generalized manner without specifying the types of procedures performed.

The data presented in Table 9 below refer to nuclear medicine exams performed by the SUS in adults > 20 years old in the last five years [33].

The data presented in Table 10 refer to nuclear medicine exams performed by the Unified Health System (SUS) and private healthcare providers in the last five years.

The number of nuclear medicine procedures performed by the SUS and the private sector differ significantly, especially in terms of diagnostics. The SUS performed 50 exams, while the private sector performed 69 exams. This difference in procedure numbers was expected, since the SUS also finances procedures performed in the private sector through direct payments or prepayments to health plan operators. Another point to consider is that between 2013 and 2019, private health plan expenditures increased by almost 40% in real terms, while SUS funding increased by just over 5%. The volume of amount allocated to private health plans was 58% higher than the value of the expenditure by the SUS, and one of the main factors that hindered the real growth of public spending was Constitutional Amendment 95/16, which determined a 20-year halt of real growth of federal primary spending [1].

Considering the exams performed by the SUS on adults over 20 years old from 2017 to 2022, the most frequently performed exam during that period was bone scintigraphy, while the least performed exams were related to the hematological system—determining red blood cell survival. There were also differences between years and genders. In 2017, the most performed exam among men was myocardial perfusion scintigraphy under stress conditions, while for women it was bone scintigraphy. In 2018, the most performed exam among men was myocardial perfusion scintigraphy under resting conditions, and for women it was once again bone scintigraphy. In 2019, the most performed exam remained the same for men as in 2018, while for women it was consistent with previous years. In 2020 and 2021 it remained the same for both men and women, and in 2022, myocardial perfusion scintigraphy under stress conditions was the most performed exam among men, while for women it remained the same.

Table 10 Nuclear medicine exams performed by the Unified Health System (SUS) and private healthcare from 2017 to 2022 [33]

System	Procedure numbers	
	Unified Health System (SUS)	Private healthcare
Cardiovascular	9	13
Digestive	10	9
Endocrine	5	7
Osteoarticular	3	2
Nervous	3	9
Respiratory	4	3
Hematological	3	6
Oncology/Infectiology	4	11
Genitourinary	-	8
Therapy	-	7
Others	9	5
Total	50	80

One of the reasons for myocardial perfusion scintigraphy being the most performed procedure among men is the higher prevalence of cardiomyopathy and myocarditis in the men than in women [34]. Cardiovascular diseases are the leading cause of death in Brazil, and are responsible for 30% of deaths worldwide each year. Furthermore, they account for about 8% of the total healthcare cost in Brazil. Myocardial perfusion scintigraphy plays a significant role in rationalizing financial resources for patients with established or suspected cardiovascular diseases [35].

The most performed procedure among women is bone scintigraphy, which is used to investigate osteometabolic diseases, including osteoporosis. It is estimated that 50% of women aged 50 or older will experience an osteoporotic fracture during their lifetime, compared to 20% of men in the same age group. Osteoporosis is one of the leading causes of morbidity and mortality in the elderly, and the high cost of treatment by the healthcare system requires the development of methods capable of identifying the highest-risk group to implement preventive measures for osteoporotic fractures [36].

Table 9 Nuclear medicine exams performed by the SUS in adults > 20 years old in the last five years [33]

System	Year						
	2017	2018	2019	2020	2021	2022	Total
Cardiovascular	26,206	25,3500	26,2780	19,8008	22,3402	77,434	127,7138
Gastro-intestinal	1,814	1,754	2,007	1,262	1,175	297	8,310
Endocrine	12,072	10,773	10,854	7,379	9,101	3,200	53,379
Oncology	1,378	1,311	1,360	989	1,104	229	6,371
Others	15,582	15,2609	15,4309	13,9839	15,4082	53,502	81,7225

Another point to consider is influence of gender on patient attendance for exams and medical consultations. Historically, the focus of healthcare and life has been on children and women (in terms of their reproductive aspects), with less emphasis on male demands [37]. One hypothesis for the reluctance of men to seek medical assistance is their stereotype as being strong and virile. In general, men tend to suffer more from fatal chronic diseases such as ischemic heart disease, atherosclerosis, emphysema, cancer, stroke, cirrhosis, and kidney problems. In this sense, characteristics such as sensitivity, caring for others and oneself, and vulnerability are seen as feminine traits, prompting reluctance of men to seek medical care and also causing them to engage more often in risky behaviors that predispose them to diseases, injuries and death [37].

Conclusion and perspectives

The data presented here are exploratory and support decision-making regarding the development of nuclear medicine (NM) in Brazil. The provision of NM services in Brazil has important social and regional disparities, due to significant socioeconomic inequalities and the country's large size. This situation causes a need to expand the supply of radiopharmaceuticals and nuclear medicine services focused on the neediest people.

From a technological point of view, NM in Brazil has kept up to date with the rest of the world, but the country has struggled to increase its competitiveness both in research and assistance. The lack of a structured support network and specific incentives is a problem that needs to be addressed.

Among the specific problems are shortages of specialized personnel and equipment, and bureaucratic difficulties that hamper the inclusion of new procedures offered by the SUS, among others. This culminates in difficult public access to the NM services rendered by the SUS,

Finally, because of these needs, Brazil is fertile ground for international investments in the area of nuclear medicine.

Funding This study was funded by Carlos Chagas Filho Foundation for Research Support of Rio de Janeiro State (FAPERJ), CNPq and CAPES.

Data Availability All data will be available under request.

Declarations

Conflict of interest All Authors declares that they have no conflict of interest.

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