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Quality and quantity assessment of tomographic exams that can be performed on existing hybrid equipment at Botucatu Medical School Nuclear Medicine Facility

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ABSTRACT

Computed Tomography (CT) has been one of the greatest innovations for medical diagnosis. Among the main features of CT is its ability to provide high-quality anatomical and functional images. Another important imaging modalities are the ones conducted in Nuclear Medicine (NM), which utilizes radiotracers to obtain metabolic and molecular images in vivo. The union of NM and CT imaging modalities is possible through hybrid equipment. The purpose of this research is to evaluate the quality and quantity of tomographic exams that can be performed in hybrid equipment. To complete this research an analyzes of the ability to perform CT exams in the room that holds a Single Photon Emission Computed Tomography/Computed Tomography (SPECT/CT) equipment in an NM facility was carried out. The evaluation criteria were: equipment quality control, image quality assessment by a subjective method as per European Guidelines on Quality Criteria for Computed Tomography (EUR) and assessment of shielding of the room, as an indicator of how many exams can be performed. Considering the results of the barrier thickness, the Botucatu Medical School and Nuclear Medicine facility is capable of performing 100 tomography exams per week. According to information obtained in the facility there are approximately 20 CT scans performed weekly. This indicates an opportunity to increase up to 80 exams per week. Therefore, the analyzed hybrid equipment was qualified to perform diagnostic tests with superior image quality, compared to those performed in dedicated CT equipment.

Keywords: **Computed Tomography, Nuclear Medicine, Hybrid Equipment, Image Quality Assessment.**

1. INTRODUCTION

Since its creation in 1972, Computed Tomography (CT) has been one of the greatest innovations for medical diagnosis. One of the main characteristics of CT is its ability to provide high-quality anatomical and functional images of all body regions, in a non-invasive manner and in short acquisition times. Thus, CT is an important tool for diagnosing acute and chronic diseases. CT also contributes to decision-making in treatments and therapies, becoming an essential instrument for hospital practices. Other important imaging modalities are found in Nuclear Medicine (NM), which utilizes radiotracers to obtain metabolic and molecular images *in vivo*. The union of NM and CT imaging modalities is possible through hybrid equipment, such as Single Photon Emission Computed Tomography/Computed Tomography (SPECT/CT) and Positron Emission Tomography/Computed tomography (PET/CT). These equipment allow the anatomical co-registration of metabolic and functional images [1-4].

The Botucatu medical School Hospital (HCFMB) performed an average of 34.800 CT tests between 2019 and 2020, covering outpatient and emergency care [5]. With the current scenario of the SARS-CoV-2 pandemic (COVID-19), there was an increase in the use of CT equipment for diagnosis in respiratory examinations. This resulted in an 11% rise in hospital routine tests. Since SARS-CoV-2 is a virus with a high transmission rate, the institution reserved a CT equipment exclusively for COVID-19 care - leading to an overload of the sector. To reduce the burden of the tomography sector, a study was conducted to evaluate the use of examination rooms with existing hybrid equipment in the NM facility to perform CT scans only. This scenario of use is mentioned in the Brazil's National Nuclear Energy Commission's (CNEN, Comissão Nacional de Energia Nuclear) regulation 3.05/2013 "*Safety and Radiological Protection Requirements for Nuclear Medicine Services*", Art.15 which presents the requirements for this implementation [6].

This research aimed to evaluate the quality and quantity of tomographic exams that can be performed on hybrid equipment existing in the NM facility of the Botucatu Medical School so that this implementation reduces the overload of exams in the tomography sector. It was necessary to study and evaluate the facility's physical structure and equipment's image quality to achieve this goal.

2. MATERIALS AND METHODS

This research was developed by the Medical Physics and Radioprotection Nucleus of the Botucatu Medical School, in the computed tomography and NM sectors. The work was subdivided into three sections:

- Evaluation of equipment compliance to quality control standards.
- Evaluation of equipment's image quality by a subjective method, according to European Guidelines on Quality Criteria for Computed Tomography (EUR 16262).
- Evaluation of the equipment's room shielding to assess examination capacity.

This research was conducted with the approval of the Ethics Committee of the São Paulo State University (Unesp), Botucatu Medical School (Protocol Number: 54284616.0.0000.5411).

2.1 Materials

In this research, the following equipment were used:

- SPECT/CT Hybrid Equipment - Discovery NM 670/CT – 16-slice (GE - General Electric, Waukesha, United States);
- CT Toshiba – 16-slice Activion (Toshiba Corporation, Tokyo, Japan); Electrometer (RADCAL CORPORATION, model 9015);

The following equipment was used to perform the quality control tests:

- Ionization Chamber (Radcal® 10x5-3ct) with an electrometer Radcal® model 9015; PMMA head and body phantom from the manufacturer (GE SN 2002903); metric ruler (30cm).

2.2 Methodology for Equipment Quality Control

The QC tests performed in the SPECT/CT followed the publication of Anvisa (Brazil`s National Health Surveillance Agency), the Resolution of the Collegiate Board of Directors (RDC no. 330/2019) - Normative Instruction (IN) n°93/2021 [7]. This publication establishes the minimum ratio of QC and acceptance tests that must be performed by health services, determining tolerances and restriction levels. For each test, the methodology was performed according to the protocols described in Table 1.

Table 1 - Tests performed and their respective protocols.

Test	Method
CTDI High Contrast Resolution Slice Thickness Couch Top Alignment and Accuracy Image Artifacts	IAEA No. 19/2012 [8]
CT Number Accuracy Image Uniformity Image Noise	ACR/2017 [9]

CT – Computed Tomography

The importance of acceptance and QC tests is to guarantee that the equipment is functioning properly and in compliance with reference standards. Although this study focusses on CT performance, it should be mentioned that equipment was also tested and approved according to the NM regulations [6,10].

2.3 Methodology for Image Quality Assessment by Subjective Method According to the European Guidelines on Quality Criteria for Computed Tomography

Image quality from the equipment was evaluated by a subjective method according to the European Guidelines on Quality Criteria for Computed Tomography (EUR) [11]. A database of 120 patients' chest scans from the SPECT/CT and TOSHIBA CT equipment was preselected and first analyzed. Out of these, 15 patients from each equipment were selected according to the inclusion and exclusion criteria.

Inclusion criteria: patients with age between 20 and 70 years; thoracic cavity with 24.5 cm between the sternum bone (in the anterior) and the spine (at the back); standard patient weight of 75 kg to 90 kg [11].

Exclusion criteria: patients with thoracic cavity above 27 cm; patients with pulmonary comorbidities, such as lung cancer or COVID-19.

In the second analysis, the CT scans of the 30 chosen patients were subjectively evaluated by a radiologist, who used the EUR criteria to assess image quality. The evaluation criteria are described in Table 2 and were classified on a 5-point scale, according to Table 3 [12].

Table 2: Criteria for image quality assessment according to the EUR.

Evaluation criteria	Criterion to be evaluated
Noise	Grain in the image
Thoracic aorta and vena cava	Visually clear reproduction of the thoracic aorta and vena cava.
Inner heart	Visually clear of myocardial structures, including the walls of the ventricles.
Pulmonary vascular weft	Visually clear reproduction of the pulmonary parenchyma
Arterial veins	Visually clear reproduction of large and medium-sized pulmonary vessels
Lung	Visually clear reproduction of segmental bronchi
Acceptability and diagnostics	Acceptable visualization for a given diagnosis
Definition of contours (borders)	Visually clear reproduction of the boundary between the pleura and the chest wall
Inner chest wall	Clear visualization of the chest wall

Table 3: Criteria scores for image quality evaluation [12].

Score	Quality
2	Very good
1	Good quality
0	Acceptable
-1	Low quality
-2	Unacceptable

2.4 Capacity Evaluation of Performed Exams

To assess the examinations performance capacity in the hybrid's equipment room, it was necessary to evaluate the facility's shielding. The examination room scheme in which the SPECT/CT equipment is installed is described below.

Figure 1 presents the illustrative diagram of the examination's room floor plan, in which it can be observed: a door for patient access (a), with a 2 mm coating of lead (Pb). Four walls (b) totaling an area of 33.29m², in addition to a plumbiferous glass (c) (2mm of Pb equivalence) between the console room (d) and the examination room (e).

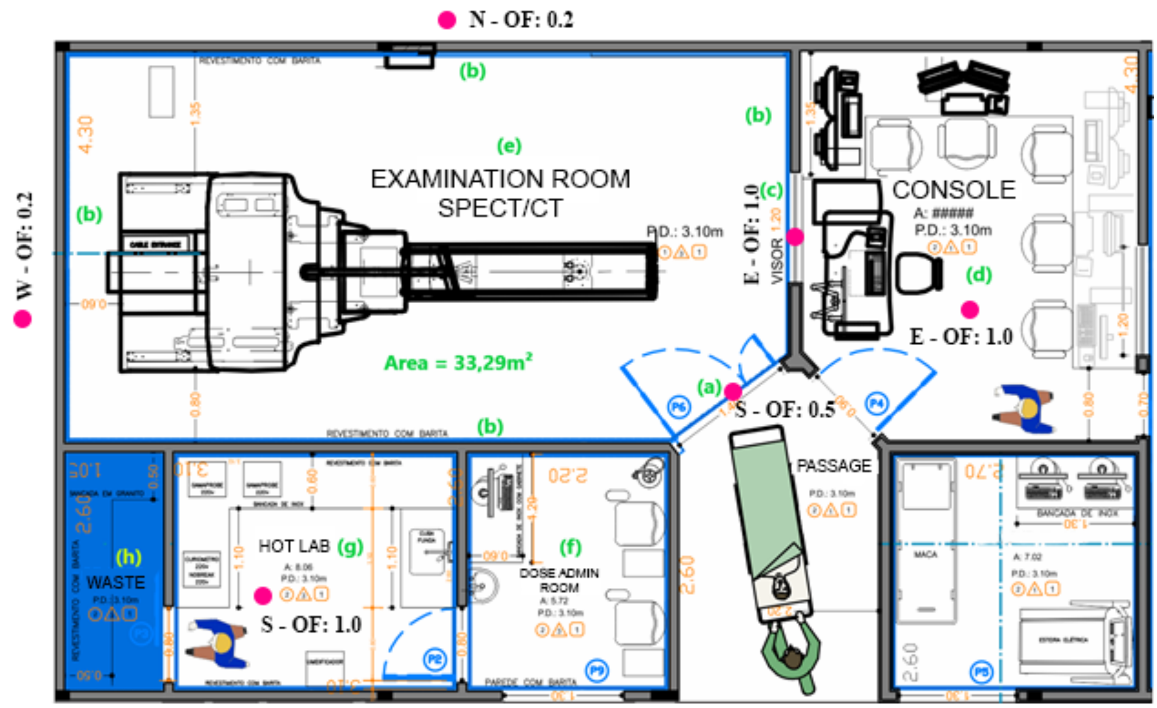

Figure 1: *Illustrative scheme of the architectural blueprint of the SPECT/CT room from the Nuclear Medicine Facility of Botucatu Medical School.*
Source: Author (2022).

Considering that NM's SPECT scans use radionuclides, such as Technetium-99 Metastable and Iodine-131, that emits radiation and thus contribute to shielding calculations, it was necessary to calculate the workload from each of these radioactive sources. This was done by extrapolating the weekly dose generated by every radioactive source at one meter from each one. These radioactive sources were theoretical point sources with the maximum activity that the facility has permission to use and were positioned at the center of each room. Adjacent rooms, in which radioactive material is stored and used, such as the hot lab (g), dose administration room (f), and waste room (h), also contributed to computing the total dose at a given point of interest [13].

To determine the shielding thickness, Archer's equation was used. The parameters adopted for the predicted energies and the reduction factors used were obtained from a paper published in the journal Health Physics, by Kusano and Caldwell [14].

For the shielding calculation analysis of the CT dose adopted in the NM facility, a workload of 100 weekly SPECT/CT exams (thus 100 CT) divided between 90 full-body exams and 10 cranial exams was considered. The calculations presented were approved by CNEN at the facility's commissioning and were performed following the guidelines established by the publication of the National Council on Radiation Protection and Measurements (NCRP) - Report No. 147, with a maximum voltage of 140 kVp and a maximum current of 300 mA. According to regulations, the point to be protected is 30 cm after the barrier [13]. For each subsequent point of the barriers, derived dose limits of 20 μSv/week and 100 μSv/week were used to classify free and controlled areas, respectively, following current standards [13].

3. RESULTS AND DISCUSSION

The results of this research were subdivided into three sections: evaluation of image quality by a subjective method, the capacity of examinations to be performed, and quality control of the equipment.

3.1 Equipment Quality Control Results

Uniformity, accuracy, and noise of CT numbers are essential tests related to image quality in exams. In order to maintain a quality standard in all exam sequences, the values obtained in the tests are always compared to established limits. Table 4 presents the results of QC tests performed on the SPECT/CT equipment in October 2020, along with the limits adopted as reference [15].

Table 4: QC test performed on SPECT/CT equipment [15].

Test	Result	Limit
CTDI (head)	66.63 mGy	70.00 mGy
CTDI (body)	7.63 mGy	25.0 mGy
High Contrast Resolution	8.3 pl/cm	> 6.0 pl/cm
Image Artifacts	Adequate	No artifacts
CT Number Accuracy - Water	0.05 HU	0±5 HU
CT Number Accuracy - Air	-1,001.93 HU	-1,000±10 HU
Image Uniformity - Water	2.8 HU	≤5 HU
Image Uniformity - Air	9.7 HU	≤10 HU
Noise - Water	0.10%	≤15%
Noise - Air	0.5%	≤15%
Slice Thickness	0.5 mm	≤1 mm

CT – Computed Tomography

3.2 Evaluation of Image Quality by the Subjective Method According to European Guidelines on Quality Criteria for Computed Tomography

The evaluation performed by the radiologist certified that the SPECT/CT apparatus has diagnostic acceptability for CT acquisitions. The assessment did not show any score lower than 'Acceptable'. Figure 2 shows the average scores for the SPECT/CT and dedicated CT equipment tests.

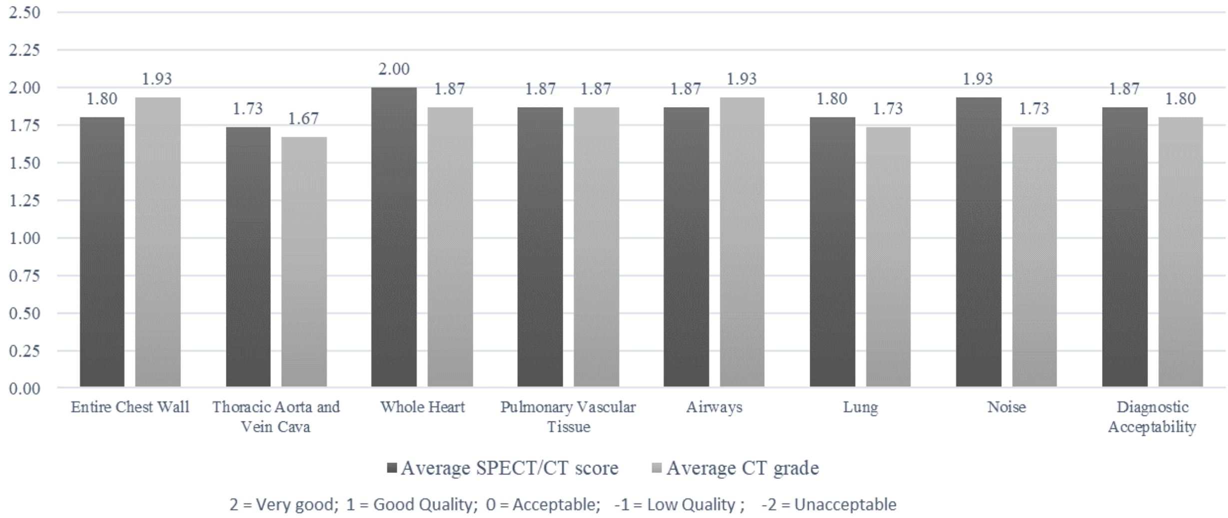

Figure 2: *Average scores among the exams evaluated for SPECT/CT and CT.*
Source: Author (2022).

3.3 Results of Capacity Assessment and Exams Performed

The results related to the scintigraphy exams were calculated for doses generated at 1 m away from the radioactive sources, for a combination of every radionuclide and drug. This calculation considered: the number of patients, type of examination, procedure's durations and reduction factors (due to radioactive decay). Derived dose limits were established for classifying free areas (20 µSv/week) and controlled areas (100 µSv/week). This resulted in a total dose per week of 349.478 µSv (SPECT/CT room only). Table 5 shows the contribution at 1 m from each source in µSv/week [13,15].

Table 5: Radionuclides used in Botucatu Medical School's Nuclear Medicine Facility and their respective dose per week at 1 m from the source (values given for the two examination rooms available at the facility).

Radionuclide	Symbol	Maximum activity to be requested per week (MBq)	Contribution to 1m from source (µSv/week)
Technetium 99 Metastable	^{99m}Tc	1,11E05	591.125
Indium 111	^{111}In	222	5.795
Iodine 131	^{131}I	1,85E04	5.425
Gallium 67	^{67}Ga	1,110	5.275
Iodine 123	^{123}I	740	4.501
Lutetium 177	^{177}Lu	7,400	43.348
Samarium 153	^{153}Sm	3,700	42.578
Thallium 201	^{201}Tl	370	0.909

The Archer equation was solved to determine the thicknesses for each examination room wall. It was considered that when the wall is bordered between two rooms containing radiation sources, the largest shielding prevails. Table 6 presents the face (Wall), which is defined by the patient's position, by the target closest to the wall, the respective transmission factor, corresponding to shielding thickness, occupancy factor of the area protected, derived dose limits of the area after shielding and predicted dose per week.

Table 6: Shielding required for each wall from the predicted dose for neighboring targets, Occupancy Factor (OF) [13], and minimum wall thickness required of concrete (2.35 g/cm³).

Face (Wall)	Derived Dose Limit per week (μSv/week)	Predicted Dose per week (μSv/week)	Required Concrete Wall Thickness (mm)
External corridor (N) Limit: 20μSv/week - OF: 0.200	100	91.894	–
Console room (E) Limit: 100μSv/week - OF:1.000	100	131.027	3.9
Hot lab (S) Limit: 100μSv/week - OF: 1.000	100	177.530	6.7
External corridor (W) Limit: 20μSv/week - OF: 0.200	100	83.644	–
Exam room access door (S) Limit: 100μSv/week - OF: 0.500	200	195.126	–
Display / Console (E) Limit: 100μSv/week – OF: 1.000	100	131.027	0.2 mm Pb

In the determination for the shielding calculations for the CT modality, the guidelines established by the publication of the NCRP – Report Nº 147, was used in Archer equation. Table 7 shows the parameters used for the calculation [13].

Table 7: Parameters used to determine the thickness of the shielding for tomography equipment [13,16].

Parameter	Considered Value
Derived Dose limit for classifying Controlled Area (RDC 330/2019)	5.0 mSv/year (0.1 mGy/week)
Derived Dose limit for classifying Free Area (RDC 330/2019)	0.5 mSv/year (0.01 mGy/week)
Patient flow per week (CT)	100 (90 Body – 10 head)
Occupancy factors	NCRP - N°147, Page. 31
Maximum Operating Voltage	140 KVp
Maximum Current	300 mA
Shields estimated by the equation for energy	140 KeV

In determining barrier thickness, the Archer equation used data from table C1 of NCRP - Report No. 147 (page 147 - 148) which contains parameters of wide beam secondary transmission according to the energy and type of barrier material. From the applied methodology, the thicknesses of shielding found are presented in Table 8 [13].

Table 8: Results found for SPECT/CT room barriers. Thickness and densities of barriers considered for three types of materials.

Local	Lead	Concrete (2.35 g/cm^3)	Barite (3.2 g/cm^3)
Outer Corridor (north)	1.1 mm	110.0 mm	16.0 mm
Console	0.5 mm	58.0 mm	8.0 mm
Hot Room/Injection Room	1.0 mm	103.0 mm	15.0 mm
External Corridor (left)	1.2 mm	119.0 mm	19.0 mm
Plumbific Display	0.5 mm	-	-
Patient Gate	0.1 mm	-	-

Comparing the thicknesses found for the SPECT modality (Table 8) with the one found for CT alone, the final thickness adopted was the highest value calculated for the same phase (barrier). Table

9 presents the final thickness implemented in the HCFMB's Nuclear Medicine Facility SPECT/CT room.

Table 9: Results adopted for SPECT/CT room barriers. Thickness of barriers for each given material.

Local	Thickness required
External Corridor	11.0 cm of concrete
Console	5.8 cm of concrete
Hot Room/Injection Room	10.3 cm of concrete
External Corridor	11.9 cm of concrete
Plumbic Display	0.5 mm of Pb
Patient Gate	0.1 mm of Pb

Considering the results of the barrier thickness HCFMB's Nuclear Medicine Facility has the capacity to perform 100 CT exams per week, using the hybrid equipment SPECT/CT - GE Discovery NM 670/CT. According to information collected in the sector, approximately 20 exams per week are currently performed.

In a complementary analysis, Figure 3 presents various combinations of the number of full body and head examinations to be performed without changing the shielding of the hybrid equipment's room. The graph shows variation between 90 full-body examinations and 10 head scans, up to 10 whole-body scans and 54 head scans. This reduction from 100 to 64 in total exams is due to higher doses related to head scans.

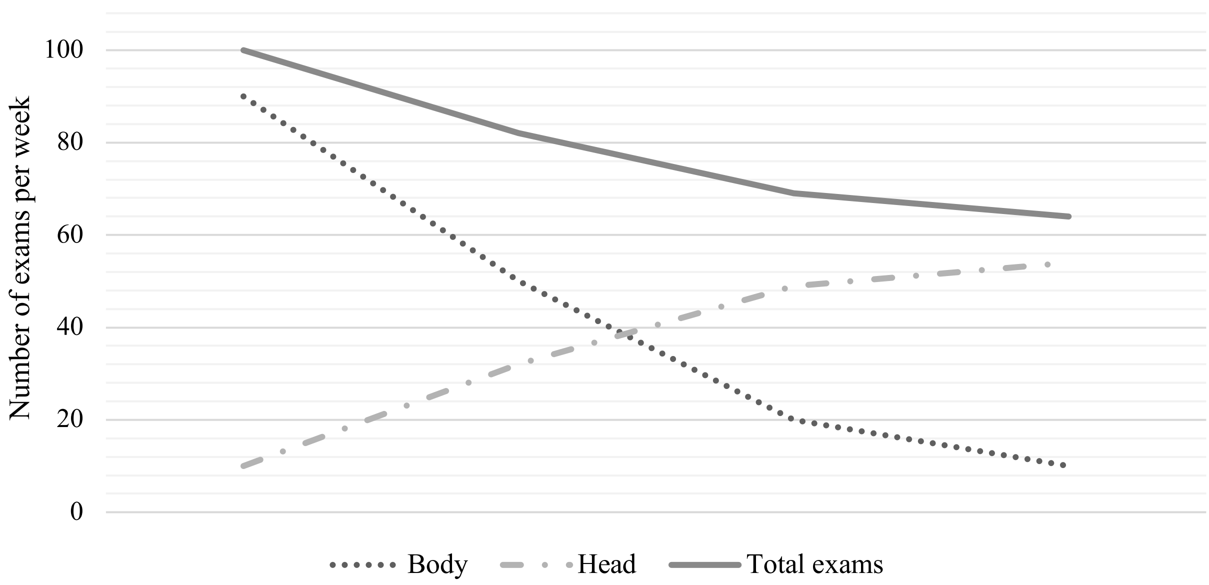

Figure 3: *Possibility of the number of exams per week to be performed in the room of hybrid equipment SPECT-CT, without the need to change the existing shielding.*

3.4 Viability Analysis

As observed, the equipment's performance complies with the necessary image quality for diagnostic CT scans, as assessed by the radiologists, and the physical parameters of visualization in the QC tests performed. The shielding of the room also was no limiting factor.

According to CNEN 3.05/2013 some requirements must be met to use hybrid equipment to perform hospital routine CT-only scans in an NM facility. This aims at improving the safety of the patient and staff who will participate in the examinations. The Botucatu Medical School's Nuclear Medicine Facility has a current procedure's demand that could be adapted to leave some shifts of the week vacant. These vacant shifts could then be used to attend only patients pre-scheduled to perform CT scans, thus preventing them from having contact with patients who were administrated radiopharmaceuticals. Another important aspect of scheduling is the time between CT examinations, as most hybrid equipment does not have an all-x-ray cooling system, as in dedicated CT equipment, so hybrid equipment requires a longer cooling time between CT-only scans [6].

4 CONCLUSION

The research aimed to evaluate the quality and quantity of computed tomographic exams that can be performed in a hybrid equipment existing in the Nuclear Medicine Facility of the Botucatu Medical School.

This evaluation observed the possibility of performing 100 exclusive CT scans weekly, 90 of the whole body and 10 of the head, or other variations of these scans. This could be done with some adaptations in the facility's schedule, to optimize the number of tests according to the needs of the service. Currently, an average of 20 SPECT with CT exams are performed.

It was also observed that the shielding present in the room is sufficient to perform CT scans to meet the increased demand for the service, with increased availability of up to 80 CT-only exams per week.

The hybrid equipment SPECT/CT - Discovery NM 670/CT is qualified to perform diagnostic tests with superior image quality than those achieved in existing dedicated CT equipment in the Botucatu Medical School.

With this implementation, the viability of CT examinations in the hospital increased since the use of hybrid equipment relieves the demand for CTs in the tomography sector.

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