Safety Protection in the procedures of Sentinel Lymph Node Technique

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***Abstract* - The accuracy of the sentinel lymph node technique in breast cancer depends, beyond the experience and training of the surgeon, the quality of the probe system. The use of radioactive materials in the procedure generates a significant concern about radiation exposure. The main goal of this thesis was to develop a set of studies to evaluate the performance of the intraoperative gamma probe, and subsequently evaluate the individual doses absorbed by each professional involved in the sentinel lymph node technique. Performance evaluation of the surgical probe was performed by using four types of physical tests: detection sensitivity, angular resolution, spatial resolution and linearity. The evaluation of the radiological exposure of the professionals was developed into three types of studies: Geiger Müller counter to measure dose rates at different distances from the radioactive site; TLD dosimeters to measure equivalent dose at extremities and chest region, and computer simulation of the dose rate through PENELOPE software. The physical tests of the quality control demonstrated that the surgical gamma probe has a good performance, revealing only one imprecision in the angular measurements. In terms of radiation exposure, the data revealed that the radiation doses of the professionals involved in the procedure are less than 1 mSv.**

***Key-words* - Sentinel lymph node technique; Sentinel node; Surgical gamma probe; Quality control; Safety Radiation; Monte Carlo simulation.**

I. Introduction

Breast cancer is the most frequent cancer in women, with increasing incidence worldwide. Metastases located in the armpit are considered a major cause for the increased morbidity that is associated with breast surgery. The first lymph node to receive lymphatic drainage, in the breast, has the domination of sentinel lymph node (SLN). The sentinel lymph node technique permits the pattern of lymphatic drainage from a tumour to be investigated. [1]

Radioactively marked colloids are commonly used in procedures of sentinel lymph node technique. These procedures involve the identification, removal, and histological examination of sentinel lymph nodes. Colloids marked with small amounts of ^{99m}Tc are injected into patients subdermally in the breast. [2]

After the colloids marked with ^{99m}Tc injections, the patient is imaged with a conventional gamma camera (lymphocintigraphy), and nuclear medicine physician will do a mark on patient's skin, which corresponds to the location of highest uptake, besides the injection place. The lymphocintigraphy allows the surgeon to focus his attention on the correct location of the armpit, thus enabling a quick surgical procedure and high precision in performing sentinel node biopsy, when aided by the use of intraoperative probe. [3] This procedure is done on the day before the surgery, due the characteristics of lymphatic drainage.

In the moment that the surgery occurs, the location of the sentinel node must be confirmed by using the surgical gamma probe. After confirming the location of the SLN, the surgeon may choose to remove the primary tumour and then make in the first instance the sentinel node biopsy and subsequently remove the tumour while waiting for the results from Pathology, regarding to histopathology of the SLN.

The surgical gamma probe, which consists on a compact and programmable system of counts of gamma photon, searches the SLN based on a focal point containing radioactivity accumulated within the area of interest. This equipment is easy to use with a high sensitivity detection and collimation, and must have a high repeatability and accuracy. [4][5]

The quality and performance of intraoperative probe influence the success of sentinel node surgery. The basic design and operating influence the performance of the surgical gamma probe. Main performance characteristics that the gamma probe must have are: sensitivity detection, spatial resolution, energy resolution and contrast. [4][5][6]

The evaluation of occupational radiation exposure of professionals involved in sentinel lymph node technique is important to maintain a safe environment of work. This evaluation, in addition to predicting which is the risk of radiation, also allows the application of safeguards and care to professionals, to ensure that they are not unnecessarily exposed to radiation sources. [7][8]

The medical staff of Nuclear Medicine, Operating Room and Pathological Anatomy, are in direct contact, through their hands with tissue that contains small amounts of radioactivity.

According to ICRP directives and Portuguese legislation, a person that is susceptible to be exposed to radiation during their practices, is considered as worker exposed. This worker, in a period of one year, is considered as a real worker exposed and must have a record of radiation dose superior to 1 mSv/year. Once considered as a worker exposed, the dose limit must be respected, i.e., during a year the worker must not exceed the limit of 20mS/year in all body, and 500 mSv/year in their hands. [9][9]

One of the techniques applied to estimate the equivalent dose of the professionals involved in the sentinel lymph node technique, was the Monte Carlo simulation. The Monte Carlo simulation is an algorithm that relies on random repetitive sampling to calculate results. Usually this method is used for simulating physical and mathematical systems, and is also used when it is impracticable or can calculate an accurate result with a deterministic algorithm. The software used to apply the Monte Carlo simulation was PENELOPE. This software develops Monte Carlo simulation for photon and electrons transport in arbitrary materials for a wide energy window (100 eV to 1 GeV). A geometry package called PENGEOM allows the production of random electron-photon showers in material systems consisting of homogeneous bodies limited by quadric surfaces.[10]

The main aim of this study is to develop a set of studies to evaluate the performance the intraoperative gamma probe, and subsequently evaluate the individual doses of each professional involved in the sentinel lymph node technique. The development of this research took place, in the Hospital Garcia de Orta (HGO), EPE, in Almada – Portugal, during the stage in the Nuclear Medicine Service.

II. Materials and Methods

As referred previously, this study consists in an evaluation of several crucial aspects to understand the radiation exposure of each professional involved in sentinel lymph node technique. To perform this evaluation, the study was divided into three distinct phases.

Quality Control of Surgery Gamma Probe

In order to evaluate the performance of intraoperative probe, was developed a series of physical tests that allow assessing the response of the probe before a radioactive source:

a) Detection Sensibility: evaluation of the relationship between the number of photons that is deposited and the number of photons emitted by the source;

b) Angular Resolution: analysis of the variation of photon counts distribution with the distance, due to the relative position of the incoming radiation and detector;

c) Special Resolution: ability of the surgical probe to differentiate the SLN activity from the injection activity;

d) Linearity: evaluation of the behaviour of intraoperative probe before the radioactive decay of a source.

The physical tests was executed with a surgical gamma probe GAMMED IIB EURORAD, and radionuclide sources of ^{99m}Tc. Before started to perform the main physical tests, was necessary to determine which activity remains in the SLN, when the sentinel lymph node technique is applied. Performing a weighting between the amounts of activity counts in the administration area and the SLN, and knowing the activity that was administered, it was possible to determine the activity that remains in SLN.

a) Detection Sensibility

To implement the detection sensibility test was prepares a source of ^{99m}Tc, with an activity of 133±0,02 µCi (4,92±0,02MBq), which correspond to the range of values obtained for the activity present in SLN, since whether to determine the sensibility of detection of the crystal before the SLN. In order to evaluate the behaviour of the probe before another type of radioisotope with different ranges of energy was also performed sensitivity test for locked sources of ^{57}Co and ^{137}Cs.

b) Angular Resolution

The angular resolution test was implementing with a source activity of 697±0,02 µCi (25,79±0,02 MBq) of ^{99m}Tc, placed a minimum distance of 5,0±0,1 cm from the probe in a fixed position (0 cm). The surgical probe was until a maximum distance of 9,0±0,1 cm. The photon counts were acquired for a range of angles between -90º and90º. The physical test was also executed for the locked sources of ^{57}Co and ^{137}Cs.

c) Spatial Resolution

The physical test of spatial resolution was more complex to perform than the others. For this study, was created a phantom as shown in figure 1. The phantom consists in a polypropylene container containing water, with 25,0±0,1cm of diameter and 14,0±0,1 cm of height. At the top of the container was placed acrylic ruler (millimetre scale), which allowed to perform the probe scanning over the surface of water. At the bottom of the container was fixed another ruler, which allowed the positioning of the two sources used in order to study the ability of the probe to identify, separately, the activity of the injection point and SLN.

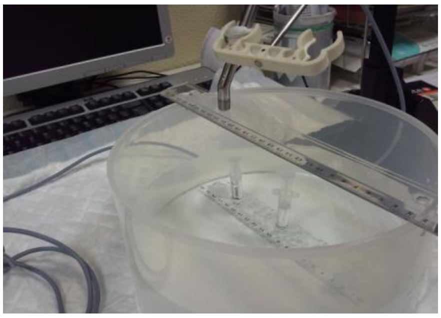


Figure 1 **– Position of the ^{99m}Tc sources in a phantom composed of the polypropylene container.**

The radioisotope ^{99m}Tc, was placed into two small acrylic cylinders. The acrylic cylinder that represent the injection point (IP) had an activity of 1,54±0,02 mCi (56,98±0,02 MBq) and the SLN source had and activity of 180±0,02 µCi (6,66±0,02MBq), both sources were separated by a distance of 3,0±0,1 cm.

The probe scanning above the water was executed in steps of 5 mm.The distance between the surface of water and source IP was 1,0±0,1 cm, although the source SLN was 2,0±0,1 cm. During the test, both sources were apart by a distance between 3,0±0,1 cm and 6,0±0,1 cm, wherein the IP source was always fixed.

d) Linearity

The linearity test was performed with a ^{99m}Tc source of activity 140±0,02 µCi (5,18±0,02 MBq), in 1ml of serum. The measurements were realized for distances of 1,0±0,1 cm, 2,0±0,1 cm, 3,0±0,1 cm and 4,0±0,1 cm, in intervals of 1h between the series of measurements.

Dosimetry of the professionals involved in SLN technique

Between May and September 2012, 44 patients who underwent axillar sentinel node research, were studied to determine the radiation exposure of professionals, and 22 patients in this sample were internal to HGO and other 22 were outside the hospital.

For each procedure performed, the duration of administration, subcutaneous SLN research, breast surgery and pathology analysis of SLN was recorded. During the study, on average, was administered in each SLN technique ~2,3±0,02 mCi (85,1±0,02 MBq) of radiocolloid in a volume of 1ml, usually on the day before surgery.

Of the total sample, 22 patients internal of HGO, only 15 patients underwent surgery belonging to a gynaecology clinic. On average, each surgery lasted 2h, depending on the extraction process of tumour, response time of results of the histopathological analysis of SLN and consequent result.

A. Dosimetric control with Geiger – Müller counter

The main goal was to evaluate the radiation exposure of professionals involved in SLN technique in both services of Nuclear Medicine, Surgery and Pathology, using a GM counter to analyse the dose rates at which professionals may be liable. It was used a portable dose rate monitor LB 123 UMo of Berthold® connected to a dose rate detector LB 1236-H10.

For each patient were obtained two dose

rates (chest and hands) at 4 different distances (3,0±0,5; 30,0±0,5; 100,0±0,5 e 120±0,5 cm). Assuming that the positions of professional during procedures remain constants, we calculated the radiation doses for each professional involved.

SLN technique begins in Nuclear Medicine with the injection of the radiopharmaceutical in the patient to the research of SLN. Therefore, in order to simulate the exposure that physician may be exposed, an evaluation was performed after administration at a distance of 3,0±0,5 cm and 30,0±0,5 cm from the patient. These distances correspond, respectively, to the hands of physician and abdomen region.

After the administration occurs the subcutaneous search with the aid of the gamma camera, which provides the location of the SLN. To confirm this location the physician uses the surgical probe. On average, each set performed in Nuclear Medicine lasts 2 min to 4 min.

The next day, the patient is taken to the operating room where surgery was performed by the staff of medical service Gynaecology. At this stage of the procedure are effected measurements in relation to the patient before and after the surgery. Thus, the measurements were performed: 3,0±0,5 cm (hands) and 30,0±0,5 cm (chest) to simulate exposure to the physician; 100,0±0,5 cm (chest) to simulate exposure of the anaesthetist, and 120,0±0,5 cm (chest area), whose distance corresponds to the position of instrumentalist nurse.

The pathologist is in direct contact with the ganglion at the time when the preparation is carried with staining haematoxylin-eosin, being a process of performing relatively fast (2-5 minutes).

B. Dosimetric control with TLD dosimeters

The study of the using of TLD dosimeters was applied in the administration of the radiopharmaceutical and during surgery radioguided. Professionals who are most exposed to radiation during the SLN technique is the physician of Nuclear Medicine and the medical gynaecologist, thus representing the maximum risk of exposure to any other person in the room. The study was applied in 23 administrations, and 5 surgeries.

The dosimetric control was performed with a whole body dosimeter and extremity dosimeter (ring). In Nuclear Medicine, the professionals always used both dosimeters during the procedures. However, in the operating room, gynaecologists only used throughout the surgery the whole body dosimeter and the extremity dosimeter before starting the surgical procedure because of aseptic techniques.

According to ORAMED project, the Nuclear Medicine professional used extremity dosimeter in the index finger of the non-dominant hand, ie, the hand not used to manipulate the syringe so as to intraoperative probe. Regarding the use of the dosimeter ends by gynaecologists, based on study of LAW. M. *et al* (2004) and MORTON, R. *et al* (2003), it was also decided to use the index finger of the non-dominant hand as the place for the use of dosimeter ring.

Monte Carlo Simulation

Through the Monte Carlo simulation software, we intended to simulate the radiation dose accumulated by both the nuclear medicine physician as the gynecologistduring the SLN technique. Therefore, two simulations were developed, one for the administration process and another surgery.

To develop the simulation, it was first necessary to define the geometry that best approached the real scenario. For this we used the anthropometric information of each segment of the female and male human body in order to create a geometric structure, such as near real. In geometry was defined the patient lying on the bed according to the position commonly used, i.e., lying on his back with arms extended at an angle of ~ 90 °. The physician was set positioned laterally to the patient, perpendicular thereto (figure 2). The physician upper limbs are flexed creating a bend angle between the upper arm and forearm of 90 º.

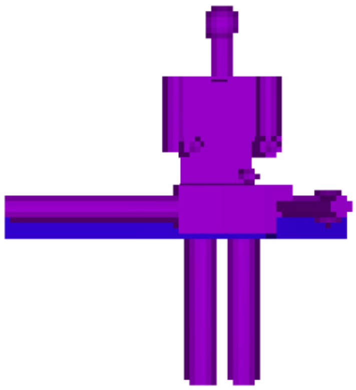


***Figure 2* – Illustration of 3D geometry.**

The geometric shapes used were quadratic surfaces, namely cylinders to simulate the upper and lower limbs and neck, sphere to simulate the breasts, SLN and hands, at least parallelepiped to create the chest. The quadratic surface defined for the patient as the main orientation y axis, although the physician quadratic surface has x axis orientation.

In order to simulate the dose absorbed by each professional was chosen as a homogeneous material of the surface created the skin

Considering the breast, where the radiopharmaceutical was injected, as a main radiation source this was divided into two layers, an outer layer and an inner layer. The outer layer is composed of skin (dermis). In turn, the inner layer is composed of water, since the tracer compound is a mixture of serum (eluted with 99m Tc) labeled albumin nanocolloids.

The main difference between the simulation for Nuclear Medicine physician and gynaecologist was the definition of SLN in the simulation regarding the surgery procedure. In this simulation, we defined a spherical body near the axillary region, composed of water (representative of the radiopharmaceutical). In this simulation, the SLN also as a point source of radiation.

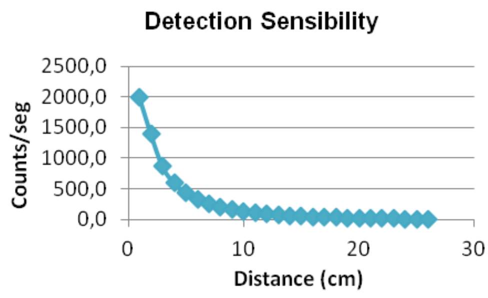
Sometimes there are patients who are suffering from breast cancer in both breasts, these cases requires the research radioguided in both axillary regions of the patient. In order to simulate these cases, we also created a geometry that considers the existence of one sentinel node in each armpit.

III. Results and Discussion

Using the oblique image of lymphocintigraphy, it was determined that the minimum activity of SLN is about 0,11±0,02 mSV, while the maximum obtained from the previous image, was about 0,18±0,02 mSv.

Quality Control of Surgery Gamma Probe

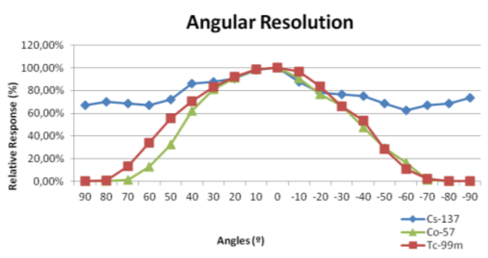
In accordance with the data obtain in the physical tests performed for quality control of surgical probe; it appears that the probe used in SLN technique shows a good performance in terms of reading sensibility of which allows to safely detecting the presence of a focal point to the distance of 15,0±0,1 cm (graphic 1).



***Graphic 1* – Detection Sensibility graphic representation.**

The distance of 15,0±0,1 cm corresponds to the level of the curve where the values start to stabilize as the distance increases up to 26,0±0,1 cm (maximum reading distance). In terms of detection sensibility of crystal, it appears that the presence of the high energy sources of the same response is not as linear as when before low power sources, revealing more variations in the readings taken.

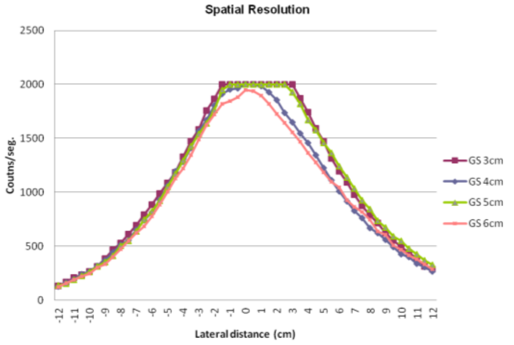
To obtain a good angular resolution is required that the crystal has a good sensitivity in the angular readings recorded. Given the angular resolution test, it was found that the crystal of the probe supports a better sensitivity angular for readings taken from the right side of the crystal than to the left (graphic 2).



***Graphic 2* – Angular resolution graphic representation of the ^{99m}Tc, ^{57}Co e ^{137}Cs source, at a distance of 5 cm.**

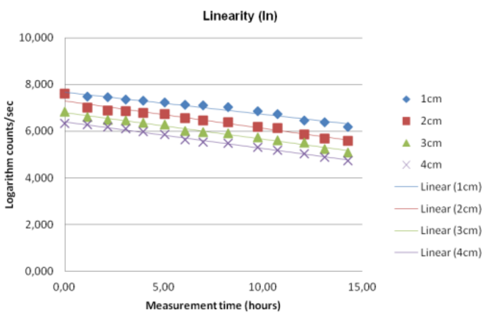
However, the data collected have revealed that the crystal has a good angular sensitivity to low energy sources. But, for high energy sources, the detection crystal allows detecting the photons emitted, although with low efficiency. In terms of variation with the distance between the source and crystal, it was found that the behaviour of the crystal corresponds to expected, i.e., as the distance increases the value of the count decreases.

Given two nearby point sources, the spatial resolution test shows that detection crystal in terms of lateral distance, displays the same pattern of spatial sensitivity that before only one source. Being evident the presence of a second source only in increasing the amount counts, which translates into a “tail” of the curve higher (graphic 3).



Graphic 3 **– Spatial resolution graphic representation. PI source fixed in 0 cm, and SLN source in 3 cm, 4 cm, 5 cm and 6 cm.**

The crystal has a higher sensitivity for detection of sources of higher activity than for lower activity, showing a pattern of linearity. In linearity test, it was also found that the distance from the source to the crystal also influence the linearity pattern. This pattern becomes more linear at a distance of 4,0±0,1 cm between the source and the probe, than at distances closer (graphic 4).



Graphic 4 –Linearity **graphic representation.**

Dosimetry of the professionals involved in SLN technique

A. Dosimetric control with Geiger – Müller counter

This study provides data on professionals’ exposure radiation involved in the SLN technique, which can be conducted in a variety of recommendations for radiological protection.

Table 1 **– Average of the data register during the SLN technique with GM counter.**

Professional	Dose Rate (µSv/h) Hands	Dose Rate (µSv/h) Chest
Physician NM	332,54±0,03	9,71±0,03
Gynaecologist	16,82±0,03	0,73±0,03
Anaesthetist	2,75±0,03	0,26±0,03
Nurse	0,00±0,03	0,21±0,03
Pathologist	0,690±0,03	0,13±0,03

According with the data (table 1), the Nuclear Medicine physician is subject to an average dose rate at the hands of 332,54±0,03 µSv/h and in the chest of 9,71±0,03 µSv/h. For the professionals present in the operating room, it appears that the gynecologistis subject to an average dose rate at the hands of 16,82±0,03 µSv/h, and in the chest of 0,73±0,03 µSv/h. For the anaesthetist the average dose rate in the hands is 2,75±0,03 µSv/h and in the chest is 0,26±0,03 µSv/h, at least, the nurse instrumentalist is subject to an average dose rate of 0,21±0,03 µSv/h in the chest. The pathologist is subject to an average dose rate of 0,69±0,03 µSv/h in the hands and 0,13±0,03 µSv/h in the chest.

The Nuclear Medicine physicians, according to their practices, are considered as exposed workers of category A, and are therefore controlled by whole body dosimeters. However, at the hands do not have any dosimetric control.

As it was evident that the gynaecologist was the person receiving the highest radiation dose in the operating theatre, only the exposure of this subject was considered, representing the maximum risk to any person in the room. For a year, the average value of equivalent dose in the chest of gynaecologists 41,76±0,03 µSv representing a small fraction of the dose limit of 1 mSv defined for the public member in Portuguese legislation.[9] Regarding the pathology physician, the average annual dose equivalent in chest is 0,34±0,03 µSv and is also far below the annual dose limit defined for public member.

In terms of hands limit dose, was considered the limit of 500 mSv/year assigned for exposed workers. For a year, the professionals register an equivalent dose <1 mSv. In Nuclear Medicine service is where there is the greatest value of equivalent dose in the extremities. For Nuclear Medicine physician the value is of 3142,46±0,03 µSv while the gynecologist records a value of 962,10±0,03 µSv, and finally, the pathologist has an equivalent dose of 1,82±0,03 µSv. In view of this data, it is considered unlikely that the dose limit defined to the hands will be exceeded in practice.

B. Dosimetric control with TLD dosimeters

TLD dosimeters allow understanding the magnitude of the effective dose of professionals, when involved in SLN technique, due to record cumulative dose.

Table 2 **– Dosimetric registers for professionals of Nuclear Medicine service. *Professional that doesn't use guard syringe.**

Physician NM	Proced.	Effective dose (mSv)	
		Ring	W. Body
Dr. A	8	0,09	0,00
Dr. B	8	0,07	0,00
Dr. C *	4	0,05	0,00
Dr. D *	3	0,09	0,00

According to table 2 and table 3, it can be seen that there is only effective dose in the region of the hands, due to the proximity of the dosimeter whit the region irradiated.

Table 3 **– Dosimetric registers for professionals of Operating Room.**

Gynaecologist	Proced.	Effective dose (mSv)	
		Ring	W. Body
Dr. F	5	0,00	0,00
Dr. G	2	0,02	0,00

The values of effective dose for each professional are low, and the largest value recorded is 0,09 mSv, which correspond to a least 1/5000 of the dose limit allows in the hands of the exposed workers. In terms of effective dose limit in the chest, we see that the value of dose register is very low, which makes negligible in terms of quantification (<0,01 mSv).

Upon the registration of effective dose, it appears that the professionals of Nuclear Medicine service have a value greater than the professionals of Operating Room. However, it should be appreciated that the control dosimetric in the hands of gynecologist was performed for 1/6 of the total time of surgery.

Comparing the values obtained by the GM counter and TLD dosimeters for the Nuclear Medicine physician, it can be seen that the dose values collected by dosimeters are superior due to their proximity to the radioactive source, i.e., the dosimeters recorded radiation dose from the moment that the physician started manipulate the syringe with the radiopharmaceutical.

Taking place 189 procedures, during a year, the Nuclear Medicine physician obtained an effective dose of 17,01 mSv. For exceeding the limit dose defined for the region of the hands of 500 mSv/year, the physician would have made each year more than 5556 procedures. For one year, the gynecologist is subject to an effective dose of 1,76 mSv/year, whit the completion of 88 procedures. For the gynecologist exceeding the dose limit would have to make more than 25000 surgeries.

According to the hospital practices, this number of procedures is difficult to precede.

Monte Carlo Simulation

The simulation developed by the software PENELOPE, provides a dose rates both for the left hand (non-dominant) as the right hand (dominant), which facilitated the understanding of what hand is more exposed to radiation. According to the table 4, it can be seen that the left hand is subject to a higher dose rate, which goes against the studies reported by ORAMED project.

Table 4 **– Data record from Monte Carlo simulation, for the Nuclear Medicine and Operating Room professionals.**

Service	Hands (µSv/h)		Chest (µSv/h)
	Left	Right	
Nuclear Medicine	33,25±0,26	15,45±0,17	0,00±0,00
Operating Room	4,35±0,04	1,77±0,02	0,00±0,00

It is understandable that the non-dominant hand is the one that receives a higher radiation dose, in Nuclear Medicine the non-dominant hand of the physician holds the support of syringe to administrate the radiopharmaceutical. During surgery, the non-dominant hand remains longer near to the region that irradiates.

The difference in magnitude between the data obtained by the simulation method and the GM counter, was expected, due the restriction of interest area. Regarding to the data obtained by the simulation and TLD dosimeters, it was found that the values obtained for the hands are very diverse. Comparing the accumulated dose of the dosimeters and the simulation values for the non-dominant hand, it was found that the values of simulation are much lower.

One of the reasons why the values are

lower is due to the fact that it was considerate that the radioactive source was a breast instead the syringe hold in physician hands, during the administration process.

IV. Conclusion

The success of the location of SLN depends largely on the physical performance of surgical probe used. In general, it was concluded that the surgical probe used in the study, provides reliable readings for the detection of SLN, which contributes to the successful location of the same.

According to the study conducted, Nuclear Medicine physician are those which are subject to a greater amount of radiation dose during the radiopharmaceutical administration procedure, necessary to perform the search of sentinel node. The reason why these workers are exposed to a large dose of radiation, is due to the direct manipulation of the radioactive source, i.e., the syringe containing the radiopharmaceutical. So that surgery occurs only on the day following the sentinel node detection, it is necessary to administer an activity of radiopharmaceutical greater that which would be prepared if the patient was operated on the same day.

The gynecologists, who perform radioguided surgery of SLN, are the elements in the operating theatre that receive the highest radiation dose, and are only exposed to a minimal risk of radiation, far below the maximum allowed.

The professionals of Pathology are exposed to much lower doses of radiation compared to other professionals involved, and may even be said that the amount of radiation dose to which they are exposed is below the detection limit of TLD dosimeters. Thus, this study demonstrated that the SLN technique represent a safety technique for the professionals involved.

The GM counter is a useful device for measuring the radiation dose rate at different distances from the irradiated area and in various compartments, allowing thereby performing a detailed analysis of the professionals who are subject to greater radiation dose.

TLD dosimeters were the most accurate device for evaluating the radiation dose in the SLN technique, at the hands. Extremity dosimeters were able to capture more accurately the values of radiation dose that was issued by both the radiopharmaceutical prior to administration as the radioactive tissues, thus allowing quantifying the dose of radiation that is absorbed by the professionals during their practices.

The software PENELOPE is a useful tool for simulating situations that involve radioactive sources. Although the dose rate values obtained were lower than those obtained during the monitoring, this simulation allowed understanding more precisely which regions are further irradiated. As suspected, the region of the hand that receives the highest dose of radiation is the left hand.

The Monte Carlo simulation, used in conjunction with techniques for measuring radiation is very important to obtain relevant results in terms of dose distribution.

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