Original article

Nuclear Medicine Communications

Comparison of sentinel gamma probes for ^{99m}Tc breast cancer surgery based on NEMA NU3-2004 standard

Mariangela Zamburlini[a], Kristien Keymeulen[b], Marc Bemelmans[b], Boudewijn Brans[a] and Gerrit J. Kemerink[a]

Purpose **Hand-held γ-probes are used for the identification of the sentinel node location during intra-operative radio-guided surgeries. Various γ-probes, which use different detectors, collimation and electronics, are available on the market. Spatial resolution, sensitivity and angular resolution of the probes are believed to be determinant for the success of the identification of the sentinel node during radiosurgery.**

Materials and Methods **We compared the above-mentioned performances of sentinel probes from six manufacturers available in the European market by means of the NEMA NU3-2004 standard, which allows the users to evaluate the probes during a situation which mimics a intra-operative radio-guided surgery.**

Results and conclusion **This study presents a summary of characteristics to be expected when using the tested γ-probes during intra-operative radio-guided surgeries, with particular emphasis on breast cancer sentinel node surgery. The results from this study can be used as the guidance for the selection of a sentinel lymph node probe.** ***Nucl Med Commun*** **30:854–861 © 2009 Wolters Kluwer Health | Lippincott Williams & Wilkins.**

Nuclear Medicine Communications 2009, **30**:854–861

Keywords: breast cancer, gamma probe, NEMA, sentinel node

Departments of [a]Nuclear Medicine and [b]Surgery, Maastricht University Medical Center, Maastricht, The Netherlands

Correspondence to Dr Mariangela Zamburlini, PhD, Department of Nuclear Medicine, Maastricht University Medical Center, PO Box 5800, Maastricht 6202 AZ, The Netherlands
Tel: +31 43 387 47 48; fax: +31 43 387 67 46; e-mail: mzamburlini@yahoo.com

Received 3 March 2009 **Revised** 8 June 2009
Accepted 8 June 2009

Introduction

Sentinel lymph node biopsy is the standard procedure for breast cancer staging in clinically node negative patients. It allows axillary staging in breast cancer without the need of a complete axillary lymph nodes dissection, reducing the morbidity associated with the intervention and increasing postsurgery quality of life [1–3]. The sentinel lymph node concept was first introduced for penile cancer [4] and melanoma [5] and implemented soon after for breast cancer staging [6]. Apart from the above-mentioned applications, the sentinel radio-guided surgery is used for cancer staging in gastrointestinal, head and neck and gynaecologic malignancies. For a review on the application of radio-guided surgery in cancer staging, see [7].

Two techniques are most commonly used for the identification of sentinel nodes during surgery: blue dye and radiocolloid injection. In the radiotracer technique, ^{99m}Tc-labelled colloids are injected intradermally and around the primary tumour site several hours before the surgery. The tracer drains through the lymphatic system to the sentinel node/nodes, which will experience an accumulation of tracer, with a small fraction passing through to secondary nodes. A γ-probe is used transcutaneusly during the surgery to localize the accumulation of radioactivity guiding to the sentinel node. The γ-probe is a hand-held device, which is able to detect the photons emitted by the ^{99m}Tc radionuclides. It was first used in sentinel node surgeries in 1993 [6]. Since then, various γ-probes have been made available in the market, which differ in the choice of detector material (semiconductor or scintillator), size (minimally invasive vs. standard), collimation (standard vs. electronic) and electronics (photomultipliers or photodiode). The successful identification of sentinel nodes during the surgery has been shown to be determined not only by the surgeon skills, but also by the performance of the sentinel probe [8], and in particular, its sensitivity, spatial resolution, angular resolution and side shielding [9,10]. The sensitivity determines the probe ability of detecting nodes which are deep-seated or in which the tracer uptake is low; spatial and angular resolution are essential for the detection of lymph nodes close to each other or close to the radiocolloid injection site; side shielding increases the probe directionality and therefore prevents radiation coming from unwanted directions to interfere with the lymph node search. The dilemma between using a probe which privileges sensitivity or one that privileges spatial resolution has already been discussed in the literature [11].

Up to now, these performance characteristics as listed by the manufacturing companies, as well as the comparative

0143-3636 © 2009 Wolters Kluwer Health | Lippincott Williams & Wilkins DOI: 10.1097/MNM.0b013e32832f34e7

studies published [8–10,12], vary greatly according to the method of testing, hampering the right assessment of relative quality of the different probes. The NEMA NU3-2004 protocol was released [13] to create a common standard to compare performances of different probe configurations in a situation, which mimics a sentinel node surgery in cancer staging. Up to date, no study has been reported which compares sentinel γ-probes based on the NEMA standard. In this study, we tested sentinel γ-probes from six manufacturers commercially available in Europe by using, what we considered, the most important tests within this protocol.

Even though the focus of the study is on the comparison of the probes based on NEMA testing, the probe ergonomics also play an important role in the success of sentinel node surgery [9,10,12] and was also evaluated in this study. The probe should be light, easy to handle and small enough to be introduced inside a small incision and still offer enough visibility of the measurement site. The main unit should be easy to operate, but also contain advanced features for optimization or quality control measurements. The screen should be easy to read. The audio signal should be correlated to the count rate and should possibly include autoranging, which provides an automatic rescaling of the audio signal when the sound saturates, without the need for the surgeon to manually change the audio scale.

Methods

Sentinel probes

Sentinel probes from six companies were considered for this comparison, as part of the testing for the purchase of a new probe for the hospital (Table 1). The systems that were tested are:

C-Trak from Canberra (*http://www.carewise.com/*). This system is equipped with a caesium iodide [CsI(Tl)] scintillator probe for the detection of photons in the energy range 27–400 keV. Two click-on collimators are available, the normal collimator and a high-resolution collimator, called Lechner collimator. The system is battery powered and has backup batteries.

Europrobe from Euromedical Instruments (Le Chesnay, France, *www.em-instruments.com*). This system is available with two sentinel probes, one having a CsI(Tl) scintillator detector (large probe) and one having a cadmium telluride semiconductor detector (small probe). The large probe is designed to detect photons of higher energies and it can be nominally used to detect photons from 110 keV to 1 MeV. The small probe is indicated for energies in the range 20–170 keV. Both the probes therefore can be used for the detection of ^{99m}Tc in sentinel nodes, even if the large probe is expected to have a higher sensitivity. Each probe can be used in conjunction with an extra collimator to increase the spatial resolution. The system is powered by main electricity.

Navigator GPS system is distributed by RMD Instruments (Watertown, Massachusetts, USA, *www.rmdmedical.com*). There are several probes available with this system, but we tested the standard sentinel probe, which was already available in our hospital and used for breast cancer sentinel node procedures since 2002. This probe uses a semiconductor cadmium telluride crystal. The system can be powered by main electricity or by batteries.

Neoprobe Bluetooth is distributed by Johnson & Johnson (Dublin, Ohio, USA, *www.neoprobe.com*). They offer a

Table 1 Detector type, weight, head diameter and ergonomics of the probes (or probes with click-on collimators) considered in this study

	Detector type	Weight (g)	Diameter (mm)	Display readability	Ease of handling	User friendliness of main unit	Auto-ranging
C-Trak							
Probe with normal collimator	CsI(Tl)	191	15	3	3	5	No
Probe with Lechner collimator	CsI(Tl)	199	15		3		
Europrobe							
Large probe	CsI(Tl)	150	16	4	3	5	Yes
Large probe with collimator	CsI(Tl)	224	19		2		
Small probe	CdTe	104	11		5		
Small probe with collimator	CdTe	135	15		4		
Navigator							
Probe without collimator	CdTe	182	14	3	3	3	No
Neoprobe bluetooth							
Probe	CdZnTe	142	14	4	5	4	Yes
Probe with collimator	CdZnTe	160	17		4		
Node Seeker							
Bent-tip probe	LYSO	133	14	5	5	3	Yes
Straight probe	LYSO	113	14		5		
Narrow-tip probe	LYSO	85	6.8		5		
γ-locator							
Electronic collimation	CsI(Tl)	330	23	3	NA[a]	3	NA

A score between 1 (poorest) and 5 (best) was assigned to the display readability, the ease of handling and the user friendliness of the main unit.
CsI(Tl), cesium iodide; CdTe, cadmium telluride; CdZnTe, cadmium zinc telluride; LYSO, lutetium yttrium orthosilicate; NA, not applicable.
[a]Probe diameter not optimized for sentinel node breast cancer surgery therefore not possible to test it during surgery.

standard sentinel probe, which is able to operate wireless, and can be used in conjunction with an additional click-on collimator to improve its spatial resolution. The probe uses a semiconductor cadmium zinc telluride detector, which enables photon detection in the energy range 27–364 keV. The control unit is powered by mains electricity, and the wireless standard probe is powered by batteries.

Node Seeker is distributed in Europe by GE-Healthcare (Los Angeles, California, USA, *www.intra-medical.com*). Each probe uses lutetium yttrium orthosilicate as the detector element, which is connected through a light guide to a built-in photomultiplier. Two standard sentinel node probes (straight and bent-tip) and a narrow-tip γ-probe were tested. No additional collimators are available. The control unit is powered by mains electricity.

Gamma locator by GF&E TEC GmbH (Seeheim, Germany, *www.gfe-service.de*). This probe makes use of a completely different approach for photon localization, called electronic collimation, in which small detector units, placed in the front and in the back of the detector head, are used to identify the direction from which photons enter the detector head. In this way, no external collimation is needed. The detectors employed are CsI(Tl) scintillators with approximately 2.7 cm^3 of detector volume. The probe is specifically designed for radio-guided surgery when PET tracers are employed; however, the probe is also sold for sentinel node detection with ^{99m}Tc and that is the particular application under consideration in this study. The direction of the incoming photons is determined by applying an algorithm, which takes into account the signal intensity measured by the different detectors. Various algorithms are supported by the probe, which provide different levels of focusing and background suppression. In this study, we tested four different algorithms (A1, R6, R6m, R6ma). For each of the first three algorithms, we performed the measurement using three different focuses (focus 1, 4 and 8). For the last algorithm, only measurements with focus 1 were performed. Not all the measurements were performed with each combination because the probe was available only for a restricted amount of time; however, spatial resolution, angular resolution and sensitivity in medium at 3 cm were performed for all of them. The testing was done on two different occasions (on the first occasion the algorithms A1, R6 and R6m; whereas on the second the algorithms A1 and R6ma were tested) and we observed a significant difference in the measured quantities between the two tests with the A1 algorithm. As this could be because of a different detector calibration (e.g. different threshold set by the company), we report in this study both the measurements, for comparison.

NEMA testing

We chose to test the quantities that, in our opinion, were the most important to determine the γ-probe performances during the surgery. These quantities were: sensitivity in air and in a scatter medium, sensitivity through side shield in air, sensitivity to scatter, spatial and angular resolution in a scatter medium and shielding. In each case, the energy window settings were those recommended by the manufacturer for a ^{99m}Tc source.

Each quantity was measured following the NEMA NU3-2004 protocol [13] using ^{99m}Tc 'point' sources, prepared by drawing up 0.1 ml of liquid in a 1 ml syringe. The activity used for each test was low enough to guarantee that the system was operating in its linear count rate region, which was determined experimentally. The activity was measured using an ISOMED dose calibrator 2000 (Nuklear-Medizintechnik Dresden, Germany) with an accuracy of better than 5%. The measurement in a scatter medium were performed using a water tank 55 cm long × 36 cm wide × 15 cm water depth and the finger of a surgical glove was used to prevent water damage to the probe.

Sensitivity in air

A source was aligned with the centre of the detector head and fixed at 3 cm and then at 5 cm from it. The source-to-probe centreline was at least 5 cm away from any surface. At least 10 000 counts were recorded for each position. The sensitivity in air is reported as count rate per unit of radioactivity.

Sensitivity in a scatter medium

A point source was positioned in a water tank at 3 or 5 cm depth. The probe was positioned with its head touching the water surface and was clamped in such a way that the source was in line with the probe axis. At least 10 000 counts were recorded for each position. The sensitivity in a scatter medium is reported as count rate per unit of radioactivity.

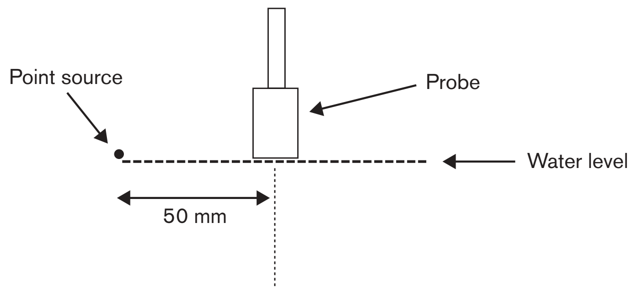
Sensitivity through side shield in air

A point source was positioned at 90° from the probe axis, just behind the probe tip and 5 cm from the probe surface (Fig. 1). At least 1000 counts were recorded. The sensitivity through side shield is reported in count rate per unit of radioactivity.

Sensitivity to scatter

The same set-up as the one used to measure the sensitivity through side shield in air was used (Fig. 1); this time, however, the probe tip was touching the surface of the water tank and the source was just outside the water surface. At least 1000 counts were recorded. The value of the sensitivity to scatter was compared with the value of the sensitivity through side shielding in air. If the latter exceeded 10% of the former, the

Fig. 1



Schematic representation of the sensitivity to scatter measurement. The same set-up was used for the measurement through side shield in air, with the only difference that, in the latter case, the measurement was done without the aid of the water tank.

sensitivity to scatter value was corrected by subtracting the value of the sensitivity through side shielding in air. It was reported for each case whether the correction was applied.

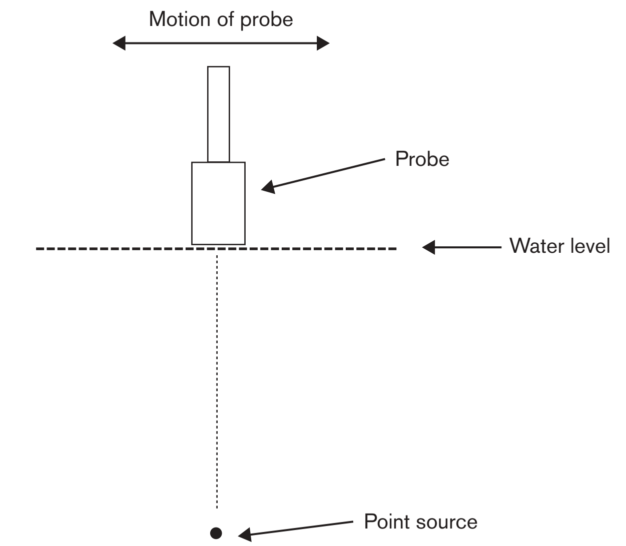
Spatial resolution in a scatter medium

The probe was clamped in such a way that its axis was in line with a point source, positioned 3 cm from the probe head (Fig. 2). The source was positioned inside a water tank at 3 cm depth and the probe tip was touching the water surface. The point source was secured to a travelling stage, which allowed the lateral position of the point source with respect to the probe axis to be changed with a 0.5 mm accuracy. The position of the source with respect to the probe axis was changed from −50 to 50 mm, taking care that at least 10 points were recorded within the probe full width half maximum (FWHM). For most probes, measurements were taken in 2.5 mm steps within −15 and +15 mm, and in 5 mm steps beyond ±15 mm. At least 5000 counts were recorded for the peak and at least 500 counts were recorded for each position. The maximum was calculated by fitting a parabola through the highest 3–5 points, and then the FWHM and the full width tenth maximum (FWTM) were calculated using linear interpolation around the 50% (FWHM) or 10% (FWTM) level. In a few cases, the curve did not have a clear peak, but rather a flat region of a few points with equivalent count rate. In this case the average of the count rate over the region of constant values was taken as the maximum value.

Angular resolution in a scatter medium

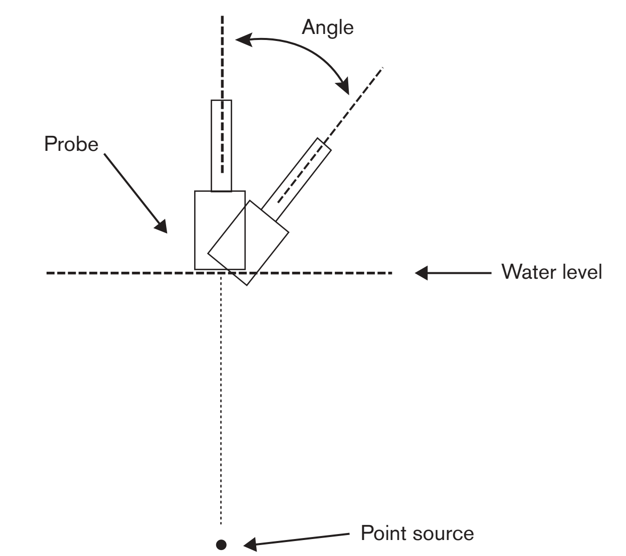
The probe was clamped in such a way that its axis was in line with a point source, positioned 3 cm from the probe head (Fig. 3). The source was positioned inside a water tank at 3 cm depth and the probe tip was touching the water surface. The probe was secured to an angular stage, which allowed the angle between the perpendicular axis to the water surface and the probe axis to be varied in steps of 5°. Measurements were done changing the angle between −80 and +80°, taking care that at least 10 points were recorded within the probe FWHM. For most probes, measurements were taken in 5° steps within −30 and +30°, and in 10° steps beyond 30°. At least

Fig. 2



Schematic representation of the spatial resolution measurement. The point source was fixed at 30 mm depth inside a water tank 55 cm long × 36 cm wide × 15 cm deep. The probe was clamped and moved horizontally in 2.5 mm steps within −15 and +15 mm, and in 5 mm steps beyond ±15 mm; or in such a way that at least 10 measurements were taken within the probe full width half maximum.

Fig. 3



Schematic representation of the angular resolution measurement. The point source was fixed at 30 mm depth inside a water tank 55 cm long × 36 cm wide × 15 cm deep. The probe was clamped and rotated about the center of the probe window in 5° steps within −30 and +30°, and in 10° steps beyond ±30° or in such a way that at least 10 measurements were taken within the probe full width half maximum.

5000 counts were recorded for the peak and at least 500 counts were recorded for each position. As in the case of the spatial resolution, the angular resolution was quantified by calculating the FWHM and FWTM of the curve, using the same procedure as described in the spatial resolution section.

Side and back shielding

A point source was slowly moved along the probe surface and in contact with it, taking care that the source did not shine directly into the probe head. The highest count rate detected by the probe during the whole measurement was recorded, as well as the position at which this occurred. The side and back shielding was reported as count rate for unit of radioactivity.

To perform the measurements described above, it is essential to have a means to position reliably the source and the probe. In our case, the measurements were made more difficult by the fact that each probe is different from the others, for example, has a different diameter, or length, or tip angle, and therefore the system used to fix the probe needed to be flexible enough to accommodate the different designs. This flexibility, however, came at the price of some loss in robustness in positioning. We introduced several checks in our procedure to ensure that the position was as close as possible to the described one, but still we wanted to have a crude estimate of the impact of small differences in the positioning. Our crude estimate was obtained by repeating the whole set of measurements, including reclamping of the probe, for one of the probes, on a separate day.

Probe ergonomics

The surgeon tested all the probes, except the γ-locator, during at least one sentinel node breast cancer surgery and assigned a value between 1 (poorest) and 5 (best) for each of the following characteristics: display readability, ease of probe handling and user friendliness of main unit. The γ-locator was not tested because the probe diameter is not optimized for sentinel node breast cancer surgery and is too big with respect to the incision dimension.

It also became clear during the surgery that the audio auto-ranging capabilities is a very important feature, as it allows the surgeon to concentrate on the surgery without having to adjust the audio range.

Results

The crude reproducibility measurement performed in one of the probes shows that the error in the positioning has a rather low impact on the measurement of the spatial and angular resolution. The error was 0.5 mm and 1° in the spatial and angular resolution, respectively. The effect of the uncertainty in the positioning had a larger impact on the sensitivity measurements, in air and in a scatter medium, where the difference in the two measurements was 15%. Therefore, even if our estimate of the impact of the positioning uncertainty in the sensitivity is only a crude estimate, we decided to add a 15% error in quadrature to the statistical error associated with each measurement to take this effect into account.

Table 2 shows the results for the sensitivity in air and in a scatter medium at 3 and 5 cm distance from the probe tip. Table 3 shows the 'sensitivity', defined in this case as the number of counts displayed per unit of radioactivity in air and in a scatter medium at 3 and 5 cm distance from the probe tip for the γ-locator. Table 4 shows the spatial and

Table 2 Sensitivity (cps/MBq) in air and in a scatter medium at 3 and 5 cm from the probe tip

	Air		Scatter medium	
	3 cm	5 cm	3 cm	5 cm
C-Trak				
Probe with normal collimator	1500 ± 200	680 ± 100	900 ± 150	400 ± 60
Probe with Lechner collimator	850 ± 130	380 ± 60	550 ± 90	220 ± 30
Europrobe				
Large probe	1900 ± 300	770 ± 120	1700 ± 300	600 ± 90
Large probe with collimator	1240 ± 190	560 ± 80	920 ± 140	330 ± 50
Small probe	420 ± 60	160 ± 20	340 ± 50	109 ± 16
Small probe with collimator	310 ± 50	140 ± 20	250 ± 40	86 ± 13
Navigator				
Probe without collimator	510 ± 80	210 ± 30	400 ± 60	150 ± 20
Neoprobe bluetooth				
Probe	2200 ± 300	800 ± 120	1600 ± 200	530 ± 80
Probe with collimator	950 ± 140	390 ± 60	700 ± 110	230 ± 30
Node Seeker				
Bent-tip probe	2300 ± 300	940 ± 140	1700 ± 300	620 ± 100
Straight probe	2200 ± 300	930 ± 180	1700 ± 300	600 ± 90
Narrow-tip probe	250 ± 40	98 ± 15	250 ± 40	82 ± 12

cps/MBq, count rate per unit of radioactivity.

Table 3 'Sensitivity', defined as number of counts displayed on the screen per MBq, in air and in a scatter medium at 3 and 5 cm from the probe tip, for γ-locator

	Air		Scatter medium	
Focus/algorithm	3 cm	5 cm	3 cm	5 cm
F1-A1	670 ± 100	240 ± 40	460 ± 70	130 ± 20
(F1-A1)			(750 ± 110)	(270 ± 40)
F1-R6	300 ± 50	96 ± 14	170 ± 30	48 ± 7
F1-R6m	NE	NE	160 ± 20	NE
(F1-R6ma)			(230 ± 34)	(79 ± 12)
F4-A1	610 ± 90	210 ± 30	370 ± 50	86 ± 13
F4-R6	280 ± 40	71 ± 11	150 ± 20	29 ± 4
F4-R6m	NE	NE	119 ± 18	NE
F8-A1	480 ± 70	92 ± 14	240 ± 40	15 ± 2
F8-R6	200 ± 30	28 ± 4	82 ± 12	6.3 ± 0.9
F8-R6m	NE	NE	53 ± 8	NE
(F8-R6ma)			(210 ± 30)	(7.0 ± 1.1)

The values in parenthesis for the γ-locator refer to measurements performed on the second software version.
MBq, unit of radioactivity; NE, not evaluated.

Table 4 Spatial and angular resolution in a scatter medium with the source at 3 cm from the probe tip

	Spatial resolution		Angular resolution	
	FWHM (mm)	FWTM (mm)	FWHM (degrees)	FWTM (degrees)
C-Trak				
Probe with normal collimator	28	56	61	100
Probe with Lechner collimator	19	35	38	63
Europrobe				
Large probe	43	88	102	144
Large probe with collimator	22	42	46	81
Small probe	39	79	90	131
Small probe with collimator	22	38	45	72
Navigator				
Probe without collimator	35	69	70	111
Neoprobe bluetooth				
Probe	53	119	141	> 160
Probe with collimator	28	51	58	88
Node Seeker				
Bent-tip probe	37	79	81	128
Straight probe	35	72	79	121
Narrow-tip probe	42	103	115	175
γ-locator				
F1-A1 (F1-A1)	57 (66)	> 100 (> 100)	> 140	> 140
F1-R6	52	94	> 140	> 140
F1-R6m (F1-R6ma)	34 (10)	68 (18)	> 140 (18)	> 140 (28)
F4-A1	52	82	> 140	> 140
F4-R6	50	> 100	> 140	> 140
F4-R6m	24	54	> 140	> 140
F8-A1	38	54	> 140	> 140
F8-R6	37	54	> 140	> 140
F8-R6m	NA	NA	> 140	> 140

NA, profile in which only one value was different from zero, the values in parenthesis for the γ-locator refer to measurements performed on the second software version. FWHM, full width half maximum; FWTM, full width tenth maximum; NA, not applicable.

Table 5 Sensitivity to events originating outside the probe field of view

	Sensitivity through side shielding in air, cps/MBq at 50 mm lateral	Sensitivity to scatter, cps/MBq at 50 mm lateral	Side and back shielding, maximum leakage cps/MBq
C-Trak			
Probe with normal collimator	$(6.8 \pm 1.0) \times 10^{-3}$	1.13 ± 0.17^{b}	0.8 ± 0.2
Probe with Lechner collimator	$(4.5 \pm 1.0) \times 10^{-2}$	$(1.8 \pm 1.7) \times 10^{-2a}$	0.8 ± 0.2
Europrobe			
Large probe	2.0 ± 0.3	22 ± 3^{b}	17.0 ± 0.7
Large probe with collimator	0.20 ± 0.03	2.9 ± 0.4^{b}	0.06 ± 0.04
Small probe	0.71 ± 0.11	3.0 ± 0.6^{a}	8.7 ± 0.5
Small probe with collimator	$(4 \pm 3) \times 10^{-3}$	0.38 ± 0.06^{b}	0.2 ± 0.1
Navigator			
Probe without collimator	0.54 ± 0.09	1.3 ± 0.3^{a}	NA
Neoprobe bluetooth			
Probe	3.1 ± 0.5	43 ± 6^{b}	47.9 ± 1.6
Probe with collimator	3.3 ± 0.5	1.5 ± 0.9^{a}	79 ± 2
Node Seeker			
Bent-tip probe	1.7 ± 0.3	23 ± 3^{b}	77 ± 2
Straight probe	1.12 ± 0.17	16 ± 2^{b}	6.8 ± 0.6
Narrow-tip probe	3.0 ± 1.0	3.2 ± 1.4^{a}	74 ± 2
γ-locator			
F1-A1	14 ± 2	0^{b}	0
F1-R6	2.4 ± 0.4	0^{b}	0
F4-A1	0	0^{b}	0
F4-R6	0	0^{b}	0
F8-A1	0	0^{b}	0
F8-R6	0	0^{b}	0

cps/MBq, count rate per unit of radioactivity; NA, not applicable.
[a]Sensitivity to scatter performed with correction for side shield in air.
[b]Sensitivity to scatter performed without correction for side shielding in air.

angular resolution of the different probes at 3 cm in a scatter medium. Table 5 shows the quantities associated with sensitivity to scattered and unshielded counts.

Figure 4 shows a comparison of the spatial resolution profile of the probes without collimator (top), with collimator (middle) and different algorithms with γ-locator (bottom). In Figure 4, the counts were normalized to the source activity and therefore the height of the curve is the probe sensitivity in water at 3 cm distance, whereas the width of the curve is related to the probe spatial resolution. An ideal probe would have a profile, which is high and very narrow. For the Node Seeker (IntraMedical Imaging LLC, Los Angeles, California, USA), because of the similarity between straight and bent-tip probe, only one of the two was plotted.

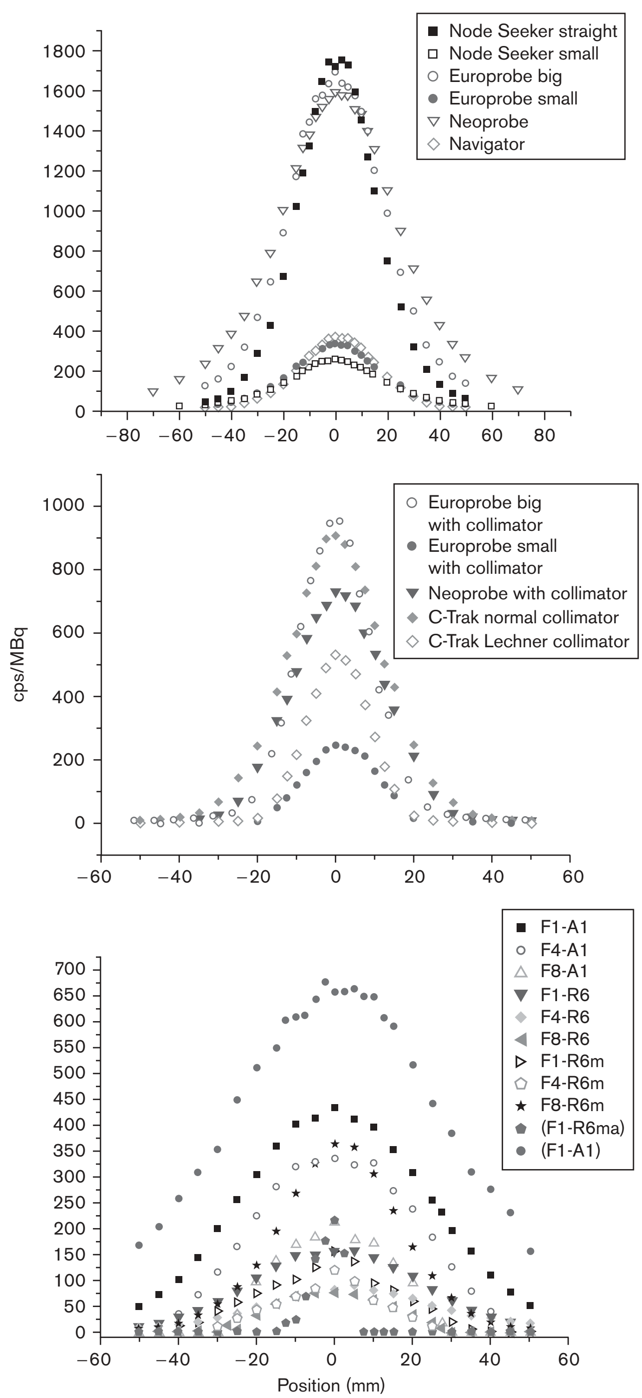
Table 1 reports the weight and diameter of the different probes tested, as well as a semiquantitative estimation of the ergonomics. A score between 1 (poorest) and 5 (best) was assigned to display readability, ease of handling and user friendliness of main unit.

Discussion

This study reports for the first time a comparison of sentinel node probes based on the NEMA NU3-2004 protocol. Apart from the NEMA results, we also reported the results on the probe ergonomics, which is thought to contribute to the success of a sentinel lymph node surgery.

Although the final choice of a surgical probe heavily depends on the type of the surgery and surgeons' preferences, our data (Fig. 4) show important differences in performance between the probes that should be known to make an informed choice. The comparison showed that the standard sentinel probes could be divided into three groups. To the first group belong the probes ('sensitivity probes') that do not make use of an additional external collimator and show high sensitivity, at the loss of spatial resolution. To the second group, belong the probes ('resolution probes') that have a higher degree of collimation. These probes showed a better resolution with about half the FWHM of the ones belonging to the first group, but also about half of the sensitivity. To the third group belong the small probes, narrow-tip Node Seeker and small probe, Europrobe ('minimally invasive probes'), which can be used in minimally invasive

Fig. 4



Spatial resolution profile of the measured probes for a source at 3 cm depth in a scatter medium. Probes without external collimator (top). Probes with external collimator (middle). γ-locator (bottom). cps/MBq, count rate per unit of radioactivity.

surgeries or in situations where the node is difficult to reach, but had neither good sensitivity nor spatial resolution when used with ^{99m}Tc. The only probe that showed to be outside this scheme is the Navigator, which is a not exceptionally small, but had worse spatial resolution and sensitivity than the others. Even though it could be argued that this probe has been used in our hospital since 2002, and therefore is not new any more, constancy testing showed no deterioration over time nor did the surgeon detect any changes, and the same type of probe is still commercialized by RMD Instruments.

All the probes worked properly and did not give problems during testing. The screen readability was better for the probes, which operated by main power than those that are battery operated (C-Trak and γ-locator). Neoprobe offers the interesting advantage of providing a wireless probe; however, the probe showed poor spatial resolution compared with the others when used without collimator, and medium sensitivity, when used with the collimator. Europrobe – large probe – provided with good spatial resolution and sensitivity, with the option to be used with and without an external collimator; however, when used with the collimator it becomes a rather large (diameter 19 mm) and heavy (about 220 g) probe. Node Seeker – standard probe – showed the best overall performances in the 'sensitivity group' and it is also particularly light in comparison with the other probes (Table 1). C-Trak showed good spatial resolution and sensitivity among the probes with external collimator; however, this probe is considerably heavier than the other probes tested.

Gamma Locator represents a completely new concept for sentinel node detection and the NEMA testing has not been written with this type of probe in mind. One immediate difficulty in comparing γ-locator with the other probes is the fact that the number of counts that are read in the display are not the actual number of photons detected, but rather the result of an algorithm used to process the photons detected by the detectors. It was not possible to determine a 'noise equivalent' count rate because the system did not allow to accumulate counts during a fixed time interval, unlike all other systems, which supported a 10-s count. This made it difficult to compare the 'sensitivity' of γ-locator with the sensitivity of the other detectors. Comparing number to number would result in γ-locator having a rather low sensitivity, in this application. The spatial resolution of γ-locator depends heavily on the algorithm/focus used to process the data. The higher the focusing, the better the spatial resolution, but the smaller the 'sensitivity'. In particular, the algorithm R6ma, which was introduced after our first measurements, showed a very sharp spatial resolution. The angular profile of γ-locator was flat for every choice of algorithm/focus except with the algorithm R6ma in which the angular profile was narrow. Because of this behaviour of the angular profile of γ-locator, we think that the only viable choice for the application of γ-locator to sentinel node detection in breast cancer surgeries would be to use the R6ma algorithm. With this algorithm, the probe spatial and angular resolutions are exceptionally good. However, as the sensitivity (as measured in number of counts recorded per unit time and unit activity) is not known, further studies are necessary to fully evaluate this probe's performance in sentinel node detection. Moreover, γ-locator has a large diameter (23 mm) and therefore can be used only when the incision is big enough, which hampers its application for breast cancer surgery.

We would like to bring to the attention of the reader that γ-locator has been designed for PET radiotracer detection and therefore was not specifically optimized for ^{99m}Tc sentinel node surgeries, even if it is also sold for this application. Future work should compare the performances of this probe with other probes available in the market for PET radiosurgery. Furthermore, the γ-locator could be more successfully applied to sentinel node nontrancsutaneous radio-guided surgeries where the probe diameter is less critical.

We were not able to compare directly the results of this study with previously published data on comparisons of sentinel node probes [9,10,12]. This is because of the difference between the protocol used in these studies and the NEMA protocol; and to the possible differences between the probes available in the market 4–10 years ago and the ones available at this moment. We strongly advocate the use of the NEMA standard in further comparative studies, as a means to standardize the comparison procedure and to help companies to always develop better products. The NEMA protocol was found to be relatively simple to perform (Figs 1–3), and most nuclear medicine departments should be able to perform the experiments described in this study.

Conclusion

This study can serve as a guide to compare the performances of probes available in the market to make a scientific-based choice. If a higher sensitivity is preferred to the spatial resolution, then the Node Seeker and Europrobe – large probe – gave the best overall performance in this study; if the spatial resolution is the preferred characteristic, then C-trak or Europrobe – large probe with collimator – seemed to be the probes of choice; if the possibility of operating wireless is the preferred characteristic, then Neoprobe is the only one at the moment in the market that offers this choice. Our study shows that the use of small probes is associated with a considerable loss of sensitivity. γ-locator showed good spatial resolution when the algorithm R6ma was used to process the data, but it was not possible to determine its sensitivity. Moreover, the large diameter of this probe could be problematic when small incisions are performed.

Acknowledgements

The authors would like to thank Canberra, Euromedical Instruments, Johnson & Johnson, GE-Healthcare and GF&E TEC GmbH for kindly providing the probes that were used for testing. The authors are indebted to Mr Verjans for manufacturing the source and probe holders, which were essential for performing the measurements reliably.

References

1 Veronesi U, Paganelli G, Galimberti V, Viale G, Zurrida S, Bedoni M, *et al*. Sentinel-node biopsy to avoid axillary dissection in breast cancer with clinically negative lymph-nodes. *Lancet* 1997; **349**:1864–1867.

2 Veronesi U, Paganelli G, Viale G, Luini A, Zurrida S, Galimberti V, *et al*. Sentinel-lymphnode biopsy as a staging procedure in breast cancer: update of a randomised controlled study. *Lancet Oncol* 2006; **7**:983–990.

3 Krag D, Weaver D, Ashikaga T, Moffat F, Klimberg VS, Shriver C, *et al*. The sentinel node in breast cancer – a multicenter validation study. *N Engl J Med* 1998; **339**:941–946.

4 Cabanas RM. An approach for the treatment of penile carcinoma. *Cancer* 1977; **39**:456–466.

5 Morton DL, Wen DR, Wong JH, Economou JS, Cagle LA, Storm FK, *et al*. Technical details of intraoperative lymphatic mapping for early stage melanoma. *Arch Surg* 1992; **127**:392–399.

6 Krag DN, Weaver DL, Alex JC, Fairbank JT. Surgical resection and radiolocalization of the sentinel node in breast cancer using gamma probe. *Surg Oncol* 1993; **2**:335–340.

7 Povoski SP, Neff RL, Mojzisik CM, O'Malley DM, Hinkle GH, Hall NC, *et al*. A comprehensive overview of radioguided surgery using gamma detection probe technology. *World J Surg Oncol* 2009; **7**:11.

8 Classe JM, Fiche M, Rousseau C, Sagan C, Dravet F, Pioud R, *et al*. Prospective comparison of 3 gamma-probes for sentinel lymph node detection in 200 breast cancer patients. *J Nucl Med* 2005; **46**:395–399.

9 Tiourina T, Arends B, Huysmans D, Rutten H, Lemaire B, Muller S. Evaluation of surgical gamma probes for radioguided sentinel node localization. *Eur J Nucl Med* 1998; **25**:1224–1231.

10 Wengenmair H, Kopp J, Sciuk J. Quality criteria of gamma probes: requirements and future developments. In: Schauer AJ, Becker W, Reiser M, Possinger K, editors. *The sentinel lymph node concept*. New York, NY: Springer; 2005. pp. 113–125.

11 Mariani G, Vaiano A, Nibale O, Rubello D. Is the ideal gamma-probe for intraoperative radioguided surgery conceivable? *J Nucl Med* 2005; **46**:388–390.

12 Britten AJ. A method to evaluate intra-operative gamma probes for sentinel lymph node localization. *Eur J Nucl Med* 1999; **26**:76–83.

13 NEMA NU3 Performance measurements and quality control guidelines for non-imaging intraoperative gamma probes. 2004.