Gamma Probes for Sentinel Lymph Node Localization: Quality Criteria, Minimal Requirements and Quality of Commercially Available Systems

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1. Introduction

Intraoperative localization of sentinel lymph nodes opens up new possibilities in the treatment of lymphogenous metastasizing tumors [1]. The accuracy of the diagnostic statement depends on the clear pre- and intraoperative identification of the sentinel lymph node (SLN) [2, 3, 4]. Experience and training of the user as well as the quality of the probe system are the decisive factors. The appropriate strategy of measurement has to meet the anatomical and clinical situation as well as the performance of the probe system. Some authors [7, 8] have already defined some quality criteria for gamma probes which in our opinion have to be complemented. The steadily increasing number of probe systems requires simple, expressive and reproducible control methods [5, 6]. In extension of the already presented quality control proposals the goal of this work is to:

- define standard regulations to evaluate quality parameters
- establish minimal requirements for probe systems
- compare various commercial systems
- discuss the value of these quality parameters in various clinical applications

2. Quality Criteria

To evaluate the quality of a probe system we measured or discussed the following parameters [Figure 1]:

- Spatial selectivity (radial sensitivity distribution at defined distance)
- Spatial resolution (lateral sensitivity distribution)
- Maximum sensitivity
- Quality of shielding (maximum penetration outside the measurement field)
- Energy resolution and spectral discrimination according to ^{99m}Tc
- Display of signal

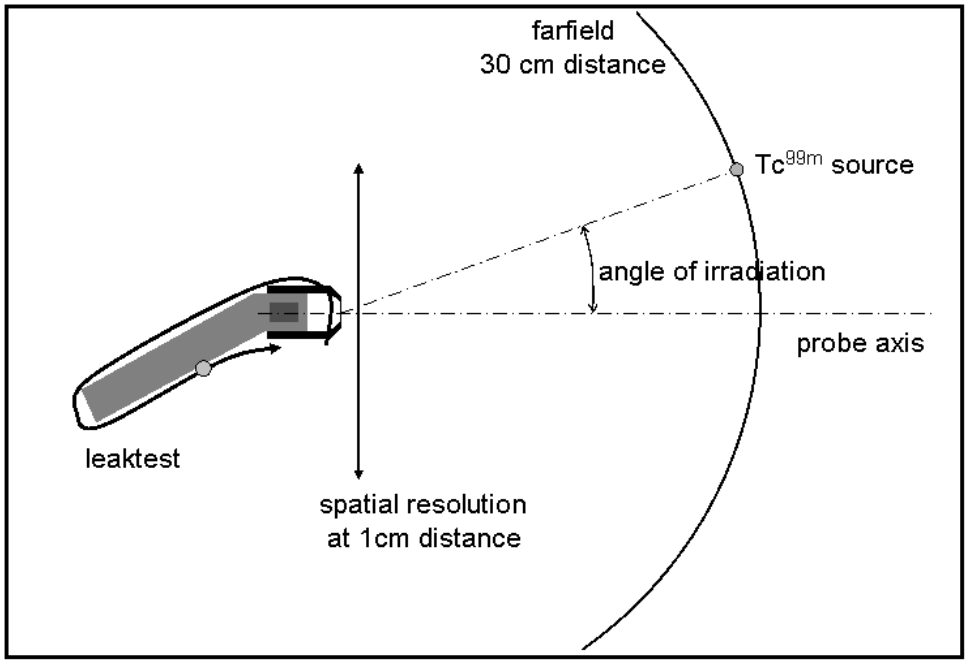

Figure 1: Arrangement of quality control measurement

2.1 Radial Sensitivity Distribution

The sensitivity distribution is evaluated equidistant to the measurement area (frontal radiation entrance window) dependant on the polar angle. Variations of the distribution with the distance are mainly due to the relative position of radiation entrance window and detector crystal. The radial sensitivity distribution at 30cm distance (farfield) describes the width of the measurement cone out of which radiation is detected.

The full width at half maximum (FWHM) of the distribution function is a good quality criterion for the **detectability** of lymph nodes in presence of non target radiation (injection depot, background). With a broad measurement cone the background signal can exceed the target signal of the lymph node, which then cannot be detected. A small cone mainly reduces background maintaining a constant target signal [Figure 2]. Therefore with increased background in the target area (e.g. mamma carcinoma, prostate carcinoma) a smaller FWHM of radial sensitivity distribution is desired.

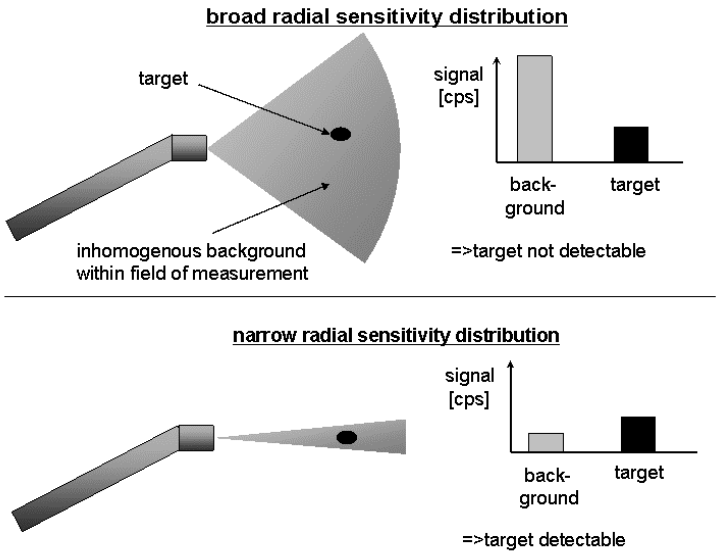

Figure 2: Radial sensitivity distribution and detectability of a lymph node

2.2 Spatial Resolution

The spatial resolution (lateral sensitivity distribution) can be determined if a probe is scanned laterally above a ^{99m}Tc point source (Ø 3mm). The FWHM gives the minimal distance at which two point sources (lymph nodes) can be detected separately. [Figure 3]

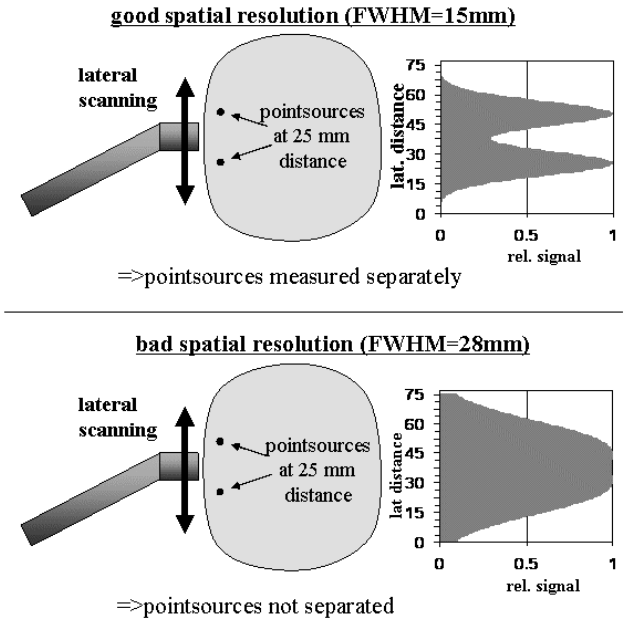

Figure 3: Resolution and separation of two lymph nodes

Spatial resolution depends on the distance between source and probe crystal. For comparison and simplification we measured at a minimal distance of 1cm to the front end of the probe which is inside the variation of true lymph node depth. To separate neighboring lymph nodes and perform an adequate exact localization the FWHM of the lateral sensitivity distribution should be better than the typical distance between neighboring lymph nodes or a typical node diameter in the preparation region. Therefore we recommend a spatial resolution better than 25 mm for lymph nodes in the axilla, inguinal and illiacal region. Increased requirements have to be set up for lymph nodes that are close together (e.g. in the head-, neck- and supraclavicular region). Probes or probe/collimator combinations for these applications should have a FWHM of less than 15mm.

2.3 Sensitivity

The sensitivity of the probe was determined directly at the tip of the probe or collimator. In general the necessary sensitivity depends on radionuclide uptake, measurement geometry and time between injection and SLNE. The maximum radionuclide uptake of the sentinel lymph node typically varies between 0.01% and 1% with a median at around 0.1%. The SLNE is mostly performed at the day after ^{99m}Tc-Nanocolloid injection. Then about 0.05% to 0.005% of the administered activity can be found in the lymph node intraoperatively. Assuming a typical activity application of 80 MBq a spot of activity between 4 and 40 kBq has to be localized. The sensitivity of the measurement system therefore should be better than 5 cps/kBq.

2.4 Shielding

Out of constructional reasons the shielding of a probe mostly has a weak area. A high background source (e.g. injection spot at mamma- or prostate-carcinoma) in the direction of such a leakage can lead to false orientation [Figure 4]. The lymph node should produce a higher signal than any background source. Assuming an uptake of 0.1% for a lymph node the leak sensitivity should not exceed 0.1% of the system sensitivity.

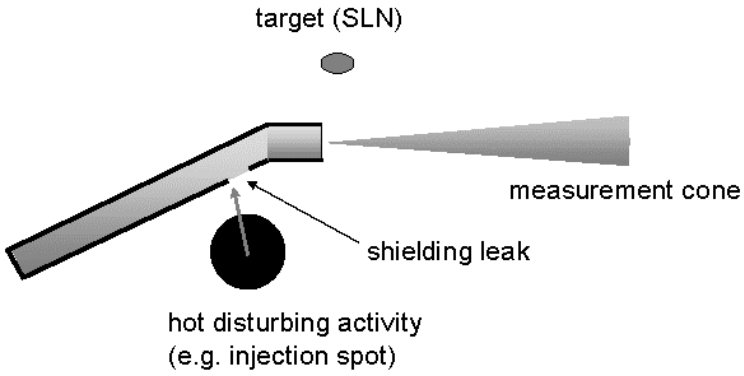

Figure 4: Apparent SLN in the measurement cone by background activity nearby a shielding leak

2.5 Energy Resolution

With the presence of scatter medium and high background activity compton photons produce an additional blurring of the spatial information. An energy discrimination that separates compton- and photopeak-signal is therefore important.

2.6 Display

All kinds of display have to be adapted to the special situation in an operation cabinet. An acoustic display should enable the user to visually concentrate to the operation field during measurement. Therefore a clear correlation between the acoustic tone and the measurement signal has to be available. For the quantitative results either a digital or analogue display is necessary which has to be clearly readable from at least 2m distance. To cope with the statistical variation and to influence the inertia of the display measurement interval respectively time constant should be adjustable.

3. Measurement conditions

The measurement conditions to localize SLN depending on the spatial distribution of the activity in the patient. The measurement situation at various tumors [9, 10] is described in Table 1.

Melanoma:
- most often large distance between SLNs and injection-spot
- good radionuclide accumulation in the SLNs

Mamma carcinoma:
- short distance between SLNs and injection-spot
- poor uptake in the SLNs

Prostate carcinoma:
- high background out of prostate, bladder and bone marrow
- strongly varying uptake in the SLN
- several lymph node-regions

Head and neck tumors:
- short distance between SLNs and injection-spot
- small lymph nodes in head and neck region

Table 1: Intraoperative measurement conditions for different gamma-probe applications

4. Minimal requirements of gamma probe systems

Based on the described method of measurement and our clinical experience we set up minimal requirements to system for intraoperative localization [Tab. 2].

Criterion	**Minimal Requirement**
Spatial Selectivity: Radial sensitivity distribution (farfield) Spatial Resolution	**FWHM ≤ 40°** High demands at lymph nodes in head-, neck-, supraclavicular region**:** **FWHM ≤ 15mm** Normal requirements at extremeties, axilla, groin: **FWHM ≤ 20mm**
Sensitivity	**>> 5 cps/kBq**
Shielding	**≤ 0,1 % of maximum system sensitivity**
Energy selection	Compton/photopeak discrimination; check of energy selection possible
Display Acoustic digital **or** analogue	 Good correlation between measurement signal and tone digital: continuous display with adjustable measurement time interval analogue: suitable measurement interval with adjustable time constant

Table 2: Minimal requirements for an intraoperative probe system

Through the different measurement situation the evaluation of the single criteria depends on the tumor entity (Table 3). The plus sign indicates the importance of the marked parameter in the evaluation of the performance of the system for a certain application.

	Melanoma	**Mamma carcinoma**	**Prostate-carcinoma**	**Head and neck tumors**
Sensitivity	**(+)**	**+**	**+**	**+**
Spatial selectivity (rad. sens.-distribution)		**+**	**+**	**+**
Spatial resolution	**+ (head-, neck-, supraclavicular-region)**			**+**
Shielding		**+**	**+**	**+**
Energy discrimination		**+**	**+**	**+**

Table 3: Evaluation of quality control parameters

5. Quality of Commercially Available Systems

Up to now we tested more then 50 probe/collimator combinations with 13 measurement systems from 8 manufacturers. Figure 5 shows the actual commercially available probes. Table 4a and 4b summarizes the results for the different probes and collimators. The results indicate marking differences in performance. These characteristics of a system have to be integrated into the performed method of detecting the SLN and the user has to be trained in the optimal strategy of measurement for the distinct system. These results also contain the improvements that could be achieved by the efforts of various companies.

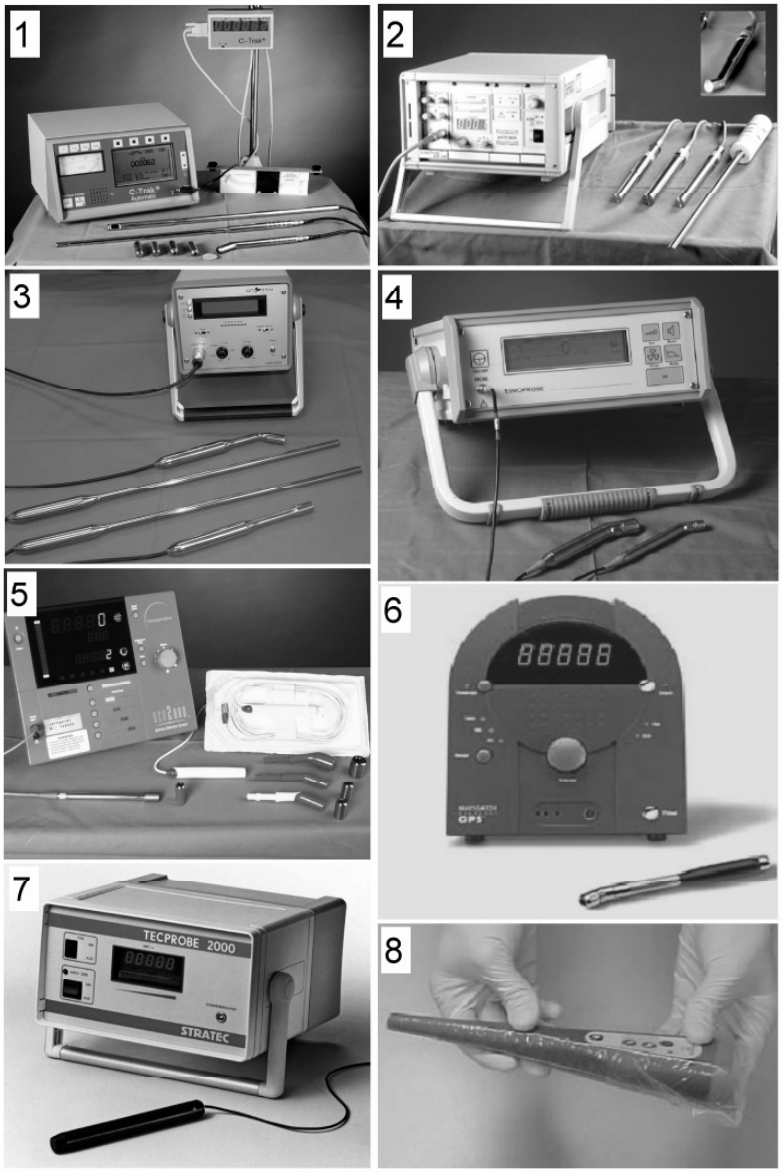

Figure 5: Commercially availabe gamma probes

1. C-Trak, Care Wise (Morgan Hill, California, USA), www.carewise.com
2. Szintiprobe MR-100, pol.hi.tech. (Carsoli, Italy), www.vilage.flashnet.it/users/polhitec
3. Crystal CXS-OP, Crystal (Berlin, Germany), www.crystal-gmbh.com
4. Europrobe, Eurorad (Straßburg, France), www.eurio.fr/eurorad
5. Neoprobe 2000, Neoprobe (Dulin, Ohio, USA), www.neoprobe.com
6. Navigator, Auto Suture (Norwalk, Connecticut, USA), www.autosuture.com
7. Tecprobe, Stratec (Birkenfeld, Germany), www.stratec-biomedical.de
8. Gamma Finder II, W.O.M. World Of Medicine (Ludwigsstadt, Germany), www.world-of-medicine.com

Manufacturer and type		Measure-ment cone (FWHM) farfield	Spatial resolution (FWHM) at 1cm distance [mm]	Max. sensitivity [cps/kBq]	Rel. sensitivity at shielding leak in comparison to max. sensitivity	Correlation of acoustic signal to the measurement signal Marking: ++ + − −−	Probe shape	
							Diameter [mm]	Angled probe [yes/no]
C-Trak Omni-Probe, Care Wise	Standard-Collimator	50°	15	23	0,02%	++	15	yes
	Lechner-Collimator	33°	9	9,5	0,04%		15	
	Lechner 0,66- Collimator	31°	9	9	0,02%		17	
ScintiProbe 15-B, pol.hi.tech.		45°	20	12	0,1%	+	16	yes
Crystal Flex-Probe CXS-SG03 OPSZF	40°-Collimator	51°	18	21,5	0,03%	++	15	variable
	20°-Collimator	40°	12	11,3	0,06%			
Crystal CXS-SG03, gerade Sonde		40°	17	10,5	0,03%	++	15	no
Stratec straight probe		36°	14	11	**0,5%**	+	20	no
Stratec angled probe		40°	19	13,3	0,08%	+	17	yes
Europrobe CsJ high sensitivity, Eurorad	Without Collimator	**85°**	**25**	30	0,15%	+	16	yes
	Standard-Collimator	35°	14	12	0,003%		19	yes
Europrobe CsJ, Eurorad	Without Collimator	**75°**	21	18	0,17%	+	16	yes
	Standard-Collimator	35°	14	7	0,003%		19	yes
Europrobe CdTe, Eurorad	Without Collimator	**74°**	15	10	0,35%	+	11	yes
	Standard-Collimator	35°	11	**3**	0,01%		15	yes
ScintiProbe 18LVR, pol.hi.tech.	Collimator-Step 1	42°	20	11	0,3%	+	18	no
	Collimator-Step 2	49°	22	14	0,2%			
	Collimator-Step 3	**65°**	23	19	0,2%			
	Collimator-Step 4	**80°**	**25**	33	0,1%			
Neoprobe 2000 14mm straight probe	Without Collimator	**118°**	**26**	54	0,03%	+	14	no
	With Collimator	36°	15	9,8	0,14%		16	
Navigator 14 mm, Auto Suture		**58°**	20	**5**	**0,9%**	++	14	yes/no
ScintiProbe 22LV, pol.hi.tech.		26°	13	**2**	**0,5%**	+	22	no
Gamma Finder II, W.O.M.		**68°**	19	10	0,09%	−−	13	no

Table 4a: Quality of commercially available handheld probes (stage: December 2005). Substantial deviations from the minimal requirements (table 2) are marked grey.

Manufacturer and type		Measure-ment cone (FWHM) farfield	Spatial resolution (FWHM) at 1cm distance [mm]	Max. sensitivity [cps/kBq]	Rel. sensitivity at shielding leak in comparison to max. sensitivity	Correlation of acoustic signal to the measurement signal Marking: ++ + — ——	Probe shape	
							Diameter [mm]	Measurement direction to probe axis
Laparoscopic probe								
Stratec lap. probe, measurement direction parallel to probe axis,		38°	13	6,2	0,3%	+	11	0°
C-Trak lap. probe, measurement direction parallel to probe axis, Care Wise		**66°**	16	9,5	0,04%	++	10	0°
C-Trak lap. probe, measurement direction 20° to probe axis, Care Wise		48°	12	5,1	0,4%	++	10	20°
C-Trak lap. probe, measurement direction perpendicular to probe axis, Care Wise		51°	12	6,5	0,06%	++	10	75°
Crystal lap. probe, measurement direction perpendicular to probe axis	alongside	**77°**	18	22,5	0,24%	++	10	90°
	crosswise	**65°**						
Crystal lap. probe, measurement direction 42° to Probe axis	alongside	**77°**	17	16,5	0,7%	++	10	42°
	crosswise	**62°**	15					
Crystal lap. probe, measurement direction parallel to probe axis		**56°**	14	13,5	1,0%	++	10	0°
ScintiProbe 11L, measurement direction parallel to probe axis, pol.hi.tech.		**54°**	19	5,6	0,3%	+	12	0°
ScintiProbe 11/20, measurement direction 40° to probe axis, pol.hi.tech.	alongside	30°	10	5,6	0,3%	+	11	40°
	crosswise		8					

Table 4b: Quality of commercially available laparascopic probes (stage: December 2005). Substantial deviations from the minimal requirements (table 2) are marked grey.

6. Summary

The quality criteria of gamma probes available in Germany were determined. As a result of this it became clear that also gamma probes are used which measurement characteristics are not adapted to the measurement situation in sentinel lymph node diagnostic. The suitability of these probes to localize SLN reliably is doubtful.

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