

The Surgical Probe

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In the early 90's the introduction of the Sentinel Node by Morton et al [1,2] caused renewed interest in the use of a simple detector to localize small foci with a low amount of radioactivity in the human body during surgery.

Principle

The basic principle is similar to the concept of a Geiger-Muller counter: to localize radioactivity in the environment. Such a counter will not be sufficient because of its limited counting sensitivity and limited directional sensitivity.

The most important feature of a surgical probe is its counting sensitivity: to detect a sufficient number of counts within a short time from a minimum amount of radioactivity. Typically only a few kBq need to be detected and therefore the sensitivity should at least amount to 10 cps/kBq. This can not be achieved with air or gas filled GM-counters. Alternatives are formed by scintillation crystals or semi-conductors. The most well-known scintillation probe is the thyroid probe: a NaI(Tl) crystal mounted on a photomultiplier (PMT), a pre-amplifier and an electronic counter (fig.1).



Figure 1: The scintillation probe for thyroid uptake measurement.

The length of the probe (crystal + PMT) is approximately 50 cm. The crystal is cylindrical with a diameter of 10 – 15 cm and a comparable thickness. The PMT behind the crystal has a length of 20 cm. Just miniaturizing this concept

is not advisable. Commercially available PMT's are at least 10 cm in length. In addition, these PMT's need a relatively high voltage supply of over 100 V. This is not desirable for use in an operating theatre.

Practical surgical probes consist of a small detector: a scintillation crystal and a (avalanche) photodiode (APD) with pre-amplifier. Since NaI(Tl) crystals are hygroscopic, CsI crystals are preferred. In general the configuration is as shown in figure 2: fit in a cylinder of a few cm and typically 1 to 1.5 cm in diameter. This cylinder is typically made of tungsten, 1 to 2 mm thickness, and serves as a collimator to give the probe directional sensitivity. Furthermore the total assembly is put in a stainless steel casing. Initially emphasis was put on ways to sterilize the probe. However, by placing the probe in a sterile plastic sheath, as is done with ultrasound equipment during surgery, this issue has become of minor importance.

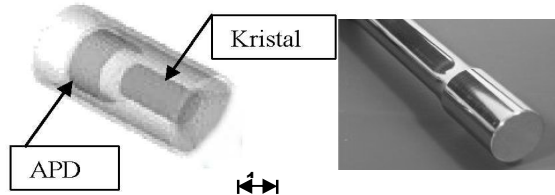


Figure 2: Schematic configuration surgical probe (left) and the actual design (Crystal Probe).

With the use of CsI crystals, the principle of scintillation is applied. Photons entering the crystal collide with electrons, which in turn will leave their orbit. When these electrons fall back in their orbit, an almost visible photon of light will be emitted in the crystal. This light is converted by an APD into an electric pulse. The APD requires only a low voltage. The amplitude of the electric pulse is a measure for the energy of the photon entering the crystal. Subsequently, the electric pulse is fed into the electronic counting unit. Using an energy analyser, the unit can be set up for a defined energy range.

Instead of the scintillation principle, a different technique can be applied which converts the photon directly into an electric pulse, without

producing a light photon first. This is done by using semi-conductors. In materials like CdTe and ZnS a photon changes the electron valence band configuration in the material, thereby affecting its conductivity. Because of the (low) voltage on the detector material, small pulses are generated again with the amplitude being proportional to the energy of the incoming photon. As with the CsI-probe the pulse is fed into a (pre-)amplifier and subsequent electronics. In general it is not noticeable from the outside to see whether a probe contains a crystal or a semi-conductor. With respect to the electric pulses, the semi-conductors produce more noise than the crystals at photon energies < 60 keV. Both types of probes are suitable for photon energies between 100 and 200 keV. For higher photon energies CsI probes are more efficient.

To provide more directional sensitivity, extra collimation may be needed. This is achieved most often with an extra tungsten collimator which can be placed over the probe.

In the Guidelines for Instrumentation of the Dutch Nuclear Medicine Society (NVNG) most of the relevant features of surgical probes are described. Most of them refer to the International Standard for Quality Control NU-3, published by NEMA. A few of these features will be described separately here:

Counting sensitivity

This sensitivity determines the count rate per kBq (cps/kBq). A point source of low activity is measured in front of the detector (distance 10 mm). The counting sensitivity of detectors varies between 5 and 50 cps/kBq, depending on size of the detector (10 -20 mm) and thickness of the crystal or semi-conductor (3 – 10 mm). With increasing distance between point source and detector, the sensitivity will decrease (quadratic).

Field of view

By means of the collimator the field of view of the probe can be restricted. By moving a point source at a distance of 30 mm side ways in and out of the field of view (Fig. 3), the angle of view (from -60° to + 60°) can be determined (fig. 4) as well as the spatial resolution (fig. 5). In general the spatial resolution lies within 15 to 25 mm (fig. 6).

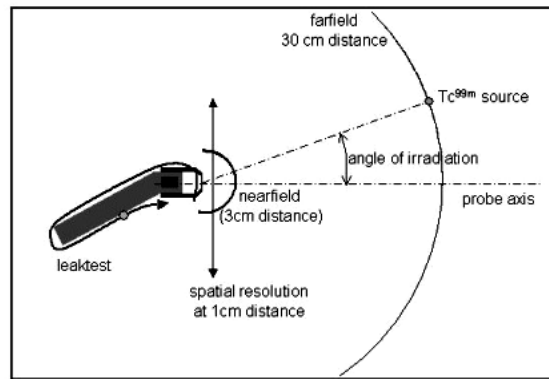


Figure 3: Measurement of the directional sensitivity.

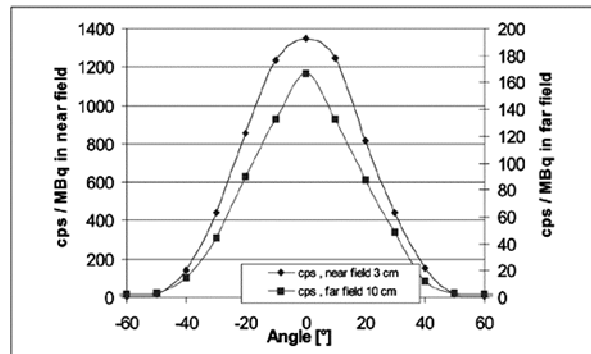


Figure 4: Directional sensitivity

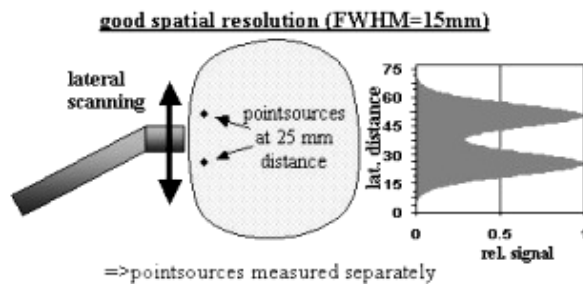


Figure 5: Measurement of spatial resolution

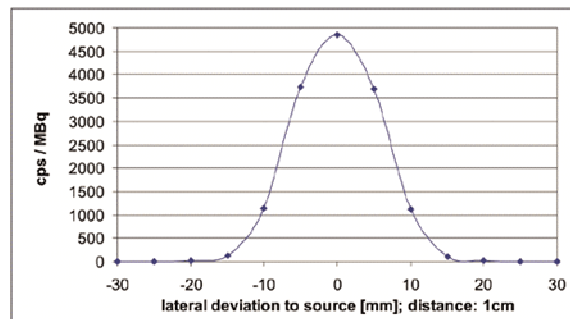


Figure 6: Spatial resolution

Stability

Stability is a measure of the precision of the counting sensitivity. This should stay constant over time. By regular measurements a trend can be estimated (fig. 7). This trend can be caused by aging of the detector material or drift in the electronics. For a proper trend analysis monthly measurements over a year period are recommended and even better if measurements are done before every use of the probe.

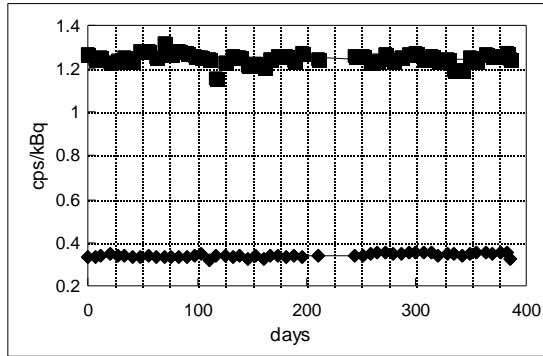


Figure 7: Stability of the counting sensitivity of a gamma probe

Linearity

The count rate should be proportional with the amount of activity in the field of view, up to a few MBq. Higher activities may cause deviations caused by the processing speed of the electronics.

Side shielding

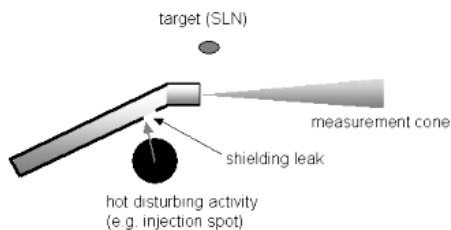


Figure 8: Side shielding of a gamma probe

When measurements are done near an injection site, there should not be any interference from that site on the measurements. The count rate of a (very) small amount of activity could be masked by large activity nearby (fig. 8). A typical value for the transmission through the shielding on the side of the probe is 0.1% or less.

Sound

It is not practical when the operator has to keep an eye on the read out to see when the highest count rate is encountered. For this purpose the

counter is equipped with a sound unit. The intensity or the frequency of the sound signal is proportional with the count rate. It takes some practice to guide the probe "by ear". It is strongly recommended to practice this with small sources of activity in a container filled with water.

Safety

Because the equipment is used in the operating theatre, in Europe this equipment should (at least) comply with the directive IEC 601-1.

The laparoscopic probe

A special variant of the surgical probe is the laparoscopic probe (fig. 9). In general it is smaller in diameter (< 10 mm) but much longer (40 cm), such that it can be lead through a surgical trockard. This laparoscopic probe is applied mostly for localisation of lesions in the abdomen (fig. 10). The tip of the probe is special (fig. 11): it can look side ways in an angle of 45° or 90°. The reason for this is that e.g. the uterus is approached from the side. A straight forward looking probe would not apply.

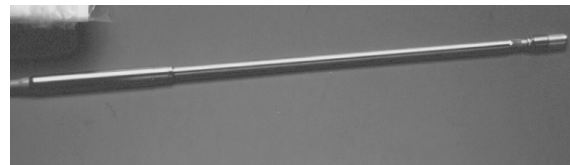


Figure 9: The laparoscopic probe



Figure 10: The laparoscopic probe in a trockard

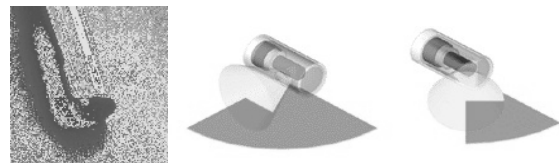


Figure 11: Laparoscopic probes looking side ways: 90° (left and middle) and 45° (right).

Future developments

The disadvantage of the surgical probe is that sometimes there is still a need for imaging capabilities of the activity distribution during surgery, especially if activity is spread extensively over a larger area. Since 2000 surgical gamma imaging probes have become

available commercially. These devices have a field of view of a few cm, typically 5 cm x 5 cm (fig. 12).

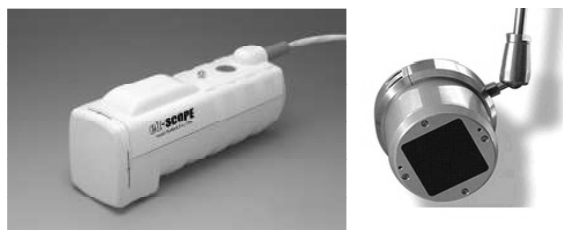


Figure 12: Mini gamma camera's (left: Anzai, FOV 42 x 42 mm, right: Euromed, FOV 48 x 48 mm)

These detectors consist of a matrix of e.g. 12 x 12 CdTe elements of 4 x 4 mm. A collimator with holes matching the pattern of the elements is fitted to the matrix. The individual signals are lead to a central read-out unit (often called analogue signal interpretation circuit or ASIC), which creates the image (fig. 13).

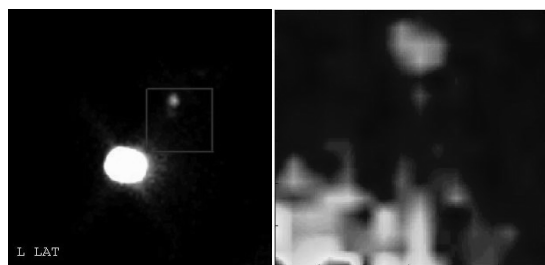


Figure 13: Images of a lymph node near the injection site, acquired with a mini gamma camera (Euromed).

In general the counting sensitivity of these imaging probes are rather low, resulting in a long acquisition times for a recognizable image. This, in turn, makes it difficult to use the imaging probe during surgery and also keep the device manually in one position.

Another development in the field of surgical probes is the stethoscopic probe (fig. 14). The inside of this probe is comparable to that of the regular surgical probe, but the outside looks like a stethoscope: small housing (4 cm diameter) 4 cm high but with a wide ring on the bottom, which makes it easier to tape the device to a patient. Also the electronics (amplifier, energy-analyser and read-out) are coupled to a laptop or PC, on which dedicated software is implemented to set up the acquisition parameters. The special feature of this system is that a complete energy spectrum acquired in a few seconds is stored on disk for analysis at a later moment. By storing these data in a

dynamic sequence (e.g. every ten seconds during half an hour), time-activity curves can be generated for kinetic analysis. An example of such an application is reported in a study concerning protein leakage from the lung in patients with lung injury [4].

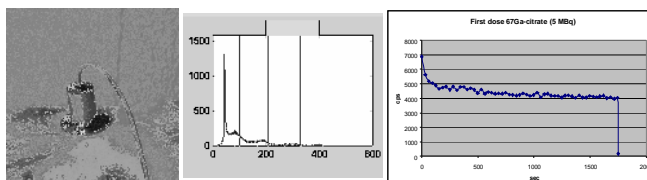


Figure 14: The stethoscopic probe positioned on the left lung of a patient (left), the acquired energy spectrum (middle) of ^{67}Ga -citrate and the time activity curve (right) of the activity distribution in the blood within the field of view of the probe.

Eventually with the introduction of positron emission tomography (PET) there is interest in the use of surgical probes to locate ^{18}F -FDG accumulations. This may be before surgery or even during surgery. Because a positron emitter is used, it would be ideal to detect both the annihilation radiation of 511 keV for detection at a larger distance (cm range) from the focus and the beta-particle at short distance (mm range). For instance with lung cancer, the laparoscopic probe would apply during bronchoscopy, but the thick shielding for the 511 keV may still form a practical problem to solve.

Acknowledgement

For the illustrations with this article pictures have been used obtained from the website of Nuclear Fields USA Corp. (www.surgicalprobe.com).

Literature

1. Morton DL, et al., "Technical details of intraoperative lymphatic mapping for early stage melanoma," Arch. Surg. 127:392-9, 1992.
2. Morton DL, et al., "MSLT Group: Validation of the accuracy of intraoperative mapping and sentinel lymphadenectomy for early-stage melanoma," Ann. Surg. 230: 453-465, 1999.
3. NEMA NU-3 2004: Performance measurements and Control guidelines for Non-imaging intraoperative gammaprobes
4. Verheij J, et al., "Effect of fluid loading with saline or colloids on pulmonary permeability, edema and lung injury score after cardiac and major vascular surgery." Br. J. Anaesth 2005; 96 21 – 30.