IN-VIVO DOSIMETRY USING MOSFETs, Diodes and TLDs

In-vivo or patient dosimetry is used as a Quality Assurance tool to measure the radiation dose to patients during radiotherapy. These dose measurements are compared with the target doses specified by the oncologist and calculated by the radiotherapy treatment plan.

There are currently three methods of measuring patient dose viz. MOSFET, Diode and TLD.

1. TLD – Thermoluminescent Dosimetry

This was one of the first techniques to be used for in-vivo dosimetry in radiotherapy. It is still used today.

In this method the dosimeter is usually a small (1mm x 1mm) crystal of a thermoluminescent material such as LiF. The crystals to be used for patient dosimetry are annealed in an oven 24 hrs prior to use. They are individually calibrated since their calibration factors are wide (+/- 15%). They are placed on the patient during treatment with the LINAC and read afterwards by placing them one by one in an oven at temperatures of ~ 400^{0} C. TLD material emits light when heated and this light is detected using a Photomultiplier tube. The amount of light output is proportional to the dose received by the crystal.

The major disadvantage of TLD is that it is very time consuming and needs a highly trained technician who specialises in this procedure.

2. Diodes

This was the second technique to be used for in-vivo dosimetry. Diodes are a semiconductor analogy for ionisation chambers, which are too large and fragile to be used on patients.

Diode dosimeters are semiconductor devices which have active areas of 2 to 3 mm^{2} and are packaged at the end of a coaxial cable that are > 5 mm diameter. There are different styles of packaging for different energies and modalities of use.

The radiotherapy diode is operated in the same way as a photodiode where light absorbed by a diode generates a photo-induced current. In the radiotherapy application, ionising radiation induces a current in the diode. The current is proportional to the dose rate of the radiation passing through the diode (~ 10 pA/cGy/min). Larger areas produce larger currents. The diode must be

connected continuously to an electrometer top, measure this current and integrate the current with time. The time-integrated current is proportional to dose.

Diodes are simpler to use than TLDs. The major disadvantages of diodes are size, coaxial cables and the fact that they need several correction factors for even simple use in clinical radiotherapy. A recent paper lists six correction factors for modern diode systems ("In-vivo dosimetry: Intercomparison between p-type based and n-type based diodes for the 16 – 25 MV energy range", N. Jornet et.al. Med. Phys. 27 (6) pp 1287 – 1293.)

Among the correction factors for diodes are :

a) SSD (Source to Surface Distance)
b) Angle of incident radiation
c) Temperature
d) Energy

a) **SSD** is due to the fact that diode response is a function of dose rate. The current generated in the diode is dependent on recombination rates in the Si which depend on dose-rate.

b) **Angle** is due to the fact that diodes are large and not isotropic in response.

c) **Temperature** is due to the fact that leakage current in a semiconductor is temperature dependent.

d) **Energy** is because diodes are designed for specific energy ranges (e.g. 4 MV, 6 MV, 18 MV etc) and use within a range requires a correction factor. In addition, a different diode is required for electron energies since the thick packaging material used on a photon diode (e.g. for 18 MV) would attenuate an electron beam.

3. MOSFETs

MOSFET (Metal Oxide Silicon Field Effect Transistors) are the most recent development for in-vivo dosimetry compared with TLDs and Diodes. They have been in use in clinical radiotherapy for six years. Prior to that they were used in spacecraft.

MOSFET dosimeters were designed to be used as an electronic replacement for TLDs with the size advantages of TLDs and fewer correction factors compared with diodes. The dosimeter is a small silicon chip (1 mm x 1mm) with an active area of 0.2 mm x 0.2 mm. MOSFETs are a semiconductor analogy for TLD or film dosimetry.

Radiation absorbed by a MOSFET results in a permanent change in its threshold voltage due to radiation-generated charge trapped in the gate oxide. This change in voltage is proportional to absorbed dose. It is a true integrating dosimeter.

The MOSFET threshold voltage sensitivity to radiation is a function of gate bias during radiation and sensitivities are typically 1 to 3 mV/cGy. In use, the electronic reading instrument measures the MOSFET's threshold voltage before irradiation. The same instrument measures the voltage after irradiation and the change is calculated by the instrument and displayed in cGy.

The MOSFET overcomes the correction factors required for diodes in the following manner:

a) **SSD** – the MOSFET is not dose-rate dependent since the small voltage on the gate during radiation sweeps charge through the oxide quickly and it has no time to recombine.

b) **Angle of incidence** – MOSFETs are isotropic in response because of their extremely small size, the angle of incidence of the radiation does not matter.

c) **Temperature** - Thomson Nielsen's MOSFET design uses two matched MOSFETs on the same chip whose threshold voltage outputs are subtracted to measure dose. One MOSFET is made more sensitive to radiation than the other so that the result is an output which is independent of temperature.

d) **Energy** - MOSFET chips are so small and their packaging material is minimal (< 1mm) that the MOSFET's response is independent of energy. The same MOSFET may be used for all energies and modalities (e.g. electrons and photons). It is left to the physicist to add appropriate build-up materials where required (usually flexible bolus).

The above advantages of the MOSFET are among the reasons they are being used, not only in routine in-vivo dosimetry, but also in the more advanced treatment techniques such as brachytherapy and 3-D conformal treatment. Isotropic response and small size are the features that are important for all in-vivo dosimetry and essential for brachytherapy and 3-D treatments such as IMRT.