Review of Intravascular Brachytherapy Physics for Prevention of Restenosis

Howard Amols, Memorial Sloan Kettering Cancer Center, New York, NY

Intravascular Brachytherapy (IVB) is rapidly gaining acceptance as a new treatment modality for reducing restenosis and improving the success rate of PTCA. Some clinical studies report reductions in restenosis of up to 70%. IVB confronts the medical physicist with an array of new problems including:

- Safely introducing high activity radioactive sources into the cardiac catheterization laboratory.
- Assessing the multitude of radiation delivery systems such as catheter based seeds and wires, radioactive stents, gas and liquid filled radioactive balloons, gamma versus beta isotopes, miniature x-ray tubes, etc.
- Determining dose with sub-millimeter accuracy at distances $\leq$2 mm from a brachytherapy source.
- Utilizing treatment planning information from `unfamiliar' imaging systems such as Intra-Vascular Ultra Sound (IVUS) and Angiography.

The dosimetric requirements for IVB can be summarized as follows:

- Single fraction dose of 8-40 Gray to a 2-5 cm length of arterial wall, approximately 2-4 mm inner diameter, 0.5-3 mm wall thickness.
- Minimize dose to normal tissues and to cath lab staff.
- Dose rate >2 Gy/min (to keep treatment time <10 minutes).
- Radioactive source design suitable for use with cardiac catheters.

We estimate the `biological dose window' for IVB to be 8-40 Gy; with 8 Gy the minimum curative dose, and 40 Gy the normal tissue tolerance. Thus, the dose falloff from the radiation source must be no more than 40Gy/8Gy over the thickness of the vessel wall. If the dose falloff is more severe then it will not be possible to deliver 8 Gy of radiation to the adventitia without exceeding 40 Gy to the lumen wall. This biological window (if true) is a key issue for IVB dosimetry.

These dose requirements are best met by a low energy (<100 keV) photon emitter with activity >1 Ci. This would provide the best dose fall off, and is easily shielded by a few millimeters lead. No such source currently exists. Thus, all IVB trials utilize alternative sources:

- Ir^{192} (7 de-excitation gammas with energies 296-612 keV).
- Beta minus emitters, such as P^{32}, Sr^{90}, Y^{90}, W^{188}, Re^{188}.
- One of several `exotic' dose delivery systems.

Ir^{192} provides an ideal dose distribution, but the high gamma energy presents radiation safety concerns. Beta emitters simplify radiation safety, but may not provide adequate depth dose penetration. In a typical IVB geometry, dose decreases by approximately 35% per millimeter for Ir^{192} and by nearly 70% for P^{32}. Beta safety versus gamma depth penetration defines the great `gamma vs. beta debate' in IVB. The search for the `ideal isotope' continues. Other more `exotic' dose delivery systems are also being tested, such as:

- radioactive stents.
- radioactive gas and liquid filled balloons.
- radioactive coated balloons.
- miniature x-ray tube for catheter insertion.
- teletherapy photon beams.
- intravascular laser therapy.

Educational Objectives:

1. Discuss the clinical and biological criteria which determine radiation dose and isotope selection.
2. Discuss and compare different radiation delivery systems and isotopes being used to treat restenosis.
3. Discuss techniques for dose calculations and source calibration.