A Monte Carlo Study of the Out-of-Field Dose from IMRT

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Introduction:

The study of dose outside of the treatment field is important for evaluating the potential for late effects. Determining the out-of-field dose can be done through measurements, however, such measurements are time consuming, may be difficult, and are specific to the irradiation conditions and phantom used. Monte Carlo may be a viable tool for studying the dose outside of the treatment field. We previously developed a Monte Carlo model of a Varian 2100 accelerator head and treatment vault. It was shown that head leakage and collimator scatter could be simulated with good accuracy for square fields incident on a rectangular acrylic phantom. To be clinically useful, the Monte Carlo model must be shown to be much more versatile. To this end, the delivery of low- and high-energy intensity-modulated radiation therapy (IMRT) was simulated, incident on an anthropomorphic phantom.

Materials and Methods:

The Monte Carlo model of a Varian 2100 accelerator was developed in MCNPX (1). The delivery of step-and-shoot IMRT for the prostate was simulated on a segment-by-segment basis using treatments developed in Corvus v4.6 at both 6 MV and 18 MV. The treatment plans were developed for a Rando phantom, a complete CT data set of which was imported into MCNPX using the software Scan2MCNP (White Rock Science, Los Alamos NM). The out-of-field photon and neutron dose equivalent were calculated throughout the Rando phantom at locations corresponding to organs, focusing on those sensitive to second cancer induction. The calculated out-of-field doses were compared to doses that we previously measured for these same two treatment plans (6 MV and 18 MV IMRT) physically delivered to the Rando phantom (2).

Results:

The calculated out-of-field photon dose resulting from 6 MV IMRT of the prostate is shown in Figure 1 for numerous organs of interest as a function of distance from the central axis. This figure also shows our previous measurements of the dose from the same therapy (2). The figure insert shows the absolute percent difference between the measured and calculated doses. The average absolute difference between the measured and calculated doses was 14%, with a systematic tendency to underestimate the dose.

The calculated out-of-field photon dose resulting from 18 MV IMRT of the prostate is shown in Figure 2. This figure also shows our previous measurements of the photon dose from the same therapy (2). The figure insert shows the percent difference between the measured and calculated doses. The average absolute difference between the measured and calculated doses was 13% and there was no systematic difference.

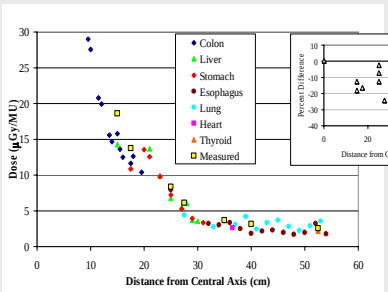

Figure 1. Out of field photon dose from 6 MV IMRT. Calculated dose to various organs as well as previous measurements (2). Insert shows percent difference between calculations and previous measurements.

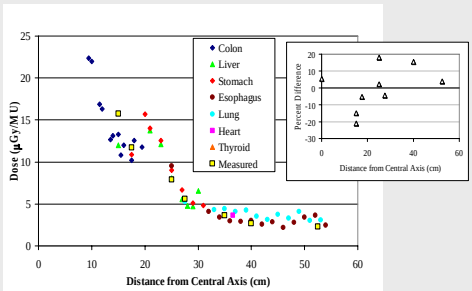

Figure 2. Out of field photon dose from 18 MV IMRT. Calculated dose to various organs as well as previous measurements (2). Insert shows percent difference between calculations and previous measurements.

The calculated out-of-field neutron dose equivalent resulting from 18 MV IMRT of the prostate is shown in Figure 3. Previous measurements are not shown on this figure because substantial disagreement was found between the calculated and measured values. Table 1 shows the calculated values from the current study as well as our previous measurements (2) and measurements from 2 similar studies (3, 4) that also examined 18 MV IMRT of the prostate using a Varian 2100 accelerator. The very wide range of dose equivalents illustrates that measurement of the neutron dose equivalent at specific points within a patient is highly uncertain.

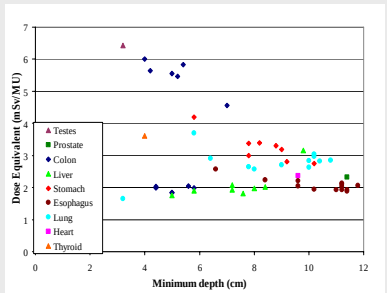

Figure 3. Out-of-field neutron dose equivalent from 18 MV IMRT. Calculated dose to various organs.

The results of the Monte Carlo model are lower than those we measured previously. This difference results primarily from the dependence of the measured dose equivalent on the average neutron energy. For our previous measurements, we used the neutron energy recommended by the NCRP (Report 79), which appears to overestimate the neutron energy and therefore leads to an overestimation of the neutron dose equivalent.

Based of the large uncertainty in neutron dose equivalents found in the literature, our Monte Carlo model is not inconsistent with measurements, even though there was discrepancy with our previous measurements. Clearly the issue of neutron dose equivalent requires further study.

Study	Average Organ Dose (μSv/MU)							
	Colon	Liver	Stomach	Esophagus	Lung	Thyroid	Testes	20 cm
Current	3.7	2.1	3.2	2.1	2.8	3.6	6.4	-
Ref 2	12.0	11.0	11.1	7.0	9.1	12.7	-	-
Ref 3	1.9	2.7	1.2	0.5	0.6	17.0	25.7	-
Ref 4	-	-	-	-	-	-	-	6.6

Table 1. Neutron dose equivalent calculated in the current study and measured in studies in the literature from 18 MV IMRT. The average organ dose is presented except for Ref. 4, which presented the neutron dose equivalent at 20 cm from the edge of the treatment field.

Conclusions:

The Monte Carlo model was found to be fairly accurate for calculating the out-of-field photon dose, and within the wide range of published values for calculating the out-of-field neutron dose equivalent. This was true even for complex therapies incident on a complex phantom. Such a model would therefore be a useful tool for evaluating the out-of-field dose received by patients undergoing radiotherapy. This may be useful for determining the dose to sensitive structures such as the fetus in a pregnant patient, or it may be useful for estimating the risk of late effects such as secondary malignancies.

The Monte Carlo model also helped illustrate the large uncertainty that exists in neutron dose equivalents at specific points within the patient. This issue warrants further study.

References:

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