AN EVALUATION OF COMMERCIAL TREATMENT PLANNING SYSTEMS WHEN CALCULATING DOSE UNDER SHIELDING BLOCKS

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ABSTRACT

Several commercial computerized treatment planning systems were compared when calculating dose under shielding blocks in soft tissue and lung tissue. A test case was studied in which a water-equivalent phantom containing a removable cork insert was exposed to ^{60}Co radiation with and without a lead block in the beam. For simplicity, all cross sections were square and only central axis doses were considered. Manufacturers of treatment planning systems were asked to calculate doses for the test case for comparison with corresponding experimental values determined from ionization chamber measurements. When the initial replies seemed to indicate the existence of errors or misinterpretations, the manufacturers were informed and asked to submit revised values. The results for eight systems demonstrate that their predictions of the doses under the block differ appreciably. Furthermore, most of the systems did not take into account patient density and shielding simultaneously. Although the actual dose differences are small when expressed in absolute terms and the clinical significance of these deficiencies may be debated, one would expect better accuracy and more of a consensus when elaborate computer systems dedicated to radiation therapy deal with a relatively simple problem. The results emphasize the need for verification of all computational options by users of treatment planning systems before they are implemented for routine work.

KEY WORDS

Radiation therapy, Treatment planning, Computerized treatment planning, Dosimetry.

INTRODUCTION

Radiation oncologists and physicists have recently shown increasing interest in treatment plans that take into account variations in density within the patient, in particular when lung tissues are included in irradiated volumes.[4] Absorbing blocks are often superposed in the radiation beams in such cases to shield all or part of the lungs. The physician may wish to know the magnitudes of the residual doses in shielded regions and how the dose behaves near block edges. For answers to these questions, it is natural to turn to computerized treatment planning systems, which are designed to calculate dose for a wide range of clinical applications. On the basis of many years of experience, there is general confidence that, given appropriate beam and patient data, the algorithms used by these systems are capable of producing accurate isodose distributions for combinations of photon beams in homogeneous patients. However, methods of correcting dose calculations for patient density and shielding have not been as well tested.

We have undertaken a study to evaluate the abilities of commercial treatment planning systems to handle situations in which shielding blocks and patient density variations exist concurrently, a combination not included in previously reported investigations of treatment planning systems.[1,3,5] In an earlier paper, we presented preliminary results for a test case involving

^{60}Co radiation, a cork inhomogeneity in a water-equivalent phantom and a lead shielding block.[6] For simplicity all the cross sections were square and only central axis doses were considered. In spite of the basic nature of the test, relatively large differences were noted in the dose values supplied by four manufacturers. In this work we give the results of an expanded survey for the same test case in which eight systems are represented.

METHODS AND MATERIALS

Test Case

Figure 1 shows the set-up of the test case. The phantom consisted of water-equivalent slabs with a cork insert (relative density 0.3) 10x10x20 cm^3 in size to simulate a lung. A 5x5x5 cm^3 lead block was supported by a Lucite tray 0.5 cm thick at a height of 38 cm from the phantom surface. The field size was 20x20 cm^2 and the SSD was 80 cm. The radiation source was ^{60}Co to allow the use of standard dosage data in the computations.

The manufacturers were asked to perform calculations of dose in the test phantom at three depths on the central axis of the beam under the following conditions:

1. Water-equivalent phantom.
2. Water-equivalent phantom with cork.

3. Water-equivalent phantom with lead block.
4. Water-equivalent phantom with cork and lead block.

Normalization was specified in terms of the dose at depth 0.5 cm in the water equivalent phantom.

Corresponding experimental values were obtained from ionization chamber measurements in the phantom. The ratios of the ionization chamber readings are a good approximation to the dose ratios.[7]

Calculation of Dose

For comparison with the treatment planning systems, we calculated the doses using a simple model based on the separation of radiation beams into primary and scattered components.[2] The following formulae were used.

Dose in unshielded water:

$$D_W(d)/D_{air} = TAR(d, W_d) \qquad (1)$$

Dose in unshielded cork:

$$D_C(d)/D_{air} = CF \times TAR(d, W_d) \qquad (2)$$

Dose in water under the block:

$$D_{WB}(d)/D_{air} = T \times \{TAR(d,0) + SAR(d,shadow)\} + SAR(d,open) \quad (3)$$

Dose in cork under the block:

$$D_{CB}(d)/D_{air} = T \times CF \times \{TAR(d,0) + SAR(d,cork)\} + T \times \{SAR(d,shielded\ water)\} + SAR(d,open) \quad (4)$$

where

- d is depth in the phantom.
- D_{air} is the reference dose in air at the point in space corresponding to depth d.
- W_d is the equivalent field width at depth d.
- TAR(d,0) is the tissue-air ratio at depth d for a field of zero area.
- The SAR's are scatter-air ratios at depth d, evaluated for the regions designated in the parentheses.
- T is the transmission factor of the lead block.
- CF is the density correction factor.

When applied to the shielded heterogeneous phantom, the model is rather crude and ignores effects such as decreased attenuation in the cork of radiation scattered from the water.

Since all the cross sections are square in this example, the required SAR's can be taken from standard TAR tables for ^{60}Co. When the conventional effective source-skin distance (ESSD) or Batho power low TAR methods are used to compute the density correction factors, the formulae can easily be evaluated manually. To use the more general equivalent TAR (ETAR) method, a computer is required.

Systems Included in the Survey

The major manufacturers of computerized treatment planning systems were contacted by mail or at their booths at equipment exhibitions and asked to participate in the study. Those who responded before the manuscript was completed are listed below in alphabetical order.

Company	System
ADAC	RTP
Atomic Energy of Canada	Theraplan
Capintec	Cap-Plan
Computerized Medical Systems	Modulex/RTP
General Electric	RT/Plan
Philips	Oncology Support
Picker International	Synerplan ARP
Siemens	Sidos

The participants were given an opportunity to submit revised values when their original ones seemed to indicate the occurrence of errors or misinterpretations of the problem.

RESULTS

The results of the measurements and calculations are summarized in Table 1. The variations in central axis depth dose values indicate that different beam data were employed by the different systems. Since a fair evaluation should be based on identical basic data, the comparisons are presented anonymously and only to illustrate general trends. Not all the manufacturers provided descriptions of their algorithms and full details on the test case calculations. For uniformity, no such information is included in the table.

For the unshielded heterogeneous phantom, the ESSD and ETAR correction factors are similar in this example and the ratios of dose in cork to dose in water (C/W) are consistent with these methods for all of the systems except for system 7 which used the Batho method. Results for both the ESSD and Batho methods were supplied for systems 2 and 5 and, in the latter case, ETAR values were included as well. When multiple results were submitted, the "best" set, i.e., the one closest to the experimental findings was selected. When compared with the measurements, the ESSD corrections tend to overestimate the dose and the Batho corrections tend to underestimate it, while the ETAR method is somewhat more accurate. This is in agreement with previously reported results for lung inhomogeneities having cross sections smaller than the beam area.[8,9]

In the presence of the shielding block, a large spread in the magnitudes of the calculated dose ratios is apparent for both the homogeneous and heterogeneous phantoms. Although the general differences are reduced if only revised values are included, the range of the variations still remains appreciable, with the maximum and minimum values for the same conditions differing by a factor of two.

Some of these variations may be due in part to different choices of transmission factors and different ways of specifying the position of the block. Quoted values of transmission factors ranged from .036 to .067. Our calculations are based on a transmission factor of .056, which was measured in air for the test geometry. Since the transmitted dose is small, dependence on the transmission factor is relatively weak. To illustrate this, the relative contributions of the different dose components were calculated for the water phantom using equation 3. The results show that the most important component is scatter from the unshielded part of the irradiated volume (Table 2). The maximum difference in the shielded dose corresponding to the above limits in the transmission factor is about 30%. Neglect of absorption in the Lucite tray will lead to an error of about 3%.

Since the edges of the actual block are not shaped to conform with ray lines, the size of the projected shadow depends on how the block elevation is defined. The block cross section may be specified at locations from the top to the bottom of the block. The dose difference for the two extremes is about 10%. In our calculations, the block cross section was taken at the middle of the block.

When cork replaces water under the block, the dose on the axis should increase because of decreased attenuation of primary and scattered radiation in the cork. This increase is seen in our measured and calculated results although, as expected, the simple model accounts for it only partially. Only systems 1, 8 and 5 show an enhancement of dose in the shielded cork. For the latter system, the computed magnitude of the effect is different for each of the 3 correction methods, ranging from nonexistent for the ESSD method to maximum for the Batho method. The ETAR results are listed. The original results for systems 4 and 7 also demonstrated the increase, but the revised values no longer do so, even though they are better in other respects.

CONCLUSIONS

In a test of eight commercial computerized treatment planning systems, it has been shown that they differed appreciably when calculating central axis dose under a shielding block in homogeneous and heterogeneous phantoms irradiated by a ^{60}Co beam. Most of the systems did not take into account patient density and shielding simultaneously. While in relative terms, the dose differences for the shielded phantoms are large, the absolute dose differences are small and their clinical importance may be debated. Notwithstanding, one would expect better accuracy and more of a consensus when elaborate computer systems dedicated to radiotherapy deal with a relatively simple application. These results emphasize the need for verification of all computational options by users of treatment planning systems before they are implemented for routine work.

Table 1

Summary of Measured and Calculated Dose Ratios for the Test Ca

	d=10 cm				d=15 cm				d=20 cm			
	CADD	C/W	B/NB	B/NB	CADD	C/W	B/NB	B/NB	CADD	C/W	B/NB	B/NB
Source	W	NB	W	C	W	NB	W	C	W	NB	W	C
Author	60.8	1.09	.13	.14	45.0	1.23	.16	.20	32.5	1.46	.20	.26
Author	–	1.14	.15	.16	–	1.32	.19	.21	–	1.52	.22	.24
Author	–	1.02	.15	.16	–	1.16	.19	.20	–	1.33	.22	.23
Author	–	1.11	.15	.16	–	1.29	.19	.20	–	1.49	.22	.24
Syst. 1	60.5	1.14	.12	.14	44.4	1.33	.12	.16	32.5	1.56	.12	.18
Syst. 2	59.0	1.14	.15	.14	43.0	1.33	.19	.19	32.0	1.53	.22	.22
Syst. 3	63.0	1.11	.13	.11	48.0	1.27	.15	.15	35.0	1.49	.20	.17
Syst. 4	61.1	1.13	.10	.14	46.6	1.26	.09	.17	33.6	1.49	.09	.22
Syst. 4	59.5	1.10	.16	.14	43.4	1.30	.19	.18	31.7	1.50	.24	.24
Syst. 5	60.8	1.11	.13	.14	44.7	1.27	.17	.19	32.9	1.46	.21	.23
Syst. 6	60.2	1.14	.24	.22	43.7	1.34	.30	.29	31.8	1.56	.35	.37
Syst. 7	59.5	1.03	.08	.08	43.2	1.18	.09	.11	31.9	1.37	.11	.15
Syst. 7	59.5	1.03	.16	.16	43.2	1.18	.18	.17	31.9	1.37	.20	.19
Syst. 8	60.2	1.10	.15	.17	44.2	1.26	.20	.25	32.6	1.47	.21	.31

Table 1 Notes:

The second row refers to dose ratios and the third row specifies the conditions during the irradiations. The symbols are defined as follows:

CADD = Central axis depth dose

W = Homogeneous water phantom

B = Block in place

NB = No block in place

C = Water phantom with cork insert

ESSD = Effective SSD method for density correction

Batho = Batho method for density correction

ETAR = Equivalent TAR method for density correction

The measured values of CADD are normalized at d = 5 cm to Johns & Cunningham data for ^{60}Co.[2]

Table 2

Contributions to the Dose on the Central Axis in

Water Under the Shielding Block

Dose Components	Relative Contributions		
	d=10 cm	d=15 cm	d=20 cm
Attenuated primary	24%	17%	13%
Scatter from blocked part	9%	8%	7%
Scatter from open part	67%	75%	80%

REFERENCES

1. Constantinou, C., Curran, B., Sternick, E.S.: A comparison of three computerized dose planning systems. (Abstr.) Int. J. Radiat. Oncol. Biol. Phys. 11, Supp. 1:218, 1985.

2. Johns, H.E., Cunningham, J.R.: The Physics of Radiology, 4th ed. Springfield, IL, Thomas, 1983.

3. McCullough, E.C., Krueger, A.M.: Performance evaluation of computerized treatment planning systems for radiotherapy: External photon beams. Int. J. Radiat. Oncol. Biol. Phys. 6:1599-1605, 1980.

4. Orton, C.G., Mondalek, P.M., Spicka, J., Herron, D., Andres, L.: Lung corrections in photon beam treatment planning: Are we ready? Int. J. Radiat. Oncol. Biol. Phys. 10:2191-2199, 1984.

5. Rosenow, U.: An intercomparison of commercial treatment planning systems based on standardized field data and prescribed treatment plans. Proceedings of the Sixth International Conference on the Use of Computers in Radiation Therapy. Gottingen, West Germany, pp. 777-793, 1977.

6. Tatcher, M., Palti, S.: Dose in lung tissue under shielding blocks: A comparison of calculations by commercial systems with measurements. Proceedings of the Eighth International Conference on the Use of Computers in Radiation Therapy. Toronto, Canada, 1984.

7. Tatcher, M., Palti, S.: Evaluation of density correction algorithms for photon beam dose calculations. Radiology 141:201-205, 1981.

8. Tatcher, M., Palti, S.: A simple equivalent tissue-air ratio method for calculating absorbed dose in a heterogeneous medium. Radiology 146:527-529, 1983.

9. Van Dyk, J., Battista, J.J., Rider, W.D.: Half-body radiotherapy: The use of computed tomography to determine the dose to lung. Int. J. Radiat. Oncol. Biol. Phys. 6:463-470, 1980.

LEGEND

Fig. 1 Phantom set-up.

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