OPTIMIZATION OF DOSE DISTRIBUTIONS IN INTRAOPERATIVE HDR BRACHYTHERAPY

Bulski W[1], Kawczynska M[1], Łyczek J[2], Olszewska A[1]

[1]Medical Physics Dept. and [2]Brachytherapy Dept., M. Skłodowska-Curie Memorial Centre of Oncology, Roentgen str.5, 02-781 Warsaw.

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ABSTRACT

The authors present their initial experience in physical aspects of treatment planning in HDR intraoperative brachytherapy. The examples are given of implantations in various tumour localizations: head and neck, pancreas, soft tissue sarcomas in the abdomen. The technical and dosimetric problems which may occur in such situations are discussed. The capabilities of dose distribution optimization by the Abacus HDR treatment planning system are presented.

INTRODUCTION

Intraoperative radiotherapy (IORT) is a promising modality with which it is possible to increase tumour dose and, therefore, tumour control, without increasing therapy-induced morbidity. It has the distinct advantage of directly irradiating the tumour bed, while eliminating the surrounding normal tissues and organs from the field of treatment. The combination of maximal tumour irradiation and minimal normal tissue irradiation can maximize the therapeutic ratio and the efficacy of the treatment. Intraoperative radiotherapy is especially useful when the required radiation dose exceeds the tolerance dose of the surrounding normal tissues.

However, the application of IORT with external beams has been significantly limited by cost, logistic issues, and technical problems. On the other hand, intraoperative brachytherapy makes it possible to deliver treatment to difficult anatomic areas. The high dose rate (HDR) afterloading brachytherapy is a very suitable method, being cost effective, logistically sound, and suitable for a wide range of anatomic sites (Verniers, 1992). The inherent possibilities of remote afterloading HDR techniques offer several important advantages over conventional LDR techniques. They improve radiation protection of the medical and nursing staff, and significantly facilitate the optimization of dose distribution.

The intraoperative HDR brachytherapy in most cases is performed as a multi-fraction irradiation when the HDR catheters are placed and sutured to the tumour bed during the surgery and left there with their open ends sticking out through the surgical scar. Several days after the surgery, when the post surgery swelling has stabilized, the actual catheter position may be accurately established by radiography and irradiation may be planned.

The intraoperative brachytherapy applications in our department are limited so far to pancreatic tumours, soft tissue sarcomas, and head and neck tumours. The aim of this paper is to present our initial experience in physical aspects of treatment planning and dose distribution optimization in HDR intraoperative brachytherapy.

MATERIALS AND METHODS

Since 1996 we have treated intraoperatively over 50 patients for pancreatic tumours, soft tissue sarcomas, and head and neck tumours. All the irradiations were performed using the Gammamed 12i stepping source afterloader with the Ir-192 source provided by the Isotopen-Technik Dr.Sauerwein GmbH. The activity of the source was between 10 Ci (new source) and 5 Ci (before source replacement). The treatment times ranged between 5 - 15 minutes per fraction.

Dose distributions were calculated and optimized using the Abacus 1.6 treatment

planning software from the same company. 3-D dose volume histograms (DVH) were used for comparison of various treatment plans. A detailed analysis of the functioning of the optimization algorithm will be the topic of another paper.

Pancreas

Intraoperative interstitial brachytherapy has been used during laparotomy for tumours localized in the pancreas. The volume to be implanted is determined by measuring three mutually perpendicular dimensions of the tumour during laparatomy [Bodner, 1997]. The extent of the tumour is marked by surgical clips. Flexible guide tubes are used. The size and shape of the tumour determine the number of catheters. The catheters are inserted into the pancreatic tumour and are as parallel to each other as possible. The optimal distance between the catheters is approx. 1 cm but in clinical situations in most cases it is impossible to fix them parallel to each other. The catheter localization was done by two orthogonal X-ray films and CT examination. The target volume was defined as a volume including all surgical clips with a 1 cm margin. In a group of 30 patients treated this way, the tumour dose was 30 Gy in daily fractions of 3 Gy in a continuous regime (including week-end). Seven days later, brachytherapy was followed by a radio-chemotherapy treatment , with the external beam tumour dose of 45 Gy, combined with two 5 day courses of 5Fu as a radiosensitizer. In most cases, a three field technique was used: one frontal field and two lateral wedge fields.

Head and Neck

When cancer recurs in an area of earlier radiation, further external beam irradiation is usually impossible. Salvage surgery alone has a low curative potential and, therefore, should be combined with interstitial intraoperative brachytherapy (Harrison, 1997). Because of the specific anatomical situation, precise intraoperative tumour volume definition is very difficult. In these regions, large margins (2.5 cm) around the resected area should be irradiated. Flexible guide tubes are implanted parallel to each other with a 1.5 cm distance between them. The day after the operation the localization of the catheters is established by two orthogonal X-ray films. Target volume delineation is based on the pre-surgery CT examination, check films and intraoperative examination. In a group of 12 patients treated up till now, a tumour dose of 40 Gy was delivered in 3 Gy fractions two times a day with a 6 hour interval (13 fractions in 7 days).

Soft tissue sarcomas (STS)

In STS two different clinical situations occur. When the tumour is localized in the extremities, the target volume delineation is relatively easy. The tumour bed after primary tumour resection should be encompassed by the isodose corresponding to the curative dose. The number of catheters is determined by the size of the tumour bed and in most cases it is possible to place them fairly parallel to each other and in equidistant positions (Harrison, 1993). When the STS is localized in the extraperitoneal region it requires a cyto-reductive operation and careful placement of surgical clips. Target delineation is based mainly on the orthogonal X-ray films, CT scans and intraoperative examination. The margins should be as large as possible, a limiting factor being the neighbouring late reacting organs at risk [Hilaris, 1997]. Dosage and fractionation in our group of 9 patients were individualized according to the clinical and histological situation and to previous radiotherapy treatment.

DISCUSSION

Once the catheters are placed in the patient, stepping source brachytherapy offers two degrees of freedom: the dwell position and the dwell time. Usually the dwell positions are placed in the sections of the catheters, which are inside the target volume. Then optimization of the dose distribution is performed by manipulation of the dwell times by dedicated software. Because brachytherapy radiation begins within two-three days after the operation, it gives the physicist enough time to work out an optimal treatment plan. The optimized isodose distribution should match the requirements specified by the physician and fulfil the recommendations of the ICRU on dose and volume specifications for reporting interstitial therapy (ICRU, 1997).

Despite the efforts of radiotherapists to follow the rules of proper catheter placement during the implantation procedure, in numerous cases the resulting distribution of catheters is far from being ideal. According to our experience, the HDR treatment planning may pose certain technical problems. The eventual position of the catheters may differ from that planned, some of the catheters may get bent to such an extent that the source cannot be entered into them, etc. In Figs. 1 and 2 we show two pancreatic tumour implants. One implant follows relatively well the rules of the Paris System, while the other clearly does not. Fig. 3 presents the dose distribution in 3D for the latter implant, which was attained thanks to the

optimization procedures of the Abacus treatment planning system. The optimization is based on a set of predefined dose points at the borders of the target volume which are supposed to receive a predefined dose. The dose points are automatically generated by the planning software at equal distances from peripheral catheters.

The mathematical optimization, called optimization on distance, aims at determining the dwell positions and relative dwell times such that the reference isodose surface passes through these dose points (Van der Laarse, 1991). The 1.6 version of the Abacus planning software provides the option of entering additional user-defined dose points inside the target volume, which improves optimization capabilities.

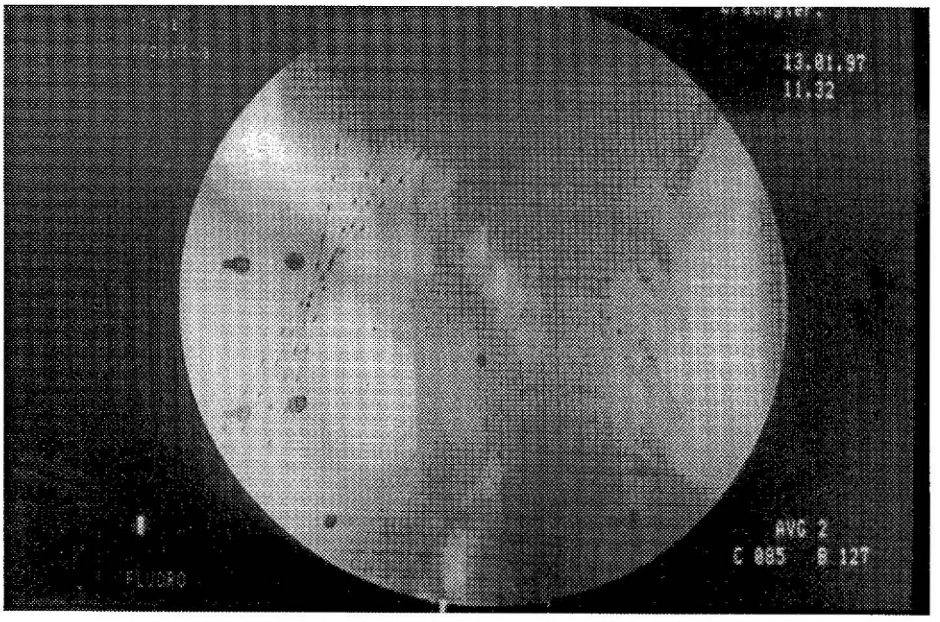

Fig. 1. Pancreatic tumour implant. The catheters are fairly parallel to each other. It is relatively easy to get a fomogeneous dose distribution.

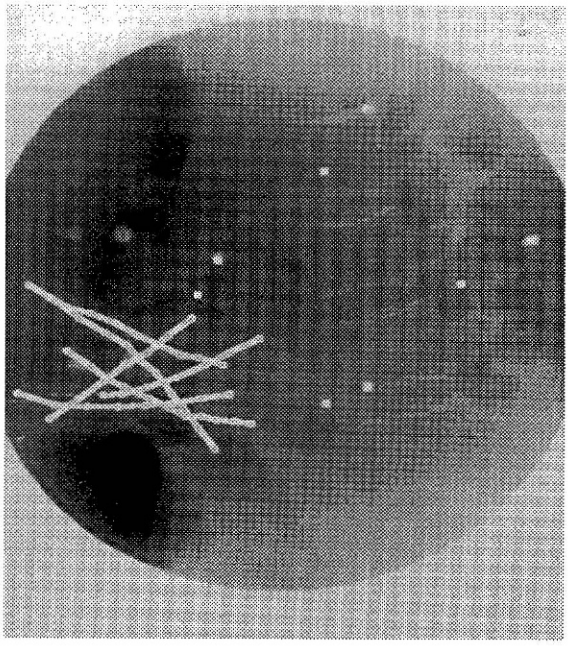

Fig. 2. Pancreatic tumour implant. Six catheters within the target volume are clearly not parallel to each other, which largely complicates the optimization of the dose distribution.

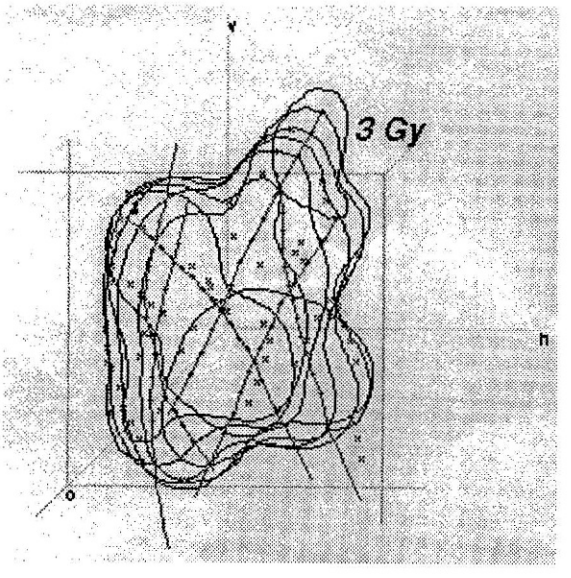

Fig. 3. The dose distribution in 3-D for the implant presented in Fig. 2. The optimization procedures of the planning software made it possible to get quite satisfying dose distribution for a relatively irregular implant. The 3 Gy isodose surface is presented together with the position of catheters (red) and reference points (blue).

The next set of illustrations presents an example of the brachytherapy of the STS in the abdominal region. Five guide tubes were implanted fairly parallel to each other. However, it turned out that one of them was too tightly sutured and the source could not enter into it. The treatment plan had to be prepared for four out of five catheters. The optimization was still based on the dose points as defined for the five catheter implant.

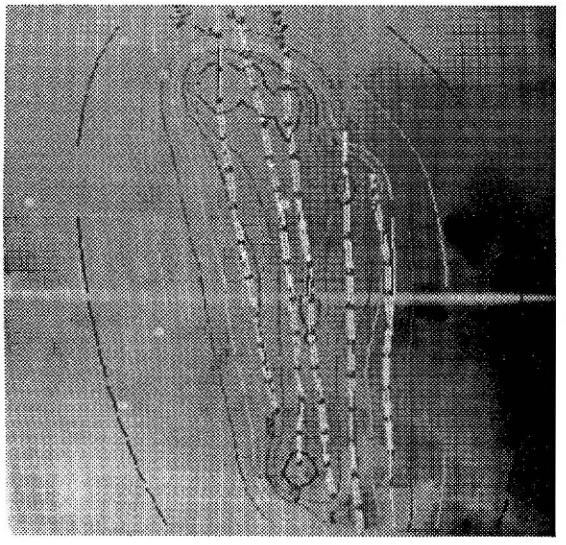

Fig. 4. Soft tissue sarcoma (STS) implant in the abdominal region. Five catheters are implanted fairly parallel to each other. One of the catheters, too tightly sutured, did not let the source in. Later, during the treatment, the second catheter became unusable and the treatment had to be re-planned. The position of active and inactive catheters is shown in Figs. 5 and 6.

The resultant dose distribution is presented in Fig. 5. After several fractions the situation became even worse because one more catheter became unusable. The treatment had to be re-planned and the resultant dose distribution is presented in Fig. 6. The reference isodose still encompasses the target volume. The analysis of the 3-D DVH's for the two plans shows that the volume encompassed by the 1.5 Gy isodose (reference isodose optimized to the same set of predefined reference points) increased only by 5% and that of 1 Gy isodose by 7.5%. The volume of 2.25 Gy isodose (150% of the reference dose) decreased by about 1% and the volume of 3 Gy isodose decreased by 7%. This proves the versatility of the Abacus optimization procedure. The relatively small changes in dose homogeneity are not likely to cause any late complications.

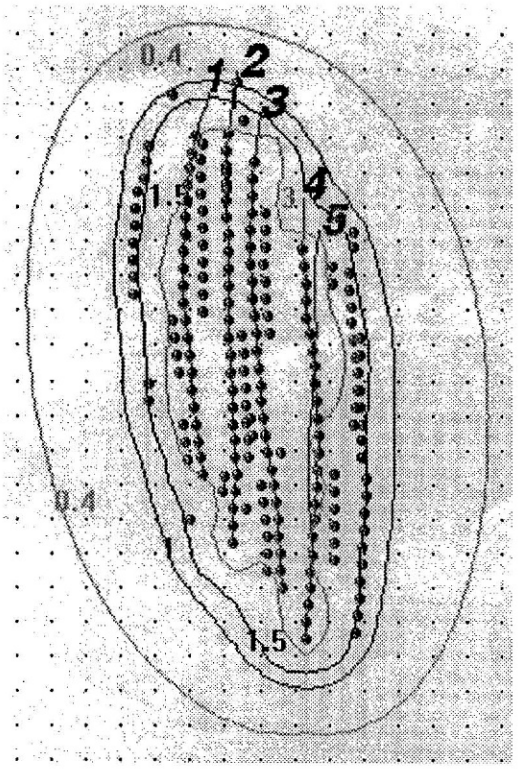

Fig. 5. The dose distribution for the implant presented in Fig. 4. Four out five catheters (1, 2, 3, 4) are used for treatment. The reference isodose of 1.5 Gy covers the target volume.

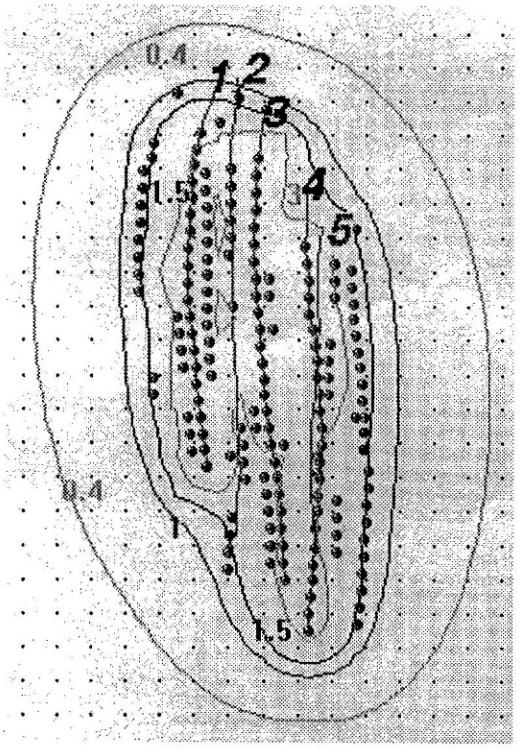

Fig. 6. The dose distribution for the implant presented in Fig. 4. Three out of five catheters (1, 3, 4) are used for treatment. The reference isodose of 1.5 Gy still encompasses the target volume. The difference in homogeneity is discussed in the text.

To summarize, it should be emphasized that the quality of brachytherapy applications depends on the choice of the target volume, dose distribution homogeneity, and on radiation injury to critical tissues. The individual adjustment of the dose shape to the target volume by careful treatment planning is essential for better treatment quality. Imaging methods play a significant role in planning procedures. In order to define the target volume properly various imaging techniques may be used: orthogonal X-rays, CT, etc. The dose distribution calculations should be performed in 3-D for better evaluation of the treatment plan. However, one should bear in mind that with all the computer power, display techniques and optimization methods available, the degree to which a brachytherapy implant will be effective is determined not by how well the implant is optimized, but how well the physician has physically placed the catheters or applicators. The optimization software cannot provide a good dose distribution around a badly placed implant.

CONCLUSIONS

1. If the placement rules for the catheters of a given target volume are not adhered to, it is difficult, if not impossible, to obtain a good dose distribution;
2. A mathematically optimized dose distribution does not always represent the best possible distribution in and around the implant, it depends very much on the number and positions of the selected dose points;
3. If an implant is not covering the target volume geometrically, special techniques, manual or mathematical, of changing relative dwell times may be required to cover the target volume with the reference isodose surface;
4. Clinical experience is always required to evaluate the mathematically optimized dose distribution for actual patient treatment.

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