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Original papers

Matched peripheral dose & dose-volume histograms: fusing an old concept with modern technology for brachytherapy prescription

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Modern imaging and dosimetry technology are invaluable for defining a three-dimensional target when tumour can be visualised; it is far more difficult to identify a target volume after the tumour has been excised. The Paris system was devised prior to the introduction of modern high dose rate (HDR) equipment, and cannot utilize the flexibility that it offers. A prescription point, such as 'a depth of 10 mm', is often used as a target surrogate, but the localisation of this 'point' is arbitrary. Small variations in its selection may result in large differences in the delivered dose. We sought to devise a more objective method to prescribe post-excision tumour bed brachytherapy. To achieve this aim, an old concept, ***matched peripheral dose*** *(MPD) was revived, and fused with* ***dose-volume histograms*** *(DVH) generated by modern dosimetry technology. The results are that an objective technique was formulated for retrospectively assessing delivered dose, or prospectively prescribing treatment for tumour bed brachytherapy.*

Key words: matched peripheral dose, dose-volume histograms, HDR brachytherapy, dose assessment

Introduction

Brachytherapy has been revolutionised by modern imaging technology, computer dosimetry, and high dose rate (HDR) delivery systems. It is now possible to image the gross tumour, define a clinical target volume, and deliver radiation to this volume in a highly conformal manner.

Difficulty arises, however, when brachytherapy is delivered after the tumour has been excised. Typically, afterloading catheters are placed in the tumour bed, and the patient is imaged after the surgical wound is closed. As there is no longer a *gross tumour volume* (GTV), definition of a *clinical target volume* (CTV) is highly subjective. We sought a more objective method of prescription when high dose rate brachytherapy is utilised for this situation.

Case report

A 69 year-old man related an eight month history of a slowly growing subcutaneous mass on the medial aspect of his right upper arm. Biopsy was consistent with malignant high grade sarcoma. Magnetic resonance imaging (MRI) of the extremity demonstrated an enhancing soft tissue mass between the biceps and the triceps muscles, adjacent to the neurovascular bundle; its dimensions were 6.5 x 3.5 x 7.8 cm^3. Staging studies were negative for distant disease.

The patient underwent wide local excision of the mass in September 2005. Catheters were placed across the tumour bed (Figure 1a), and the wound closed with a myocutaneous flap (Figure 1b). Surgical pathology confirmed the tumour to be a 5.5 x 4.5 x 3.1 cm^3 malignant fibrous histiocytoma. Although all margins were negative, the deep margin, which was contiguous with the neurovascular bundle, was less than 1 mm.

HDR dosimetry was calculated so that a dose of 450 cGy per fraction was delivered to a depth of 1 cm (Figure 2). Three fractions were delivered over 24 hours, spaced at least six hours apart, beginning seven days after surgery. The catheters were removed without complication following completion of brachytherapy. External beam irradiation to a total dose of 4500 cGy in 25 fractions was begun four weeks after surgery. A simple treatment plan utilised 6 MV photon beams of field size 6.4 cm x 16.3 cm. Treatment was delivered without incident, and there were no wound healing complications or evidence of neurological injury.

Implantation technique & treatment planning

The surgeon outlines the tumour bed with several clips at the time of resection. The radiation oncologist, who is on standby, is summoned to the operating theatre and confers with the surgeon. He/she then places parallel

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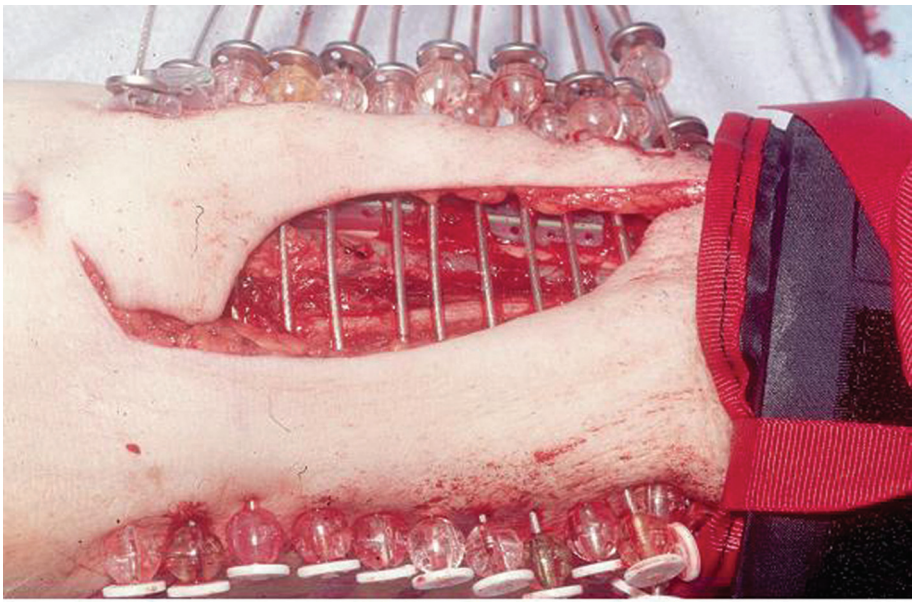

Figure 1a

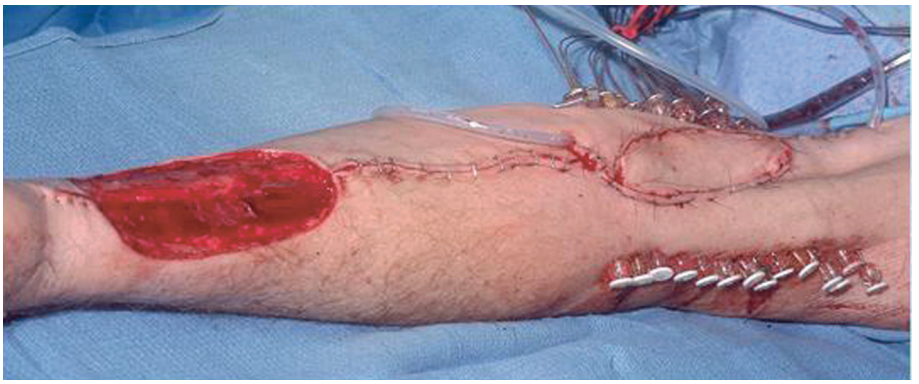

Figure 1b

Figure 1. Example of the intraoperative portion of the treatment. **1a**. Catheters were placed across the tumour bed. Note that they were applied directly over the exposed nerve. **1b**. A flap, harvested from the forearm, was used to close the surgical wound. The site of the flap's origin was repaired by a split-thickness graft. (Note. The case depicted in Figure 1 is not the patient described in the text or Figure 2, but rather a similar case utilised to depict the procedure.)

afterloading catheters across the tumour bed, approximately 10 mm apart. The catheters are arrayed perpendicular to the axis of the limb; each entering and exiting through a separate skin puncture. The most proximal and most distal catheters are placed to bracket the tumour bed by 2 cm. The catheters are stiffened by a wire or plastic filament, to prevent kinking. Securing buttons are tightened after wound closure. Closing the wound with a musculocutaneous flap reduces concern that dwell locations will be too close to the dermis.

The limb undergoes CT scanning within three days of the implant. Wires or dummy ribbons facilitate catheter definition on the scan. The outermost dwell positions on each catheter are placed 1.5-2.0 cm beyond the tumour bed. No dwell position is placed within 1 cm of a skin entry point.

The physicist designs a plan with the intent of achieving a homogeneous dose at 1 cm depth from the implanted catheters, by geometrical optimisation and manual manipulation of the dwell times. This is achieved by the following adjustments of *relative* dwell times [1]. Dwell times are more heavily weighted at each catheter end [2]. All dwell times in the most proximal and distal catheters are more heavily weighted [3]. Weighting of dwell times is adjusted to compensate for regions of suboptimal catheter spacing.

The physicist confirms that the prescription isodose surface forms a slab of roughly 2 cm thickness by converting the cursor to a circle of 2 cm diameter, and placing the circle between the prescription isodose lines.

A simple calculation defines a *standard treatment volume* (STV). The transverse dimensions of the implanted area (average length of the dwell position train in each catheter, multiplied by the average distance between the most proximal and distant catheters) is multiplied by a standard thickness: 2 cm.

A dose-volume histogram (DVH) for the whole dose matrix is calculated, and the plan is normalized, by

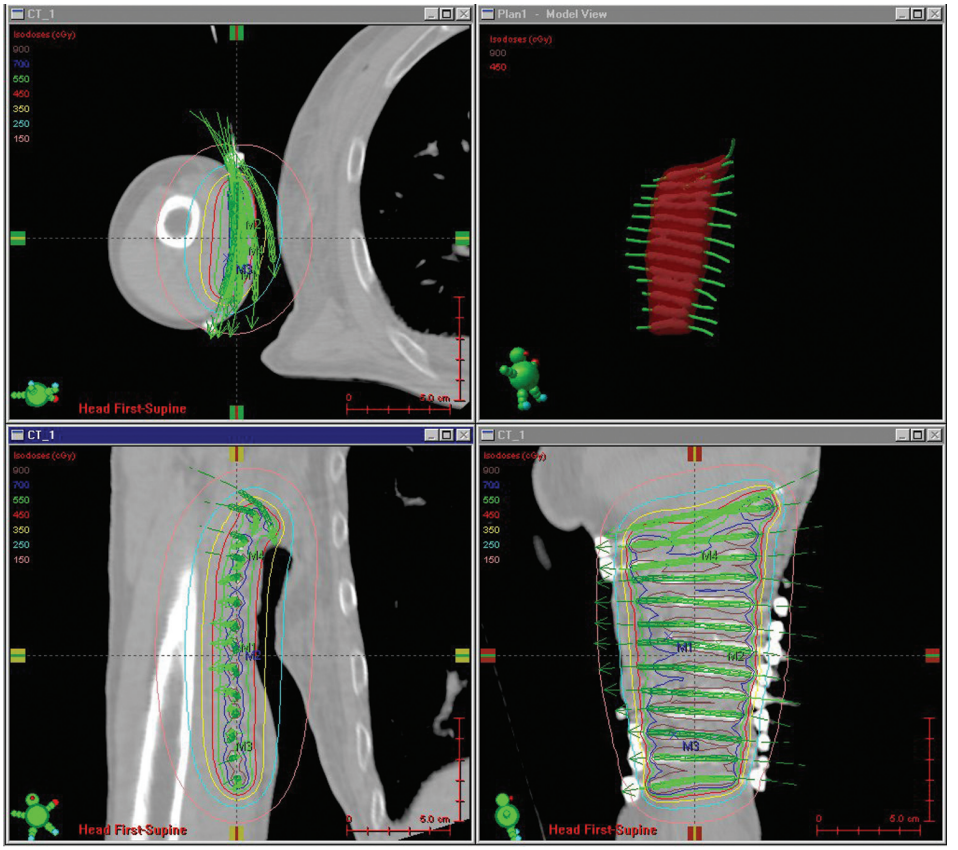

Figure 2. HDR planning. The fractional dose (450 cGy) was prescribed to a target of 2 cm thickness (the red isodose line) which was defined by the surgeon's clips and by the brachytherapist's catheter placement.

adjusting the *actual* dwell times, so that the dose delivered to a volume *equivalent* to the STV equals the prescription dose.

Brachytherapy begins 4-6 days after surgery. Analysis of our experience indicates that 13.5 Gy in three equal fractions or 15.0 Gy in four equal fractions, are safe and effective regimens when brachytherapy is combined with 45–50 Gy external beam therapy [1].

Discussion

Current imaging capabilities are invaluable in defining a three-dimensional target volume when tumour can be visualised. However, post-resection therapy poses the challenge of defining a target volume, and consequently a delivered dose, when the target itself is nebulous. A prescription point, such as 'to a depth of 10 mm' is often used as a surrogate target volume. Nevertheless, the locus in the tumour bed from which the specified depth is to be measured is subjective. As rapid dose fall-off is the hallmark of brachytherapy and the isodose surface of an implant is undulating, small variations in 'point' selection may result in large differences in dose delivery.

The Paris system, devised to prescribe radiation in the face of new technology (small afterloaded sources such as ^{192}Ir) has a built-in method of defining target volume. This is based upon the placement and spacing of the catheters. However, the Paris system's rules specify that linear activity should be uniform among and along source lines [2]. This constraint negates the wonderful flexibility of HDR to manipulate dwell times.

Lowell Anderson recognised this problem decades ago. "If accurate registration of the dose distribution is available with respect to 3D images, it may be possible to determine the target region's minimal peripheral dose, which is generally accepted as the dose of greatest clinical significance. In many instances, however, 3D images of the region ... fail to show clearly the target outline". Anderson proposed a solution, the *matched peripheral dose.* First, he relied on the surgeon to correctly define the tumour bed intraoperatively, and the brachytherapist's appropriate placement of afterloading catheters to adequately bracket the tumour bed. Then, "the matched peripheral dose is defined as the dose for which the contour volume is equal to the volume of an ellipsoid having the same dimensions as the measured, mutually perpendicular dimensions of the target region … In such situations, the matched peripheral dose can serve as a useful approximation to the minimum peripheral dose" [3].

We resurrected Anderson's concept to use with the DVHs generated by modern dosimetry programs. First, we agreed that the tumour bed was best defined by the surgeon at time of resection, and delineated by the placement of clips along the bed's borders. The brachytherapist then determines the target volume by the intraoperative positioning of afterloading catheters. The physicist or dosimetrist then manipulates dwell times and

weighting of peripheral dwell positions more heavily, to generate a homogenous dose distribution. Manipulation of weighting is also used to partially compensate for uneven catheter spacing.

A standard thickness of 2 cm (1 cm deep on either side) is specified for all our planar implants. By multiplying the average width by the average length of the dwell positions, the area of the implant is calculated in the plane of the catheters. The STV is defined by multiplying this area by a standard target thickness which, in our institution is taken to be 2 cm. We then adjust dwell times so that the prescribed dose is delivered to a volume equivalent to the STV.

Purists would argue that this technique delivers dose to an artificially created volume that may have no bearing to the true tumour volume. However, if the surgeon, brachytherapist, and dosimetrist have performed well, an ellipsoid isodose will be delivered to the best possible estimation of the target.

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