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● *Technical Innovations and Notes*

DOSIMETRIC PROPERTIES OF MEGAVOLTAGE GRID THERAPY

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Purpose: Grid therapy is a technique used to deliver a high dose of radiation (15–20 Gy) in a single fraction to many small volumes within a large treatment field. This treatment modality is used for the palliative treatment of large, deeply seated tumors, which have either been treated to tolerance with conventional radiation, or, due to massive tumor bulk, would most likely not benefit from a conventional course of radiation therapy. As the dose distribution from megavoltage grid therapy differs significantly from that of conventional radiation therapy (i.e., many large dose gradients exist within the tumor volume), we have measured various dosimetric properties inherent in this unique treatment modality.

Methods and Materials: The grid is a 16 × 16 array of 1-cm diameter holes in a 7-cm thick piece of custom blocking material. The ratio of shielded to open surface area is 1:1. Depth dose, valley-to-peak ratios, and output factors for this square array grid were measured in a water phantom for several field sizes, as well as for a 1-cm diameter narrow beam using 6 MV and 25 MV photon beams.

Results: The depth dose curves for the grid fields lie between those for an open portal and a narrow beam. For the 6-MV beam at d_{max}, the ratios of the doses delivered to the center of the shielded regions to that under the center of the holes, expressed as valley-to-peak ratios, range from 15 to 40%. At 10 cm, the ratios increase to between 25 and 45%. At 25 MV at both d_{max} and 10 cm, the valley-to-peak ratios are between 40 and 60%. The output factors, 0.89 for 6 MV and 0.77 for 25 MV, do not depend on field size.

Conclusion: Megavoltage grid therapy is a unique treatment modality where the dose is delivered differentially to a large volume in one fraction. Characterization of the dosimetric properties has allowed clinical implementation of the grid.

Grid therapy, Photon beam dosimetry.

INTRODUCTION

Grid therapy is a technique used to deliver a very high, single fraction dose of radiation by converting a large treatment field into many smaller fields. The use of grids in the treatment of cancer goes back to the beginning of this century, when orthovoltage radiation was the primary tool for external beam radiation therapy. First Kohler (5, 6) in 1909, and then Liberson (8) in 1933, described irradiation through perforated screens of steel, lead, and lead-rubber. The rationale behind using grids in the treatment of cancer was based on the premises that (a) protecting areas of skin within the radiation field permitted higher than normal doses of radiation to be administered without causing complications due to skin tolerance, and that (b) by reducing the volume of normal cells irradiated in the vicinity of the tumor, their protective role would be preserved. Both of these premises were subsequently borne out (1–4, 10, 11).

It was found that when areas of skin were irradiated, the larger the area, the more severe the resulting damage, despite maintaining a constant dose per unit area (2–4). However, when small areas of the skin within an irradiated field were shielded from direct radiation, they served as centers for the regrowth of normal skin tissue (11). Consequently, up to six times the conventional open portal doses could be given without an increase in the severity of skin reactions or complications to underlying structures (1, 10).

In addition to providing centers for skin regrowth,

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the normal tissue underlying the shielded skin exerts an influence on the irradiated cells (3). Fluids produced by these tissues not only provide nutrition to the region, but serve to cleanse the area of cells that were killed within the irradiated volume. Complications and adverse reactions are minimized when normal tissues can exert their maximum protective roles (2–4). A comprehensive review of the dosimetric, biological, and clinical aspects of grid therapy as used throughout the orthovoltage era of radiation oncology is given in the review article by Loevinger (9).

The advent of megavoltage radiation, with its better depth dose and skin-sparing properties, marked the decline of and eventual abandonment of grid therapy. During the past 5 years at Jefferson University Hospital, grid therapy has been revived as a method for delivering high doses of megavoltage radiation to bulky, deeply seated tumors (12, 13, 15). Adapting the same principles that were used with orthovoltage radiation, single fraction doses of up to 10 times the conventionally fractionated open portal dose have been given to patients who have either been treated to tolerance with conventional radiation, or who have massive tumor bulk that would most likely not benefit from a conventional course of radiation therapy.

This paper reports the physical characteristics and the dosimetric properties of depth dose, valley-to-peak ratios (ratio of the dose delivered under a shielded area to that under a hole at a given depth), and grid output factors of the grid when used with 6 MV and 25 MV photon beams.

METHODS AND MATERIALS

In grid therapy, ideally one would like the dose delivered under the shielded portions of the grid to be zero; practically, one tries to minimize this in designing the grid. A 1:1 ratio of open to shielded area was chosen to maximize the dose differential between the open and shielded areas. The square array grid has each hole equidistant from its nearest four neighbors and can accommodate field sizes up to 20 cm × 20 cm.

The grid consists of one 5-mm thick acrylic plate separated from a second similar plate by 7-cm long aluminum spacers bolted to the corners. Each plate, with 256 holes arranged in a 16 × 16 square lattice, has its corresponding holes placed such that their centers follow the divergence of the photon beam. Stainless steel tubing (inner diameter = 7 mm, outer diameter = 8 mm), which connects the corresponding holes in the two plates, forms the open areas of the grid while Low Melting Alloy #158,[1] which fills the spaces between the tubes, forms the shielded areas.

As the grid is designed to fit into the shadow tray on any of our linear accelerators,[2] no custom blocking is used. With the bottom of the grid at 70 cm from the accelerator target on all of the accelerators in our institution, the diameter of the holes projects to 1 cm at the level of the isocenter (source-to-axis distance = 100 cm). The 16 × 16 hole lattice fills a field size of 20 cm × 20 cm at the level of the isocenter, maintaining the total open area to total shielded area ratio of 1:1. A photograph of the grid is shown in Fig. 1.

In addition to the grid, a block with a single hole of the same dimensions as those in the grid was constructed. This hole, aligned with the central axis of the beam, was used to measure the narrow beam dosimetric properties associated with the grid.

Three aspects of megavoltage grid dosimetry have been studied. Depth dose, valley-to-peak ratios at depths of d_{max} and 10 cm, and the output through the grid relative to the corresponding open field were measured for photon energies of 6 MV and 25 MV and for field sizes of 20 cm × 20 cm, 12 cm × 12 cm, and 6 cm × 6 cm. All measurements were made in a commercial water phantom[3] using a waterproof, p-type silicon diode[4] (60 μm thick with an active area of 4.9 mm^2). The diode was designed primarily for dose measurements in photon beams and has a flat response over the energy range of interest. The orientation of the detector was such that its active plane was perpendicular to the direction of the beam. The data collected was analyzed using the software analysis package accompanying the water phantom.

Film and thermoluminescent dosimeters (LiF TLD 100 ribbon dosimeters[5]) were used to verify the valley-to-peak ratios obtained from the in-water measurements. Ready pack photographic films[6] were placed orthogonal to the beam direction at various levels in an acrylic phantom, whose surface was at the level of the isocenter. All the films were subsequently removed from the ready pack paper and processed at the same sitting under identical conditions in an automatic film processor[7] and scanned with a scanning film densitometer.[3]

RESULTS

Depth dose

Due to the geometry of the square array grid, the central axis of the beam is actually in a shielded region. To

[1] Acme Alloys, Philadelphia, PA. Chemical composition: bismuth 50.0%, lead 26.7%, tin 13.3%, cadmium 10.0%; melting point: 158°C.

[2] Philips SL75/5 and Philips SL25, Philips Medical Systems, Crawley, Sussex, England.

[3] Wellhofer Dosimetrie, Schwartzbruck, Germany.

[4] Manufactured by Scanditronix, Uppsala, Sweden.

[5] STI/Harshaw dosimeter material, Harshaw Chemical Company, Solon, OH.

[6] Kodak XV-2 film, Eastman Kodak Company, Rochester, NY.

[7] Kodak RP X-Omat, Eastman Kodak Company, Rochester, NY.

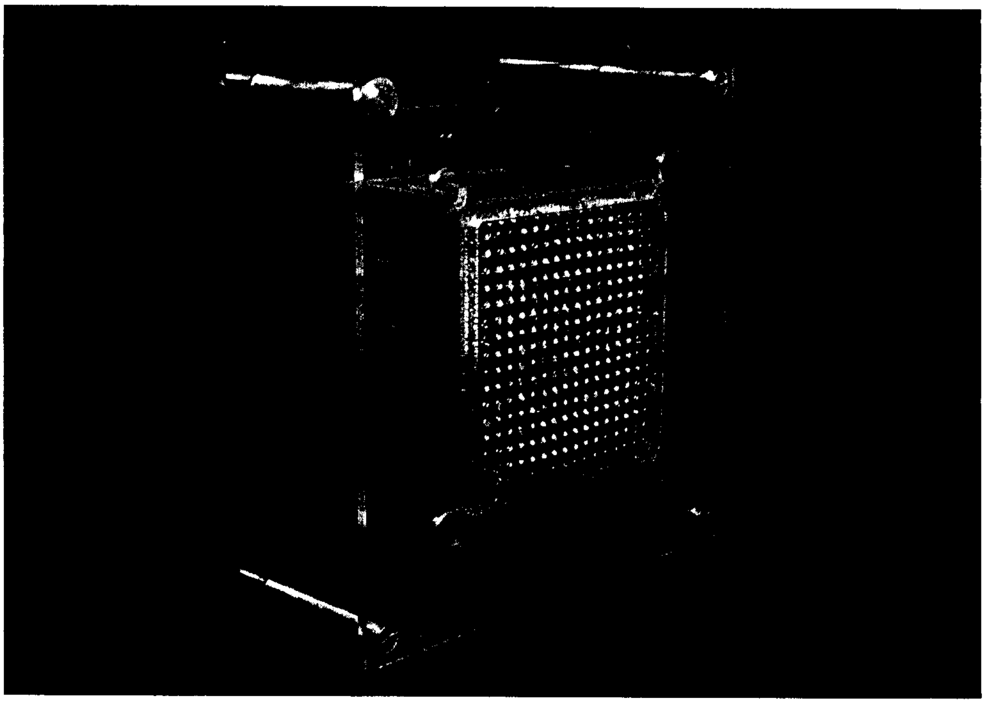

Fig. 1. The square array grid, which fits in the treatment head of a Philips SL75/5 or SL25 linear accelerator.

measure the depth dose characteristics of the grid beam in water, the diode was aligned under one of the four holes closest to the central axis to minimize beam divergence. It did not matter which of the four holes was used, as no observable differences in the depth dose data were found. Depth dose measurements were taken from the surface (source-to-surface distance = 100 cm) to a depth of 30 cm and were normalized to the dose delivered at d_{max}.

For the 6-MV photon beam, the depth of maximum dose under the grid was 1.2 cm and did not change with field size. Figure 2 shows a direct comparison of the depth dose curves obtained from a 20 cm × 20 cm open portal, 20 cm × 20 cm grid field, and the 1 cm narrow beam.

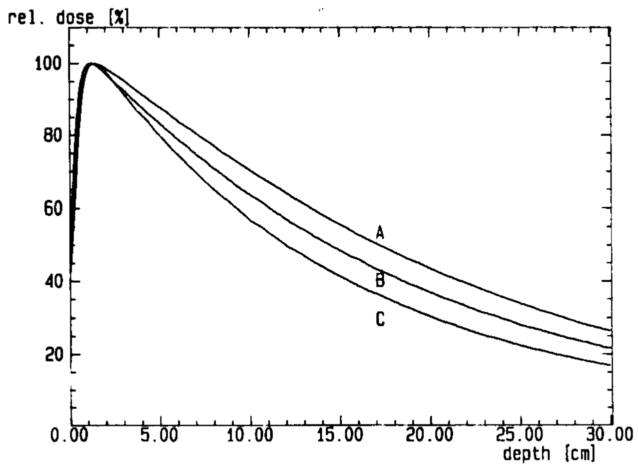

Fig. 2. The 6-MV depth dose curves for the (a) 20 cm × 20 cm open field, (b) 20 cm × 20 cm grid field, and (c) the 1-cm diameter narrow beam.

The 6 MV percentage depth dose values for 20 cm × 20 cm, 12 cm × 12 cm, and 6 cm × 6 cm fields under the grid are presented in Table 1.

With the 25-MV beam, as the field size decreases from 20 cm × 20 cm to the 1-cm diameter beam, the depth of maximum dose under the grid increases from 2.4 cm to 3.4 cm. For depths between d_{max} and 16 cm, the percentage depth dose decreases with increasing field size; in the 16-cm to 20-cm range, the depth dose is virtually

Table 1. Percentage depth dose variation with field size under the grid

Depth (cm)	20 cm × 20 cm	12 cm × 12 cm	6 cm × 6 cm
		6 MV	
1.2	100.0	100.0	100.0
5.0	83.1	82.6	81.8
10.0	63.6	62.3	60.1
15.0	48.5	46.8	44.2
20.0	36.9	35.1	32.7
25.0	28.0	26.6	24.3
30.0	21.6	20.2	18.3
		25 MV	
2.4	100.0	Buildup	Buildup
3.0	99.1	100.0	Buildup
3.4	98.3	99.4	100.0
5.0	92.6	95.0	96.4
10.0	75.9	77.7	77.9
15.0	61.7	62.9	62.8
20.0	50.6	50.8	50.4
25.0	41.6	41.6	40.7
30.0	34.2	34.0	32.8

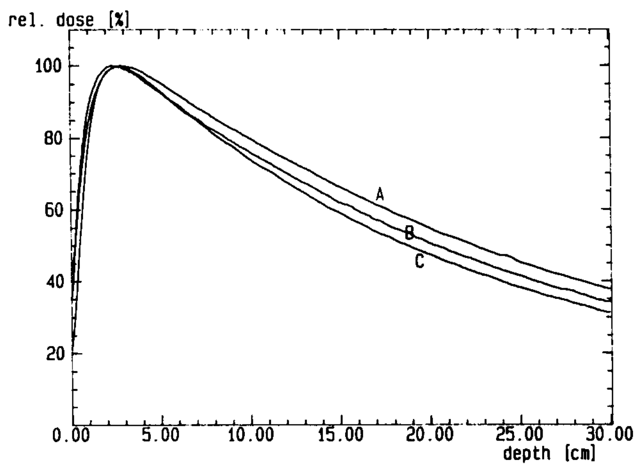

Fig. 3. The 25-MV depth dose curves for the (a) 20 cm × 20 cm open field, (b) 20 cm × 20 cm grid field, and (c) the 1-cm diameter narrow beam.

independent of field size. At depths greater than 20 cm, depth dose increases with field size at a given depth. The percentage depth dose curves for the 20 cm × 20 cm grid field, as well as the open portal 20 cm × 20 cm field and the 1-cm diameter beam at 25 MV, are presented in Fig. 3. The percentage depth dose values for the 25-MV beam for the 20 cm × 20 cm, 12 cm × 12 cm, and 6 cm × 6 cm grid fields are shown in Table 1.

Valley-to-peak ratios

It is of interest to the physician to know the ratio of the minimum dose to maximum dose at a given depth under the grid. This ratio, called the valley-to-peak ratio, was determined by obtaining beam profiles under the grid in the water phantom using 6-MV and 25-MV photon beams and field sizes of 20 cm × 20 cm, 12 cm × 12 cm, and 6 cm × 6 cm. The scans, and therefore, the ratios, were taken along the principal axes and the diagonals at the depths of maximum dose for the particular energy and field size, as well as at 10-cm depth. The beam profiles obtained under the grid at a depth of d_{max} using the 6 MV photon beam with a field size of 20 cm × 20 cm are shown in Fig. 4 (prinicpal axis scan) and Fig. 5 (diagonal scan). All profiles were normalized to the peak dose delivered under one of the holes closest to the central axis. The valley-to-peak ratios calculated from the scans taken in the water phantom are tabulated in Table 2. The error bars quoted reflect only the variations in the actual data and do not include the errors inherent in the measurement technique. Additionally, film and TLD measurements were made for comparison.

With the 6-MV photon beam, at the depth of maximum dose, the shielded areas along the principal axes receive approximately 40% of the peak dose. Along the diagonals, this value is reduced to approximately 15%. Although these ratios vary slightly with field size, the differences are within the experimental uncertainties. At a depth of 10 cm, the ratios increase due to increased phantom scatter. Along the principal axes, the minimum dose given is about 45% of the maximum dose delivered under a hole. Along the diagonals, this value decreases to about 25%. Again, to within the experimental uncertainties, these values are independent of field size.

The valley-to-peak ratios for the 25-MV beam at a given depth are similar to those for the 6-MV beam in that they do not depend on the size of the irradiated field. At a depth of d_{max}, the minimum dose in the directions of the principal axes is about 60% of the maximum dose delivered under a hole. Parallel to the diagonals this dose is approximately 40% of the maximum. At 10-cm depth, these values remain essentially the same, as the scatter component is small and predominantly in the forward direction.

The results of the water phantom measurements were verified by film measurements in an acrylic phantom for the 20 cm × 20 cm field size. The valley-to-peak ratios obtained from film dosimetry are about 5% higher than those obtained from measurements in water at 6 MV, and are within the experimental uncertainties at 25 MV. One possible explanation for the difference at 6 MV is the increased sensitivity of film to low energy radiation. Because the 6-MV beam produces more low energy scattered photons than the 25-MV beam, the minimum dose between the holes as determined by film dosimetry will be higher.

Due to the size of the TLD chips (3.2 mm × 3.2 mm × 0.9 mm), these measurements could only confirm the valley-to-peak ratios along the diagonals of the grid. The chips were placed in an acrylic phantom at depths equivalent to the depth of maximum dose in water under a hole, and also at the equivalent of 10 cm. The data obtained agree with the results of the measurements made in water to within 2%.

Grid output factors

The grid output factor is defined for a given radiation and field size as the ratio of the dose through one of the holes closest to the central axis at a specified depth to the dose along the central axis of the corresponding open

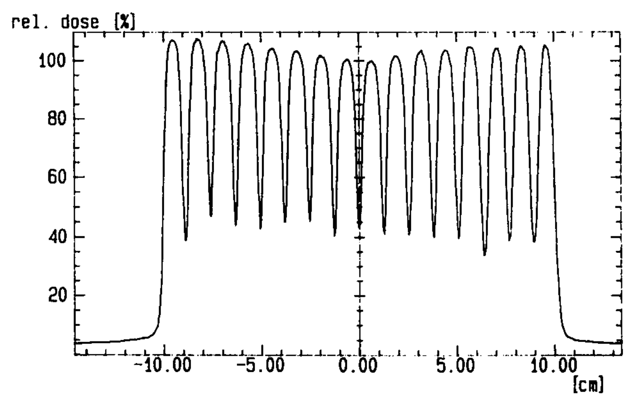

Fig. 4. Principal axis dose profile of the 6 MV, 20 cm × 20 cm grid field at the depth of d_{max} in water.

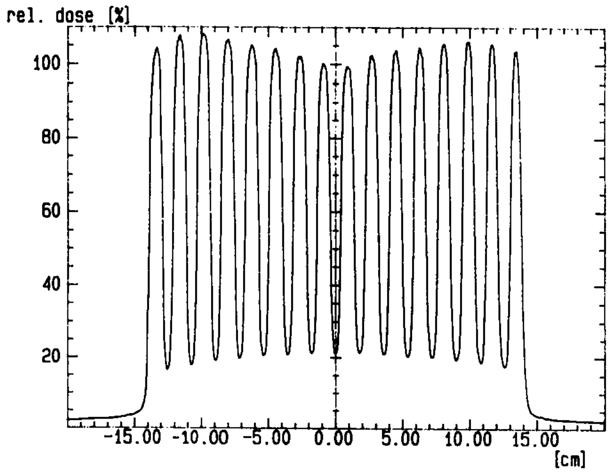

Fig. 5. Dose profile along one of the diagonals of the 6 MV, 20 cm × 20 cm grid field at the depth of d_{max} in water.

field at the same depth. This depth was taken to be the depth of maximum dose for the 10 cm × 10 cm open field; that is, 1.5 cm for the 6-MV beam and 3.5 cm for the 25-MV beam. These are the depths at which we calibrate our machine output.

The grid output factors for both 6-MV and 25-MV photon beams were measured with the diode in the water phantom for the 20 cm × 20 cm, 12 cm × 12 cm, and 6 cm × 6 cm field sizes. While the grid output factors are energy dependent, they are independent of field size at a given energy to within 1%. These values were found to be 0.89 and 0.77 for the 6-MV and 25-MV photon beams, respectively.

DISCUSSION

Depth dose

As expected, the 6-MV depth dose curves obtained with the grid lie between those for an open portal and a narrow beam. Similar to open fields at this energy, the percentage depth dose under the grid increases with field size at any given depth due to an increased phantom scatter contribution to the dose (Table 1). The depth of maximum dose at 1.2 cm does not vary significantly with field size from the maximum field size of 20 cm × 20 cm down to the 1-cm diameter beam, nor is it very different from that of the standard 10 cm × 10 cm open portal d_{max} of 1.5 cm.

With the 25-MV photon beam, both the depth of maximum dose and the percentage depth dose at any given depth under the grid vary with field size. A standard, open portal 10 cm × 10 cm field at 25 MV has its depth of maximum dose at 3.5 cm. With the grid, the decrease in d_{max} is from 3.4 cm to 2.4 cm with increasing field size. This decrease is due to the increasing electron contamination from the acrylic plate attached to the bottom of the grid. The changes observed in the percentage depth dose curves as a function of field size using the grid (Table 1) are similar to those for open field high energy photon beams (7, 14).

Valley-to-peak ratios

One important property of grid therapy is that throughout the entire treatment volume, at any given depth, a lower dose is delivered to shielded areas, while areas under holes receive a much greater dose. The square array geometry of the holes in the grid forces the distance between the centers of the holes along the diagonals to be 1.4 times greater than the corresponding spacing along the principal axes. Because the dose to a shielded region decreases with increased hole separation, the valley-to-peak ratios are smaller along the diagonals than along the principal axes; that is, there is a greater variation in the dose along the diagonals.

Clinically, the measured valley-to-peak ratios can be used in conjunction with the appropriate depth dose curve to determine the dose to a point under a shielded area of the irradiated volume. For this single field, high dose treatment, at our institution the treatment dose is prescribed to d_{max} with a source-to-surface distance (SSD) of 100 cm. Monitor units are calculated by dividing the prescribed dose by the appropriate field size factor and the grid output factor, as these two factors have been measured at d_{max} with an SSD of 100 cm. As dose under a hole at any particular depth can be obtained from the depth dose curve for the energy and field size used, the dose under an adjacent shielded area can be obtained by multiplying the dose under the hole by the valley-to-peak ratio that is appropriate for that specific energy, depth, and geometric location (i.e., along a principal axis or a diagonal).

Assuming a typical grid treatment scenario where a tumor extends from superficial depths down to a depth of 10 cm, the dose delivered to the target volume when 20 Gy from a 6-MV beam is prescribed to d_{max}, ranges from a maximum of 20 Gy (under a hole at d_{max}) down

Table 2. Valley-to-peak ratios under the grid

Field size	Depth	Principal axes	Diagonals
		6 MV	
20 × 20	d_{max}	0.40 ± 0.03	0.18 ± 0.02
12 × 12	d_{max}	0.39 ± 0.02	0.16 ± 0.01
6 × 6	d_{max}	0.38 ± 0.01	0.15 ± 0.01
20 × 20	10 cm	0.47 ± 0.03	0.27 ± 0.03
12 × 12	10 cm	0.45 ± 0.02	0.24 ± 0.02
6 × 6	10 cm	0.43 ± 0.02	0.21 ± 0.01
		25 MV	
20 × 20	d_{max}	0.59 ± 0.03	0.39 ± 0.03
12 × 12	d_{max}	0.59 ± 0.02	0.38 ± 0.02
6 × 6	d_{max}	0.58 ± 0.01	0.37 ± 0.01
20 × 20	10 cm	0.62 ± 0.02	0.43 ± 0.02
12 × 12	10 cm	0.61 ± 0.02	0.42 ± 0.02
6 × 6	10 cm	0.60 ± 0.01	0.41 ± 0.01

to 3.40 Gy (under a shielded area along a diagonal at 10-cm depth) when a 20 cm × 20 cm field size is used.

Grid output factors

In addition to measuring the grid output factors as previously described, for comparison these factors were also measured by comparing the dose at the d_{max} for the particular grid field of interest to that of the open portal at its d_{max}. No differences in output factors were found for field sizes whose d_{max} did not differ significantly from that of an open 10 cm × 10 cm field (i.e., all field sizes with the 6-MV beam and the smaller field sizes with the 25-MV beam). For fields where the d_{max} did shift significantly, a 2% variation in the output factor was noted. This was not considered to be clinically significant.

Clinical implementation

The use of grid therapy has permitted the care and treatment of patients who have unusually large or bulky tumors and/or have exhausted conventional modalities of radiation therapy. Sites of disease treated with megavoltage grid therapy include the neck, colon, rectum, liver, vagina, kidney, prostate, and chest wall, as well as various bones and soft tissues. Histologies treated at these sites include squamous cell carcinoma, adenocarcinoma, melanoma, and various sarcomas (13, 15). This technique has been used on over 60 patients to date with about 25% of them resulting in a complete response of deleterious symptoms (elimination of pain, shrinkage of the tumor, or cessation of bleeding), and approximately 80% showing at least a partial response (15). No acute morbidity has been observed despite the large single fraction doses administered, nor were any patients found to develop subcutaneous soft tissue fibrosis. Although most of the patients treated with grid therapy have end-stage disease and follow-up times have been rather short (1 month to 28 months with a median of 18 months), patients followed for at least 6 months have not shown any untoward late radiation effects.

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