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Evaluation of dosimetric characteristics of a grid block fabricated for Mega-voltage grid therapy purposes

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Background: In conventional radiation therapy, regarding normal tissue tolerance, the treatment of bulk tumors is one of the remaining challenges. Grid Radiation Therapy (GRT) is a technique to deliver high doses, approximately 15 – 20 Gy per fraction, to several small volumes located in a large radiation field. This can be performed using a grid block. The current work has concentrated on the dosimetric characteristics of a designed mega-voltage grid, used for a unique treatment modality. ***Materials and Methods:*** All measurements performed using a Neptune linear accelerator (9 MV photon beam). A square 16 × 16 array grid block was designed and fabricated. Several dosimetric characteristics including: depth dose, Valley To Peak (VTP) ratio, and grid out-put factor were evaluated using a calibrated diode dosimeter for a range of radiation fields. ***Results:*** The percent depth dose curves, measured in the presence of grid block, lie within those measured for the corresponding open field and a narrow beam. At the D_{max}, the VTP ratio was found to be within 17% - 28%, while these ranges between 23% - 35% at a depth of 10 cm. The grid out-put factor found to be 0.78 and it slightly decreases with increasing of radiation field size. ***Conclusion:*** The VTP ratio found to be dependent strongly on the grid design and manufacturing properties. However, other parameters such as radiation field size and the depth of measurement should also be addressed as important factors. The measured dosimetric characteristics of grid block indicate that the mega-voltage grid therapy can be applied as a possible clinical modality for palliative cases. **Iran. J. Radiat. Res., 2011; 9(1): 49-56**

Keywords: *Grid therapy, palliation, mega-voltage, radiation dosimetry.*

INTRODUCTION

The treatment of bulky tumors is remaining as a serious challenge in radiation therapy. Due to the limitation of normal tissues tolerance to radiation, increasing the tumor volume decreases the ability of conventional radiation therapy. Even though with the application of newly developed radiation techniques, such as altered fractionation and accelerated fractionation, the treatment of large sized tumors is still a problem in radiation therapy (1-6).

In order to deliver a uniform dose to a target volume, two options can be suggested. Firstly, an open field can be used. However, normal tissues and Organs At Risk (OARs) in the radiation fields, receive a significant radiation dose and therefore this causes a limitation to deliver a sufficient dose to the target. In contrast, partial protecting normal tissues and OARs would be helpful method to increase the delivered dose to the target seven to ten times compared to an open field in which shielding is not applied (7). In addition, in the second approach, the dose delivered to the surrounding tissues is generally lesser than tolerance dose and there is no serious concern for (8, 9).

In order to protect some parts of a radiation field, especially for large target volumes, a grid can be utilized (10-12). The grid, in fact, is a plate made of lead or lead alloy and can be positioned in applicator/

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tray position. Several apertures are designed in a large lead alloy block and a considerable partial region of radiation field is therefore protected against direct beam incidence. The radiation therapy technique with the application of grid is also called: "Spatially Fractionated Radiation Therapy" in literatures (10, 11, 13). The grid therapy technique can be used for several purposes including: Large tumor shrinkage before the main radiotherapy regimen, Palliation of the patients who receive the maximum tolerance dose using conventional radiotherapy, Palliative treatment of large tumors where conventional radiotherapy cannot be used, and in inoperable bulky tumors, the gird improves local-regional control (14).

In this method, a single fraction, with radiation dose around 15-20 Gy can be delivered to target volume which is 7 to 10 times more than a single session dose delivered in conventional radiation therapy (11).

The first generation of grid was used on the early years of twenty century, when Ortho-voltage machines were working as the best option for cancer treatments. The main aim of grid therapy, in those decades, had been defined to minimize the radiation dose effects to the skin and connective tissues. In these studies, the grid was a plate made of steel, lead and plastic in the form of a perforated screen. Application of the same Ortho-voltage grid therapy techniques, for mega-voltage is called Mega-voltage Grid Therapy. Using this technique, high doses of radiation can be delivered in a single radiotherapy course (11-13).

In mega-voltage grid therapy, a radiation field is divided into several small areas, around 250 sub-fields. It is also a confidence that there is no overlap among small areas irradiated in a radiotherapy session (15). A relevant report indicates that the above-mentioned dose can be delivered without any serious side effect for palliative treatments (16) and locally advance tumors (14).

In majority of recent investigations, reported for megavoltage grid therapy, a hexagonal pattern grid has been utilized. It has been, then, concluded that regarding grid therapeutic gain independency on holes' spacing, the grid's therapeutic gain seems to be independent of grid design (16). In order to investigate the grid's dosimetric properties dependence on the grid design, a new prototype of grid was designed and fabricated. More details about the grid's design and structure is reported elsewhere (17). The current study has concentrated on the physical and dosimetric characteristics of a manufactured grid including depth dose, the Valley To Peak (VTP) dose ratio, and machine output factors when the grid is utilized (8, 13, 15, 18).

MATERIALS AND METHODS

All measurements were performed using a Neptune 10PC medical Linear accelerator (linac), established at the Imam Reza Hospital (Mash-had, Iran). The linac produced a 9 MV photon and several electron beams. The machine calibrated to deliver one cGy dose for each Monitor Unit at the iso-centre.

The grid used in the current study was a $23 \times 23 \times 8$ cm^3 block made of a lead alloy (85% lead and 15% Antimony) and consisted 256 apertures incorporated in a square 16×16 array having a circular aperture with a 13 mm diameter in the iso-centric plane. The ratio of open area to the shielded area in grid defined to be 1:1. The maximum available radiation field size on the iso-centre was a 30×30 cm^2. The mean distance within center of two contiguous apertures was 1.8 cm. The divergency for off-axis areas was the main consideration for grid design. The apertures, incorporated in grid, obeyed a divergency rule similar to the focused grid used in diagnostic radiology machines (15). The grid positioned at the machine head such that the distance between the button surface of the grid and iso-centre was 70 cm (See figure 1A). The shape and dimension of the grid used in this study is shown in figure 1B. In addition, in order to evaluate dosimetric characteristics of a narrow circular field, a rigid block with the same contents used for grid, (85% lead and 15% Antimony) with a single hole at the centre of the field, similar to the apertures of main grid, was also prepared (See figure 1C).

Majority of measurements were performed using a commercial water phantom, Radiation Field Analyzer RFA 300 (Scanditronics, Wellhoffer, Germany), and a Photon Field Diode (PFD) type P with active area 2 mm^2, width of 60 μm, and sensitivity of 35nc/Gy. The diode, used in this study, has a linear response for 9 MV photons [10, 19, 20]. The in-plane, cross-plane and diagonal line profiles were then acquired using Omnipro software (Scanditronix, Wellhofer, Germany).

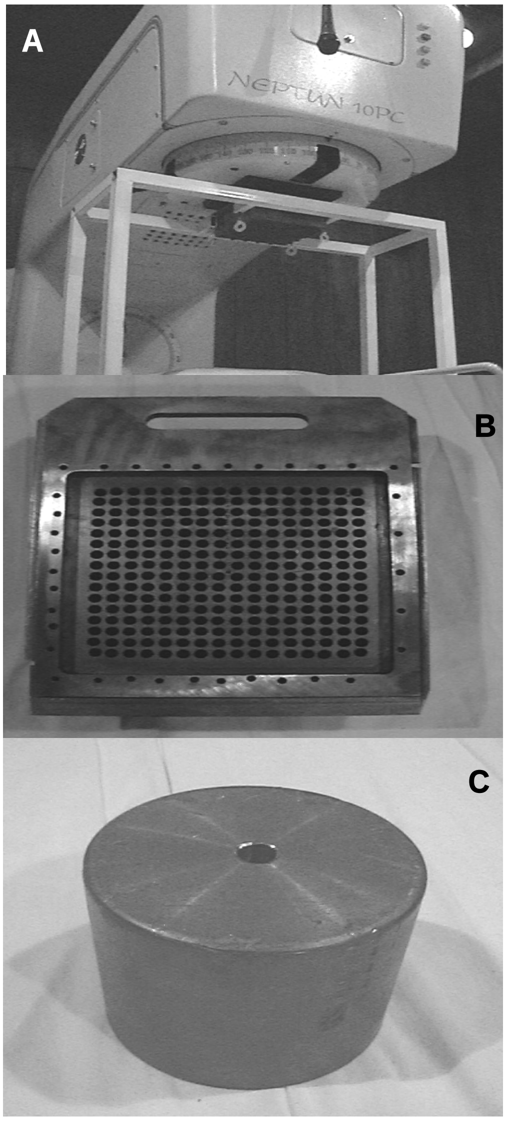

Figure 1. The grid used in the current study (A) attached to the linac radiotherapy set and (B) aside, and (c) a view of a single hole rigid block.

In order to evaluate the dosimetric properties of the abovementioned grid, the percent depth dose, the VTP ratio, as well as the grid out-put factor was investigated for a range of conditions. Three independent data set were then collected for an open field, in the presence of a grid, as well as for a single hole block.

The measurement of the percent depth dose

Due to the especial arrangement of apertures in the manufactured grid, the central axis of radiation beam positioned in the area shielded between apertures. In order to measure depth dose in the presence of the grid, a semi-conductor detector is located in the centre of the one of the four apertures located around the central axis of radiation field. The averaging of four series measurements, controls drawbacks arose from beam divergency. The depth dose measured from water surface to 30 cm depth of water tank for a range of radiation fields. The same measurements were performed for a narrow beam with a 1.3 cm diameter using a single hole block (see figure 1C). After normalizing the acquired dose values for all measurements to D_{max}, results compared to that measured for an open field.

The measurement of the Valley to Peak ratio

The VTP ratiodefined as "the ratio of the lowest dose in off-axis shielded areas (Valley regions) to maximum dose delivered at open areas (peak points)" investigated for different depths. This can be extract from a dose line profile measured in a water tank. Line profiles, including in-plane, cross-plane and diagonal profiles measured at the D_{max} and the 10-cm depth of water tank. For average VTP ratio, two last picks and valleys ignored in all line profiles. The VTP ratios calculated for all consequent pick and valleys and the average was calculated. The procedure performed for a range of radiation fields: 5×5, 10×10, 15×15, 20×20, 25×25, and 30×30 cm^2.

In order to confirm the diode dosimetry results, the VTP ratio also measured using Thermoluminescence dosimeters (TLDs). TLDs are known as accurate and reliable point dosimeter for radiation therapy dosimetry purposes for in-field [(21-24)] and off-field dose evaluation [(25)]. 20 TLD chips (TLD-100 (Lif:Mg,Ti) with dimensions of 1 × 1 × 1 mm^3) were incorporated in an acrylic phantom such that half of them were placed at the center of open areas and others consequently positioned at shielded areas at the depth of D_{max} and 10 cm, in an acrylic phantom. in the presence of grid block for a 30 × 30 cm^2 radiation field.

The measurement of grid output factor

The grid output factor defined as "the ratio of dose delivered to the phantom/ patient from one of the central apertures, to the dose measured at the same point for an open field with the same beam specification". In order to measure grid output, all measurements performed using a silicon diode at a 10 cm depth of water tank for all abovementioned radiation fields for open fields and in the presence of grid.

RESULTS

Depth dose

Results showed that the maximum depth dose, D_{max}, for 9 MV photons in the presence of grid to be 1.8 cm. This value was consistent and no significant variation was observed with the variation of radiation field size. The same results were also observed for corresponding open fields.

The percentage depth dose curve for a narrow beam with 1.3 cm diameter, a 30 ×30 cm^2 open field and a corresponding grid field is shown in figure 2. As figure shows, no significant difference was observed at pre -build-up region for all measurements. In contrast, with an increase in the depth of measurement, a significant difference was observed for post-build-up region. Different gradient for dose deposition for a narrow beam was observed compared to those measured for a 30 × 30 cm^2 fields.

The valley to peak ratio

Several rectangular and diagonal profiles for 30 × 30 cm^2 radiation fields

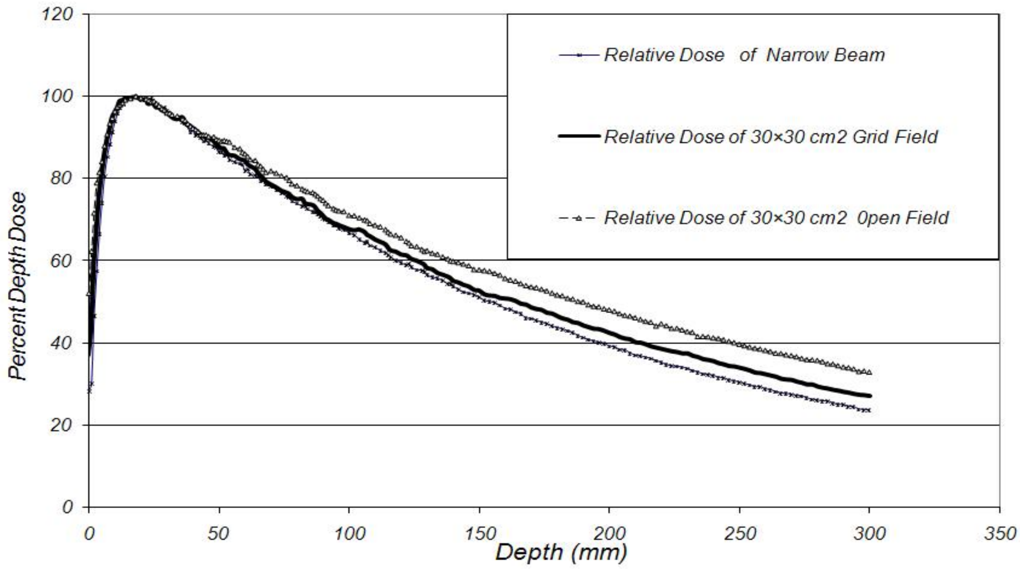

Figure 2. Percent depth dose curves achieved for a 30 × 30 cm^2 open field, a 30 × 30 cm^2 grid field , and a circular narrow field.

measured at D_{max} and at the depth of 10 cm is shown in figure 3. All profiles were normalized to the iso-centre.

The VTP ratios for a range of radiation fields achieved at D_{max} and 10 cm depth are shown in table 1. As table 1 indicates, the VTP ratio strongly depended on the radiation field size. With an increased in radiation fields, the ratio increases for all measurements. The average VTP increased up to 40.3 and 63.2%, respectively, for diagonal and rectangular profiles, when the measurements were transferred from D_{max} into the 10 cm depth in water. The comparison of VTPs showed that there was a significant discrepancy for VTPs measured at the same conditions for IP/XP profiles compared to the diagonal profiles.

Relative dose profiles measured at D_{max} for a 30 × 30 cm^2 radiation field showed that the maximum delivered dose to the points shielded using a grid was about 28% of the dose delivered to the unshielded area, defined as Peak points. For diagonal profiles, this was reduced to 17%. For dose profiles acquired at a 10 cm depth in water, for a rectangular 30×30 cm^2 field, the VTP ratio was also found to be 35% and 24%, for rectangular and diagonal profiles, respectively. This showed that an increase of radiation field would have increased the VTP ratio (see figure 4). The main reason for the increase of VTP with depth was the increase of forward and back scattering reaching the point of interest.

Results of TLDs read out using a TLD reader (Harshaw 3500, Harshaw-Bicron, Newbury, OH) indicate that there was a reasonable agreement between diode and TLD measurements. The results of TLD dosimetry are shown in table 2.

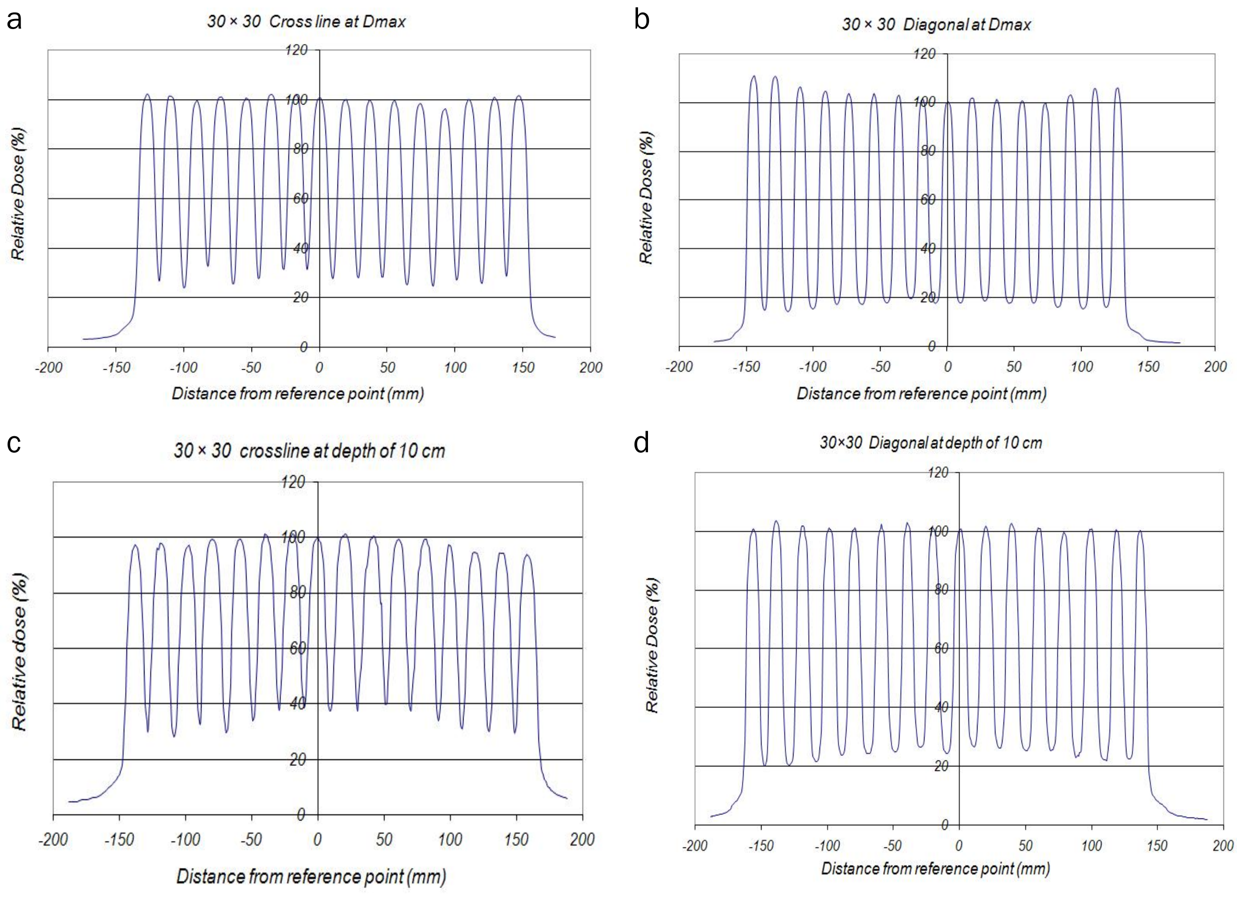

Figure 3. Relative in-plane profiles acquired (a) at D_{max} and (b) at 10 cm depth. Relative diagonal profiles acquired (c) at D_{max} and (d) at 10 cm depth.

Table 1. The Valley To Peak dose ratio for a range of radiation fields.

Radiation Field size (cm^2)	The Valley To Peak dose ratio			
	Diagonal profiles at:		IP/XP profiles at:	
	10 cm	D_{max}	10 cm	D_{max}
5 × 5	12.04 ± 0.65	8.58 ± 0.75	24.63 ± 3.31	15.90 ± 0.40
10 × 10	18.05 ± 0.84	13.00 ± 0.96	30.62 ± 1.96	25.10 ± 1.67
15 × 15	20.49 ± 1.59	14.53 ± 1.57	30.67 ± 3.25	25.74 ± 2.36
20 × 20	21.72 ± 1.18	15.21 ± 1.28	32.00 ± 3.06	25.35 ± 2.62
25 × 25	22.24 ± 1.61	16.10 ± 1.55	35.10 ± 3.50	26.75 ± 2.91
30 × 30	23.93 ± 2.11	16.50 ± 1.69	34.89 ± 3.11	27.66 ± 2.54

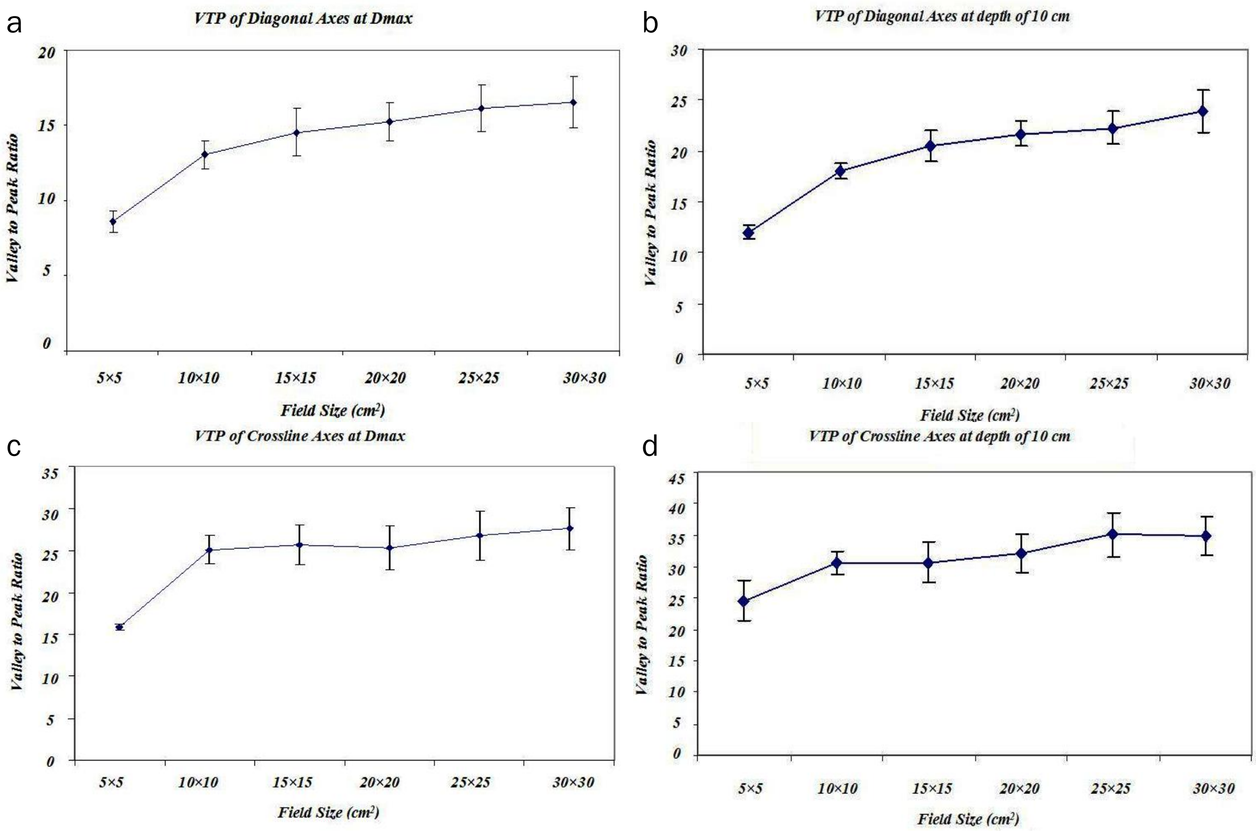

Figure 4. VTP ratios for a diagonal axis at (a) Dmax (b) a 10 cm depth, and for a cross-plane profiles at (c) Dmax (d) and a 10 cm depth.

Table 2. Results of TLD dosimetry for VTP ratios for 30 × 30 cm^2 radiation field.

Axis	**VTP ratios for 30 × 30 cm^2 (TLD Dosimetry)**	
	Depth of D_{max}	Depth of 10 cm
Cross-line	28.37	31.23
Diagonal	14.49	20.57

Grid output factor

The grid output factor was found to be about 78% for a 30×30 cm^2 radiation field, and it slightly decreased with increasing of radiation field. The Pierson correlation factor for two variables, (grid output factor and radiation field size) was determined to be as follows: b = 0.004 and r = -0.946. The Output factor for range of radiation fields is shown in table 3.

Table 3. The Output factor for range of radiation fields.

Radiation Field size (cm^2)	Grid Output factor
5 × 5	86.27
10 × 10	82.86
15 × 15	80.63
20 × 20	79.48
25 × 25	78.29
30 × 30	78.05

DISCUSSION

One of the main aims of mega-voltage grid therapy is to deliver a maximum dose to areas located under grid apertures while a lesser dose is delivered to the shielded areas (12, 15). As shown in figure 5, the grid apertures are arranged that the distance between two holes (centre-to-centre spacing) in diagonal axes is 1.4 times larger than those arranged in straight axes. Increasing the distance between grid holes has decreased the dose supposed to be delivered to the protected areas in the radiation fields. Therefore, the VTP ratio was different for diagonal and straight-line profiles. Regarding different VTP ratios, the dose delivered in open areas and shielded areas were different. Knowing the VTP ratios in different situations would be helpful to determine the dose delivered to shielded areas in the grid radiation fields. This caused a different therapeutic ratio, when the protected areas had received lesser dose compared to a hexagonal pattern grid (16).

An improvement in VTP dose ratios was observed comparing the results reported so far for grid therapy. For instance, VTP ratio achieved in the current study was lesser than those reported by former studies (16). The comparisons are briefly shown in table 4. These differences might have arosen from the grid design and its manufacturing properties.

The comparison showed that the grid VTP ratio was strongly dependent to the grid design, and the photon beam energy used. In contrast to the former studies (16), this showed that the number of apertures and their positioning respect to each other also was an important issue that should be taken into consideration.

For further studies, the determination of a correlation between VTP ratio and the positioning of grid apertures can be suggested. In addition, the same study for electron beams can also be recommended (13).

In conclusion, the physical characteristics of grid, investigated in the current

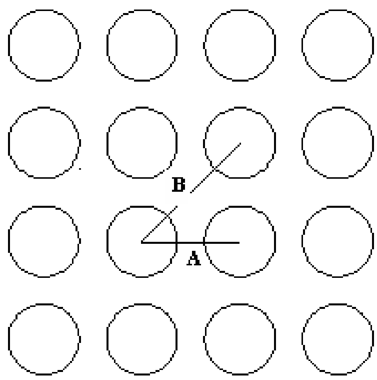

Figure 5. The arrangement of grid apertures diagonal and straight axes.

Table 4. Comparison of VTP ratios and grid output factors achieved in the current study and those reported by former studies.

Study	Photon Energy (MV)	Maximum Dose deposition (mm)	VTP ratio for a 20×20 field: Straight profiles at D_{max}	VTP ratio for a 20×20 field: Straight profiles at 10 cm	VTP ratio for a 20×20 field: Diagonal profiles at D_{max}	VTP ratio for a 20×20 field: Diagonal profiles at 10 cm	Grid output factor
Rieff *et al.* (1995)	6	12	40%	45%	15%	25%	0.77
	25	24 - 34	60%	60%	40%	40%	0.89
Current study	9	18	25.35%	32%	15.21%	21.72%	0.78
Trapp *et al.* 2002	10	---	30% for a 10×10 field at 5 cm depth		19% for a 10×10 field at 5 cm depth		---

study, showed that the grid therapy could be addressed as an option for curative and palliative purposes for large bulky tumors. However, the therapeutic ratio strongly depends on the grid design and its manufacturing.

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