Evaluation of dosimetry effect of lack of side-scatter volume on large field measurements with a MapCheck detector array

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Abstract In this paper, we describe a quantitative evaluation of the dosimetry effect of lack of side-scatter volume (LSSV). MapCheck, an integration diode array, was used to measure dose maps for three large non-IMRT fields (30cm ×30 cm and 40 cm×40 cm open fields, and 30 cm×30 cm wedge field with wedge angle of 60°) and 19 large IMRT fields. For each field, measurement was performed twice, under the conditions of (1) full scatter volume and (2) LSSV. Condition 1 was satisfied by adding PMMA slabs against the side of the MapCheck, and Condition 2, without PMMA slabs. The measured dose maps were compared with pass rate and their difference was scored when the acceptance criterion was set to 0.5%, 1%, 2%, 3%, etc. For very large open fields, the effect of LSSV may be clinically significant, while for large wedge fields and IMRT fields, the effect is negligible.

Key words Large field, Lack of side-scatter volume, Diode array

1 Introduction

Dosimetry verification of patient plans is a quality assurance procedure for intensity modulated radiation therapy (IMRT)[1-8]. One common method to perform this is dose mapping for all treatment fields with a diode array or ionization chamber array, or by electronic portal imaging devices[9-12]. However, the measuring area of a detector array in current design is smaller than the maximum field. One solution to such scenarios is to measure individual parts of the field in multiple exposures, and merge the measurements into the field under investigation. This maximizes the measurement area of the detector array, at the expense of dose reading due to lack of side scattering. According to dosimetry protocols such as IAEA code of Practice TRS-277[13], to assure enough scatter volume, the phantom should extend to at least 5 cm beyond all four sides of the largest field size at the measurement depth. There should also be a margin of at least 5 cm beyond the maximum measurement depth. The purpose of this study is to evaluate the dosimetry effect of lack of side-scatter volume (LSSV effect) by comparing large field dose maps obtained under measurements with and without the side-scatter volume.

2 Materails and methods

2.1 Brief description of MapCheck merging function

We used a diode array, MapCheck, to acquire dose maps for large fields. It has been demonstrated that MapCheck is an accurate and reliable tool for the IMRT treatment verification [11,12]. It has 445 diodes positioned in an area of 22 cm×22 cm, with just a few diodes being outside of the central area of 20 cm× 20cm, hence our assumption that the maximum measurable field size is 20 cm×20 cm. For a larger field, a software of merging function is provided to get a full dose map from multiple partial exposures, and one obtains the full dose map through merging dose maps of all exposures with the information of the orientation and offset. The dose at any diode location is equal to the averaged dose measured at the location. Fig.1 illustrates the setup of 4 exposures. The square formed by the dotted lines is the 40 cm×40 cm field. The intersection of the crosshairs is the center of the

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field. When the four exposures are taken, MapCheck is sequentially placed in the four quadrants.

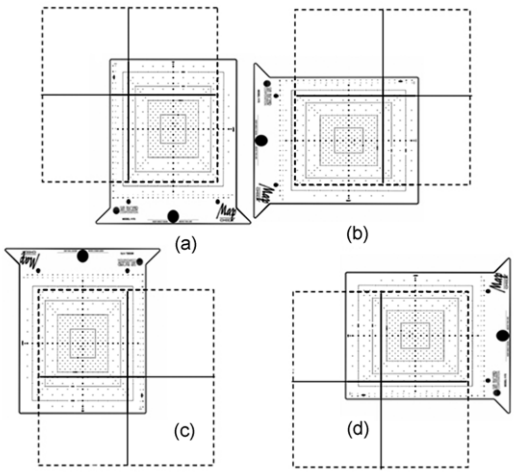

Fig.1 Schematic drawing of MapCheck merging function.

2.2 Determination of field center in MapCheck coordinate system

2.2.1 Description of MapCheck coordinate system

MapCheck has a Cartesian coordinate system. The centre detector with coordinates (0, 0) is numbered (23, 23)[14]. If a detector coordinates are (x, y), the detector number of (N_x, N_y) can be calculated by Eq.(1), where the 0.5 cm is the minimum distance between any detector pairs along X or Y direction.

$$\begin{cases} N_X = 23 + x/0.5 \\ N_y = 23 + y/0.5 \end{cases} \quad (1)$$

2.2.2 Determination of field center in MapCheck coordinate system

In doing measurements with the merging function, one should determine the field center in the coordinate system. For a large enough scatter volume, the field center should be close as much as possible to the center of MapCheck. For a field size of over 20 cm ×20cm in X or Y direction, two-exposure merging is needed. For two-exposure merging, if the field center is at detector (N_x, N_y), N_x and N_y are calculated by Eq.(2)

$$\begin{cases} N_X = 23 \\ N_y = 23 + \left(\mathrm{Max}\left|y_1, y_2 - 10\right)/0.5 \right. \end{cases}$$

or

$$\begin{cases} N_X = 23 + (\mathrm{Max}\left|x_1, x_2 - 10\right)/0.5 \\ N_y = 23 \end{cases} \quad (2)$$

where x_1, x_2, y_1 and y_2 are collimator jaw positions defining the field. As an example, for a field of x_1=5cm, x_2=10 cm, y_1=12 cm and y_2=18 cm, the field size is x_1+x_2 =15 cm in X direction and y_1+y_2= 30 cm in Y direction, hence the need of two-exposure merging in Y direction. According to Eq.(2), the field center is at the detector of N_x = 23, and N_y= 23 + (Max|12,18 – 10)/0.5=39.

With the field size of >20 cm in both directions, four-exposure merging is needed, and the field center is at the detector (N, N) to maintain rotational symmetry, with N being determined by Eq.(3).

$$N = \mathrm{Max}\left|N_x, \mathrm{N}_y\right. \quad (3)$$

where N_x = 23 + (Max | x_1, x_2 –10)/0.5, and N_y= 23+ [Max |y_1, y_2 –10]/0.5. This shows that the field center can be in Quadrant 1 and 2 rather than Quadrant 3 and 4 of the MapCheck coordinate system. This preference is for protecting the electronic section.

2.3 Test fields

Test fields included 19 IMRT fields and three regular fields (30 cm×30 cm and 40 cm×40 cm open fields, and 30 cm×30 cm wedge field with wedge angle of 60°). In terms of intensity-modulation, they changed from no modulation, to one dimensional modulation, and then to two dimensional modulation. According to Section 2.2, the regular fields needed four-exposure merging. In the 19 IMRT fields, 9 came from a lymphoma case, in widths ranging from 12.1 cm to 25.3 cm, and lengths from 20 cm to 37 cm. Similar to regular fields, they needed four-exposure merging. The other 10 IMRT fields came from two esophagus cancer cases, in widths ranging from 9.5 cm to 11.7 cm, and lengths from 27 cm to 32 cm. According to §2.2, they needed just two-exposure merging.

For all test fields, the measurement setup was the same as that for dosimetry verification of patient IMRT plans in our clinic. The detector array is located in the isocenter plane. The beams irradiate downwards from a gantry angle of 0°. The measurement depth is 5.33 cm equivalent water by adding 3 cm PMMA on the top of MapCheck. For the regular field, measurements were performed with both 6 MV and 18 MV X-rays; whereas for the IMRT field, measurements were performed with 6 MV X-rays, because it was found in the measurements for regular fields that LSSV effect was less severe for high energy beam.

2.4 Measurement procedure

For each field, measurement was performed twice, one under the condition of full scatter volume, and the other under the condition of lack of side-scatter volume. The first condition was satisfied by adding PMMA slabs against the side of the MapCheck, while the second condition used no PMMA slabs. For four-exposure merging, the full measurement procedure is demonstrated in Fig. 1 and described as follows:

(a) Place MapCheck with the intersection of crosshairs on detector (N_x, N_y) and the front of MapCheck pointing towards the gantry (Fig.1a).

(b) Expose the field;

(c) Put PMMA slabs to the MapCheck to form the full scatter volume;

(d) Expose the field;

(e) Remove the PMMA slabs, and rotate the MapCheck clockwise 90° around detector (N_x, N_y);

(f) Expose the field;

(g) Repeat Steps c, d and e, and by then the MapCheck will have been rotated for 180° (Fig.1c);

(h) Repeat Steps b, c, d and e, and by then the MapCheck will have been rotated for 270° (Fig.1d);

(i) Repeat Steps b, c and d.

For two-exposure merging, the above procedure should be modified. MapCheck should be rotated clockwise 180° in Step e and just the first seven steps are needed.

2.5 Dose map comparison

For each field, we obtained two merged dose maps, one for full scatter volume (FSV map) and the other for lack of side-scatter volume (LSSV map). We used FSV map as reference, and compared LSSV map against it. The comparison was done with MapCheck software. The agreement between the two measured dose maps was evaluated through determining the percentage of diodes passing a specific acceptance criterion (i.e., passing rate). Only those diodes with relative dose more than 10% were taken into consideration. The acceptance criterion was composed of percent difference (%Diff) and distance to agreement (DTA) criteria. The location of normalization point affects pass rate, and should be selected in the high dose, low dose gradient region. Otherwise, the pass rate may not objectively reflect the dose maps' difference.

In this study, the acceptance criterion of relative dose difference was set to 0.5%, 1%, 2% and so on, and the threshold was fixed to 10%. For dosimetric verification of patient IMRT plans, the pass rate of dose points is usually required to be at least 95% when the acceptance criterion are 3% dose difference and 3mm distance-to-agreement[15]. Considering that the LSSV effect will underestimate expected dose, and cause a systematic error in measurement results, we assumed in this study that this effect is clinically significant and can not be ignored if the pass rate is less than 95% when the acceptance criterion is 1% dose difference. We did not use distance-to-agreement, since MapCheck disables this criterion when comparing two measured dose maps.

3 Results and discussion

3.1 Regular fields

Field size, beam energy, and with or without wedge are influence factors of LSSV effect, which becomes significant at low energy and large open field. Among all the six measurement cases the 40 cm×40 cm open field with 6 MV X-ray has the largest LSSV effect (Fig.2). In this case, PR was 92.7% for 1% acceptance criterion, and thus the LSSV effect is clinically significant and can not be ignored. For the other five cases, PR was always more than 95%, and the LSSV effect is negligible. The results of regular fields are consistent with physics principles that the bigger the field is and the lower the energy is, the more lateral scatter exists.

Fig.3 displays the comparison result of LSSV map and FSV map with the 0.5% dose difference for the 40 cm ×40 cm open field. A square dot means that LSSV dose at this position is lower than FSV dose by more than 0.5%, while a circle dot means that LSSV dose is higher than FSV dose by more than 0.5%. We can see that the squares form a clear cross shape inside the field, and few circles and squares distributed along field edges. The cross shape means that this region lacks of scatter volume the most, and just like what we expected. But we did not expect the appearance of circles and squares along field edges. We analyzed this phenomenon, and found two possible causes. One cause was that MapCheck might shift invisibly when we removed PMMA slabs in Step e of measurement procedure (see Section 2.4). Another cause was that jaw positions might have changed by sub-millimeter during two measurements.

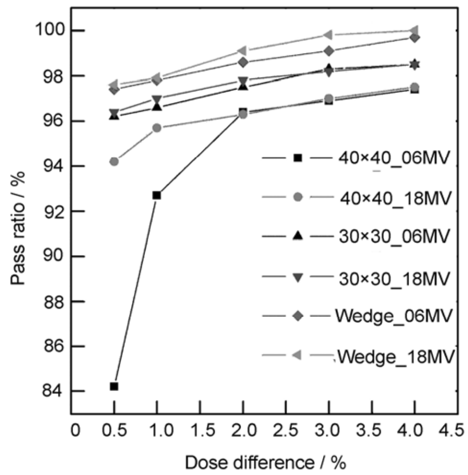

Fig.2 Pass rate (PR) curves for regular fields.

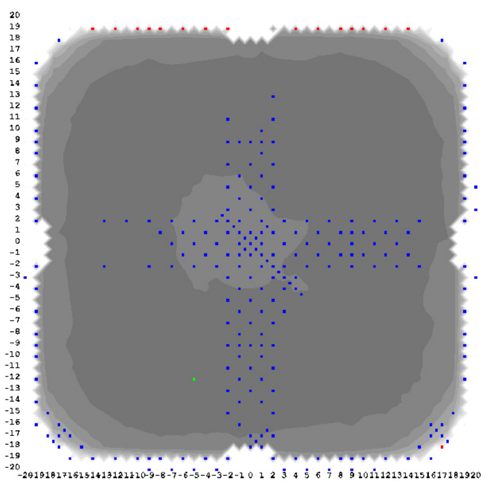

Fig.3 Dose map comparison for the 40 cm × 40 cm open field. A square dot means the dose measured under the condition of lack of side-scatter volume is 0.5% less than that measured under the condition of full scatter volume. A circle dot means the opposite.

3.2 IMRT fields

For the nine IMRT fields using four-exposure merging, PR ranged from 95.1% to 98.4% with an average of 97.0% when the acceptance criterion was 1%. Compared to the regular fields that also used four-exposure merging, IMRT fields had higher PRs. That means intensity modulation reduces LSSV effect. Compared with the nine fields using four-exposure merging, the 10 fields using two-exposure merging had even higher PRs. Their average PR was 99.6% when the acceptance criterion was 1% (Fig.4a). That means two-exposure merging has less LSSV effect than four-exposure merging.

All 19 IMRT fields, no matter whether they were measured through four-exposure merging or two-exposure merging, their PRs were always more than 95% when the acceptance criterion was 1% or higher (Fig.4). Therefore, the LSSV effect can be concluded as clinically insignificant.

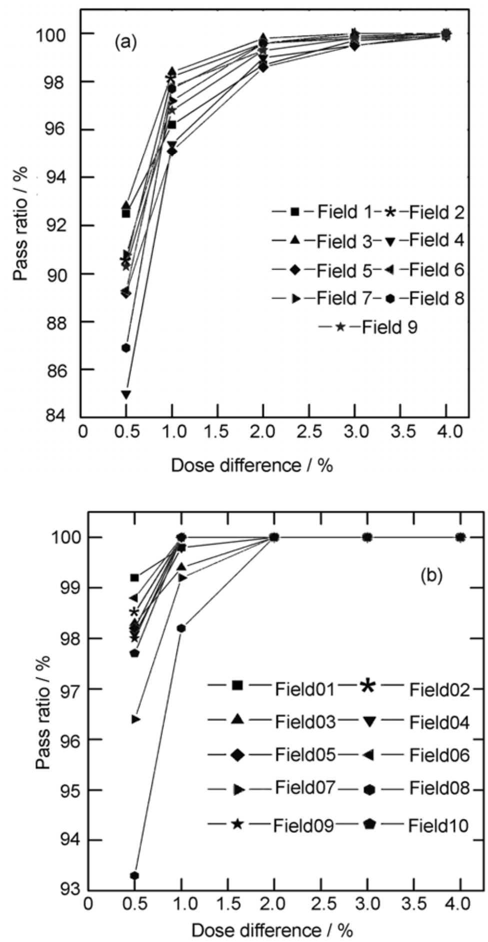

Fig.4 Pass rate (PR) curves for the IMRT fields need (a) two-exposure merging and (b)four-exposure merging.

The lateral scatter of the IMRT fields is less than the regular fields, hence the less significant effect than that of the regular fields.

4 Conclusion

The LSSV effect happens when a large field is measured with a detector array of limited measuring area through merging multiple exposures. Field size, beam energy, intensity-modulation are key factors of LSSV effect. For large open fields, the effect is significant; while for large wedge and IMRT fields, the effect is negligible.

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