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Evaluation of treatment planning system monitor unit calculations for three intensity modulated radiotherapy delivery techniques

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Background: We have validated the monitor unit calculations from a commercially available treatment planning system (TPS) for three intensity modulated radiotherapy (IMRT) planning techniques for tangential breast irradiation by using ionization chamber measurements. ***Materials and Methods:*** Treatment plans were generated for forty-two breast patients by a forward planned field in field technique, electronic tissue compensation (ETC), and an inverse planned sliding window technique. We also performed a reproducibility of delivery and dose linearity analysis for each technique. The treatments were delivered to a phantom using a Varian CL21EX linear accelerator. A 2571 0.6 cm^3 Farmer type ionization chamber and Farmer 2570/1 electrometer from NE Technology was used to measure output of the linear accelerator and the dose at predefined point in the verification plan. ***Results:*** The agreement between the measured and calculated dose was -0.87% ± 0.54% for field in field technique, -0.74% ± 0.23% for electronic tissue compensators, and -1.26% ± 0.48% for the inverse planning technique and. In terms of reproducibility the mean deviation was -1.10% ± 0.44% for the field in field technique, -0.38% ± 0.42% for electronic tissue compensators, -1.04% ± 0.42% for inverse planning technique. Dose linearity experiments showed no significant variations for clinical situations but a breakdown was observed in relative dose for very low monitor units. ***Conclusion:*** We have found that the monitor unit calculations for all three planning techniques are correct to the order of 1%, and that the plans can be delivered in a reproducible and accurate manner.
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Keywords: *IMRT QA, dose delivery system, dose calculation accuracy, electronic tissue compensators, reproducibility, dose linearity.*

INTRODUCTION

Intensity modulated radiation therapy (IMRT) has been increasingly used in radiotherapy departments during the last several years. Dosimetric studies have established intensity-modulated radiotherapy (IMRT) as superior to three-dimensional conformal radiotherapy (3D-CRT) [1-3] in terms of target coverage, conformity, and sparing of normal tissues. In addition, IMRT offers control and survival outcomes equivalent to those with 3D-CRT. Different types of algorithms are employed in the IMRT dose calculation. These types of algorithms may have some approximations that can potentially affect the dose results, especially considering that in an IMRT plan beamlets may be present for which electronic disequilibrium and inhomogeneity effects are of paramount importance [4].

For intensity-modulated radiotherapy (IMRT), dose delivery throughout the target volume is sensitive to multi leaf collimator (MLC) positioning and transmission because of the relatively small subfields and the increased monitor units (MUs) characteristic of IMRT plans. Leaf transmissions typically account for 10–15% of the dose delivered to the target volume [5]; however, their optimal values are not universally applied. The average MLC transmission increases with the field size, but most treatment planning systems use a single value, and interleaf effects are often ignored. Therefore IMRT requires an enhanced quality assurance procedure. This

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applies in particular to the step of MU calculation verification. Because of time constraints, treatment planning systems (TPSs) normally deal only in an approximate manner with the physical processes of the interaction of ionizing radiation in the treatment head and dose deposition inside the patient. Therefore the determination of the absorbed dose needs experimental verification [6-11].

Our goal is to study the accuracy of MU calculations through the use of a single point measurement using an ionization chamber for three IMRT planning techniques generated from a commercially available treatment planning system (TPS). The techniques examined include forward planned step and shoot (Field in Field) IMRT, a planning technique using electronic tissue compensators (ETC) implemented by means of the dynamic multileaf collimator (DMLC) and an inverse planning technique also using DMLC delivery. The validation of dose in a volumetric or planar context has been previously performed at Montreal General Hospital Canada as part of other IMRT commissioning exercises and is beyond the scope of this work.

A study of delivery reproducibility and dose scalability and linearity was also performed for the 3 types of IMRT. The need for reproducibility is obvious considering the patients come for multiple visits, and the dose linearity is an important component in case of changes in dose fractionation or treatment interruptions.

MATERIALS AND METHODS

Phantom

The calibration phantom having a dimension of 20×20×20 cm^3 was used for photon beam calibration and IMRT QA phantom having a dimension of 30×30×17 cm^3 was used for point dose measurements. Both the phantoms are made up of solid water having the mass density =1.042 g/cm^3, Z_{eff} =7.40 and electron density relative to water = 1.013.

Measurement equipment

A 2571 0.6 cm^3 Farmer type ionization chamber and Farmer 2570/1 electrometer from NE Technology was used to measure output of the linear accelerator and the dose at predefined point in the verification plan. The output of the linear accelerator was determined using TG51 dosimetry protocol [12].

Philips AcQSim CT Simulator

The IMRT QA phantom was scanned with a 3mm slice thickness with a Philips AcQSim CT simulator (Philips, Andover, MA). The scanned images were exported via DICOM to the TPS.

Treatment planning system

The TPS in question is the Eclipse system version 8.1 (Varian Medical Systems, Palo Alto, CA). The dose was calculated using the pencil beam convolution algorithm (Version 8.1.17). Heterogeneity corrections were not used. A computational grid size of 5 mm×5 mm was used for dose calculation.

Treatment plans

Treatment plans for forty two patients were generated for a randomly selected cohort of breast patients requiring tangential breast irradiation only. For each patient, plans were generated using each of the three techniques. All plans used 6 MV photon beams. A physician specified the target anatomically on the patient as well as on the planning CT scan. The planning target volume was drawn based on the anatomical landmarks. The treatment isocenter was located near the center of this volume such that each tangential beam cleared the breast tissue in the anterior aspect by 2 cm, and such that no more than 2 cm of lung was included in the treatment field. The inferior and superior limits were defined anatomically.

The field in field technique for treatment planning consists of using multiple superimposed MLC fields each with its own field weight. The shape and size of these

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fields is determined by the treatment planner by the trial and error method. Generally the dose is compensated on the central plane perpendicular to the beam incidence, and the MLC is used to reduce dose judiciously to hot spots. Once an adequate plan is obtained, the system generates a leaf sequence file that is delivered automatically at time of treatment. A single monitor unit calculation is performed for each group of fields.

The electronic tissue compensator is a field modifier implemented by means of the DMLC that replaces a mechanical or the step-and-shoot compensator. Improved dose homogeneity can be obtained using electronic tissue compensation, in which the fluence distribution required to produce an isodose surface perpendicular to the central axis at a specified depth is calculated by the TPS. The fluence distribution is calculated by ray tracing and the determination of the amount of missing tissue along each ray line. The fluence is converted into a deliverable DMLC field sequence with the total number of MU calculated for each field sequence.

The inverse planning optimizer uses user specified dose-volume constraints, in this case for the target structure only, to generate the required DMLC sequence to achieve the planning goals through the use of a gradient based cost function algorithm.

For the three types of plans, the target coverage requirements were a minimum 95% of the prescription dose (100%) to be delivered to 100% of the target volume, with no volume of patient or target receiving more than 107%.

Verification plans

Each of the patient's plans was copied to a CT scan of the IMRT phantom with the ionization chamber in place. A verification plan was prepared where the dose from the leaf sequences used in the patient plans were recalculated, and distributions obtained for the phantom. The dose to the ionization chamber was noted from the verification plan, and was compared to the dose measured during delivery of the patient plan to the phantom.

Delivery equipment

All the measurements were performed on Varian CL21EX linear accelerator (Varian Medical Systems, Palo Alto, CA) fitted with a Millennium 120 leaf MLC.

Reproducibility experiment

The stability and precision of measuring equipment, setup procedure and beam delivery was investigated by measuring the dose for ten fractions of the same plan delivered on separate occasions. This test was performed for one typical case for each type of IMRT delivery.

Linearity experiment

For checking the dose linearity, the phantom was irradiated with different number of monitor units using the same leaf sequence. The goal was to establish that the dose/MU would be constant. The measurements were performed at two dose rates i.e. nominal dose rate of 400 cGy/min as well as low dose rate of 100 cGy/min. The dose linearity is determined in terms of relative dose. The relative dose (RD) is defined as the ratio of dose per MU at the testing condition to the dose per MU for the actual plan. This test was performed for one typical case for each type of IMRT delivery.

RESULTS

Deviation was determined in terms of the ratio of measured dose to calculated dose. The results of the ionization chamber measurements at isocenter for three delivery techniques are shown in figure 1. The mean deviation was -0.87% ± 0.54% for field in field technique, -0.74% ± 0.23% for electronic tissue compensators, and -1.26% ± 0.48% for and the inverse planning technique.

Figure 2 shows the comparison of the reproducibility of the three techniques for

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ten fractions. The mean deviation is -1.10% ± 0.44% for field in field technique, -0.38% ±0.41% for electronic tissue compensators, -1.04% ± 0.42% for inverse planning technique.

Figures 3-5 show the linearity of the measured dose as a function of monitor units for three delivery techniques. The dose and number of monitor units are represented on logarithmic scale. Ideally RD should be unity over the range of MU used clinically. For field in field technique the RD is within 1% for monitors units ≥ 10 MU and within 2% or better for monitor units >1 MU. For electronic tissue compensators technique the RD is within 1% for monitor units ≥ 10 MU and within 2% or better for monitor units >3 MU. For IMRT with the full inverse planning DMLC technique the RD is within 1% for monitors units ≥10 MU and within 2% or better for monitor units >2 MU. We also note that for the lower dose rate (100 MU/min) the linearity problems are diminished due to the fact that the MLC has more time to reach it's position. This would indicate that the errors are more a function of the irradiation time than dose delivered.

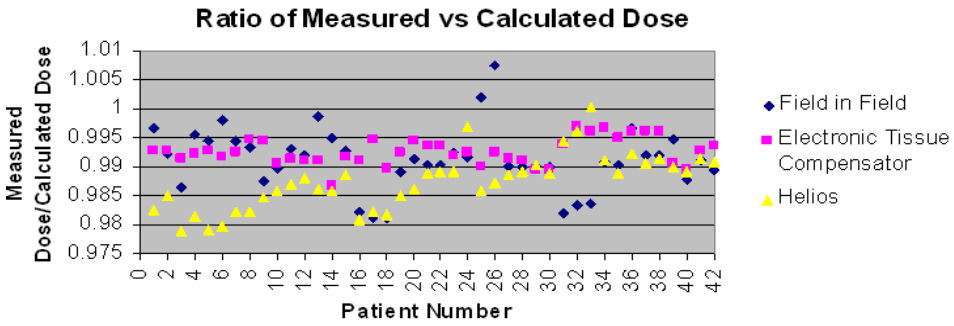

Figure 1. Deviations of the ionization chamber measurements from treatment planning system calculations for three IMRT techniques.

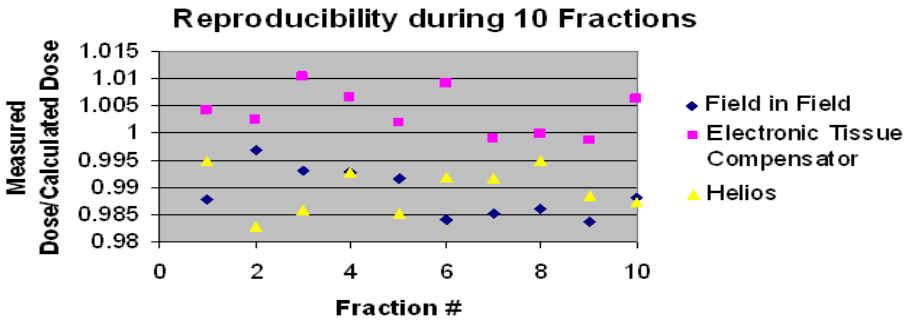

Figure 2. Deviations of the ionization chamber measurements from treatment planning system calculations for three IMRT techniques.

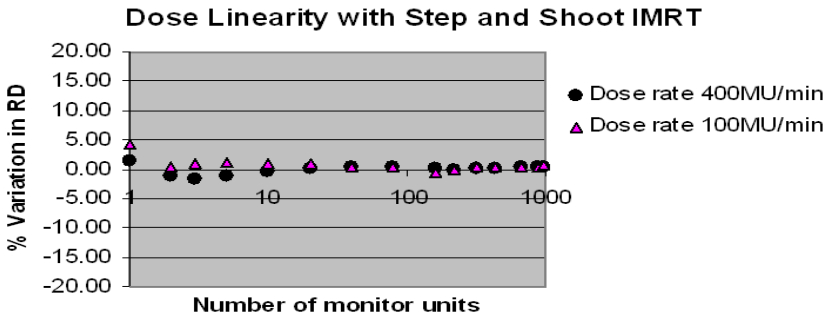

Figure 3. The % variation of the relative dose for step and shoot IMRT with the two dose rates. The MUs are expressed on logarithmic scale.

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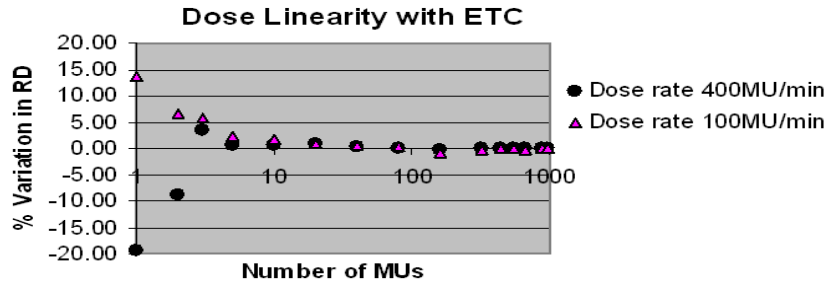

Figure 4. The % variation of the relative dose for IMRT with electronic tissue compensators with the two dose rates. The MUs are expressed on logarithmic scale.

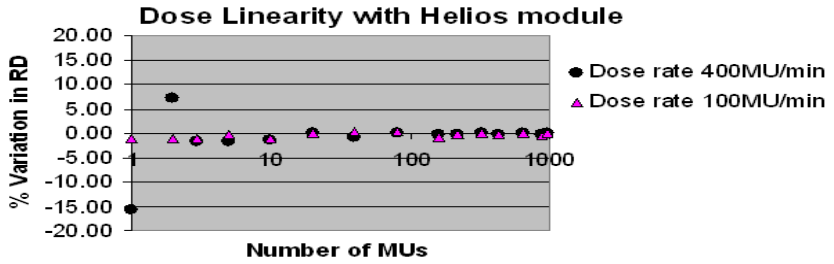

Figure 5. The % variation of the relative dose for IMRT with Helios module with the two dose rates. The MUs are expressed on logarithmic scale.

DISCUSSION

IMRT gives rise to many smaller field sizes therefore the position of ionization chamber is critical in IMRT dosimetry. To avoid the volume averaging effects and to eliminate the high sensitivity to small errors in positioning placement of the ionization chamber in the region of high dose gradient or near the edges of the field was avoided. Fransisco *et al.* [13] analyzed the deviations of the measured dose from the calculated dose by using different detectors. They showed an agreement of -1.5% ± 1.47% for step and shoot IMRT and 2% ± 1.99% for dynamic MLC IMRT. In this study a good agreement is found between the measured and calculated dose for all the three techniques but the electronic tissue compensators technique showed the best result i.e. -0.74% ± 0.23%.

To study the reproducibility Budgell *et al.* [14] performed the ion chamber measurements for five fractions of the same plan and found the standard deviation of 0.7%, with a range of 1.6%. In this study the reproducibility for ten fractions was investigated and similar results were found for all the techniques but the electronic tissue compensator technique showed slightly better result than the other techniques.

Cheng *et al.* [15] studied the linearity of the linear accelerator for 6 MV photon beam and there results showed the linearity within 2% or better for MU larger than 2 MU and better than 1% for monitor units greater than 5 MU. Ravikumar *et al.* [16] investigated the dose delivery accuracy for low monitor unit settings. They found that the dose delivery to be dependent on dose rate for 6 MV and significant variation in RD below 10 MU. In this study no significant effect of the dose rate on the RD was observed. However significant variation was observed in RD for lowest monitor units. Field in field technique showed the value of RD below 2% for monitor units above 2 MU and within 1% for monitors units >5 MU. It should be considered while analyzing these results, that although for our setup, the linearity and dose scalability breaks down for cases with very few MU, this does not affect clinical practice since typically patients are treated with a large number of MU. Table 1, lists the average MU per field used for each planning

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Table 1. Description of the average MU per field used for three planning techniques.

Technique	Average # of MLC Segments	Average# of MUs
Field in Field	14	220
Electronic tissue compensators (ETC)	102	230
Inverse planning	150	350

technique.

CONCLUSION

Using a single point ionization chamber measurement is an established technique for the verification of treatment deliverability and TPS monitor unit calculation for cases planned with IMRT. This study has shown that for breast cancer cases treated with tangential field irradiation and planned with three different IMRT techniques, the ionization measurement validated the TPS monitor unit calculation. Care must be taken of course to commission the TPS carefully and to validate the volumetric dose deposition in the patient as well. This work is presented as a validation of the TPS calculated MU values only. The results however show that the accuracy of the TPS calculation is high, and it is felt that after a sufficient number of representative measurements have been performed for a given technique, it may not be necessary to perform this type of measurement for MU validation if a more efficient and less laborious system is employed, such as using empirically based tabulated values or an alternative software based solution.

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