Quality Assurance of TPS: comparison of dose calculation for stereotactic patients in Eclipse and iPlan RT Dose

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Received: 29.11.2008
Accepted: 15.03.2009
Subject: original paper

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SUMMARY

BACKGROUND: Quality assurance (QA) in the radiation therapy planning process is essential to ensure accurate dose delivery to the patient and to minimize the possibility of accidental exposure. In recent years, several reports have been developed addressing issues related to the commissioning and quality assurance (QA) of RTPSs.

AIM: To evaluate the differences between dose distributions obtained with different dose calculation algorithms implemented in TPSs for stereotactic irradiation.

MATERIALS AND METHODS: BrainLab's iPlan v. 3.0.2 RT Dose calculates by pencil beam algorithm, while Eclipse v.7.5.18 (Varian Medical Systems) calculates by different types of pencil beam / AAA algorithms (selectable).

RESULTS: The largest difference was found in the lung patient, where a difference of 10.3% in the number of monitor units and 8.3% in dose to the isocentre occurred (with calculation by AAA algorithm of Eclipse in relation to iPlan PB algorithm). The average difference in all other cases (AAA compared to iPlan) was 2.2% for MUs and 1.5% for dose to the isocentre. The average difference in all other cases (PB compared to iPlan) was 1.9% for MUs and 3.2% for dose to the isocentre. When data were transferred from iPlan through DICOM RT to Eclipse, for all patients an isocentre shift was observed.

CONCLUSION: The dose distribution calculated by three different photon calculation algorithms results in clinically significant dose differences in isodose distribution, especially in the area of high inhomogeneities.

KEY WORDS: treatment planning, stereotactic radiotherapy, quality assurance, dose calculation algorithms, pencil beam/convolution

BACKGROUND

Radiation treatment planning is a vital and essential component of the total radiation treatment process. Quality assurance (QA) in the radiation therapy planning process is essential to ensure accurate dose delivery to the patient and to minimize the possibility of accidental exposure [1]. In recent years, several reports have been developed addressing issues related to the commissioning and quality assurance (QA) of RTPSs. The most comprehensive of these reports include: the report of Task Group 53 (TG53) of the American Association of Physicists in Medicine (AAPM), the report by the IAEA, Technical Reports Series No. 430 [2], the report by the European Society of Therapeutic Radiation Oncology (ESTRO) and the report by the Netherlands Commission on Radiation Dosimetry (NCS). Verification of the dose calculation is recommended as a part of the overall quality assurance procedure for newly installed or upgraded clinical software packages, especially when two TPSs calculate dose values with different dose calculation algorithms. Dose calculation algorithms should be tested both to verify that the algorithm executes as specified

(by the vendor) and for accuracy (published reference data).

Teletherapy treatment planning systems, depending on the version and manufacturer, nowadays calculate doses with different algorithms [3, 4] but common to all is required high speed and high accuracy. High speed is nowadays met by the computer technology development. The accuracy of the dose calculation algorithms becomes a problem only for very heterogeneous tissues, where very detailed modelling of the energy transport in the patient is required. This is particularly important around air cavities, as in lung tissue. Almost all new developments related to dose algorithms specifically concentrate on these or equivalent areas of tissue heterogeneities, whereas for the majority of clinical cases with almost homogeneous tissues, simple calculation methods can be reliably applied [4].

AIM

This study aimed to evaluate and compare the transition from the dose calculation algorithms implemented in two clinically widely spread treatment planning systems for stereotactic irradiation (iPlan and Eclipse). BrainLab treatment planning system iPlan RT Dose v.3.0.2. and Eclipse v.7.5.18 (Varian Medical Systems) both use the same set of photon data for the same linear accelerator (Varian 2300) and both use the microMLC mounted as an accessory to the gantry of the linear accelerator. The irradiation plans were prepared with same geometric arrangement of the beams, the same beam weights, prescription points and normalization points. Also, insertion of MLC in relation to the PTV was the same. This feature is selectable in Eclipse, but is unified in iPlan.

Calculations were performed for: head of anthropomorphic phantom, and three different real patients: a head patient (organs at risk very closely positioned to the tumour volume), a lung patient (lung tissue is a special challenge for a dose calculation algorithm, especially in the case of extracranial stereotactic radiotherapy due to small field sizes in combination with large variations in tissue density [6]) and an abdominal patient. Digital data transfer of corresponding sets of CT and MRI data, contours, as well as the isocentre coordinates, were also examined and evaluated.

MATERIALS AND METHODS

The manufacturer of the stereotactic equipment, BrainLab, recently released a new version of the treatment planning software for its equipment, iPlan RT Dose v 3.0.2. The version that was previously in clinical use at the Maria Sklodowska Curie Institute of Oncology in Gliwice was BrainScan. The new software was installed in April 2008. At the beginning of use of iPlan, around 10 patients were planned with BrainScan parallel with iPlan to gain more experience with iPlan and get accustomed to the calculation results. Comparison was performed, and plans were within acceptable limits. As mentioned previously, for homogeneous tissues, as is in brain patients, no significant differences should be observed, as the simplest algorithms calculate with satisfactory accuracy.

In the radiotherapy department of the Maria Sklodowska Curie Institute of Oncology, also the external beam treatment planning system Eclipse (CadPlan), from Varian Medical Systems, is installed for 11 years. The current version v.7.5.18 has been in clinical use since 2006.

MicroMLC of BrainLab is mounted as an accessory on a gantry of the Varian Clinac 2300, and is used with 6MV photons for irradiation of stereotactic patients. It can be used for planning with iPlan RT Dose, and also with Eclipse.

Dose calculation methods

Dose calculation algorithms for high-energy photon beams were first developed for the "homogeneous" patient – a patient completely consisting of water. Measurements of a set of dose functions are measured in a water phantom for a set of regular treatment fields under reference conditions. The dose within a patient is then calculated by extrapolating these measurements to the specific chosen treatment fields and by the application of various correction algorithms, for the inclusion of missing tissues at the patient surface or the approximate consideration of tissue heterogeneities. These phenomenological "correction-based methods" rely almost completely on a set of measurements and are very fast.

To understand the underlying physical processes responsible for the energy deposition

within the patient, "dose kernels" were introduced. Dose kernels describe in different levels the energy transport and deposition in water caused by a defined set of primary photon tissue interactions. For the application to inhomogeneous patient geometries these dose kernels are "scaled" in size according to the encountered local tissue densities. That is how "model-based algorithms" are created. Besides the expected extended calculation times in comparison with the "correction-based methods," the achievable higher spatial resolution of the absorbed energy in the patient requires a more accurate description of the radiation field provided by the linear accelerator, i.e., for "model-based algorithms" generally an additional model for the radiation field emerging from the radiation source is invented. Model-based algorithms in their various implementations constitute the standard algorithms provided by currently commercially available treatment planning systems. The simplest form, the so-called pencil-beam algorithm, is still the standard and fastest dose engine. More sophisticated and accurate are the superposition algorithms. The most sophisticated approach to include almost all known physical features about the microscopic radiation–tissue interactions is the Monte Carlo approach [4].

As mentioned previously, iPlan RT Dose v. 3.0.2 calculates dose distribution by pencil beam algorithm, while Eclipse (Varian Medical Systems) calculates both by the so-called Analytical Anisotropy Algorithm (AAA7518) and pencil beam. The Analytical Anisotropy Algorithm is a 3D pencil beam/superposition algorithm [3], which uses separate Monte Carlo derived modelling for primary photons, scattered photons, and electrons scattered from the beam collimating system. AAA accounts for tissue inhomogeneities in the entire three dimensional neighbourhood of an interaction site, by using photon kernels in multiple lateral directions. The final dose is obtained by the superposition of the dose calculated with photon and electron convolution.

Correctness of data transfer

Correctness of data transfer was checked and evaluated in the following way:

– The head phantom was scanned and sent via network from the CT scanner to both treatment planning systems (iPlan and Eclipse). The same contours of a virtual head tumour were entered by keyboard, as well as isocentre, to avoid any errors in delineation by free hand, and afterwards it was planned and dose distribution was obtained by Pencil Beam algorithm. The plan with the contours and isocentre was sent via DICOM RT from iPlan to Eclipse. This head phantom with contours from the iPlan was then recalculated by two algorithms in Eclipse, AAA v.7518 and Pencil Beam v.7518. So one plan in iPlan, and four plans in Eclipse were prepared, one from the set of CT scan data sent directly from the CT scanner, and one from the set of contours sent from iPlan to Eclipse. For each set of data plans calculated with PB and AAA algorithm were prepared.
– For the other set of data, a large and a small target (in stereotactic dimensions) in the head phantom were drawn, and dose distribution recalculated in both TPSs and for three algorithms (one: PB in iPlan and two: PB and AAA in Eclipse). This was done to observe the behaviour of Eclipse algorithms in small fields and MLC positioning for both TPSs.
– For three different patients, CT scans and accompanying MRI, together with the body structures and isocentre information, were transferred from iPlan through DICOM RT to Eclipse. The plan was recalculated in Eclipse using two different dose calculation algorithms: AAA and PB. AAA is a standard clinical algorithm used for planning real patients, while Pencil Beam is set for this purpose, with the grid size resolution 2.5 mm, as is set in iPlan Pencil Beam algorithm settings.
– All plans were examined thoroughly for differences, and they were evaluated statistically.

Test configurations

All patients were immobilized by standard equipment used for immobilisation for stereotactic treatments in Maria Sklodowska Institute in Gliwice, including the head phantom. Distance between slices was 1 mm. Such a huge number of slices for the abdomen and lungs created a delay in calculation of the Eclipse PB algorithm. Treatment plans for real pa-

tients consisted of 9-11 photon beams of 6 MV. For the purposes of the study, the dose was set to 10 Gy, but patients were treated with different plans, not the one used in this study. Only their CT scans were used in this study.

Field sizes depended on the size of each target, but in Eclipse the field size was set the same as in iPlan, since iPlan automatically determines the field size, and it is same for all beams of one plan. The calculation grid was 2.5 mm. Micro MLC leaves were automatically placed around the tumour volume, with a margin as prescribed by the radiation oncologist. The insertion of leaves was such that they touched the outside line of the margin. This is an automatic function in iPlan, but has to be set for each field in Eclipse, since in clinical practice, insertion of leaves used is middle. Micro MLC leaves in the central part have 3 mm width in the isocentre, 4 mm in the inner part, and 5 mm in the outer part, measured in the isocentre.

Calculation was made for:

1. Head phantom (anthropomorphic),
2. Head patient (organs at risk very closely positioned to the tumour volume),
3. Lung patient (algorithm accounts for inhomogeneity) and
4. Abdominal patient (with inhomogeneities and organs at risk close to the tumour volume).

Note that patients were not treated with any of these experimental plans, but separate treatment plans were prepared, reviewed and approved by the radiation oncologist.

During planning, beam arrangement, normalization points, reference points, etc were used in the same way in Eclipse as in iPlan.

RESULTS

Examined were: total number of monitor units for each planned treatment, maximal and minimal doses to target, doses to isocentre, doses to organs at risk (where they were contoured).

Dose distribution

All plans calculated in iPlan were recalculated in Eclipse in the same manner. This includes the prescription point, normalisation point, micro MLC insertion, and dose prescribed.

The largest differences in doses calculated by all three algorithms were in the lung patient, where a difference of 10.3% in monitor units number and 8.3% in dose to isocentre occurred (AAA algorithm of Eclipse calculated the highest values of MUs and dose to isocentre in comparison with the same calculated by pencil beam algorithms PB of iPlan and Eclipse). The average difference in all other cases, which were rather homogeneous (AAA compared to iPlan), was 2.2% for MU number and 1.5% for dose to isocentre. The average difference in all cases except lungs (PB in Eclipse compared to iPlan) was 1.9% for MU number and 3.2% for dose to isocentre.

All maximum doses calculated by Eclipse pencil beam were higher on average for 3% than those calculated by AAA of Eclipse.

All minimal doses were for all algorithms very comparable, and within limits of 4%, which can be explained by different positioning of MLCs in relation to the margin of target.

An exception is the case of the lung patient calculated by Eclipse AAA algorithm, where the minimum dose was within limits but the maximum dose in the target was 11% higher than calculated by iPlan's pencil beam. The result of calculation of the pencil beam algorithm of Eclipse was very close to the result of the iPlan pencil beam algorithm, and within the limits mentioned before. For details, refer to Table 1.

As for the organs at risk contoured in the real patients' plans, and involved in the treatment fields, we observed the following, by comparing the maximal doses to the organs at risk:

1. head patient. Three structures were drawn: left and right optic nerve, and chiasm. The maximum difference in the left optic nerve calculated by all three algorithms was 2.09 Gy (lowest for AAA calculation). Chiasm maximum difference was 0.63 Gy (highest for PB of iPlan). Right optic nerve difference of maximum doses was 0.34 Gy (highest for PB of iPlan).

2. lung patient: spinal cord is outlined. The maximum difference in spinal cord calculated by all three algorithms was 0.69 Gy (highest for iPlan, and almost the same for PB and AAA of Eclipse).

3. abdominal patient. Fours structures were outlined: left and right kidney, liver and spinal

Table 1. Results of radiation therapy planning for different test configurations (total number of MUs, max and min doses to PTV and dose to isocentre)

Test configuration	Head phantom Small target (1 cm)			Head phantom Large target (5 cm)			Head patient			Lung patient			Abdominal patient		
TPS Algorithm	iPlan PB	Eclipse AAA	Eclipse PB	iPlan PB	Eclipse AAA	Eclipse PB	iPlan PB	Eclipse AAA	Eclipse PB	iPlan PB	Eclipse AAA	Eclipse PB	iPlan PB	Eclipse AAA	Eclipse PB
Number of beams		4			4			11			9			11	
Total number of MU	1565	1524	1488	1385	1356	1386	1513	1481	1487	1378	1520	1386	1686	1716	1670
Max dose to PTV (%)	106.3	105.3	110.3	105.2	107.2	111.0	108.0	106.3	109.5	108.0	119.2	110.5	110.1	110.7	111.5
Min dose to PTV (%)	95.8	93.5	91.4	94.5	82.8	87.9	93.3	92.1	93.1	93.8	90.6	89	91.4	91.5	90.7
Dose to isocentre (Gy)	10.45	10.87	10.47	10.29	10.54	11.00	10.67	10.52	10.85	10.40	11.26	10.73	10.85	10.74	10.86

cord. Right kidney maximal dose difference was 0.74 Gy, left kidney 0.31 Gy, for liver 0.28 Gy and for spinal cord 0.7 Gy.

Micro MLC positioning and data transfer

Micro MLC positioning by Eclipse and iPlan is different, but within 2 mm for all observed cases (see Figures 1 and 2).

When data were transferred from iPlan through DICOM RT to Eclipse, for all patients an isocentre shift was observed. The largest difference in coordinates seen by Eclipse and set by iPlan was in the abdominal case, and the smallest in the lung case. The largest isocentre coordinate shift in one direction was 1.0 cm, while the largest isocentre coordinate shift in the other direction was 0.5 cm. After careful examination of isocentre placement after DICOM RT transfer, it became clear that the new coordinates as seen by Eclipse were correct. Yet, we consider that absolute values of isocentre coordinates should stay the same after electronic transfer.

In addition, all outer contours sent by iPlan had to be deleted and new automatic body contours in Eclipse had to be drawn, as Eclipse could not calculate the dose with the outer contours from iPlan.

Discussion and Conclusion

To summarize, this study shows the influence on the dose calculation when different dose calculation algorithms for stereotactic radiotherapy are applied, implemented in two versions of different treatment planning systems for stereotaxy, which is later performed on the same equipment.

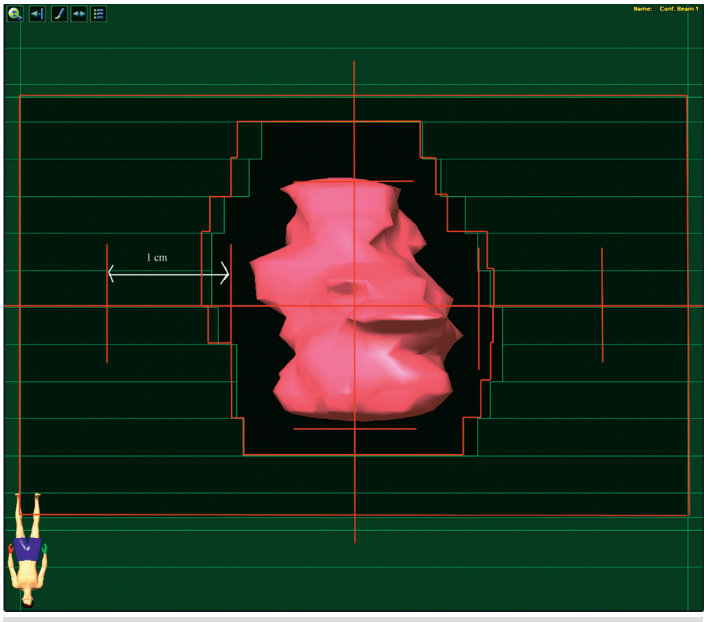

Fig. 1. Head Patient, beam-eye-view for the same beam as shown by the iPlan and Eclipse. Positioning of mMLC in iPlan is shown by the green line, while Eclipse mMLC positioning is shown by the red line. Eclipse positions mMLC more closely to the target, and that explains the lower minimums within the target

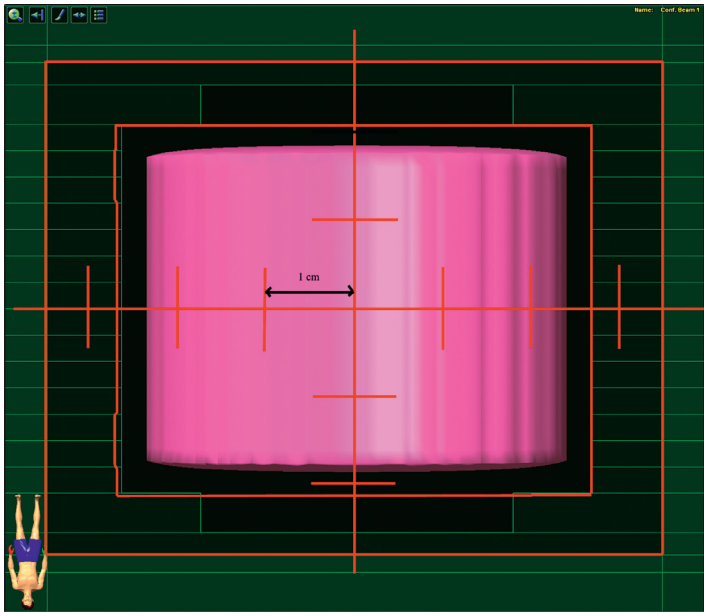

Fig. 2. Head Phantom with regular shape target, beam-eye-view for the same beam as shown by the iPlan and Eclipse. Positioning of mMLC in iPlan is shown by the green line, while Eclipse mMLC positioning is shown by the red line

The dose distributions calculated by different photon calculation algorithms lead to clinically significant dose differences in isodose distribution. Careful examination of TPS in use in the clinic is a crucial part of TPS commissioning and QA [4, 5, 6, 7].

Differences found in all geometries calculated resulted mainly from doses calculated with different algorithms. This difference (between PB algorithms iPlan and Eclipse) may be connected with configuration of TPS Eclipse. In Eclipse only mMLC was defined, without additional measurements of DD (depth dose) and PF (profile functions) when mMLC is actually mounted to the gantry. The systems use the data of the accelerator without the possible additional scatter from the mMLC. This study is in progress. The largest difference observed in the lung case is a natural consequence of the fact that the AAA algorithm has improved calculation results, and is evolving as recommended especially for regions of high heterogeneities. These results would also lead to the conclusion that treating lung patients, or other sites with heterogeneities included in the treatment field, would be recommended for calculation of the AAA algorithm as in this case, rather than with the pencil beam of iPlan, as stereotactic treatment planning systems and their algorithms are mainly meant for brain patients, where almost no heterogeneities are present, and the fast and simpler pencil beam algorithm calculates accurately enough.

Acknowledgement

This work was done during the fellowship SRB07021 in Gliwice. The fellowship was funded by the IAEA under the national technical cooperation project SRB 6002.

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