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Technical report

Development of in-house software to calculate dose for intensity-modulated radiation therapy based on lung CT-patient data

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Background: In external radiotherapy, the delivered dose is calculated from the treatment planning system. Various types of software have been used to verify the patient dose distribution.

Objective: Develop the in-house software (ISOFT) to calculate dose in intensity-modulated radiotherapy (IMRT) based on lung CT-patient data by combining the modified Clarkson integration with 3D-beam subtraction method.

Materials and methods: An ISOFT was developed for 6MV X-rays Varian Clinac21EX linear accelerator and the CT-based patient data. The multileaf collimators (MLCs) file from the Varian Eclipse treatment planning was transferred to the ISOFT. The ISOFT was used to calculate the dose distribution with correction of tissue inhomogeneity. To test the accuracy of the ISOFT, the normal MLC-shaped fields and IMRT plans were measured in a water phantom and in a thorax phantom, respectively. Then, these measurements were compared with the doses calculated from the ISOFT and the Varian Eclipse treatment planning system.

Results: The deviation between the measurements and calculations by the ISOFT for MLC-shaped fields in the water phantom fell within 0.5%. There were mostly higher calculated doses in lung compared with the measured result in the thorax phantom. The overestimated doses due to loss of scattering in the low-density materials were considered less in all methods of calculation. The measured lung dose difference from the ISOFT was within 5% criterion of acceptability.

Conclusion: The ISOFT can be used conveniently to verify dose calculation in heterogeneous media.

Keywords: Clarkson's method, inhomogeneity correction, irregular field, multi-leaf collimators, 3D-beam subtraction method

In external radiation therapy, the radiation dose is calculated from commercial radiotherapy treatment planning systems (RTPS). The optimum treatment plans are aimed to obtain sufficient prescribed dose to the tumor while minimizing the organ at risk. It is most important to know the accuracy of the dose distribution delivery in the patient. For this reason, the dosimetric verification is necessary for quality assurance (QA) process of RTPS, especially the 3D conformal and intensity-modulated radiation therapy (IMRT) techniques [1-3].

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The IMRT technique uses the multileaf collimators (MLCs) to generate different segments of intensity field by a set of leaf positions. The IMRT fields of the real patient are exported to a homogeneous phantom to measure a single point dose or the dose distribution map [4]. However, these methods are limited by the actual geometry of patients and the heterogeneous structures of internal tissues. In fact, tissues are not homogeneous in the head, neck, or lung region, where larger systematic errors may occur [5]. These errors result mainly from the algorithms for empirical dose calculation. Normally, the RTPS has used CT-based patient data to perform the heterogeneous correction [5]. This includes equivalent tissue air ratio method, power law tissue air ratio method (so- called Young and Batho) or three dimensional beam subtraction method (3D-BSM). The recent methods using superposition/convolution algorithm and Monte Carlo technique include some inhomogeneous corrections in the calculation of patient dose to provide a more accurate dose.

In this study, we developed an in-house software (ISOFT) to calculate doses with correction of tissue inhomogeneity. We combined the modified Clarkson integration algorithm with 3D-BSM for step and shoot IMRT for dosimetric verification in lung CT-patient data.

Materials and methods

We employed the 6 MV photon beams from Clinac 21EX (Varian Medical Systems, Palo Alto, USA) linear accelerator with 300 MU/min dose rate and 80 leaves of 1 cm width. The image from CIRS Model 002LFC IMRT thorax phantom (Norfolk, Virginia, USA) was taken from light speed RT CT simulator scanner (GE Medical System, Milwaukee, USA) for treatment planning. The treatment planning system used to calculate dose distribution was Eclipse Version 6.5 (Varian Associates, Palo Alto, USA).

Beam data requirement

The tissue maximum ratio $TMR_{(d, r)}$ data of 1.5 to 30 cm depths were extracted from standard measurement [6] with CC13 ionization chamber and DOSE1 dosimeter in 3D-beam analyzing water phantom (Scanditronix Wellhofer Dosimetric, Schwarzenbruck, Germany). Then, the scatter maximum ratio, $SMR_{(d, r)}$ and the tissue maximum ratio at zero field size, $TMR_{(d, 0)}$ were calculated. The total scatter factor, $S_{c, p}$ and the collimator scatter factor, $S_{c,}$ were also obtained from measurement. The phantom scatter factor at zero field size, $S_p(0)$ and the phantom scatter factor, $S_p(r)$, could be calculated. All these data were put into the ISOFT.

The MLC field dose verification

The ISOFT software was tested for the accuracy of the dose calculation in the central axis by employing MLC-shaped fields. We undertook dose measurement with 0.6 cc FC 65-P ion chamber, DOSE 1 dosimeter in water phantom at 1.5 cm depth, and 100 cm source axis distance (SAD). All fields were given 100 cGy prescribed dose at the central axis (10 cm depth) and zero degree gantry angle. The MLC test patterns consisted of square fields, rectangular fields, corner block, circular field, “Inverted” Y field and “Irregular” field.

The IMRT-plan dose verification

The two plans of step and shoot IMRT of lung region were calculated by Eclipse treatment planning system. The images of thorax region in CIRS phantom represented the patient image. A ninety-degree angle of the left lateral beam direction was selected to cover the inhomogeneity of both lungs. All plans were specified for 200 cGy prescribed dose at the isocenter where tumor located. For Eclipse treatment planning system, the grid size of 2.5x2.5 mm^2 was used in this calculation. The Eclipse treatment planning system was performed with two modes of calculation, pencil beam convolution algorithm using a modified Batho inhomogeneity correction, and an isotropic analytic algorithm (AAA) using convolution/superposition. The average subfields of IMRT plans was about 20, and the intensity levels were equal to 20. After Eclipse calculation, the image file, MLC file, and monitor unit were sent to the ISOFT for dose calculation. The external contour was drawn, and the modified Clarkson and 3D-beam subtraction were applied. The calculation was undertaken along the central axis plan passed to both lungs.

The point measurements by CC13 ionization chamber with DOSE1 electrometer were performed in the CIRS thorax phantom at the left lung, mediastinum, and right lung. The KODAK EDR2 film was used for two dimensional dose distributions. It was inserted to the CIRS phantom at the center of field with the setup in the position parallel to the beam. The films were scanned by Vidar-16 Dosimetry Pro scanner (Vidar Systems, Herndon, USA), and the doses were read out by the OmniPro IMRT software (Scanditronix Wellhofer Dosimetric, Schwarzenbruck, Germany).

Results

Code development for modified Clarkson integration algorithm with 3D-BSM

The ISOFT software was available for operation on Microsoft windows. The program could import the CT-based patient data with treatment plan of MLC position files and monitor unit for irradiation from Eclipse system. The software was capable of presenting the axial, sagittal, and coronal plane, and the contour could be constructed. The MLC treatment field could be displayed in the sagittal plane as shown in **Figure 1.**

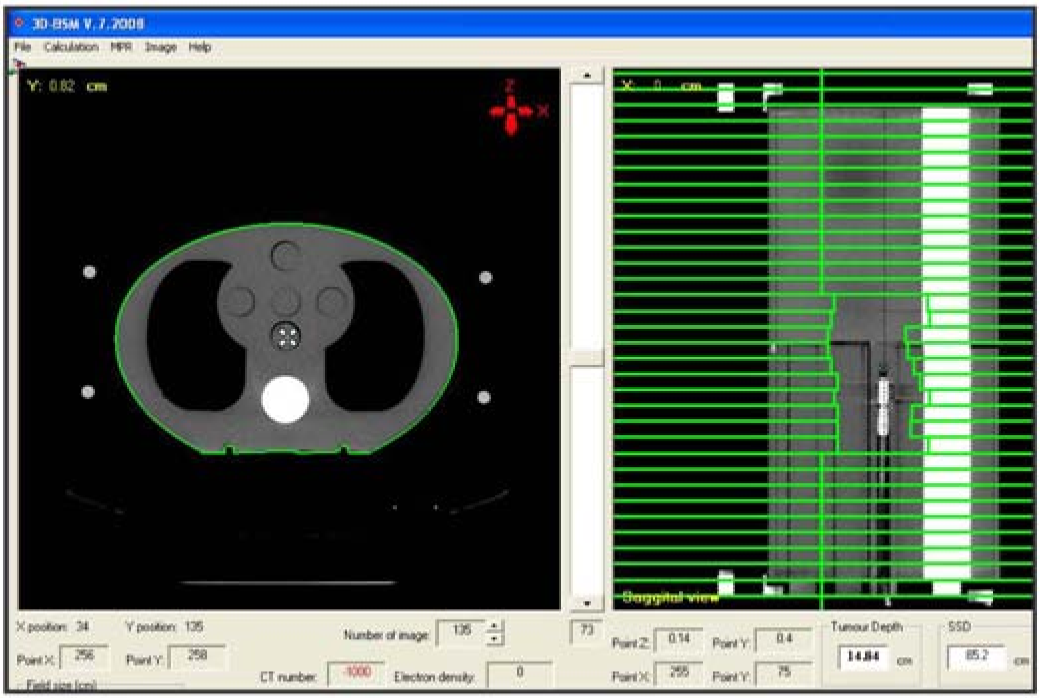

Figure 1. Screenshot of the ISOFT window that contain CT images with external contour, patient information and MLC position of treatment field

The MLC-field dose verification

Table 1 shows the dose measurement for all MLC-fields. These dose measurements agreed with the ISOFT software calculation, corresponding to the Eclipse system calculation. The MLC opening for square, rectangular, and shaped fields showed the percentage deviation within 0.5% between measurement and ISOFT software. This was also about the same number between measurement and Eclipse calculation. This level was within criteria of acceptability for the dose at normalization point, according to International Atomic Energy Agency (IAEA) [3]. This suggested that the ISOFT was suitable for the dose in homogeneous medium for all MLC fields.

Table 1. The comparison of dose measurement and calculation by Eclipse treatment planning and ISOFT of MLC fields for 6 MV photon beams at 1.5 cm depth and 100 cm source axis distance.

Beam	Measured Dose (cGy)	TPS Dose (cGy)	ISOFT Dose (cGy)	%Deviation TPS and measurement	%Deviation ISOFT and measurement
Square MLC10x10 cm^2	152.01	151.50	150.82	-0.34	-0.38
Square MLC5x5 cm^2	130.6	130.90	129.44	0.23	-0.31
Rectangular MLC30x5 cm^2	154.66	154.80	154.47	0.09	-0.12
Rectangular MLC5x30 cm^2	155.78	154.30	154.17	-0.95	-0.23
Corner blockMLC field	146.61	146.60	144.66	-0.01	-0.15
“Circular”MLC field	160.15	160.10	160.28	-0.03	0.08
“Inverted Y”MLC field	150.44	150.70	150.6	0.17	0.11
“Irregular”MLC field	153.33	154.10	153.55	0.50	0.14

The IMRT plans dose verification

The dose measurement of IMRT plans was performed in the CIRS thorax phantom using KODAK EDR2 film and CC13 ionization chamber with DOSE1 dosimeter. **Table 2** shows point dose comparisons between measurement, ISOFT software calculation, and Eclipse treatment planning system of AAA and pencil beam with the modified-Batho for two IMRT plans at the left lung, mediastinum, and right lung**.** The measured dose at the left lung and mediastinum of both plans illustrated lower dose than AAA and modified-Batho calculation. Plan 1 gave closer of the calculated and measured lung dose, while plan 2 presented more deviation dose. The dose at the left lung from the ISOFT showed higher dose than the measured while the dose at mediastinum showed lower dose than the measured level. However, the deviation of the left lung dose from the measured level fell within 4.6% for the two plans, which was slightly better than the modified-Batho. The deviation of the modified-Batho dose from the measurement was within 7.2%. The AAA deviated by only 2.1% from the measured level. The measured dose at the right lung was slightly higher than AAA, but lower than the modified-Batho and ISOFT. The deviation was less in ISOFT, compared with the modified Batho. The deviation of ISOFT dose from the measured was 3.7%, while deviation of Batho was 5.1%.

Figure 2 shows KODAK EDR2 film depth dose curve in the CIRS phantom. Interestingly, the depth dose curve in plan 1 and 2 had the same trend as the point dose measurement. The AAA dose was closer to the measured level than the other calculated level, except at the interface region. The calculated dose in ISOFT was close to the modified-Batho and higher than the measurement. There was no considerable effect due to the secondary electron at the interface for both the modified-Batho and ISOFT calculation. The measured dose in the left lung was the lowest as compared with the three methods of calculation. This indicated that the less scatter due to low density in the left lung was less accounted in the modified Batho under consideration of only some for AAA and a few for ISOFT. At the interface between the left lung and mediastinum, the three different calculation methods tended to agree with the measured doses. The doses became deviated again when passed through the right lung, but the effect was less in over-dose of the calculated methods for the right lung.

Discussion

The present ISOFT could be used easily for any type of irregular MLC fields in homogeneous phantom. The dose could be verified at the normalization points with the accuracy within 0.5%. When the Clarkson method combined with 3D-BSM, the dose correction for both irregular shaped field and the inhomogeneity effect was achieved. The program is capable of importing the CT-based patient data with the correct CT number together with the treatment plan and the MLC file. The contour could be constructed in the ISOFT. Then, the dose calculation was undertaken with the correction of the external contour and the inhomogeneity effect.

The developing software can read a large number of angular radiuses. Therefore, the correction for the inhomogeneity is more accurate, even though the Modified Batho method of inhomogeneity correction is used. The present ISOFT lung dose overestimated the measurement about 4.6%, but it was slightly better than the Modified Batho from the treatment planning. In fact, it showed 7.2% overestimate. The ISOFT lung dose was different from AAA only 2.4%. However, for the 3-D inhomogeneity, the criterion of

Table 2. The comparison between point doses measured by ionization chamber and calculated by AAA, modified Batho and ISOFT for IMRT plan at the left lung, mediastinum and right lung position.

Plan	Position	Measured (cGy)	AAA (cGy)	Modified Batho(cGy)	ISOFT (cGy)	% Deviation AAA and measurement	% Deviation Batho and measurement	% Deviation ISOFT and measurement
1	Left lung	242.96	245.4	249.34	251.25	1.00	2.63	3.41
	Mediastinum	176.97	183.4	181.4	169.21	3.63	2.50	-1.83
	Right lung	117.9	115.2	123.93	122.26	-2.29	5.11	3.70
2	Left lung	229.9	234.7	246.43	240.42	2.09	7.19	4.58
	Mediastinum	167.13	174.6	170.6	158.12	4.47	2.08	-2.24
	Right lung	112.5	109.4	118.23	116.64	-2.76	5.09	3.68

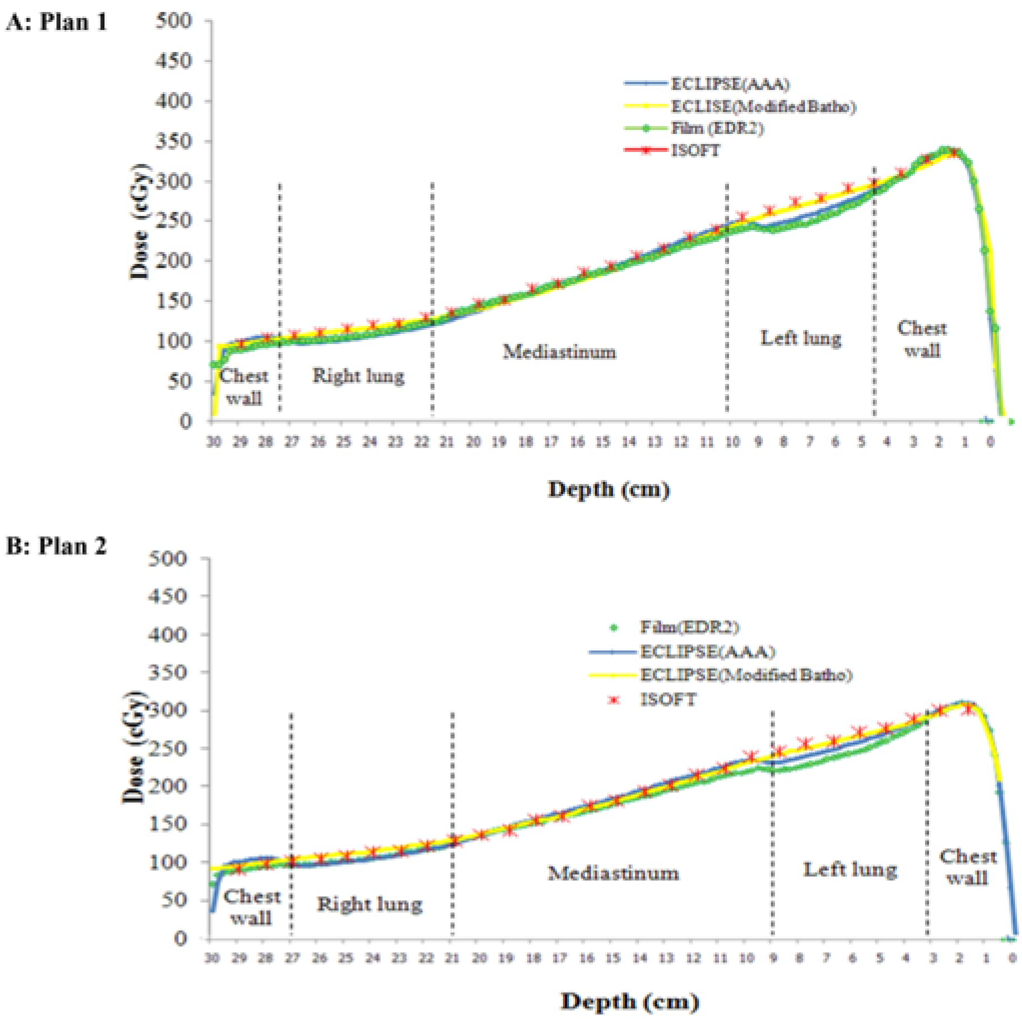

Figure 2. Depth dose curve of IMRT for plan 1 (**A**) and plan 2 (**B**) in the CIRS phantom

acceptability for the dose calculation is 5% [3]. The largest deviation from the measurement occurred at the interface, which the Modified Batho in Clarkson and 3D-BSM in ISOFT software do not account. Further development of the software would improve the calculated dose both in lung and at the interface. Kung et al. [7] reported the accuracy of the independent monitor unit verification calculation in IMRT by the modified Clarkson integration. The doses calculated with this algorithm agreed within 3% of those calculated by CORVUS. Xing et al. [8] reported the monitor unit calculation in IMRT using Clarkson's method. Their calculated dose agreed with the CORVUS calculation within 4%. Zhu et al. [9] verified a point dose calculation for IMRT/IMRS plan, which was developed using the original Clarkson's method. Compared with that reported by the treatment planning system, the present calculated dose was 2.7% different at maximum. However, these studies did not account for the inhomogeneity effect. Stathakis et al. [10] developed 3D-BSM in combination with the Clarkson method to calculate dose at any point in treatment field. This method considered the position and lateral extent of the inhomogeneity with respect to the point of calculation and the shape of irradiated fields. They presented the predicted correction factors that was nearly 1.5% compared with Monte Carlo simulation. Haslam et al. [11] implemented independent monitor unit verification software, RadCalc. The average calculation dose of IMRT fields by RadCalc was 1.4% higher than the treatment-planning dose. However, heterogeneity corrections were not performed. The contour patient's skin was manually by operators. Georg et al. [12] proposed independent dose calculation software that applied a pencil beam model based on a beam quality index. The dose of intensity-modulated beam showed the deviation of 1.1% compared between independent software and RTPS, with the maximum deviations up to 14% at the high dose region.

The dose calculation within a patient may lack accuracy if it is not regarding inhomogeneity correction. According to American Association of Physicists in Medicine (AAPM) Radiation Therapy Committee [5], the doses increase downstream beyond low-density media, and decreases downstream beyond high-density media. Additionally, the severity increases with increasing energy and decreases with increasing field size.

Conclusion

The present ISOFT is the first step for using the in-house software to verify the plan with the actual geometry of the patient. The ISOFT can reduce workload of physicists to perform the measurement and eliminate human error. In addition, the ISOFT is easy to use, reliable dose calculation. This program can be modified to serve for both 3D- and IMRT-plan verification for hospitals with limitation of personnel, equipment, and time.

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