Assessment of accuracy of out-of-field dose calculations by TiGRT treatment planning system in radiotherapy

ABSTRACT

Aim: The objective was to quantify the accuracy of dose calculation for out-of-field regions by the commercially available TiGRT version 1.2 (LinaTech, Sunnyvale, CA, USA) treatment planning system (TPS) for a clinical treatment delivered on a Siemens Primus with the single energy of 6 MV.

Materials and Methods: Two tangential open fields were planned by TiGRT TPS to irradiate the left breast of a RANDO phantom. Dose values to out-of-field points were calculated by TiGRT TPS. A RANDO phantom was then irradiated, and dose values at set points were measured using thermoluminescent detectors-100 (TLDs-100) which were located within the phantom. Finally, the TLD-measured dose was compared to the TPS-calculated dose and the accuracy of TPS calculations at different distances from the field edge was quantified.

Results: The measurements showed that TiGRT TPS generally underestimated the dose of out-of-field points and this underestimation worsened for regions relatively close to the treatment field edge. The mean underestimation of out-of-field doses was 39%. Nevertheless, the accuracy of dose calculation by this TPS for most in-field regions was within tolerance.

Conclusion: This study highlights the limitations of TiGRT TPSs in calculating the out-of-field dose. It should be noted that out-of-field data for this TPS should only be applied with a certain understanding of the accuracy of calculated dose outside the treatment field. Therefore, using the TPS-calculated dose could lead to an underestimation of secondary cancer risk as well as a weak clinical decision for patients with implantable cardiac pacemakers or pregnant patients.

KEY WORDS: Dose calculation accuracy, out-of-field, TiGRT, treatment planning system

INTRODUCTION

Along with chemotherapy and surgery, radiotherapy remains an important modality in tumor treatment. [1] Around 50% of all patients with localized cancer are treated with radiotherapy. [2,3] During radiotherapy, regions outside of the treatment field receive scatter radiation from the head of the accelerator, and internal patient scatters radiation. [4] The occurrence of secondary cancers in patients treated with radiotherapy was found in normal tissue surrounding the target volume where the highest dose was delivered. [5] An investigation on the induction of secondary cancers following radiotherapy requires knowledge of the dose profile outside the target. [6] Secondary radiation sources are able to deposit dose at far distances from the target volume. [7] Although out-of-field dose is smaller in in-field dose, these doses can induce secondary cancers with a long-latency period (especially in radiosensitive organs). [6,7] The incidence of these secondary cancers depends on the delivered dose distribution, dose, dose rate, size of the irradiated volume, and patient-specific factors. [8] Treatment planning systems (TPSs) in radiotherapy are not commissioned for out-of-field dose calculations. [9,10] It is generally accepted that the accuracy of dose calculations by TPSs is poor for out-of-field regions. [11] Measurements of out-of-field doses have gained interest in the past years. Furthermore, several studies quantified the accuracy of out-of-field dose calculations by TPSs.

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Kaderka et al.\(^\text{[6]}\) investigated characterization of out-of-field dose following the irradiation of the target with photons, carbon ions, and protons. The peripheral dose of photons was significantly higher compared to both carbon ions and protons and exceeds up to two orders of magnitude at distances >50 mm from the edge field. The out-of-field dose for photons (X-rays) increases with increasing beam energy due to the production of biologically harmful neutrons. Furthermore, La Tessa et al.\(^\text{[7]}\) investigated characterization of the out-of-field dose following irradiation of the target volume. The results for the selected planning target volume indicated that if a collimator was used in proton therapy, it reduced the dose deposited by photons or ions close to tumor as well as scanning modulation (i.e., irradiation with scanned protons and irradiation with passively modulated carbon ions) represents the desired technique for achieving the maximum dose reduction far out-of-field.

Huang et al.\(^\text{[8]}\) evaluated the accuracy of the out-of-field dose calculations by pinnacle TPS for intensity-modulated radiation therapy (IMRT) treatment plans. The results showed that pinnacle TPS generally underestimated the out-of-field dose by an average of 50% and this underestimation worsened for increment distances from the field edge. Howell et al.\(^\text{[9]}\) quantified the accuracy of the out-of-field dose predicted by the Eclipse TPS for a simple mantle field. They showed that Eclipse TPS underestimated out-of-field doses by an average of 40%. Court et al.\(^\text{[10]}\) investigated the accuracy of dose calculation in IMRT for mesothelioma (focusing on low doses to the contralateral lung). They found that both superposition convolution and pencil-beam algorithms used in Eclipse TPS underestimate lung dose parameters in mesothelioma IMRT, but the superposition convolution algorithms rather than pencil-beam algorithms offer improvements in dose calculation accuracy. Ozgüven et al.\(^\text{[11]}\) carried out quality assurance of Eclipse TPS on photon beam. Their results showed that for the region outside the beam edge (low dose-small dose gradient region), differences between measured and calculated doses (\(D_{\text{meas}}\) and \(D_{\text{calc}}\)) increased with expanding field size. Furthermore, they showed that the differences between \(D_{\text{meas}}\) and \(D_{\text{calc}}\) for lung region were outside the tolerance level (the tolerance limit for inhomogeneity geometries and regions outside the treatment field edges is 4\%\(^\text{[12]}\) that in this study was obtained 8.35\%).

To the best of our knowledge, there is no investigation on the accuracy of out-of-field dose calculations by TiGRT TPS in radiotherapy. Thus, in this research, we quantified the accuracy of out-of-field dose calculations by TiGRT TPS.

**MATERIALS AND METHODS**

**Treatment planning and phantom irradiation**

A computed tomography scan of the breast region of a RANDO phantom (the Phantom Laboratory, NY, USA) was taken to produce a standard treatment plan. The images were transported to TPS. TPS used in this study was TiGRT version 1.2 (LinaTech, Sunnyvale, CA, USA). TiGRT is a radiation therapy TPS for dose planning of patients undergoing external beam treatment in clinical oncology. TPS is used to plan radiation treatments with linear accelerators and other similar radiotherapy devices with X-ray energies from 1 to 25 MV, as well as Cobalt-60, and electron energies from 1 to 25 MeV. TiGRT TPS uses a three-dimensional photon dose calculation algorithm based on full scatter convolution.

In this study, the breast region of the RANDO phantom was selected for assessment of the accuracy of out-of-field dose calculations by TiGRT TPS. Two tangential open fields were planned, and a source axis distance technique was used to deliver 52 cGy dose to the selected point (a point in slice 18 of the RANDO phantom). On the RANDO phantom, the planned fields covered slices No. 15–22. The therapeutic range of the radiation field on the RANDO phantom is illustrated in Figure 1. Before irradiation, the thermoluminescent detector (TLD) chips were placed in appropriate points of the RANDO phantom. The RANDO phantom was irradiated based on the treatment plan with 6 MV X-rays emitted from a Siemens Primus accelerator (Siemens AG, Erlangen, Germany). Doses received by the TLD chips were measured and compared with doses calculated by TPS.

It is notable that the effective point of measurement for the TLD chips was considered at the middle of its thickness.

**Calibration of applied dosimeters and dosimetric method**

TPLD readout and analysis was carried out in the medical physics research center ( Mashhad, Iran), which has a special protocol for TLD analysis. TLD-100 produced by Harshaw Company and made of LiF, Mg, and Ti with the size of 3 mm × 3 mm and thickness of 0.9 mm were used in this research. This type of TLDs has a reproducibility of approximately ± 1.5% (1 standard deviation). Fifteen TLD chips were placed in a Perspex holder which was located on a 30 cm water equivalent phantom. A 1.5 cm water equivalent slab was placed on the holder to

![Figure 1: Therapeutic range of breast region on the RANDO phantom](Image 380x73 to 493x249)
create a build-up region. They were irradiated to determine their individual efficiency correction coefficient (ECC). Then, they were irradiated with 50 cGy and readout by Harshaw reader to determine reader calibration factor. Finally, all of the TLD chips were irradiated with 50 cGy and their individual ECC were determined. Eighty-nine dosimeters were placed in the different areas of slices of No. 17 and 18 of the RANDO phantom. Three dosimeters were used to measure the background radiation.

Analysis of results
Measured and calculated doses were determined for the same points. The percent differences between $D_{\text{meas}}$ and $D_{\text{calc}}$ were determined for these points. The results were analyzed to determine if there was evidence of underestimation or overestimation of doses in different points by TiGRT TPS.

RESULTS
Out-of-field points were placed in slices of No. 17 and 18 of RANDO phantom. In these points, doses measured by TLD-100 were compared with corresponding values calculated by TiGRT TPS. It is noted that bolded digits in following tables are the measured/calculated doses obtained for the in-field regions. Table 1 represents the measured dose, the calculated dose, and the differences between $D_{\text{meas}}$ and $D_{\text{calc}}$ in the selected points of slice No. 17. Figure 2 shows the location of TLDs in slice No. 17 of RANDO phantom. Figure 3 shows the image of slice No. 17 of RANDO phantom and the location of points corresponding to the measured points in TiGRT TPS. Table 2 represents the measured dose, the calculated dose, and the differences between $D_{\text{meas}}$ and $D_{\text{calc}}$ in the selected points of slice No. 18. Figure 4 shows the location of TLDs in slice No. 18 of RANDO phantom. Figure 5 shows the image of slice No. 18 of RANDO phantom and the location of points corresponding to the measured points in TiGRT TPS.

Furthermore, the mean differences between $D_{\text{calc}}$ and $D_{\text{meas}}$ as a function of the distance from the field edge were evaluated.

Example, Figure 6 shows the differences in the mean measured doses and calculated doses for slice No. 17 of RANDO phantom as a function of the distance from the field edge.

DISCUSSION
In this study, the accuracy of out-of-field calculated dose by the TiGRT TPS was quantified. The results show that for out-of-field regions (i.e., low dose-small dose gradient regions) the calculated doses compared to the measured doses are underestimated. Although the majority of the results showed

Table 1: The measured dose, the calculated dose, and the differences between the measured and the calculated doses in the selected points for slice No. 17

| Number of TLD | Measured dose by TLD (cGy) | Calculated dose by TPS (cGy) | $D_{\text{calc}}/D_{\text{meas}}$ (%) |
|--------------|--------------------------|-----------------------------|-------------------------------------|
| 1            | 48.67                    | 50.74                       | 104.26                              |
| 2            | 44.62                    | 46.25                       | 103.66                              |
| 3            | 39.49                    | 42.08                       | 106.56                              |
| 4            | 3.19                     | 1.29                        | 40.42                               |
| 5            | 1.58                     | 0.52                        | 32.81                               |
| 6            | 0.86                     | 0.53                        | 61.36                               |
| 7            | 0.66                     | 0.56                        | 84.85                               |
| 8            | 43.18                    | 44.79                       | 103.73                              |
| 9            | 32.00                    | 33.66                       | 105.19                              |
| 10           | 2.97                     | 2.05                        | 69.05                               |
| 11           | 1.18                     | 1.4                         | 118.37                              |
| 12           | 1.52                     | 0.47                        | 30.93                               |
| 13           | 0.71                     | 0.48                        | 67.16                               |
| 14           | 0.57                     | 0.48                        | 84.10                               |
| 15           | 0.55                     | 0.47                        | 86.12                               |
| 16           | 44.41                    | 43.81                       | 98.65                               |
| 17           | 9.51                     | 11.46                       | 120.52                              |
| 18           | 3.10                     | 1.92                        | 61.88                               |
| 19           | 1.87                     | 1.28                        | 68.53                               |
| 20           | 0.81                     | 1.05                        | 130.15                              |
| 21           | 0.46                     | 0.45                        | 97.43                               |
| 22           | 0.39                     | 0.45                        | 115.87                              |
| 23           | 0.39                     | 0.44                        | 113.01                              |
| 24           | 0.21                     | 0.4                         | 191.71                              |
| 25           | 3.68                     | 4.56                        | 123.96                              |
| 26           | 1.71                     | 0.53                        | 30.93                               |
| 27           | 1.04                     | 1.19                        | 114.67                              |
| 28           | 0.90                     | 1.05                        | 116.31                              |
| 29           | 0.86                     | 0.84                        | 97.48                               |
| 30           | 0.65                     | 0.69                        | 81.01                               |
| 31           | 1.24                     | 0.42                        | 33.80                               |
| 32           | 0.16                     | 0.36                        | 224.51                              |
| 33           | 0.13                     | 0.12                        | 92.13                               |
| 34           | 1.22                     | 0.57                        | 46.81                               |
| 35           | 1.27                     | 0.5                         | 39.35                               |
| 36           | 0.57                     | 1.67                        | 292.98                              |
| 37           | 0.95                     | 0.74                        | 77.59                               |
| 38           | 0.91                     | 0.67                        | 73.83                               |
| 39           | 0.83                     | 0.59                        | 71.08                               |
| 40           | 0.18                     | 0.14                        | 78.10                               |
| 41           | 1.02                     | 0.53                        | 52.18                               |
| 42           | 0.47                     | 0.49                        | 103.43                              |
| 43           | 0.55                     | 1.08                        | 196.45                              |
| 44           | 0.39                     | 0.63                        | 162.02                              |
| 45           | 0.41                     | 0.29                        | 70.73                               |
| 46           | 0.42                     | 0.5                         | 117.94                              |
| 47           | 0.40                     | 0.42                        | 105.00                              |

TLD=Thermoluminescent dosimeter, TPS=Treatment planning system, $D_{\text{calc}}$=Calculated dose, $D_{\text{meas}}$=Measured dose
that the TiGRT TPS underestimated the dose, there were several measurement points that were overestimated by the TPS. Nevertheless, the accuracy of dose calculation by this TPS for most in-field regions was within tolerance (<±5%). Ratios of TPS-calculated doses to TLD-measured dose times 100 ($D_{\text{calc}}/D_{\text{meas}}$ [%]) for the specific out-of-field points ranged from 26.08% to 292.98%. The results showed that the calculated doses underestimated by an average of 35%. The results of TiGRT TPS were consistent with results of Eclipse and Pinnacle as previously mentioned.\[4,12\]

Ratios of $D_{\text{calc}}/D_{\text{meas}}$ (%) for the specific in-field points ranged from 96.55% to 120.52% that for most points, differences between $D_{\text{meas}}$ and $D_{\text{calc}}$ were within tolerance, i.e., the differences were within ±5%. In terms of in-field point, results obtained in this study indicates that TiGRT TPS such as Eclipse TPS with AAA algorithm calculates the in-field doses accurately.\[8,15-19\]

Figure 6 demonstrates that underestimation of dose by TPS was reduced with increasing distance from the field edge, and more controversial are the regions relatively close to the treatment field edge. Figure 6 also demonstrates that the TLD-measured dose fell off approximately exponentially with increasing distance from the edge field. The result of TLD-measured doses is likely conventional field data from the Report of American Association of Physicists in Medicine Task Group 36 (TG 36) while TPS-calculated doses are not similar to the data of TG 36.\[20\] These results are not consistent with results of other studies on the Eclipse TPS that it is probably related to the algorithm used. For example, Howell et al.\[12\] showed that with increasing distance from the treatment field edge, the Eclipse TPS underestimated the dose with increasing magnitude (up to 55% at 11.25 cm from the treatment field border). Also Huang et al.\[4\] found that for pinnacle TPS, the magnitude of dose underestimation increased with greater distance from the treatment field edge. These studies demonstrated that at points relatively close to the treatment field edge was associated with calculated TPS errors in excess of 30% while the greater distance from the field edge the error approaches 100%.

Findings of our results are relevant to many aspects of radiotherapy research and clinical care. For patients with implanted electronic devices or pregnant patients, it is important to accurately assess the dose to the device or the fetus to guide clinical management. Dose assessment...
Table 2: The measured dose, the calculated dose, and differences between the measurement and the calculation doses in the selected points for slice No. 18

| Number of TLD | Measured dose by TLD (cGy) | Calculated dose by TPS (cGy) | \( \frac{D_{\text{meas}}}{D_{\text{calc}}} \) (%) |
|---------------|-----------------------------|-----------------------------|-----------------------------------|
| 48            | 46.59                       | 50.97                       | 109.40                            |
| 49            | 46.07                       | 44.48                       | 96.55                             |
| 50            | 44.05                       | 42.69                       | 96.92                             |
| 51            | 3.65                        | 1.2                         | 32.83                             |
| 52            | 0.77                        | 0.54                        | 70.15                             |
| 53            | 44.38                       | 43.49                       | 98.00                             |
| 54            | 37.50                       | 38.37                       | 102.32                            |
| 55            | 2.93                        | 2.08                        | 70.97                             |
| 56            | 1.35                        | 1.44                        | 106.77                            |
| 57            | 0.74                        | 0.48                        | 64.89                             |
| 58            | 0.62                        | 0.5                         | 80.42                             |
| 59            | 0.49                        | 0.52                        | 106.18                            |
| 60            | 1.18                        | 0.5                         | 42.27                             |
| 61            | 9.37                        | 9.25                        | 98.72                             |
| 62            | 2.96                        | 1.88                        | 63.45                             |
| 63            | 1.52                        | 1.22                        | 80.49                             |
| 64            | 1.01                        | 1.04                        | 102.89                            |
| 65            | 0.56                        | 0.47                        | 84.57                             |
| 66            | 0.49                        | 0.47                        | 96.56                             |
| 67            | 0.40                        | 0.46                        | 113.62                            |
| 68            | 0.24                        | 0.43                        | 180.26                            |
| 69            | 2.07                        | 0.54                        | 26.08                             |
| 70            | 1.23                        | 1.17                        | 95.30                             |
| 71            | 0.97                        | 1.03                        | 106.21                            |
| 72            | 0.51                        | 0.9                         | 175.87                            |
| 73            | 0.51                        | 0.73                        | 142.93                            |
| 74            | 0.40                        | 0.44                        | 108.90                            |
| 75            | 0.33                        | 0.39                        | 118.18                            |
| 76            | 0.69                        | 0.58                        | 83.72                             |
| 77            | 1.72                        | 0.51                        | 29.62                             |
| 78            | 1.22                        | 1.6                         | 131.50                            |
| 79            | 0.89                        | 0.9                         | 100.81                            |
| 80            | 0.47                        | 0.73                        | 153.77                            |
| 81            | 0.45                        | 0.15                        | 33.29                             |
| 82            | 0.69                        | 0.54                        | 77.95                             |
| 83            | 0.77                        | 0.52                        | 67.64                             |
| 84            | 0.59                        | 1.07                        | 182.05                            |
| 85            | 0.57                        | 0.66                        | 115.84                            |
| 86            | 0.43                        | 0.7                         | 161.57                            |
| 87            | 0.40                        | 0.38                        | 95.00                             |

CONCLUSION

TiGRT TPS was proven to underestimate doses far outside the treatment field by an average of 35% for clinical treatment delivered on a Siemens Primus with the single energy of 6 MV. Furthermore, it was concluded that underestimation of doses by TPS was reduced with increasing distance from the field edge and regions relatively close to the treatment field edge were the most affected. Research and clinical care (for example, the risk of a secondary malignancy development or poor clinical decision for patients with implantable electronic devices and pregnant patients) that require accurate out-of-field doses should apply other dose reconstruction methods, such as measurements or simulated phantom calculations.

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Conflicts of interest

There are no conflicts of interest.

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