Comparison of dose calculation algorithms model: Convolution, superposition, and fast superposition in 3-D Conformal Radiotherapy (3D-CRT) treatment plan

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Abstract. The important task of radiotherapy is to make sure that the radiation dose to the target tumour is accurate as prescribed and the dose to the organ at risk is minimized. Therefore, the aim of this study is to compare and evaluate the efficiency of the dose calculation algorithms: namely convolution, superposition, and fast superposition which installed in Treatment Planning System (TPS) (CMS XiO, USA). In this study, we modified protocols described in IAEA-Tecdoc-1583, where four typical treatment techniques such as single field, multiple field, wedge field, and multi-leaf collimated (MLC) field were analysed from the system. The measurement data for calculated dose and measured dose were taken from thorax CIRS anthropomorphic phantom. The assessment of algorithms was done by comparing the point dose calculated with the measured dose. The study shows that the superposition algorithm produced relative error less than ±3% which passed 100% of all reference points, whilst the convolution algorithm and fast superposition presented relative error more than ±3% which passed 82% and 91% of reference points, respectively. In conclusion, the evaluation of radiotherapy treatment plan shall take into account the type of dose calculation algorithm model in order to optimize radiotherapy treatment and ensure the radiation safety to the patient.

1. Introduction
Radiotherapy treatment uses megavoltage (MV) energy, and if not proper planned, could cause treatment errors and hazardous to patients [1]. In clinical radiotherapy, TPS is used to plan and calculate dose distribution to the tumor for final treatment. Some of the treatment plan is always challenging and complex (e.g lung) due to its geometry which requires high accuracy in calculating the patient dose [2]. The efficiency of treatment planning system (TPS) is highly depends on the type of algorithm used. Therefore, it is importance to understand the general principles of the algorithm and its implementation details since each algorithm suffers from limitations to deal with a complex system [3–5]. The dose calculation algorithm evolved rapidly since the 1950s, mainly caused by rapid development in the fields of nuclear physics and computer science which help us to describe the physical processes involved in the radiation interaction and to simulate the physical processes and calculate doses for a complex system.
Dose calculation algorithms are categorized into three groups which are correction-based, model-based; and principle-based [7].

Correction-based algorithm is based on dosimetric data from some basic measurements in water such as percentage depth dose (PDD), tissue-air ratio (TAR), tissue-phantom ratio (TPR), and tissue-maximum ratio (TMR)[8]. This category of algorithm such as Clarkson and IRREG are still widely used for basic homogenous media. Model-based algorithm will simplify the procedure of actual physical transport of beam particle. A beam particle interacts with media at a point, releases energy, and then is deposited or scattered away from the primary interaction site. During this process it may create secondary photons and electrons, releasing energy in the scattering path. These physical processes are simplified by using a convolution equation that convolutes the primary photon energy fluence (TERMA - total energy released in unit of mass) with a kernel that describes the contribution from scattering photons and electrons, and the method is called the convolution algorithm. Superposition method is used to replaced path length to radiological path length in heterogenous media. The last category is Monte-Carlo (MC), which makes dose calculation by simulating the real physical processes of beam particles during transportation [9].

To assess the accuracy of a dose calculation algorithm, the simplest way is to perform measurements and then compare the measured results with the calculated dose. Many researchers have done their works to evaluate the dose calculation algorithms [3,10,11]. They have concluded that, MC algorithm is the most accurate dose calculation algorithm, and the basic correction-based methods algorithm is the last. Whilst, not many researchers work on model-based method algorithm to compare the accuracy of three types of model-based algorithm as the results is not significant enough. Since no dose calculations can be performed perfectly, each must account uncertainty which can affect the dose delivery in final treatment. The International Commission on Radiation Units (ICRU) stated that dose calculation accuracy must be within 2-3% [12]. Therefore, the aim of the study is to compare and evaluate the implementation of XiO dose calculation algorithms namely convolution, superposition, and fast superposition.

2. Methodology

2.1. Beam Arrangement

In this study we have adopted protocols described in IAEA-TECDOC 1583 and four typical treatment planning techniques (TPS); single field, multiple field, wedge field, and MLC field to represent reliable clinical situation. Each of the technique was summarized in Table 1. The results of calculated and measured absorbed dose were based on the point dose measurement data of CIRS Thorax phantom.

![Figure 1. CIRS thorax phantom used in this study.](image-url)
Figure 2. Different treatment planning techniques and points of measurement from the TPS: a) single field technique, b) wedge field, c) multiple field and d) MLC field.

Table 1. Various treatment planning techniques and different beams used.

| Technique (6MV,10MV) | Description of beams (field size/wedge/MLC) | Reference point location |
|----------------------|---------------------------------------------|--------------------------|
| Single Field         | FS:5x5,10 x 10,20x20,30x30,40x40             | P1, P2, P3, P4, P5       |
| Multiple Field       | FS:15x8(AP/AP) FS:15x10(Lateral)             | P1, P2, P3, P4, P5       |
| Wedge field          | FS:10x10 Wedge 15°,30°,45°,60°              | P1                       |
| MLC field            | FS:10x10 MLC closed each corner              | P1, P2, P3, P4, P5       |

2.2. Measurement, dose calculation and analysis process
The dose calculations for each technique were performed for each algorithm in TPS. During measurement, a small volume ionisation chamber (IC) was placed in the corresponding plug. The calculated dose values were analysed to evaluate the deviation related to measured dose values. Following equation (1) was used to find the relative error from measured and calculated values.

\[
Error(\%) = 100\% \times \frac{D_{\text{cal}} - D_{\text{meas}}}{D_{\text{meas}}} \quad (1)
\]
3. Results

Table 2 summarizes the analysis of various treatment planning techniques. The superposition algorithm had produced point dose relative error less than ±3% for all reference points. Whilst convolution and fast superposition produced point dose relative error more than ±3% for some of the failed reference points. The failed reference points of convolution and fast superposition in this study were no clear dependency on the field size, technique, and energy.

| Technique               | Energy | Convolution | Superposition | Fast Superposition |
|-------------------------|--------|-------------|---------------|--------------------|
| Single Field technique  | 6MV    | 120(96%)    | 125(100%)     | 119(95%)           |
|                         | 10MV   | 120(96%)    | 125(100%)     | 124(99%)           |
| Multiple Field technique| 6MV    | 11 (58%)    | 16 (100%)     | 13 (81%)           |
|                         | 10MV   | 13 (81%)    | 16 (100%)     | 14 (88%)           |
| Wedge Field technique   | 6MV    | 8 (100%)    | 8 (100%)      | 7 (88%)            |
|                         | 10MV   | 8 (100%)    | 8 (100%)      | 8 (100%)           |
| MLC Field technique     | 6MV    | 15 (100%)   | 15(100%)      | 14 (93%)           |
|                         | 10MV   | 11 (73%)    | 15(100%)      | 15 (100%)          |

4. Discussion

The objective of this study is to compare the implementation of dose calculation algorithm model, convolution, superposition, and fast superposition in typical radiotherapy treatment planning. Each dose calculation algorithm showed differences in the dose prediction which contributed to the relative error [13]. This is due to difference in modelling approach in each dose calculation algorithms. In this experiment set-up, CIRS phantom contains high density material will cause the beam attenuation where photon beam was hardened as it passes through the phantom [14]. Dose difference between the algorithms and failed reference point could be due to inaccurate estimation and assumption of the physical processes of the beam attenuation as a result of high-density material [3]. However, calculations at reference point with low density region, dose calculation algorithm may have insufficient tissue build-up in order to achieve electronic equilibrium [3]. Therefore, the amount of low-density area in calculation region will reduce the accuracy of the dose calculations.

The accuracy of the superposition algorithms to predict dose for a variety of clinical situations was proved and accepted. However, convolution and fast superposition algorithms were slightly better under complex geometry such as lung or pelvic area, but clearly there is no algorithm that perfect for all situations [6]. We also found that the failed reference points which relative error more than ±3% were no clear dependency on the field size, technique, and energy used. However, previous researchers reported that convolution algorithms may produce errors in present of heterogeneous media in complex system, whilst reliable in simple situation in homogenous media [11]. Other researchers also have proved that fast superposition produced predicted dose within agreement with lower calculation time compared to other algorithms.

The IAEAs have outlined that all quality assurance decisions, testing and accreditation involving dosimetry data are ±3%. As a result of the analysis, superposition algorithms meet the predetermined criteria of passing 100% for all measurement points, while the 81% convolution algorithm and 91% superposition rate. The results of the analysis are in line with the hypothesis of the study which based
on the dose calculation technique used, the superposition algorithm can anticipate the dose more precisely for all treatment planning conditions compared to conventional algorithm and fast superposition. The results of the superposition algorithm model found that 91% of the grading points passed for all treatment planning techniques. In addition, the MU calculation for fast superposition algorithm is also less accurate than 1 to 2 percent of the standard superposition algorithm.

5. Conclusion
As conclusions, the results presented in this study reveal that each dose calculation algorithms have limitations in predicting accurate dose. Although in the study we find that the superposition algorithm has passed all the verification test, it is advised for medical physicist to understand the limitation of each algorithm before proceeds with treatment planning. These are to ensure accurate dose estimation to the tumour and normal tissue in order to optimize radiotherapy planning and radiation safety to the patients.

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