Determination of composite field correction factor \( k_{\text{pcsr,msr}} \) for Tomotherapy

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Abstract. The purpose of this study is to determine the correction factor of the composite field \( (k_{\text{pcsr,msr}}) \) of Tomotherapy for head and neck cases and to investigate the influence parameters of the \( \text{pcsr} \) field. This study employed Exradin A1SL and A16 as the investigated chambers, and EBT3 as the reference dosimeter. The \( \text{pcsr} \) fields were created based on cylindrical water solid phantom. The results of this study show that the \( k_{\text{pcsr,msr}} \) values for both detectors increased with increasing field width (jaw), decreasing complexity level, and increasing pitch value. The yielded results indicate several factors affecting the \( k_{\text{pcsr,msr}} \) values: target homogeneity, volume averaging effect, thread effect, and the difference of general recombination at the different field width. These results represent that \( k_{\text{pcsr,msr}} \) is specific and depends on the parameters of the composite field. The \( k_{\text{pcsr,msr}} \) values for head and neck cases vary from 0.978–1.028. This variation implies that the determination of \( \text{pcsr} \) field should be according to the parameters used in clinical conditions. Due to the different position of the chamber and the film, the target should have excellent dose homogeneity to avoid the different response of the detectors.

1. Introduction

The Code of Practice (CoP) from IAEA TRS-398 and AAPM TG-51 has become as protocols for clinical use in dosimetry practice. As the rapid development of radiation therapy techniques and equipment, these protocols were not relevant for advanced RT technologies. These protocols require a measurement condition called standard condition; it is defined as a condition with a 10 × 10 cm\(^2\) field opening and a static beam delivery mode. Meanwhile, the Tomotherapy machine uses a rectangular field opening as a standard condition. The lateral field determined by the jaw has a maximum size of 40 cm, and the longitudinal direction has three options of field width: 1.05 cm, 2.5 cm and 5.02 cm.
In addition, as a modality which provides IMRT technique in helical mode, the beam delivery becomes more complex.

In 2008, Alfonso, et al. introduced a new formalism [3] for a nonstandard field as the development of conventional CoP. The formalism introduces the concept of an 'intermediate field' as a substitution for reference conditions for two types of nonstandard field: 1) machine-specific reference (msr) for static-small fields, and 2) plan-class-specific reference (pcsr) for composite fields. This formalism produces a correction factor to minimize the differences between calibration and actual conditions in nonstandard fields. These factors will have different values for the different machine, field openings, cases, and dosimeters used. Furthermore, it can be used as an additional correction factor for patients specific QA, an important part of the quality assurance process in the implementation of clinical administration [4].

2. Methodology

2.1. Virtual target and OARs delineation
The delineation process was carried out using the Eclipse™. The virtual target and OARs configuration for the pcsr field are generally classified into the complexity and the measurement location. The configuration of complexity is consists of three levels: 1) simple; 2) intermediate; and 3) complex. Furthermore, the determination of complexity level was based on the target shape and the variation of prescription doses and OAR constraints. The measurement location of each complexity was varied as the center and peripheral. Table 1 and Figure 1 show the details of the variation of pcsr fields used in this study.

2.2. Treatment planning
The plans were generated by TomoPlan™ – Planning Station for pcsr fields. The IMRT treatment plans were made in the form of helical mode. Each pcsr field was planned by variations of three jaw widths (1.05 cm, 2.5 cm, and 5.02 cm) and two pitch values (0.43 and 0.25).

2.3. Dosimetric preparation
In this study, two ionization chambers Exradin A1SL and A16 were used as the investigated chambers, while the GafChromatic EBT3 film was used as reference dosimeter. To determine the feasibility of EBT3 film, the response tests were performed and done by calibrating the film in two different machines: Tomotherapy Hi-Art and Elekta Synergy Platform LINAC as an early study. The results of these calibrations are then evaluated to ensure the film dependency response to the radiation beam energy.

2.4. Measurement of composite correction factors
This study used $5 \times 10$ cm$^2$ open field as the msr field. For composite field measurement, the EBT3 films were cut into $2 \times 2$ cm$^2$ and placed in the middle of the cheese phantom. The investigated chamber, either Exradin A1SL or A16 was placed in the closest insertion from the phantom center. The correction factor value of $k_{pcsr,msr}$ that have been obtained were then analyzed to determine the effect of the measurement location, jaw, pitch and complexity used in the composite field.
\[ D_{\text{w}Q_{\text{pcsr}}}^{f_{\text{pcsr}}} = M_{Q_{\text{pcsr}}}^{f_{\text{pcsr}}} \cdot N_{D_{\text{w}Q_{0}}} \cdot k_{Q_{Q_{0}}} \cdot k_{Q_{\text{msr}f_{\text{ref}}}} \cdot k_{Q_{\text{pcsr}f_{\text{msr}}}f_{\text{msr}}} \]  

(1)

\[ k_{Q_{Q_{\text{pcsr}}}} = \frac{D_{\text{w}Q_{\text{pcsr}}}^{f_{\text{msr}}} \cdot k_{Q_{\text{pcsr}}f_{\text{msr}}}^{f_{\text{msr}}}}{M_{Q_{\text{pcsr}}}^{f_{\text{msr}}} \cdot k_{Q_{\text{pcsr}}}^{f_{\text{msr}}}} \]  

(2)

**Table 1.** Three levels complexities of \( \text{pcsr} \) field

|      | Simple | Intermediate | Complex |
|------|--------|--------------|---------|
| Dose | 60 cGy (33 fx) | 66 cGy (33 fx) | 70/66/54 cGy (33 fx) |
| Region | Cylinder Ø10 cm ; 5 cm | Brainstem \( D_{\text{max}} < 50 \text{ Gy} \) | spinal cord \( D_{\text{max}} < 45 \text{ Gy} \) |

**Figure 1.** Variation of measurement locations: (a) center and (b) periphery

3. **Results and discussion**

3.1. **EBT3 response at different beam quality**

In accordance with the results of the previous study[5]–[7], EBT3 films proved to have the independent responses of beam energy. The comparison between two calibration equations showed a difference of less than 2% in the dose range 150-250 Gy. Based on these results, EBT3 films can be used as reference dosimeters in this study.

3.2. **\( k_{\text{pcsr,msr}} \) value**

The measurement results of \( k_{\text{pcsr,msr}} \) value vary between 0.978-1.028 (± 3% from unity). The influence of HI, MF, measurement location, jaw width, complexity, and pitch used will be discussed in the next sub-chapter.

3.2.1. **HI and MF.** Figure 2 shows the correction factor plot for HI (homogeneity index) and MF (modulation factor). The results show that with the better HI, the correction factor values of the two
detectors tend to have a very small difference (0.2%). These results indicate that in determining the correction factor value, the volume averaging effect of the ionization chamber can be minimized by using the pcsr field with optimal HI value [8].

3.2.2. Measurement locations. Figure 3 shows the comparisons of $k_{pcsr,msr}$ values in different measurement location. In general, both A1SL and A16 have similar results. The $k_{pcsr}$ factor measured on the periphery tends to fluctuate than the values at the centre area. Due to the adjacent location, the peripheral part is an area with a high dose gradient. These results are in accordance with the theoretical review of the pcsr field proposed by Bouchard (2012), that the measurement of the $k_{pcsr}$ field correction value should be carried out on the target isocenter to avoid a non-uniform response from each angle in the ionization chamber [9].

3.2.3. Jaw width. Figure 4 shows the effect of jaw width and complexity of the pcsr field to the correction factor $k_{pcsr,msr}$. The correction factor values for different jaws are ranging from 0.2-0.8%. The correction factor for both A1SL and A16 increases with increasing jaw width. A similar pattern was found in all complexity levels. These results confirmed the research conducted by Palmans, et al. (2010) who was concerning general/volume recombination in the helical field of Tomotherapy. In the helical mode of Tomotherapy, the concept of ion recombination becomes more complicated than in the small field. The results of Monte Carlo simulation and measurements made by Palmans, et al. prove that volume recombination on Tomotherapy helical field with 1 cm jaw is only 55% of that found on 2.5 cm jaw [10]. By assuming that the initial number of electrons per pulse is constant, the collected charge at 1 cm jaw is greater than 2.5 cm and 5.02 cm jaw. This caused the correction factor value at 1.05 cm to be smaller than the other jaws.

3.2.4. Complexity. Field complexity should be represented by a metric developed specifically to provide an assessment of complexity based on the size of the field, number of segments, variations in the shape of segments, and other related parameters [11]. However, due to a number of limitations, the criteria for field complexity in this study are qualitative, which is determined based on the target shape and prescription doses and OAR constraints.

3.2.5. Pitch value. Figure 5 shows the effect of changing the pitch value on the $k_{pcsr}$ factor value. It is found that the factor $k_{pcsr,msr}$ at pitch 0.25 are generally lower than the pitch of 0.43. This result shows that changing the pitch value to 0.25 causes the rippled pattern to become more visible. This effect directly increases the probability of the active volume of the ionization chamber to be in the rippled area. As a result, the reading value obtained will be even greater so that the value of the correction factor on the pitch of 0.25 will tend to be lower.

4. Conclusion
The $k_{pcsr,msr}$ values for head and neck cases vary from 0.994–1.028. This variation implies that the determination of pcsr field should be according to the parameters used in clinical conditions. Due to the different position of the chamber and the film, the target should have excellent dose homogeneity to avoid the different response of the detectors.
Homogeneity index (%)
1.46 1.49 1.57 3.46 4.43 5.19 5.34 6.15 6.63 6.79 6.81 7.21 7.63 7.69

kpcsr,msr
0.98 0.99 1.00 1.01 1.02 1.03

Figure 2. Measured plan-class specific correction factor $k_{pcsr,msr}$ as a function of (a) homogeneity index and (b) modulation factor

Plan No.
1 2 3 4 5 6 7 8 9

kpcsr,msr
0.98 0.99 1.00 1.01 1.02 1.03 1.04

Figure 3. Measured plan-class specific correction factor $k_{pcsr,msr}$ in different measurement location: (a) A1SL and (b) A16

Jaw (cm)
1 2.5 5

kpcsr,msr
0.985 0.990 0.995 1.000 1.005 1.010 1.015 1.020 1.025

simple intermediate complex

Figure 4. Measured plan-class specific correction factor $k_{pcsr,msr}$ in different complexity levels and jaw widths: (a) A1SL and (b) A16
Figure 5. (a) Measured plan-class specific correction factor $k_{\text{pcsr,msr}}$ for A1SL in different pitch; (b) isodose distribution (coronal) in 5.02 cm jaw width.

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