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Absorbed Dose Calculation In Irregular Blocked Radiation Fields: Evaluation of Clarkson's Sector Integration Method for Radiation Fields Commonly Used in Conventional Radiotherapy

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ABSTRACT

Introduction: Irregular/blocked fields are routinely used in radiotherapy. The doses of these fields are usually calculated by means of equivalent square method that is inherently prone to uncertainty. On the other hand, Clarkson's sector integration method is a dose calculation method which offers far better accuracy in dose calculation of irregular fields. The Scatter Air Ratio (SAR) of an individual sector, in which whole field has been divided, is calculated and averaged over all sectors to find total SAR for the whole field. Percentage depth dose (PDD) and tissue-maximum ratio (TMR) for irregularly shaped beams can be calculated by the SAR values using the standard relationships of these measurement quantities.

Material and Methods: The present study was conducted on 40 actual patient treatment fields. The PDD values for depths up to 15 cm were calculated using both Clarkson's sector integration method and conventional methods, and their results were compared with the measured PDDs for all patients.

Results: Maximum deviation for Clarkson's calculation was under 2.7% for any field size, shape, and depth. However for conventional methods, this value exceeded ±5.5% for some field shapes, specifically at larger depths.

Conclusion: Better results of sector integration are more prominent for field shapes with a large field size and a shielded area of regular shape. For the treatment fields with a very large degree of approximation for assessing reduced field size, Clarkson's method is the most accurate technique for the calculation of absorbed dose.

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Introduction

Radiotherapy has long been used for cancer treatment, which involves the delivery of a prescribed dose to the tumor tissues to kill cancer cells. The main focus in radiotherapy is to fully deliver the prescribed dose to the tumor while keeping the dose to normal tissues as low as possible [1]. It is the duty of the medical physicist to ensure that the dose delivered to the tumor is the same as the one prescribed by the oncologist. International regulations allow an uncertainty of 3-5% in delivered and prescribed dose [2, 3].

Conventionally, dose calculation is performed while assuming a full scatter secondary electron equilibrium condition within and outside the radiation field [4,5]. Percentage depth dose (PDD) and tissue-maximum ratio (TMR) tables are used for dose calculation. These tables are available for regular square and circular fields in radiotherapy books and literature [5-7]. A tumor may not be confined in regularly shaped fields; therefore, additional shielding blocks or MLCs may be required to shield the organs at risk (OARs) lying within the treatment fields and confine the tumor volume, which results in an irregular treatment field.

Irregularly shaped beams are used in almost all treatment fields in conventional radiotherapy techniques. Modern radiotherapy techniques, such as three-dimensional conformal radiotherapy (3D-CRT) and intensity modulated radiation therapy (IMRT), make use of different planning algorithms to calculate dose at any point, within or out of field, for any shape of beam. In conventional radiation therapy, especially for Cobalt-60 beams, Cerroband or lead shielding blocks are used to shield the OARs lying within the treatment fields, which results in an irregular beam shape [6].

It is not practical to measure dose for every patient treated with irregular fields. Instead, different

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methods have evolved over time to assess the dose for these irregular fields. One method is to approximate the actual irregular field to a field with a regular shape by subtracting the shielded area from field dimensions and then use PDD or TMR tables to calculate the dose at the prescribed depth [7].

This method is mostly used for the dose calculation of irregular fields in the third world countries, where Cobalt-60 is the most affordable and widely used radiotherapy modality and treatment planning system cannot be afforded. This method is inherently prone to errors due to its compete dependence on the intuition and judgment of an individual. Another physical problem of approximation technique is the variation of scatter distribution from the same size shielded area with changing the positions of the block within the field.

Scatter distribution reaching at the center of the field from the shielded area mostly depends on, among other factors, the distance of the shielding block from the point of calculation, which is mostly the center of the field [5-8]. Consequently, dose at the center will change if a shielded portion is just moved from one location to another within the field. There is no way to incorporate this difference in the conventional approximation method. A little modification in the above mentioned method can be made by incorporating the scattering component (i.e., head scatter and phantom scatter) separately using *Equation 1* [5]

$$PDD(d, blocked\ field) = PDD(d, C) \times \frac{BSF(C)}{BSF\ (A)} \quad (1)$$

where A represents the equivalent square of unblocked open field, and C signifies the equivalent square or rectangular field generated by approximately subtracting the blocked areas from the dimensions of open field [5].

This formula brings a little more accuracy to dose calculation; however, the problem of scattering at different positions from the same size shielding block is still unresolved. Sector integration method, proposed by Clarkson and investigated by Cunningum et al. [9] is considered as the most accurate technique for the dose calculation of irregular fields. This method divides the treatment field into N number of small sectors each with a radius of S_i and an angle of $\Delta\theta$, and calculates scatter for every individual sector, thereby resulting in a more accurate dose calculation. The details of this method can be found in the literature, and it has been summarized in the following sections [8, 10].

Scatter air ratio (SAR) for a blocked treatment field is calculated as the average of SARs of individual sectors using the formula given below [4, 6, 8]:

$$SAR(d, blocked\ field) = \sum_{i=1}^{N} SAR\ (d, Si) \times \frac{\Delta\theta}{2\pi} \quad (2)$$

Tissue air ratio (TAR) for the blocked field can be found as the sum of SAR, calculated by the above formula, and primary air ratio (PAR) available in the literature as follows:

$$TAR(d, blocked\ field) = PAR\ (d) + SAR\ (d, blocked\ field) \quad (3)$$

$$TAR(d, blocked\ field) = TAR\ (d, 0) + \sum_{i=1}^{N} SAR\ (d, Si) \times \frac{\Delta\theta}{2\pi} \quad (4)$$

The PDD of the blocked field can be calculated by *Equation 5*:

$$PDD = 100 \times \left(\frac{TAR(d, blocked\ field)}{BSF\ (blocked\ field)}\right) \times \left(\frac{(SSD+d_m)}{(SSD+d)}\right)^2 \quad (5)$$

Backscatter factor for the blocked field can be estimated using the following formula:

$$BSF(Blocked\ field) = BSF\ (d_m, 0) + SAR\ (d_m, blocked\ field) \quad (6)$$

$$BSF(Blocked\ field) = 1 + \sum_{i=1}^{N} SAR\ (d_m, Si) \times \frac{\Delta\theta}{2\pi} \quad (7)$$

The PDD can be converted into TMR for SAD (source to axis distance) calculations [6].

The present study was targeted toward the verification of the results of Clarkson's sector integration by comparing them with the measured values, and also the results of conventional dose calculation methods. The aim of this study was to experimentally reassert the higher accuracy and reliability of the Clarkson's method in dose calculation, compared to the conventional methods. To this end, PDD was considered as the quantity of comparison between these methods.

Materials and Methods

Equipment

Dose calculation was accomplished using the PTW (Freiburg Germany) 0.62 cc water proof ion chamber in a water phantom on Cobalt-60 tele-therapy machine (Theratron Canada). Ion chamber was calibrated based on Secondary Standard Dosimetry Laboratory (SSDL) Pakistan, which traces back its calibration roots to International Atomic Energy Agency (IAEA) primary standards.

The dose was measured at the center of the field at different depths of 1-15 cm with 1 cm intervals using a one-dimensional (1D) dosimetry system, which reduced the uncertainty in depth measurement to a minimum. After finishing dose measurements, PDDs were calculated for those depths using a simple excel sheet. The IAEA Technical Report Series 398 was adopted as the reference document for dose measurement in this project [11].

Table 1. Actual and reduced field sizes of all patients as categorized in four groups

Field Shape A		Field Shape B		Field shape C		Field Shape D	
Actual field size (cm×cm)	Reduced field size (cm×cm)	Actual field size (cm×cm)	Reduced field size (cm×cm)	Actual field size (cm×cm)	Reduced field size (cm×cm)	Actual field size (cm×cm)	Reduced field size (cm×cm)
12.5×13.5	6.5×13.5	12×12.5	12×11	17×7	17×6	18×17.5	18×9.5
12.5×13.5	9×13.5	13×12.5	13×12.25	16.5×5.5	16.5×4.5	22×15	21×15
10×13.5	6.5×13.5	12.5×13.5	12.5×12.5	17.5×6.5	17×5.5	24×20.5	23.5×18.5
13×12.5	9.5×12.5	13.5×12.5	13.5×10.5	17×6	17×5.5	25×22	25×18
12×12	8.5×12	14×13.5	14×13	16.5×7	16.5×6	17×15.5	17×14
13.5×12.5	9×12	10×14	10×11.5	17×5	17×4.5	16.5×18	16.5×17
13.5×14	9×14	13×13	13×11.5	16×6	16×5.5	16.5×18	15×17
11×13	8×13	12.5×9	12.5×8.75	17×6	17×4.5	22×16	22×14
10.5×13	8×9	13×12.5	13×12	17.5×7	17.5×6.5	17×16	17×14.5
14×15	10×14	12.5×14.5	12.5×14.25	16×5.5	16×4.5	18×15.5	15.5×13.5

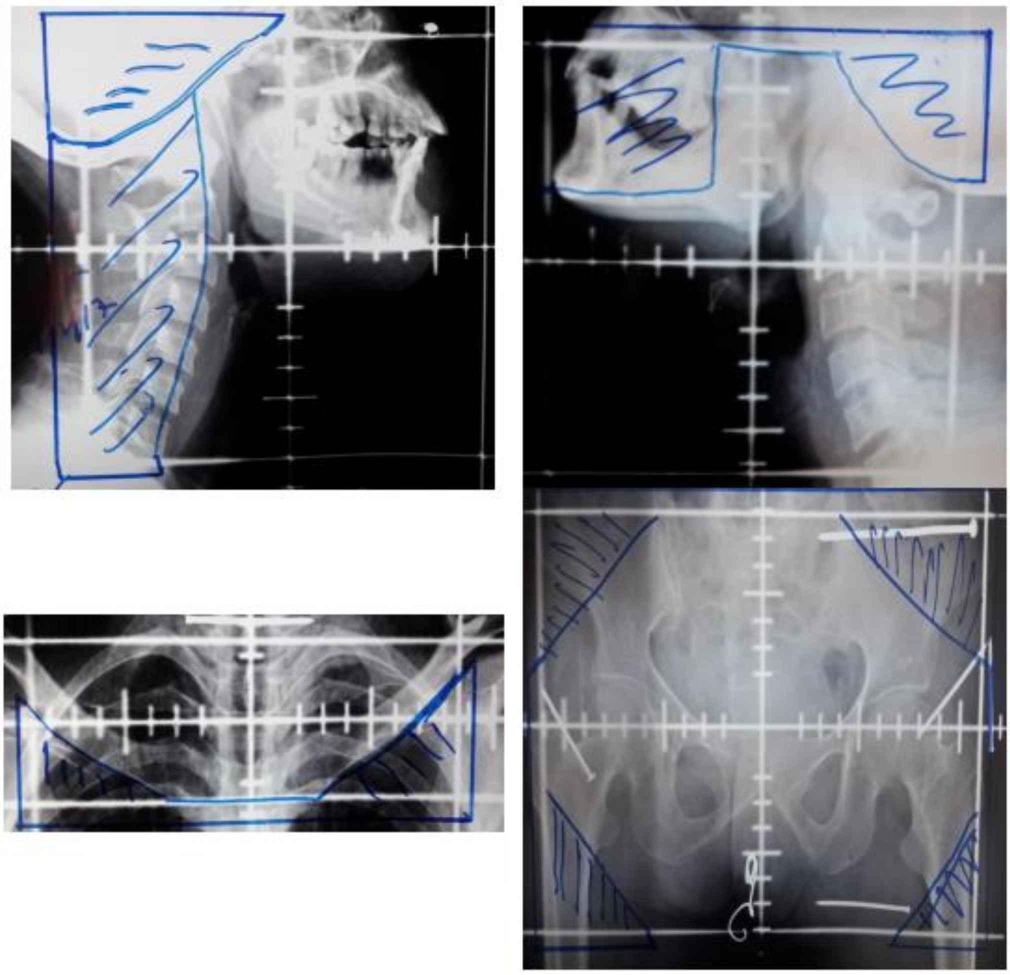

Figure 1. Radiation fields used in project; upper left field is designated as Field Shape A, upper right field is Field Shape B, lower left is Field Shape C, and lower right is Field Shape D

Field shapes

Different actual, clinically used, patient radiation fields were analyzed with different shapes and sizes. Table 1 tabulates the open field sizes and their approximate reduced field sizes for all the radiation fields used in this research. A field shape, designated in this text as 'Field Shape A' as shown in the upper left of Figure 1, represents a lateral face/neck radiation field with shielded spinal cord. Its dimensions are nearly square and have shielded the area of different dimensions but of a regular shape. In this field, the spinal cord of the patient was shielded which gave it a final shape of a rectangle asymmetric around center. In few patients, the oral cavity was also shielded.

'Field Shape B', as illustrated in the upper right of Figure 1, signifies the radiation fields of the head and neck without spinal shielding. In this field shape, only the occipital portion of the brain was shielded, while in some patients the oral cavity was shielded as well. This was nearly a square field with the same dimensions as those of the 'Field Shape A'. The shielded portion did not alter its final dimension very much. However, the shielded portion, itself, varied in dimensions and position from patient to patient.

The lower left of Figure 1 represents a radiation beam, designated as 'Field Shape C' in this article. This filed was applied on the lower neck region for the irradiation of clavicle nodes in the treatment of some head and neck carcinomas. These fields were in a rectangle shape with x dimensions larger than y dimensions. Both of their lower corners were shielded with triangular-shape Cerrobend blocks to shield a portion of lungs lying within the beam. Shielded areas in all fields were very similar with a small variation. Equivalent field size was approximated by subtracting 1 or 1.5 cm from the y-axis of the beam depending upon the size of the shielded area. Shielded area was almost symmetric with respect to the y-axis.

Another type of radiation field shape as shown in the lower right of Figure 1, designated as 'Field Shape D', represents the radiation field of comparatively large dimensions with a shielding of an irregular shape. These radiation beams were generally applied on the pelvic region with the bladder and femur head blocked or for the anteroposterior/ posteroanterior configuration of the head and neck regions while using shielding blocks for the lower corner portion of the lungs. The degree of approximation in these beams was large as compared to the field shapes discussed above because the shielded areas in these beams were in very irregular shapes, and the location of blocks within the field varied as well.

For the sector integration method, a radiation field was divided into 36 equal sectors of 10^0 intervals using the field center as the center of the circle. The length of every sector was measured, and SAR was obtained for every sector using the SAR table given in the Physics of Radiology by John Cunningum [5, 9], and then averaged over 36 sectors according to *Equation 2.* After obtaining the effective value of SAR, PDDs for up to 15 cm depth were found for each field shape using the methods described in the introduction section.

An excel data sheet was designed specifically for this purpose for the ease of calculation. The PDD values calculated based on the Clarkson's sector integration, approximation, and modified approximation methods were compared with the measured PDD values, and their percentage difference from the measured dose was calculated.

Uncertainty consideration

The data were taken in water using an ion chamber. All readings were repeated three times and averaged; however, very little deviation was recorded for all measurements. Therefore, type A (statistical) error was considered to be zero. Given the involvement of other factors in the measurement of dose (i.e. temperature, pressure, and uncertainty in dose to water calibration factor), total type B uncertainty was calculated by combining uncertainties in the individual factors involved in the measurement [3, 12].

Results

Field Shape A

The mean deviations of PDD values from the measured PDDs calculated based on the Clarkson's, conventional approximation, and modified approximation methods were obtained as 0.64±0.2%, 1.92±0.74%, and 1.475±0.61%, respectively. Regarding the Clarkson's method, the minimum and maximum deviations from the measured PDDs were estimated as 0.3% and 1.1%, respectively.

Figure 2 displays the associated data for one patient. For this patient, the mean deviations for Clarkson's method was 0.348% with the minimum and maximum values of 0.043% and 0.97%, respectively. In terms of the conventional methods, the mean deviation was obtained as 1.422% with the minimum and maximum values of 0.0168% and 3.289%, respectively. Furthermore, in this patient, the approximation method and modified approximation method resulted in a mean deviation of 1.059% with the minimum and maximum values of 0.0024% and 2.72%, respectively.

Field Shape B

Figure 3 shows the plot comparing the measured PDD values with those of Clarkson's method and conventional methods for a patient named "Begum" irradiated with beams in the 'Field Shape B'. The percentage deviations, averaged over all depths, obtained based on the Clarkson's and conventional approximation methods were 0.618% (minimum: 0.030%, maximum: 1.996%) and 1.0997% (minimum: 0.2898%, maximum: 2.768%), respectively. For 10 patients, the average percentage deviations were obtained as 0.64±0.12%, 1.22±0.2%, and 1.09±0.28% for the Clarkson', approximation, and modified approximation methods, respectively.

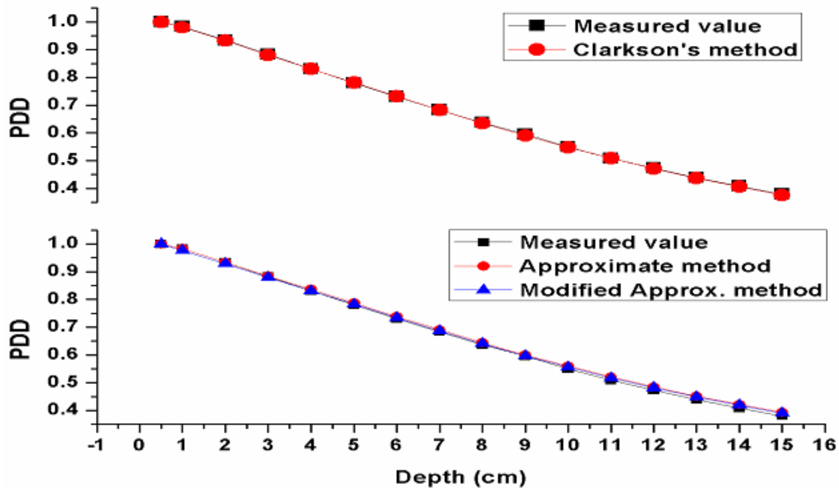

Figure 2. Data of a patient named Kashif with a field size of 13x12.5 cm and approximate reduced field size of 9.5x12.5 cm in field shape A (Figure on the top shows the comparison of the measured percentage depth dose (PDD) with that calculated based on Clarkson's method, while figure on the bottom shows the comparison of measured PDD with the PDDs calculated by approximation and modified approximation method.)

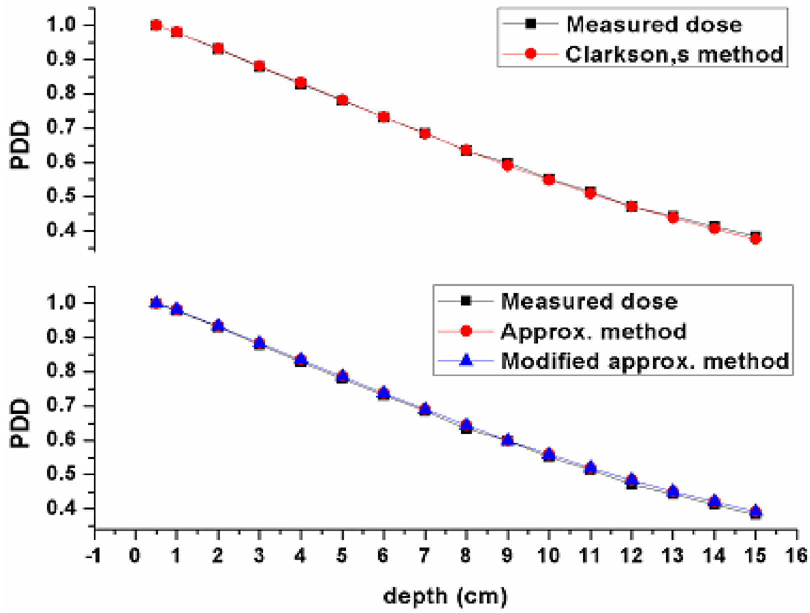

Figure 3. Data of a patient named Begum with an open field of 12.5x9=10.5 and approximate reduced field size of 12.5x8.75=10.5 in field shape B

Field shape C

Figure 4 depicts the comparison of the measured PDD values with calculated PDDs based on Clarkson's and conventional methods in one patient. The percentage deviation for the Clarkson's method, averaged over all depths, was 0.3895% with the minimum and maximum deviations of 0.0629% and 1.08%, respectively. Regarding the conventional methods, these values were 1.11% (minimum: 0.0757%, maximum: 3.26%) and 0.992% (minimum: 0.0862%, maximum: 2.9%) for the approximation and modified approximation methods, respectively. The average percentage deviations for all 10 patients were obtained as 0.55±0.3%, 1.265±0.99%, and 1.095±0.92% for Clarkson's, approximation, and modified approximation methods, respectively.

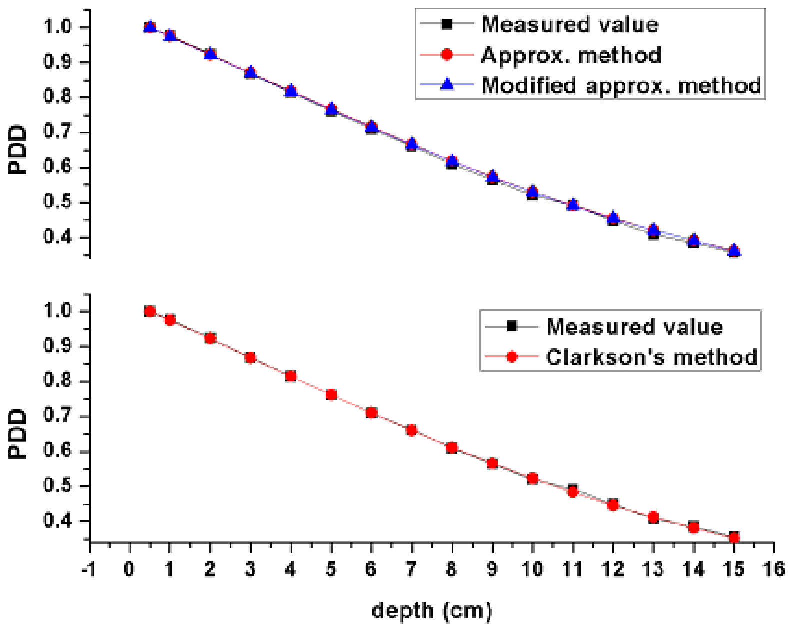

Figure 4. Data of a patient named Husssan with a field size of 17x5 cm and approximate reduced field size of 17x4.5 cm in field shape C

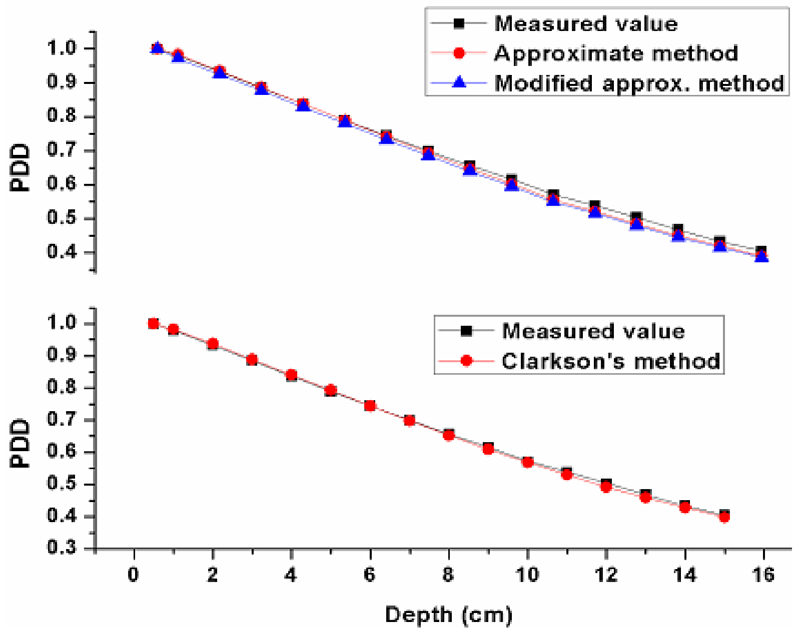

Figure 5. Data of a patient named Rab Rakhio with a field size of 18x17.5 cm and approximate reduced field size of 18x9.5 cm in field shape D

Field Shape D

Figure 5 displays the data of a patient irradiated within the 'Field Shape D'. The degree of accuracy for this patient was very good in the Clarkson's method as compared to those obtained by the conventional methods. Especially for larger depths, the results of the conventional methods differed from the measured values for up to 5%, while for all these depths, Clarkson's method deviated from the measured results for up to 2%. The average deviation for Clarkson method for the given patient was 1.483% with the minimum and maximum values of 0.074% and 2.769%, respectively.

In terms of the conventional methods, these values were 3.678% (minimum: 0.225%, maximum: 5.594%) and 3.586% (minimum: 0.16%, maximum: 5.494%) for the approximation and modified approximation methods, respectively. Furthermore, the average percentage deviation for all 10 patients, averaged over all depths, were estimated as 0.88±0.326%, 1.685±0.83%, and 1.395±0.879% for the Clarkson's, approximation, and modified approximation methods, respectively.

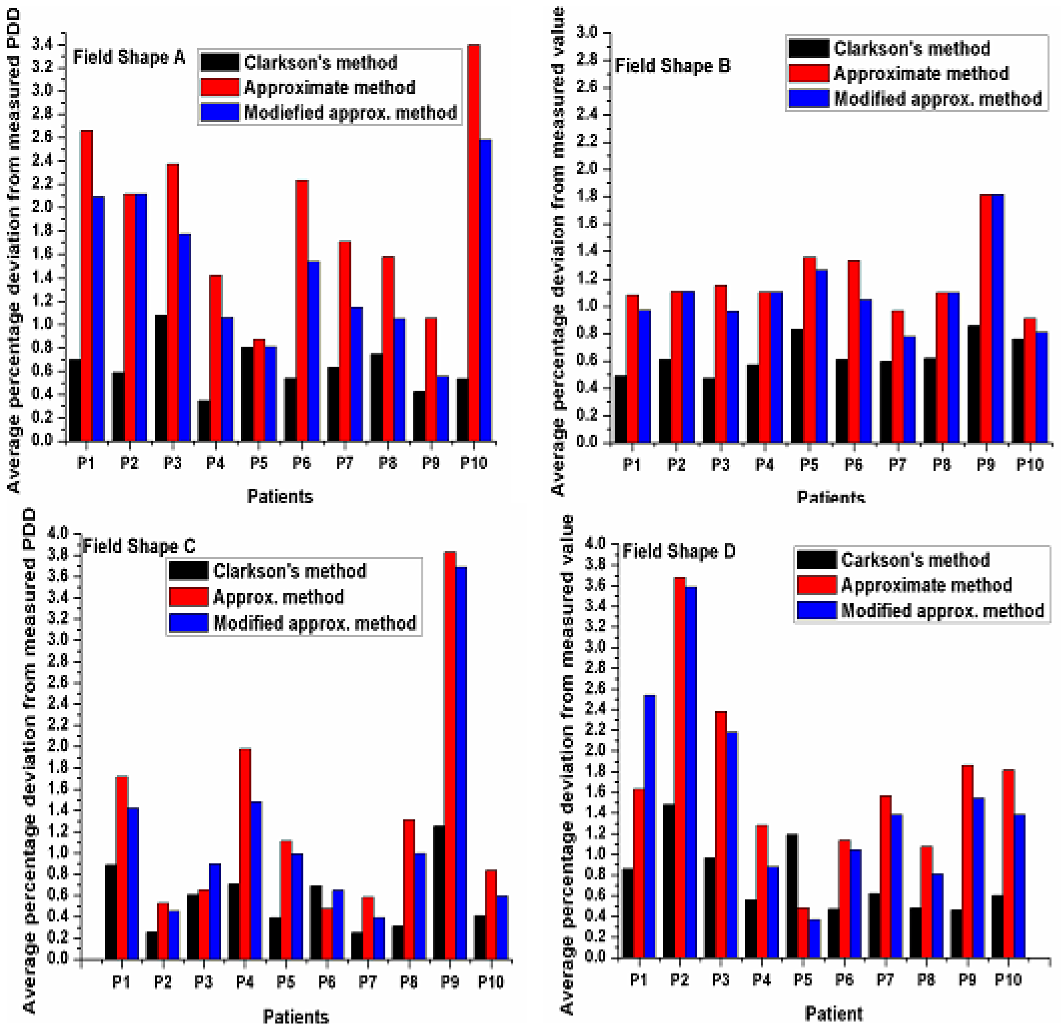

Figure 6. Comparison of percentage deviations averaged over all depths calculated based on Clarkson's method with those obtained by approximation and modified approximation methods for all patients of field shapes A, B, C, and D.

Discussion

Clarkson's method has been discussed in detail in different texts. Clarkson proposed this method to address the discrepancies in dose calculation in irregularly shaped radiation beams. John and Cunningham developed this technique in 1960s for irregular field calculation for orthovoltage and Cobalt-60 beams [13]. Steidley et al. also investigated this method and compared the results obtained by this method with those of the VARIAN IRREG calculation program and found a discrepancy of ±0.7% between the two techniques [14].

Rhodesa Cruzet used sector integration technique to compare the Cerrobend-shielded fields and multileaf collimator fields and demonstrated that the results of both shielding techniques were comparable to each other [15]. In addition, Morris Tatcher et al. compared sector integration method with Day's scatter radius approximation technique and reported that sector integration method could give better results at greater depths [16].

In a recent study, Tajiri et al. extended the concept to dose calculation in carbon ion beam therapy for symmetric and asymmetric square fields. They validated the results of Clarkson's method within a deviation of ±1% [17]. They also hinted the inefficiency of this method in off-axis dose calculation and proposed a correction method, the results of which had a deviation of -0.17±0.23 from the measured values [18].

The present study was focused on dose from the photons of Cobalt-60 gamma energy and symmetric radiation field of different shapes and dimensions. Our results revealed that the Clarkson's method was in agreement with the measured value within ±0.659±0.3% for any field size, shape, and shielding. For some PDD values at larger depths (i.e., more than 10 cm depth), percentage deviation between the measured PDD and the PDDs calculated based on the Clarkson's method exceeded a deviation of 2.7%. However, for the same depth, the deviation exceeded 5%.

Figure 6 presents a bar graph plot showing the percentage deviation of PDDs calculated based on all three methods from the measured values, averaged over all 15 depths. All field shapes are separately discussed in the following sections.

Field Shape A

Although the shape of this field was regular, the asymmetry in field dimensions along the x-axis led to inefficient approximation in field dimension, and therefore a larger deviation in the PDD values measured by the conventional methods. The Clarkson's method removed this discrepancy and showed results with very little deviation from those of the measured values.

For patients with shielded oral cavity, Clarkson's method provided very clear advantage over the conventional methods. This advantage was more pronounced at larger depths. This is due to the fact that in the conventional methods, the irregular contour of shielded portion cannot be incorporated correctly.

Field Shape B

Clarkson's method showed a clear advantage over the conventional method for this field shape as well. However, the difference was not as great as that of 'Field Shape A'. This might be due to the fact that the shielded area was not large enough to alter the amount of scattered radiation reaching to the center of the field. In other words, the amount of irregularity created by the shielded area was smaller than that of the 'Field Shape A'.

Field Shape C

This shape was mostly a regular shape with a regularly shaped mold. The shielding within this field did not alter the final field dimensions to a reasonable extent. Therefore, compared to the deviations of Field Shapes A and D, there was no significant difference between the results of the Clarkson's method and those obtained by the conventional approximation methods.

Accordingly, Figure 6 depicting 'Field Shape C' clearly shows that except for few special cases, there is not much difference in the results of Clarkson's method and conventional methods. A possible reason for this observation is that shielded areas in this field shape is of regular shape and can be approximated easily.

Field Shape D

Clarkson's method offered a very clear advantage in this field over the conventional methods. This was due to the fact that approximation for effective field dimensions was very crude and that approximation did not account for the location of the shielded area within the field. It is very much clear that for the radiation beams of this shape, conventional methods based on approximation offer very little accuracy, and this situation worsens for the beams with a large difference in actual and reduced field sizes. Especially for larger depths, the results of the conventional methods differed from the measured value for up to 5%. On the other hand, for all these depths, the maximum deviation of Clarkson's method from the measured values was obtained as 2%.

The analysis of all field shapes and sizes indicated the Clarkson's method as a more accurate and efficient method for dose calculation, especially for more irregular beams (i.e. Field Shapes B and D). In this regard, Clarkson's method was found to be more efficient for the beams of higher irregularity. Regarding the conventional methods, the modified approximation method showed lower deviation from the measured results as compared to the simple approximation method.

Conclusion

Clarkson's sector integration algorithm is a dose calculation method for the assessment of dose for irregular shielded beams. As the findings of the present study indicated, this method offered a higher accuracy than the conventional methods that are based on the approximation of blocked field dimension. This study involved the analysis of four field shapes, commonly used for the head and neck and pelvic cancers using a total of 40 patient cases. Dose was measured using water phantom and ion chamber at the depths of up to 15 cm with a 1 cm interval. The PDDs were calculated for these depths and compared with the depths calculated using approximation techniques.

According to the findings, for any field size and shape, Clarkson's method demonstrated a better accuracy, compared to the conventional methods. Moreover, this method offered very clear advantage over the conventional methods at larger depths. This difference was more prominent for more irregularly shaped blocks. Consequently, Clarkson's method can be concluded as a technique of higher accuracy than the conventional methods, especially at larger depths and for the fields in which the degree of approximation is comparatively large.

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