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Comparison of Monitor Units Obtained from Measurements and ADAC Planning System for High Energy Electrons

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The purpose of this study is to evaluate the monitor unit obtained from various methods for the treatment of superficial cancers using electron beams. Thirty-three breast cancer patients who were treated in our institution with 6, 9, and 12 MeV electron beams, were selected for this study. For each patient, irregularly shaped treatment blocks were drawn on simulation film and constructed. Using the irregular blocks, monitor units to deliver 100 cGy to the dose maximum (dmax) were calculated from measurement and three-dimensional radiation treatment planning (3D RTP) system (PINNACLE 6.0, ADAC Laboratories, Milpitas CA). Measurements were made in solid water phantom with plane parallel (PP) chamber (Roos, OTW Germany) at 100 cm source-to surface distances. CT data was used to investigate the effect of heterogeneity. Monitor units were calculated by overriding CT values with 1 g/cm^3 and in the presence of heterogeneity. The monitor unit values obtained by the above methods were compared. The dose, obtained from measurement in solid water phantom was higher than that of RTP values for irregularly shaped blocks. The maximum differences between monitor unit calculated in flat water phantom at gantry zero position were 4% for 6 MeV and 2% for 9 and 12 MeV electrons. When CT data was used at a various gantry angle the agreement between the TPS data with and without density correction was within 3% for all energies. These results indicate that there are no significant difference in terms of monitor unit when density is corrected for the treatment of breast cancer patients with electrons.

Key words: Electron conformal therapy, Monitor unit, Inhomogeneity

INTRODUCTION

In recent years, three-dimensional conformal therapy and intensity modulated radiotherapy (IMRT) is used to treat tumors that are in close proximity to vital organs using photon beams[1-4] and showed that IMRT allows improvement in dose distribution thus reducing the dose to radiosensitive organ within the treatment fields.[5-7] In these techniques, the ability to calculate dose distribution is of basic importance. Computed tomograph (CT) data is used to obtain 3D dose distributions for photon beams and it is possible to calculate the dose accurately. Electron beams are widely used to treat superficial tumors to avoid irradiation of normal organs in depth. Despite the advance in photon beam radiotherapy, the use of electron for conformal therapy is limited due to its physical properties. Thus, it must be considered differently from the photon beams.

With the development of dose calculation algorithms for electron beams, three-dimensional treatment planning systems are available for electron beam dose distribution commercially.[8-11] The currently available commercial systems for 3D electron beam planning use Hogstrom algorithm. The algorithm is based on Fermi Eyges theory and thus have problem in predicting electron transport in inhomogeneous

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material.[12-14] Many studies investigated the degree of discrepancies by comparing the dose distribution obtained from treatment planning system with measurements and/or Monte Carlo simulations. These studies showed that there are large errors in low and high density regions.[15-18] Since it is very important to calculate the dose accurately for radiotherapy, rigorous evaluation of the electron planning system is required to improve the treatment outcome. Samuelsson et al.[11] evaluated CadPlan and showed that there are good agreement for a simple two-dimensional geometry as well as more complicated three-dimensional geometries. In addition, Ding et al.,[19] studied the effects of inhomogeneity for electron beams with energies from 6 to 20 MeV. They found that there were good agreement in monitor unit between manual calculation and planning system.

Mcnutt and Wolfgang[20] provided a method of scaling dose distribution obtained from Pinnacle planning system by a single value that depends on field size, source-to-surface distance (SSD) and cone size selected for treatment. However, no studies evaluated the accuracy of monitor unit calculation with ADAC Pinnacle system for electron beams. In this study, monitor unit was determined from measurements in using irregularly shaped electron blocks and compared to monitor unit calculated from the planning system in order to evaluate the accuracy of monitor unit calculation for electron beams in clinical situation. In addition, the effects of inhomogeneity in breast region using electron beams were investigated by calculating the monitor unit in patient's CT using the 3D treatment planning system..

MATERIALS AND METHODS

A total of 33 breast cancer patients treated with 6, 9, and 12 MeV electrons in our institution was selected for this study (11 patients for each energy). After simulation, a CT scans were acquired of the patient in treatment position. Electrons blocks were drawn on simulation film to include scar and the clips implanted during surgery (Fig. 1).

1. Phantom Measurements

The measurements were performed with 6, 9, and 12 MeV electron beams to cover the energies most commonly used in the clinic for breast cancer patients as a boost radiation. For all measurements, a Primus (Siemens, USA) was used to produce electron beams. This machine was calibrated so that it delivers 100 cGy of radiation dose to water at calibration depth when 100 MU was given. Calibration depths for the 6, 9, and 12 MeV electrons were 1.2, 1.8, and 2.2 cm, respectively. Measurements were taken in a solid water phantom (30×30 cm^2) for source to surface distance (SSD) of 100 cm and gantry angle of zero degree. Mostly 15×15 cones were used in this study except several cases where 10×10 cone were used. A Parallel plate (PP) chamber (Roos, PTW, German) was located at the center

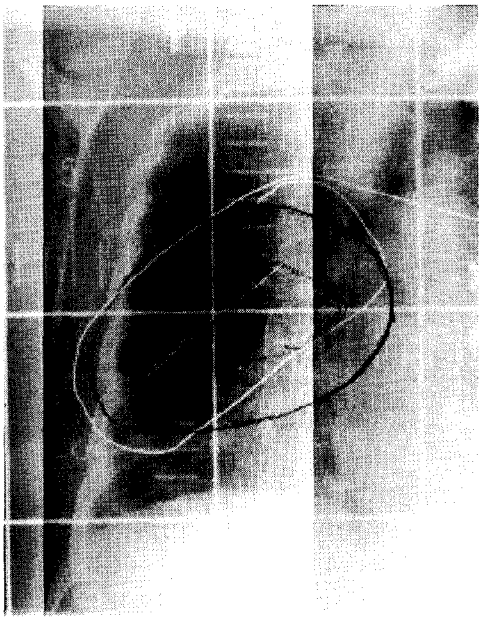

Fig. 1. A representative field shape used to compare measured vs. planned monitor unit for the electron beams on a solid water phantom.

of each field and the relative output factors were measured at the depth of 1.4, 2.2, and 3.0 cm for 6, 9, 12 MeV, respectively. Irregular electron blocks were mounted for each measurements and 100 monitor unit was delivered to solid water phantom. The measurements were repeated three times and average values were used. All measured data were normalized such that 100% equalled the maximum central-axis dose for an open 10×10 electron field incident on a water phantom at 100 cm SSD. This resulted relative dose per monitor reading for each measured data. These values were then converted into monitor units which can deliver 100 cGy to the calibration depth in water.

2. Treatment Planning

The ADAC Pinnacle6 treatment planning system (TPS) (Philips, USA) was used for all monitor unit calculations. The monitor unit calculation using treatment planning system was divided into two parts. The first part of this study was to compare monitor units obtained from measurements with the TPS values. Thus water phantom data was used to calculate monitor units. A anterioposterior beam was added and each electron blocks, used also for the measurements, were digitized into the TPS system. A prescription point was added at the center of each field which is same location as the measurement and 100 cGy was prescribed to the point. After dose computation, a comparison of monitor unit were made with the measurements.

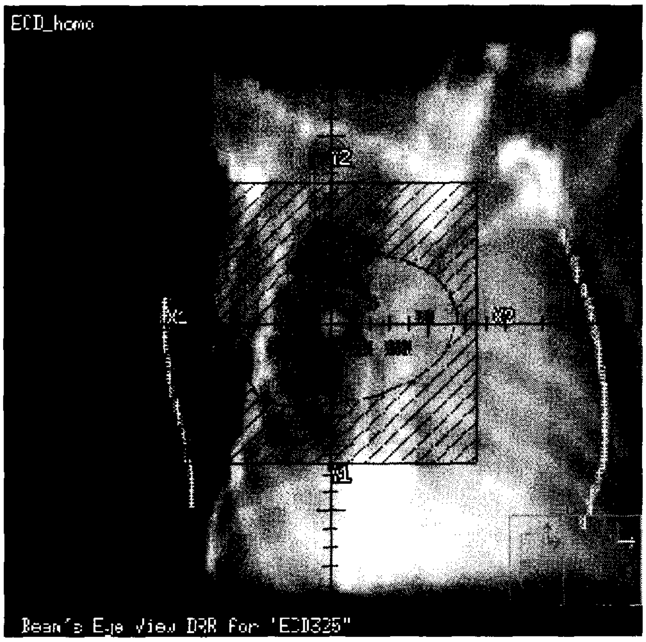

Fig. 2. Irregular electron block on CT image of a breast cancer patient.

For the second part of this study, each patient was positioned on a breast board for the planning CT scan and treatment. The planning CT scans were acquired for each patient at 5 mm intervals. Gantry angle was rotated so that uniform dose distribution is obtained around scar and clip area. Electron blocked were then digitized on the CT data for dose calculation (Fig. 2). The calculations were performed on CT data sets taken from actual treatments delivered in our radiotherapy department. Prescription depth was varied from 1.2 to 2.5 cm and gantry angle was in the 330 degree to 45 degree range. Since the purpose of this study was to study the effect of inhomogeneity in monitor unit, dose was calculated by overwriting the density value to 1 g/cm^3 inside of body contour first (Fig. 3a). Second plan was generated with same geometry as the first one but dose was computed with heterogeneity. The comparison between the homogeneous plan and heterogeneous plan was carried by calculating the difference in monitor units.

RESULTS

Fig. 4 shows the measured vs computed monitor units as a function of equivalent square for 6 MeV electron beams in water phantom. The monitor unit decreased as the equivalent sque valve increased in booth measured and computed cases and it was constart over a equivalent squae of eight. There was

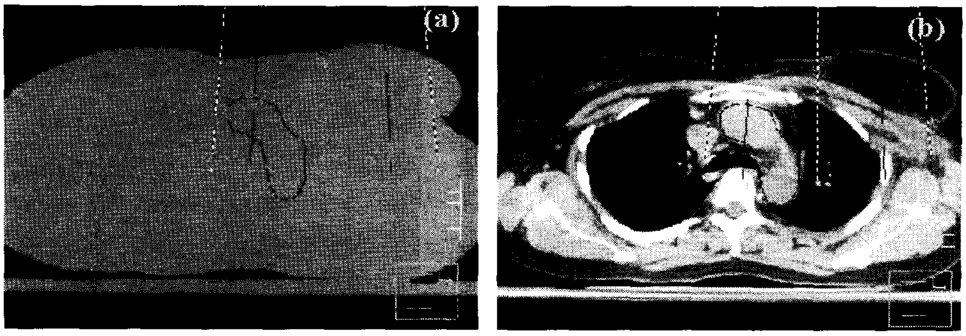

Fig. 3. Isodose distributions from Pinnacle treatment planning (a) on water phantom, (b) on CT image without inhomogeniety correction, and (c) on CT image with inhomogeniety correction.

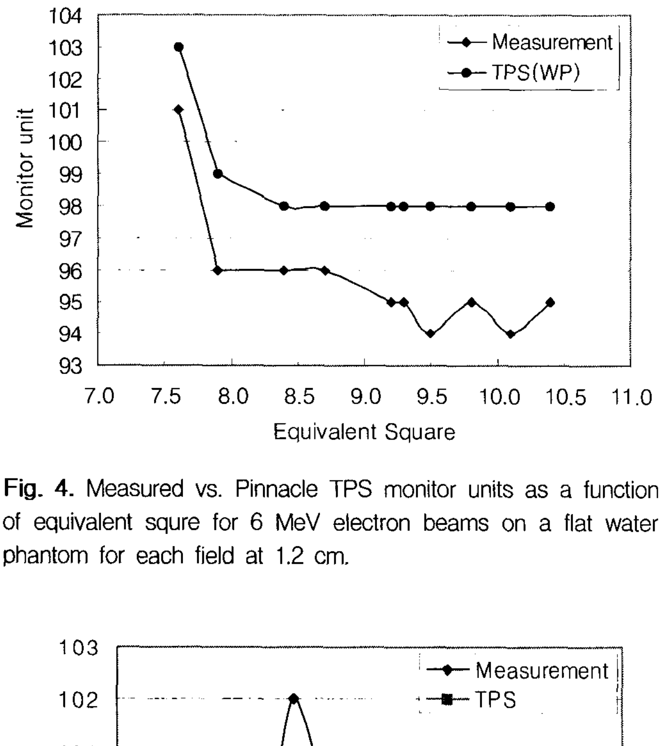

Fig. 4. Measured vs. Pinnacle TPS monitor units as a function of equivalent squre for 6 MeV electron beams on a flat water phantom for each field at 1.2 cm.

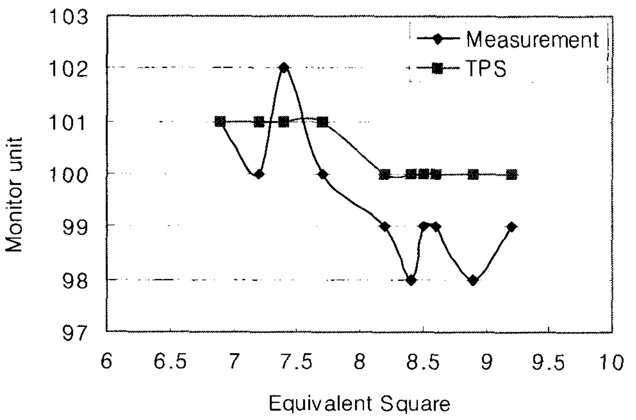

Fig. 5. Measured vs. Pinnacle TPS monitor units as a function of equivalent squre for 6 MeV electron beams on a flat water phantom for each field at 1.8 cm

consistent difference between measured and computed values. In all cases, TPS predicted more monitor units than the measured and difference ranged from 2 to 4%. Fig. 5 and 6 show the monitor units measured and calculated on water phantom for 9 and 12 MeV electrons. There was almost no field size dependance at these energies and the difference ranged from -1 to 2% for 9 MeV electrons and -2 to 1% for 12 MeV electrons. The maximum error between measurement and TPS was within 4% for 6 MeV and 2% for both 9 and 12 MeV electrons.

The comparisons of the computed monitor units in homogeneous medium and inhomogeneous medium are shown in Table 1, 2, and 3. For real treatment geometry (in the presence of a nonperpendicular entrance surface), the variations in monitor unit for CT based treatment plans in the presence of tissue inhomogeneities were within 3% for all energies. However, the difference in relative isodose distributions as shown in Fig. 5 was significant when inhomogeneity was corrected.

In addition, the deviations of the monitor unit values between the measured data on flat water phantom at gantry zero position and calculated data with CT at various gantry angle and irregular skin surface were 4, 3, and 3% on average for 6, 9, and 12 MeV electrons, respectively. However, the maximum variation ranged from 9 to 10 %.

Table 1. Monitor units calculated from TPS on patient CT data with and without density correction for 6 MeV

Patient No	TPS (WP)	Measurement	CT_homo	CT_hetero	% difference
1	99	96	100	101	1%
2	98	95	93	95	2%
3	103	101	96	97	1%
4	97	95	95	94	-1%
5	99	96	97	98	1%
6	98	95	90	91	1%
7	98	95	90	90	0%
8	98	95	96	96	0%
9	98	95	97	99	2%
10	99	96	103	105	2%
11	98	97	97	99	2%
12	97	95	100	100	0%

Table 2. Monitor units calculated from TPS on patient CT data with and without density correction for 9 MeV

Patient No	TPS (WP)	Measurement	CT_homo	CT_hetero	% difference
1	100	99	101	104	3%
2	101	100	99	102	3%
3	104	103	106	108	2%
4	100	99	92	95	3%
5	100	98	102	105	3%
6	100	99	101	101	0%
7	100	100	96	98	2%
8	100	99	93	94	1%
9	101	99	101	104	3%
10	100	99	103	100	-3%
11	101	100	101	101	0%
12	101	102	101	100	-1%
13	100	98	100	100	0%

Table 3. Monitor units calculated from TPS on patient CT data with and without density correction for 12 MeV

Patient No	TPS (WP)	Measurement	CT_homo	CT_hetero	% difference
1	101	100	102	105	3%
2	101	100	101	101	0%
3	103	103	105	106	1%
4	100	99	102	105	3%
5	100	99	96	99	3%
6	101	100	92	94	2%
7	101	101	100	102	2%
8	101	101	98	100	2%

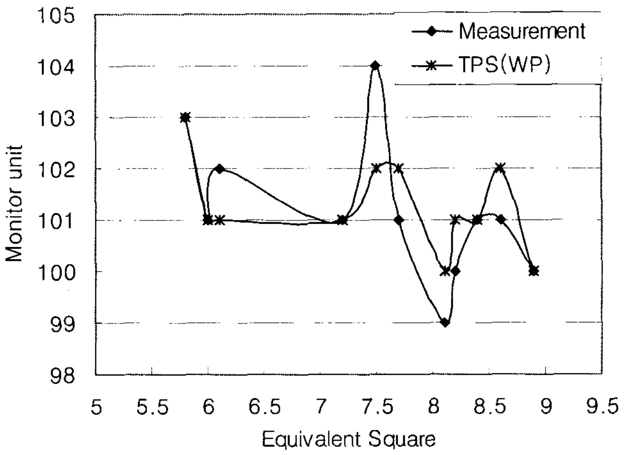

Fig. 6. Measured vs. Pinnacle TPS monitor units as a function of equivalent squre for 6 MeV electron beams on a flat water phantom for each field at 2.2 cm.

DISCUSSION AND CONCLUSION

We compared the monitor units for 33 patients with breast cancer calculated by the Pinnacle RTP system and by a measurement. For all patients studied RTP calculation showed slightly lower monitor units for 6 MeV electrons and there was almost no difference for 9 and 12 MeV electrons. These results indicates that the RTP system when water phantom was used for calculation, provide fairly accurate monitor units.

Also, CT-based plan was performed in the absence and presence of tissue inhomogeneities in breast for conformal treatment with electrons. The variations in MU in the presence of heterogeneity were within 3% for all energies. Based on these results, it is concluded that the heterogeneity correction may not be required for electrons used in breast cancer patients. However the heterogeneity correction is required for 3D conformal therapy. The maximum difference between calculated values on flat water phantom and CT data were 10%. These variations result from surface irregularity, the presence of a nonperpendicular entrance surface as well as irregularity in blcok

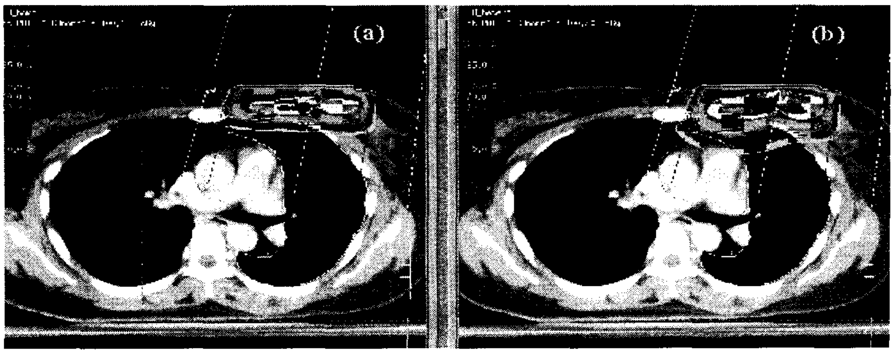

Fig. 7. Comparison of the isodose distribution for a irregular electron block (a) without density correction and (b) with density correction).

shape. Thus, it is recommended that one considers these factors when calculating monitor units in real treatments.

A comparison with measurements on an inhomogeneous phantom has to be made to evaluate the accuracy of the TPS in density correction. However, the purpose of this study was to determine the difference in monitor unit calculation. Thus, the stated work will be remain as future work.

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측정과 ADAC 치료계획 시스템에서 계산된 고에너지 전자선의 Monitor Unit Value 비교

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본 논문에서는 표면조직에 있는 종양 치료 시 사용되고 있는 고에너지 전자선의 monitor unit을 다양한 방법에 의해 계산하여 평가 하고자 한다. 본 병원에서 6, 9, 그리고 12 MeV 전자선으로 치료한 33명의 유방암 환자가 선택되었다. 각 환자마다 모의 치료기 에서 얻어진 시뮬레이션 필름에 불규칙한 모양의 전자선 블록이 제작되었다. 이러한 불규칙한 모양의 블록을 이용하여 최대선량 깊이에 100 cGy의 선량을 주기 위해 필요한 monitor unit 이 3차원 치료계획 시스템 (Pinnacle 6.0, ADAC Lab)을 사용하여 계산되었고 측정되었다. 선원과 표면 거리(SSD)가 100 cm 인 곳에서 plane parallel (PP) 이온전리함(Roos, OTW Germany) 을 사용하여 고체 물 팬텀 내에서 측정하였다. 불균등 조직에 대한 효과를 평가하기 위해 CT 데이터를 사용하였고 monitor unit을 균등조직 및 비균등조직 내에서 계산하였다. 균등조직으로 계산하기 위해 CT의 밀도를 1 g/cm^3로 지정하였다. 이러한 방법에 의해 구해진 monitor unit 값들을 비교하였다. 한 지점에서 측정된 선량과 RTP에서 구해진 선량을 비교 할때 측정된 값이 치료계획에 의해 계산된 값보다 조금 높았다. 평평한 고체 물 표면에 조사된 경우 측정된 값과 계산된 값에는 6 MeV 전자선의 경우 4%, 그리고 9 및 12 MeC 전자선의 경우 2%의 차이가 있었다. 또한 다양한 조사방향에서 CT 데이터를 사용하여 monitor unit을 계산한 경우 불균등한 조직의 밀도를 고려하여 계산된 값과 고려하지 않고 계산된 값은 모든 에너지에서 3% 이내의 차이가 있었다. 이러한 결과는 전자선을 사용하여 유방암 치료 시 조직내의 불균등한 밀도를 고려하지 않고 monitor unit을 계산해도 큰 차이가 발생하지 않는다는 것을 의미한다.

핵심용어 : 전자선 입체조형치료, Monitor unit, 비균등조직