**Dose Delivery Accuracy of Therapeutic Photon and Electron Beams at Low Monitor Unit Settings**

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**Purpose:** Dose delivery accuracy at low monitor units (LMU) was evaluated for photon and electron beams. Knowledge of this study is required for few dosimetric applications and to know the dose delivered to the patient when the treatment is delivered with few monitor units (MU).

**Material and Methods:** Dose measurements were carried out for photon and electron beams with 0.6 cm³ PTW ion chamber in white polystyrene phantom at Dmax with a field size of 10 × 10 cm² at 100 cm FSD. The relative dose, which is the ratio of dose delivered per MU at the testing to that of the calibration condition, was found out.

**Results:** Significant deviation (+20% to +25%) in dose delivery was noticed for photon and electron beams (+39% to +45%) at LMU settings. Slightly higher inaccuracy in dose delivery was noticed for 6-MV compared to 18-MV photons. The deviation in dose delivery for electron beams was found to be energy-independent and the pattern of variation was similar for all electron energies.

**Conclusion:** The dose delivery accuracy at LMU settings has to be ascertained before implementing conformal and IMRT (intensity-modulated radiotherapy) techniques. When there is dose nonlinearity, the treatment delivered with multiple small MU settings can result in significant error in dose delivery.

**Key Words:** Low monitor units · Output factors · Dose delivery · IMRT

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**Genauigkeit der Dosierung therapeutischer Photonen- und Elektronenstrahlung bei niederen Monitoreinheiten**

**Ziel:** Für Photonen- und Elektronenstrahlung wurde die Abhängigkeit der Output-Faktoren von den Monitoreinheiten gemessen. Relevant sind die Ergebnisse dieser Untersuchung für einige dosimetrische Anwendungen und zur Ermittlung der Referenzdosis, wenn mit wenigen Monitorwerten (MU) bestrahlt wird.

**Material und Methode:** Die Output-Faktoren wurden mit einer 0,6-cm³-Ionisationskammer, PTW, jeweils in Maximumstiefe mit einem weißen Polystyrol-Phantom ermittelt (Feldgröße 10 × 10 cm², Fokus-Oberflächen-Abstand 100 cm). Das Verhältnis der Output-Faktoren bei verschiedenen Monitoreinheiten zu den Standardwerten bei 200 MU wurde als relative Dosis definiert.

**Ergebnisse:** Bei niedrigen Monitoreinheiten fanden sich signifikante Abweichungen der Output-Faktoren von den Standardwerten (Photonen: 20–25%; Elektronen: 39–45%). Die Abweichungen bei 6-MV-Photonen war geringfügig höher als bei 18 MV, während die Abweichungen bei Elektronen keine Energieabhängigkeit zeigten.

**Schlussfolgerung:** Die Konstanz der Outputfaktoren bzw. deren Abhängigkeit von den Monitorwerten muss vor der Implementierung von IMRT-Techniken sichergestellt werden. Stark abweichende Output-Faktoren können signifikante Abweichungen der Dosis im Patienten zur Folge haben, wenn mehrere Subfelder mit niederen Monitorwerten im Spiel sind.

**Schlüsselwörter:** Niedere Monitorwerte · Output-Faktoren · Applizierte Dosis · IMRT

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**Introduction**

Dose estimation uncertainty of ± 2% is necessary to deliver a uniform target dose within ± 5% for better tumor control [6, 7, 10, 12, 21, 26, 27, 30]. Dosimetric studies involving TLD phosphors for radiation protection, film dosimetry at low level of radiation dose, nuclear medicine dosimetry, estimation of low β-doses and few other research applications related to environmental dosimetry require few monitor unit (MU) settings of photon and electron beams in a linear accelerator. Segmental and hyperfractionated radiotherapy are usually delivered with < 50 MU settings [5, 13]. The conformal therapy makes use of multiple multileaf collimated (MLC) beams of varying...
intensities delivered with automatic computer controls [14–16]. Sometimes the number of MU per field might vary as low as 10 MU depending on the location of the target and the neighboring normal structures [1, 8, 17, 18, 25]. With intensity-modulated radiotherapy (IMRT) technique, each individual field is divided into small beamlets and the weight of each beamlet can be adjusted by varying the number of MU delivered [2, 11, 20, 28, 29]. Minimizing the dose to the critical structures demands very low MU to be delivered for certain beamlets [19, 24]. Treatment interruptions after few MU delivered may be present when the patient tends to change the treatment position. Also, possibility of the treatment machine internal interlock terminating the treatment is common after delivering few MU when the dose rate does not build up to the specified set level. These situations require the knowledge of accuracy in dose delivery at low monitor unit (LMU) settings for photon and electron beams in order to estimate the delivered dose.

Deviations in dose delivery at LMU from the normally calibrated values were reported for photon beams from different linear accelerators [4, 23]. An inaccuracy of > 20% in the delivered dose was indicated for electron beams for the initial few MU. Dose linearity, beam flatness and the variation in beam energies were studied for different dose rate electron beams. The dose delivery accuracy for scanned electron beams was found to be random in nature [3]. Higher dose linearity ratios were reported in literature for high-energy electron beams at higher dose rates [22]. Humm et al. [9] have reviewed the dosimetric stability, linearity, dose rate dependence and flatness of both photon and electron beams for a racetrack microtron at LMU settings. Most of the studies reported in literature indicate that there is significant deviation in the delivered dose at < 10-MU settings for both electron and photon beams. In this study an attempt was made to analyze the dose delivery accuracy for two photon beams and six electron beams ranging from 6 MeV to 18 MeV.

Material and Methods
The delivered dose per MU at different MU settings was evaluated from the charge measured using a 0.6 cm³ Farmer type ion chamber (PTW, Type 30001) connected to a PTW Unidos E digital electrometer. The chamber was positioned with its effective point of measurement, which is the center of the chamber for photon beams and 0.5 cm³ upstream from the center toward the source for electron beams, at the depth of maximum in a 30 × 30 × 30 cm³ water-equivalent RW3 slab phantom (PTW T29672). The Siemens Mevatron KDS linear accelerator produced photon beams of nominal energies of 6 MV (TPR²⁰), 10 MV (TPR²⁰), 15 MV (TPR²⁰), and electron beams of nominal energies of 6, 8, 10, 12, 15, and 18 MeV were used. Measurements were carried out with 10 × 10 cm² for photon beams at 100 cm FSD. For electron beams 10 × 10 cm² opened cone at 100 cm FSD with the photon collimator fixed at 19 × 19 cm² was used.

The high-energy photons (18 MV) and electron beams are delivered at a dose rate of 300 MU/min from the accelerator, whereas the low-energy photons (6 MV) are delivered at 200 MU/min. In order to study the accuracy of dose delivery at higher dose rate, 6-MV photon beam (TPR²⁰) delivered at 300 MU/min was used from Siemens Mevatron 6700 linear accelerator. The depth of maximum dose was determined in a water phantom using WP 600 Wellhofer Radiation Field Analyzer (RFA) system and 0.14 cm³ (Wellhofer) sensitive volume ionization chamber. The linearity of the 0.6 cm³ chamber and an electrometer system to measure the low level of charge was checked using a strontium-90 check source (PTW Type 23261-935) of 25-MBq activity. The consistency in the measured charge/s over a range of measuring time (1–150 s) indicates that the measuring system is sensitive and linear for the measurement of low charge levels.

The absorbed dose to the medium was estimated using Technical Report Series 398 [10] of IAEA (TRS-398) and is given by

\[ \text{D/MU} = \left( \frac{M_r}{\text{MU}} \right) N_{D,W,Qo} K_{Qo,Qo} (1) \]

where (D/MU) is the dose to the medium per MU at the beam quality Q, M_r is the corrected charge per MU for influencing quantities, N_{D,W,Qo} is the calibration factor in terms of absorbed dose to water for the dosimeter at the reference quality Q_r and K_{Qo,Qo} is a chamber-specific factor which corrects for the difference between the reference beam quality Q_r and the actual beam quality of measurement Q.

The relative dose (RD) is defined as the ratio of dose delivered per MU at the testing condition to that of the dose delivered per MU at the normal calibration condition, usually with 200-MU setting.

\[ \text{RD} = \frac{(\text{D/MU})_{\text{TEST}}}{(\text{D/MU})_{\text{CAL}}} (2) \]

where \((\text{D/MU})_{\text{TEST}}\) refers to the dose/MU for which the dose linearity has to be estimated and \((\text{D/MU})_{\text{CAL}}\) refers to the dose/MU at which routine dose calibration is carried out (200 MU). If the dose delivered per MU is same for all MU settings, then the RD will be unity over the range of MU used clinically.

Since the ionization chamber and the beam quality are same in the above measurement conditions, \(N_{D,W,Qo}\) and \(K_{Qo,Qo}\) are constant in equation (2). As the variation in energy for the scattering foil-produced electron beam is within ±2% [3], same values of \(K_{Qo,Qo}\) were considered for the testing and calibrating MU. Hence the equation for the RD now gets reduced to the ratio of corrected dosimeter readings (MR/MU) for the testing and calibrating conditions.

Hence equation (2) can be written as

\[ \text{RD} = \left( \frac{\text{MR/MU}}{\text{MR/MU}} \right)_{\text{CAL}} (3) \]

where \((\text{MR/MU})_{\text{TEST}}\) and \((\text{MR/MU})_{\text{CAL}}\) are the dosimeter readings per MU for photon and electron beams under testing and calibrating conditions. The measured RD is plotted in a semi log graph for various photon and electron MU settings.

Results
The RD/MU for different MU settings for 6- and 18-MV photons from Mevatron 6700 and Mevatron KDS for the dose rate of 300 MU/min is shown in Figure 1. It can be observed that the