Surface dose measurements in clinical 6 MeV-X-photon beams : Comparison of Measurements and MC calculations.

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Abstract.

For radiotherapy of superficial lesions, but also in intensity modulated radiotherapy (IMRT), 6 MeV-X-photon beams are preferred, with relative surface doses, dependent on field size and SSD, of 8 % to 28 %. Depending on absorption material within the beam this values can vary considerable. The influence of a block tray, different metals and a new type of transmission detector on surface doses as well as on other beam parameters have been investigated. The surface doses as well as some other field parameters have been checked by means of a plane parallel ionization chamber (Markus chamber, type 23 343, PTW-Freiburg, Germany). Because of specific design features the readings have to be corrected, and the results have been verified by Monte Carlo (MC) simulations and calculations: Measurements agreed well with calculations within $\Delta \approx 3$ %. So it could be shown for the used Markus chamber, type 23 343, that the applied correction function is suitable for open fields as well as for blocked fields at different clinical used SSDs.

Introduction.

In radiation therapy it is mandatory to optimize the dose to the tumor as well as to minimize the dose to healthy tissue. An important parameter is the used energy of the photon beam. To treat superficial tumors and in IMRT often 6 MeV-X photons are used. For visible complications the dose to the skin is of importance. This dose is mainly dependent on secondary electrons emerging from the treatment head and accessories, such as blocks, block trays and wedges. Also the field size and the source-skin-distance (SSD) influences this parameter.

For quality assurance (QA) reasons different transmission detectors are in use, either to detect and record dose distributions and fluence matrices prior to treatment or to record actual fluence distributions during treatment. For this purpose a newly developed transmission detector system [6] has been introduced into the market. This system is capable of calculating dose distributions within the patient taking into consideration the anatomy as well as beam model parameters. But this implies a modification of beam parameters, in detail, surface

dose and fluence, according to secondary electrons and absorption, respectively [7].

For measurements of surface doses the extrapolation chamber is considered as the gold standard [8, 9]. But in most radiotherapy departments this special type of ionization chamber is not available. Therefore other types have to be used, for instance plane parallel chambers of Markus type (M 23 343, PTW-Freiburg, Germany). Dependent on some design and construction features (i. e. width of guard ring) of this version, readings of measurements in depths $d < d_{max}$ have to be corrected for scattered secondary electrons, causing an overestimation of the results for surface doses to avoid misinterpretations. By comparison with extrapolation chamber results, some correction factors [1, 2, 3, 4] have been evaluated and subsequently a correction function has been defined for that particular standard SSD and open field set up [11]. To extend the validity and to verify the correction function, MC-based calculations and simulations have been done and compared to measurements in open and blocked fields.

Materials, methods and procedures.

For measurements of surface doses D0 as well as for estimation and recording of dose profiles the Markus-type ionization chamber (M 23 343) was placed at depths d = 0 mm (surface) and d = dmax in a water equivalent solid water phantom. Dependent on field size, blocking material and SSD the surface dose was measured and calculated. In preparation for this measurements the depths of dmax for different experimental set up conditions have been determined. As blocking material polycarbonate (Makrolon®), aluminium (Al), and lead (Pb) was used. The thickness was 5.8 mm, and 1 mm, resp. This blocking plates where fixed within the accessory mounting slot of a medical linear accelerator (Clinac 2100 C/D, Varian, Palo Alto, USA). The focal spot distance was 66.4 cm in all cases, except for the transmission detector; it also fits into this slot, but with a focal spot distance of 65.0 cm. This general set up allows to realize SSDs of ≥ 70 cm, but clinical relevant distances are 80 cm to 100 cm. Because the transmission detector is a test tool in IMRT-QA, the checked field sizes are restricted to $F \leq 20 \times 20\ cm^2$, and the beam energy is limited to 6 MeV-X according to construction features. Also no measurements have been carried out with physical wedges, because in daily routine they have been replaced by dynamical (or virtual) wedges.

The results of measurements have been normalized to the particular depth of dose maximum, in case of profiles to the central axis (100 %).

For estimation of the most probable energy of the secondary electrons, depth dose profiles for the reference field size of $10 \times 10\ cm^2$ and the smallest SSD = 70 cm have been measured for open and blocked situation. The experimental results, such as energy of the secondary electrons $E_{p/0}$, surface dose D_0, depth dose profiles P, dose profiles L, absorption factors A and output factors OF, have been verified by MC-simulations and calculations. For this reasons it was mandatory to correct the experimental readings for depths $d < d_{max}$, to compensate for the overestimating caused by the Markus chamber: $\Delta d\ [\%] = -12.3 \cdot \exp(-0.0405 \cdot d)$, coefficient of regression r = 0.9925, standard

deviation σ = 0.742. For the MC-simulations of the various materials the geometrical and physical data [5] where taken into account; to characterize the transmission detector additionally some construction data provided by the vendor where implemented. Beside the parameters mentioned above, also spectral fluence and the angle distribution of secondary electrons where calculated by means of the MC program (BEAMnrc/EGSnrc) to explain modifications in dose profiles caused by the blocking materials.

Experimental and theoretical results.

Raw data of the surface dose measurements where corrected for by the correction function Δd. These results are listed in Tab. 1. Corrected depth dose data for open and blocked beams at a field size of 10 x 10 cm^2 and a SSD = 70 cm resulted in a theoretical depth dose profile, which allows the estimation of the most probable energy, assuming an energy transfer to material by electrons (Fig. 1). Negative values of the profile at depths d > dmax reflecting the absorption of the used photon beam in the particular blocking material; they are also suitable for calculation of absorption coefficients (Tab. 2).

Table. 1 Surface doses: Results for field size 10 x 10 cm^2 .

SSD	open field		BLTR		1 mm Al		1 mm Pb		TRD	
[cm]	exp.	MC	exp.	MC	exp.	MC	exp.	MC	exp.	MC
70	*16.8*	*13.9*	*55.5*	*49.2*	*38.6*	*31.4*	*36.5*	*32.6*	*52.7*	*40.0*
75	*15.8*	*14.0*	*34.4*	*30.4*	*23.0*	*21.6*	*18.6*	*19.5*	*30.9*	*22.7*
80	15.1	14.0	24.9	22.6	18.8	17.7	15.4	15.4	*23.4*	*17.3*
90	14.6	13.3	19.6	17.4	16.0	15.0	13.6	12.9	17.8	14.2
100	15.0	17.0	17.5	16.9	15.4	14.9	13.5	13.1	16.5	14.8

Table data: [%] of particular dose maximum; *italic data : impossible to realize in normal treatment mode because of technical and geometrical restrictions.*

Table 2 Transmission data.

Transmission	BLTR*	1 mm Al	1 mm Pb	TRD**
theoretical ***	0.967	0.988	0.949	0.965
experimental	0.971	0.990	0.951	0.967
MC	0.969	-	-	0.958

* block tray/Makrolon® (5.8 mm);
** transmission detector [6];
*** absorption coefficients [5], [10] .

Table 3 Output-factors OF (MC-calculations vs. measurements).

Feldgrösse [cm^2]	3 x 3	5 x 5	10 x 10	15 x 15	20 x 20
OF (MC)	0.846	0.904	1.000	-	1.073
OF (exp.)	0.842	0.899	1.000	1.058	1.098

The comparison of the experimental and the calculated dose profiles at different SSDs (80 cm and 100 cm) supports the result of the experiments for estimation of $E_{p/0}$ of the secondary electrons emerging from the blocking material: $E_{p/0} \approx 2.1$ MeV. This coincides quite well with the used photon beam: E = 6 MeV-X. Electrons of this moderate energy show significant scattering in air [10, 12]: For short SSDs the dose is increased mainly inside the photon field, for larger SSDs dose tails outside of the beam are involved (Fig. 2a and 2b), due to the mean scattering angle [12] of secondary electrons. This could be verified by calculations as

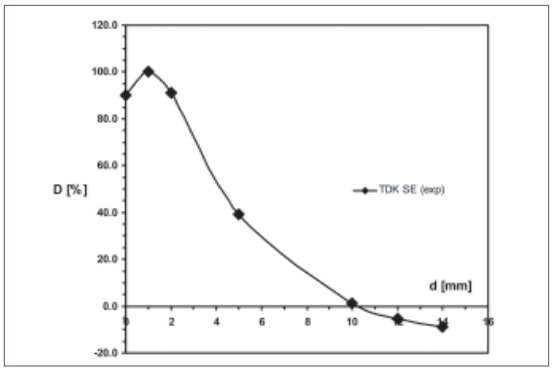

Fig. 1 Empirical depth dose profile of secondary electrons (SE). (10 x 10 cm^2 ; normalized difference D[%] : TRD-blocked field minus open field)

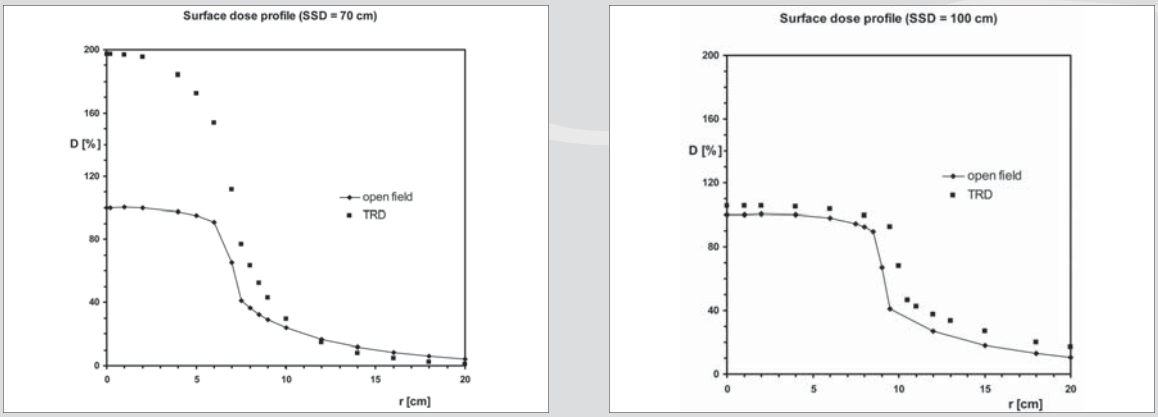

Fig. 2 Experimental dose profiles (Transmission detector TRD vs. open field).
(a) SSD = 70 cm; (b) SSD = 100 cm.

well as the shape of the output curve for field sizes 3 x 3 cm^2 up to 20 x 20 cm^2: $\Delta < 2.3$ %.

Discussion and conclusion.

The validation of the correction function Δd for the Markus chamber (type 23 343) for open and blocked photon fields is the basis for some IMRT-QA measurements, especially because this type of ionization chamber is still in use in a large number of departments. The experimental check of selected parameters for open and blocked photon fields for a variety of SSDs shows an excellent matching with MC calculations: The mean deviation of the corrected surface doses varies from $\Delta = 0.9$ % at SSD = 100 cm and $\Delta = 6.8$ % at 70 cm. The MC calculations in most cases underestimate cases measurements slightly. The reason for this might be an incomplete and non-ideal modeling of the radiation source and the beam forming components of the treatment head. Largest deviations occur with the use of the transmission detector, because some internal details stay unknown. In particular for a SSD = 70 cm the differences between measurement and calculation become apparent : $\Delta = 12.7$ %. But the extremely small deviations for clinically relevant SSDs of 80 cm to 100 cm for all set up variations justify and support the assumption, that the chosen correction function for raw data in superficial regions is reasonable : $\Delta = 2.8$ %.

Measured depth dose profiles for open as well as for blocked fields could be verified by MC calculations. And the estimation of the most probable energy $E_{p/0}$ of secondary electrons differs just slightly. Scattering of secondary electrons, influencing the dose inside and outside of the radiation beam, was predicted as well. Even calculated output factors OF coincide well with measured one's.

This excellent results justify the use of the Markus chamber (type 23 343) for checking doses in superficial regions in photon fields, instead of purchasing an extrapolation chamber for this specific reason.

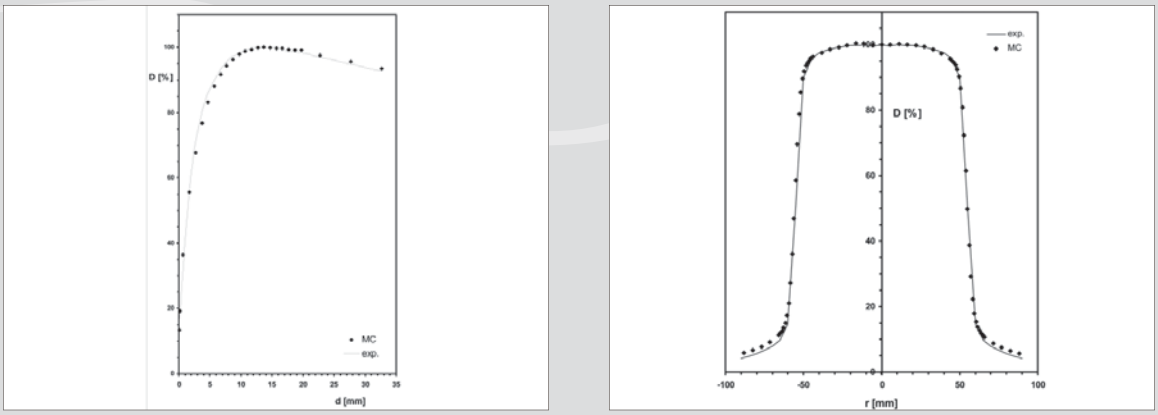

Fig. 3 Comparison of measured and MC-based profiles.
(a) Depth dose profile (SSD = 90 cm; field size 10 x 10 cm^2); (b) Dose profile (10 x 10 cm^2; depth 10 cm).

Further measurements and calculations have to be carried out, to extend the validity of the correction function to the wide range of photon energies used in radiation therapy, i.e. 4 MeV-X, 10 MeV-X, 15 MeV-X and 18 MeV-X.

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