Dosimetry of small circular beams of high energy photons for stereotactic radiosurgery and radiotherapy: the use of small ionization chambers.

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I. Introduction
The irradiation of small targets in the brain in a single fraction (radiosurgery) or with a fractionated approach (stereotactic radiosurgery) with small beams of photons requires specific conditions to measure and to model the dosimetric data needed for treatment planning.

In this work, we present the method and materials adopted in our institution since 1988 to perform the dosimetry of high energy (6-23) circular photon beams with diameters ranging from 10 to 40 mm at the isocenter of linear accelerators, and its evolution as new dosimetric material became commercially available, in particular ionization chambers of small dimensions. We want to answer the following questions:

Which are the minimal basic data needed to model small circular beams of high energy photons?
Can we extrapolate or convert data from "conventional" data of larger beams?
Which are the detectors well adapted for these kind of measurements and for which range of beam sizes?

II. Methods and materials
Measurements and treatments have been performed in our institution on a linear accelerator Saturne25 (CGR-MeV, Buc, France) at 23 MV, quality index 0.787, [1,2] and, more recently, a 15 MV beam from a Saturne41 has been prepared for the same kind of treatments. Different materials and methods have been tested previously in a inter-institutional work [3,4,5] at energies ranging from 6 to 25 MV.

Non-divergent additional collimators made of lead into brass cylinders have been built in our institution [6,7], defining circular beams with diameters of 10 to 40 mm at isocenter (distance source-isocenter 100 cm). The base of the additional collimators is at 28 cm from isocenter. The transmission of the collimation system, including a pre-collimation, is about 0.5 % of the dose at the central axis for a 23 MV beam.

The first series of measurements have been performed using a small ion chamber prototype (ORIS MN606) cylindrical with 0.01 cc, length and diameter of about 4 mm, and compared with other detector systems: ion chambers of larger dimensions (Therados RK8305, 0.12 cc, diameter 7 mm, length 25 mm; Nuclear Enterprises Type 2577 volume 0.2 cc and type 2571 volume 0.6 cc), semiconductors (Therados type A), thermoluminescent detectors (LiF powder PTL717, CEC) read with a Saphymo LDT22, and radiological films (Agfa Gevaert Structurix D2, Kodak IndustrexM and Kodak X-OmatV), read on two densitometers (Macbeth Quantalog and Wellhofer). Most of the measurements with ion chambers have been performed with the main axis of the chamber parallel to the beam axis. The evaluation of some effects like the directional response, the position of the effective point of measurements, the stem irradiation and the detector response to a non-uniform electronic flux have been presented elsewhere [8].

In order to understand the basic phenomena involved in our measurements, we perform theoretical calculations using convolution models developed by Mackie et al [9,10] from Monte Carlo kernels, getting the total and the primary dose for the simulated situations. Our results have been presented elsewhere [11].

Later on, additional measurements in the frame of quality controls of beam data, and to perform the treatments in another linear accelerator, have been performed using medium and small ion chambers (Wellhofer IC15, with 0.13 cc, 6 mm length and diam.; and IC4, with 0.03 cc, and nearly 4 mm as length and diam.) in an automatic water phantom (Wellhofer WP700) having autocentering functions when measuring lateral profiles at different depths.

The basic dosimetric data requested for clinical applications were determined by a home-made software DOSimétre des MIni-FAisceaux "Do-Mi-Fa Stéréo" [1] included in the Isis Treatment Planning System (Technologie Diffusion, France): Tissue-Phantom Ratios (or depth dose curves), Lateral Profiles and Field Dimension Factor.

I. Results
The basic set of data adopted for treatment planning calculations at 23 MV is presented in fig. 1 (Tissue-Phantom Ratios), fig.2 (lateral profiles at a given depth of 8 cm in tissue.), and fig.3 (Field Dimension Factor, FDF, at a given depth of 8 cm in tissue), including some measurements with other detectors.

Fig 4 shows the depth of the maximum for different beam sizes at different energies.

Fig 5 shows the gradient at different levels in the lateral profiles.

Fig 6 shows the total and the primary dose in a lateral profile for 4 MV beams of 10 an 40 mm diameter.
7. Discussion and conclusions

Our preliminary study [1-8,11] showed that the lack of electronic equilibrium was the origin of most of the macroscopic characteristics of the small beams of high energy photons: the field dimension factor has a strong variation, very different than what could be extrapolated from large fields; the depth of maximum increases with beam size (opposite as for large fields) and the conversion from Depth Doses to Tissue-Phantom Ratios should be done including the effect of changes of beam size with depth, as in the original Burns' formula [12] and not with a simple relation of square of distances. The most critical factor is the Field Dimension Factor (FDF), and small ion chambers were the best detector to perform the measurements. But these detectors were only prototypes, so rare. In consequence, the use of different detectors were recommended to analyze the accuracy of the results. But most of them has specific problems: large chambers loose part of the signal, giving lower values of the FDF, and have a low resolution, while diodes establish an artificial electronic equilibrium around the detector, giving a response higher than the real one under non-equilibrium conditions.

More recent measurements confirm these approaches as a solution to perform dosimetric measurements in small beams of high energy photons: small commercial ion chambers are well adapted nowadays to measure beam data for diameters as low as 10 mm. In all the cases the beam profile (that can also be easily measured by film dosimetry) must be used to evaluate (and eventually to correct) the accuracy of the ion chamber measurement.

Small chambers have the problem of a lower signal, giving in many cases more noisy data. In addition, some effects that are hidden for "large" chambers can be important for the small ones, like the stem effect. The solution of using the chamber with its main axis parallel to the beam axis can again provide an "elegant" solution to this problem.

The use of automatic phantoms allows a direct verification of the centering of the detector, and a fast data acquisition at different depths. But indeed, profiles at different depths can be easily calculated by linear projection of a profile at a single depth. The minimal set of experimental data can be limited to one Field Dimension Factor at a given depth, and a pair of curves for each additional collimator (one in depth and one profile).

Most of these conclusions and proposed solutions have been recently tested and adopted by other teams [13] and included in national [14] and international references [15] from tasks groups in small fields dosimetry. They can also be useful for measurements of data sets used to calculate dose distributions in Treatment Planning Systems for complex fields.

References

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Fig. 1: Tissue Phantom Ratios for 23 MV, beam sizes from 10 mm diameter to 10x10 cm, normalized at a reference depth of 8.2 cm.

Fig. 2: Lateral profiles for beams of 23 MV.

Fig. 3: Field Dimension Factors for different detectors at 23 MV.
Fig. 4.: Depth of maximum for different beam sizes and energies.

Fig. 5.: Gradients at different levels in the profiles.

Fig. 6.: Primary and total dose in profiles at 4 MV.