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Original article

# Low dose out-of-field radiotherapy, part 1: Measurement of scattered doses

## *Faibles dose de radiothérapie en dehors des faisceaux (première partie) : mesure des doses diffusées*

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ABSTRACT

*Purpose.* – To measure out-of-field doses in a phantom model to better quantify this radiation.
*Material and methods.* – The individual contribution of photons and neutrons to the total out-of-field dose for 6 MV and 20 MV photons at open beam were measured in a purpose-designed water phantom. Radiation doses were measured at seven separate points (P1–P7) in the phantom with thermoluminescent detectors (TLD 100, 600, and 700) and GAFchromic$^{TM}$ EBT films.
*Results.* – At a prescribed dose of 75 Gy to the isocentre, the photon dose level in the close-to-field area (P2) ranged from 2.0–2.5 Gy for 6 MV and 1.5–2.0 Gy for 20 MV; the total out-of-field doses at P2 and P7, respectively, were estimated to be as follows: for 6 MV: TLD 100 (< 3.23% and < 0.14%); radiochromic film (< 2.52% and < 0.03%); and for 20 MV: TLD 100 (< 2.94% and < 0.78%); TLD 700 (< 2.02% and < 0.14%); and radiochromic film (< 1.73% and < 0.01%). Although the dose decreased rapidly as the distance from the central beam axis increased, even distant doses could be as high as several centigrays. The neutron dose for 20 MV photons at a distance of 25 cm from the isocentre was 4.0 mSv/Gy.
*Conclusion.* – Our results show that in the close-to-field area, the dose level could be as high as 1.5 Gy assuming a prescribed dose of 75 Gy to the isocentre. By contrast, the doses delivered to more distant areas from the planning target volume were much lower (centigrays). These findings show that both 6 MV and 20 MV photons could produce dosimetrically important dose levels outside of the field. The data reported here may be of value to study the potential impact of even very low doses of radiation on human tissues.


*Mots clés :*
Doses en dehors du faisceau
Doses de neutron
Dosimétrie
Dosimètres thermoluminescents

RÉSUMÉ

*Objectif de l'étude.* – Mesurer les doses de radiothérapie délivrées par des faisceaux dans un fantôme pour mieux quantifier cette irradiation.
*Matériel et méthodes.* – La contribution individuelle des photons et des neutrons à la dose délivrée en dehors de faisceaux ouverts de photons de 6 MV et 20 MV a été mesurée dans un fantôme d'eau spécialement conçu. Les doses de rayonnement ont été mesurées en sept points distincts (P1 à P7) dans le fantôme avec des dosimètres thermoluminescents (TLD 100, 600 et 700) et des films radiochromiques GAFchromic$^{TM}$ EBT.

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*Résultats.* – Pour une dose prescrite de 75 Gy à l'isocentre, la dose de radiation dans la zone proche du faisceau (P2) variait de 2,0 à 2,5 Gy pour les photons de 6 MV et de 1,5 à 2,0 Gy pour ceux de 20 MV ; les doses totales hors faisceau aux points P2 et P7, respectivement, ont été évaluées comme suit : pour 6 MV : TLD 100 (< 3,23 % et < 0,14 %) ; le film radiochromique (< 2,52 % et < 0,03 %) ; et 20 MV : TLD 100 (< 2,94 % et < 0,78 %) ; 700 TLD (< 2,02 % et < 0,14 %) ; et le film radiochromique (< 1,73 % et < 0,01 %). Bien que la dose ait diminué rapidement avec la distance à l'axe central du faisceau, la dose délivrée à distance pourrait être de plusieurs centigrays. La dose de neutrons pour les photons de 20 MV à une distance de 25 cm de l'isocentre était de 4,0 mSv/Gy.

*Conclusion.* – Nos résultats montrent que, dans la zone proche du faisceau, la dose d'irradiation pourrait être aussi élevée que 1,5 Gy, en supposant une dose prescrite de 75 Gy à l'isocentre. En revanche, les doses délivrées dans les régions plus éloignées du volume cible prévisionnel étaient beaucoup plus faibles (quelques centigrays). Ces résultats montrent que des faisceaux de photons de 6 MV et 20 MV pourraient produire des niveaux de dose importants en dehors du faisceau. Les données présentées ici peuvent être utiles pour étudier l'impact potentiel des doses très faibles de rayonnement sur les tissus humains.



## 1. Introduction

In recent decades, highly advanced radiotherapy techniques such as intensity-modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT) have increasingly supplanted older techniques such as three-dimensional conformal radiotherapy. Although such technologies are more precise than three-dimensional conformal radiotherapy, and appear to increase survival rates through better tumour coverage and sparing of adjacent healthy tissue, the high doses of radiation delivered by these techniques may lead to long-term adverse effects — primarily second cancers — as a consequence of the significantly larger out-of-field doses [1–5]. These out-of-field doses are commonly attributable to scattered radiation from the accelerator head, treatment room (the floor, walls, ceiling), the patient's own body, and/or leakage through the collimator [6]. Lonski et al. suggested that the leakage around the gantry could vary from one linear accelerator type to another even for the same manufacturer, with the two main sources of leakage coming from the electron beam guide and the head of the linear accelerator [7]. Bezin et al. also suggested that the main contributor to the leakage is the electron beam guide, with the maximum dose under the collimator's jaws [8].

The primary concern with out-of-field radiation is that even relatively low doses outside the target have the potential to induce second cancers (stochastic effects) [9,10], and may also cause other problems such as cataracts or heart and lung dysfunction (deterministic effects) [11]. At present, sophisticated calculation algorithms are used to estimate out-of-field doses. However, these calculations are only estimates, and consequently may not represent the true out-of-field dose, particularly as the distance from the beam path increases. Commercially available treatment planning systems do not calculate correct doses more than a few centimetres (3 to 5 cm) outside the treatment fields [12,13]. As a result, the extent of the out-of-field radiation is not known with any real degree of precision. In large part, this lack of data on out-of-field radiation is a function of the numerous difficulties involved in directly measuring such doses. The primary impediment to measuring this type of radiation is the inherent complexity of the radiation components and the fact that the energy type in areas distant from the central beam axis is largely unknown. To overcome these challenges, precise and reliable measuring methods are needed but the detectors most commonly used in clinical dosimetry are not adequate for these purposes. However, thermoluminescent detectors, semiconductors, and radiochromic films are all potentially suitable for such measurements, particularly when used in combination with Monte Carlo simulations (Skrobała et al., submitted for publication). Out-of-field doses are especially relevant when high energy photons (over 10 MV) are used due to the significant neutron component and the strong radiobiological response of healthy tissues. Although a few studies have evaluated this problem for 15 MV and 18 MV photons [2,4], data for 20 MV photons are lacking.

Approximately 50% of all patients with cancer will undergo treatment with advanced radiotherapy techniques, and this percentage is expected to grow in future years. For this reason, there is a justifiable concern about the lack of information regarding accurate measurements of out-of-field radiation. To investigate this question, we carried out the present study in which we determined out-of-field dose distributions for 6 MV and 20 MV photons at open beam. Measurements were performed with both thermoluminescent detectors and radiochromic films to assess the contributions of both photons and neutrons.

## 2. Methods

### 2.1. Study concept

The study presented here is the first of three interrelated articles that together form a three-part study, which primary aims were to determine:

- the out-of-field radiation doses at varying distances from the primary beam (Part I);
- the properties of the scattered radiation responsible for these out-of-field doses (Part II; submitted for publication);
- and the impact of these doses on biological response of in vitro cells (Part III) [14].

Each segment of this three-part study contains an experiment that uses a specific technology (dosimetry, calculation algorithms, or cell studies, respectively). The current paper describes a study conducted to measure out-of-field doses.

We developed a purpose-designed water phantom (40 cm × 35 cm × 90 cm) to measure out-of-field radiation. The phantom consists of seven dual-purpose inserts that can be used to measure doses and to assess radiobiological effects at the same measuring points (Fig. 1). At each of these points, the inserts contain symmetrically-spaced holes (Fig. 2) to allow insertion of two thermoluminescent detectors in each hole. Thus, a single measurement could use up to 28 thermoluminescent detectors. The inserts are also designed for use with radiochromic films. Finally, flasks containing cells can also be inserted into these same points and irradiated under the same conditions. Radiation doses were measured at seven separate points (P1 to P7) in the phantom with thermoluminescent detectors (TLD 100, 600, and 700) and GAFchromic$^{TM}$ EBT films.