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Theoretical Models for Retrospective Dosimetry

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INTRODUCTION

Epidemiological studies of medical cohorts represent an important source of information for the radiation protection regulations, because of the accuracy of exposure data, as compared to those of the atomic bomb survivors. However the dosimetry for epidemiological studies is characterised by, poor availability and wide range of geometrical data for the patient, large diversity of anatomic sites of interest, and variable treatment units were used during different periods and in different treatment centres. In addition to the diversity of treatment modalities and protocols, depending on the available techniques, some information are missing in the old records, e.g. the verification or simulation X-ray films, blocking size and thickness, etc. Therefore, we have developed specific tools able to deal with this set of constraints and flexible enough to allow their use in such diverse situations.

The objectives of this work is to develop tools for personalised dosimetry in large cohorts of patients surviving after radiotherapy, providing therefore doses evaluated for all sites of clinical interest. The obtained dosimetric data are then combined with other treatment and clinical data to construct a useful database for epidemiological studies that can derive to improve the risk estimates of radiation-induced cancer at low doses and low dose rates over the lifetime.

MATERIALS AND METHODS

Hardware and software

The basic hardware required is a Pentium with18 MB of RAM and 22 MB available on the hard disc. The Dos_EG software runs under MS-DOS and ICTA software under Windows (Windows 3.1, Windows 95, or NT). Programming of both models is performed in the Pascal language , using Delphi for ICTA.

Basic data

The basic data required for personalised retrospective dosimetry are all patient and treatment data. These information are more or less available in medical files, treatment sheets, drawings, control and simulation X-ray films.

Models for retrospective dosimetry

Specific models for retrospective dosimetry have been developed and improved at the Institut Gustave Roussy(IGR). At present two models are currently being used to perform personalised dosimetry for cohorts of patient surviving after external radiotherapy for a solid cancer (Dos_EG) and radium or beta applicators for skin hemangioma(ICTA). The methodology adopted in both models is devoted to individual dosimetry, via the following steps: simulating the patient and treatment, then estimating doses delivered to a list of points selected for their epidemiological interest.

Dos_EG

This software is adapted to evaluate radiation doses received from external radiotherapy.

Patient simulation

The model generates first, a phantom, mathematically, equivalent to the patient using the sex and height(or age) of the patient and the auxological data(1). These data represent the growth of various parts of the body according to the age and sex over the lifetime (Table1). Any of these information or all could be used, when available, to adjust the generated phantom to fit better the patients geometry. It defines then the 3D coorditaes (x,y,z) of 151 internal points, including 10 lung and 91 bony points. Other points could be added if useful. Figure 1 illustrates the frontal(a), lateral(b), and transverse(c) views of a 4 years old girl, as simulated by Dos_EG, and the defined anatomic points.

Table 1 Auxological parameters and growth ranges (in cm) over the lifetime for the mean French population.

Auxological parameters	**Female (cm)**	**Male (cm)**
Height (feet-top of skull)	49.40 - 163.30	50,00 - 175.20
*Height of chin	37.34 - 143.60	36.93 - 154.57
*Height of sternal manubrium	34.53 - 137.65	34.61 - 144.94
*Height of breast	30.51 - 123.57	31.03 - 131.02
*Height of umbilicus	23.32 - 100.85	23.54 - 107.81
*Height of gonads	20.70 - 90.34	17,00 - 81.30
*Height of knee	10.01 - 43.76	10.52 - 47.60
Diameter of mediastinum	8.10 - 15.97	8.15 - 18.66
Diameter of knee	3.18 - 9.32	3.38 - 9.28
Thickness (post-ant) of skull	10.50 - 17.95	10.90 - 15.15
Width (left-right) of skull	8.90 - 14.40	9.50 - 15.15
Width of bi-acromial	12.60 - 35.50	12.80 - 39.10
Width of bi-illiac	8.00 - 27.20	8.30 - 27.60

*Height start from feet.

Treatment reconstruction

The anatomy generated by Dos_EG is articulated, allowing for trunk inclination and angulation of the head. This flexibility permit to a better simulation of the patient's exposure. Treatment scenarios are simulated using available technical data, e.g. notes, drawings, X-ray films, etc. All information required for dose calculation are also introduced, i.e, the total dose delivered to the target volume or to the point of maximum build-up, the type of treatment radiation, beam quality, source-skin distance, field size and shape, beam and jaw orientation, compensating wedges and blocks, etc.(figure 1 c).

Dose calculation

Dos_EG calculates doses inside and outside the treatment beam taking into account all principle sources of radiation doses. The parameters influencing the peripheral dose are patient and equipment dependent. Regarding the patients influence, in addition to the previous parameters (patient geometry and position), the lung heterogeneity is considered**.** The equipment dependence including the nature of radiation, energy spectrum, peripheral fluence, and radiation leakage, are all considered. The dos_EG model uses a methodology based on sets of measurements performed around the available units(2,3), and approximations were made for those which are no more available. The scattered radiation from the collimator and accessories, walls and other obstacles, are also considered. For all primary beam qualities, Dos_EG adopts the Percentage Depth Dose(PDD) method, and considers the bremsstrhalung scattering inside high energy electron beams. At this stage, 80 beam qualities from 28 treatment units in 8 French and UK centres are integrated in Dos_EG (Table 2). Other beam qualities and accessories for other scenarios could be integrated.

Table 2 Treatment units and beam qualities integrated in Dos_EG.

Type of treatment units and number of units	Type of radiation	Beam quality	DSP (cm)
Orthovoltage tubes (4)	Orthovoltage range X-rays	(50-400) kVp, 0.2-1mm Cu, 1-5 mmAl	2-50
Cobalt units (14)	Gamma	^{60}Co gamma	60-80
Linacs(7), Van der Graff(1), Betatrons (2)	Megavoltage X-Rays	(1-31)MV	100-200
Linacs (3), Betatrons(2)	Electrons	(4-32) MeV	90-120

The dose calculation algorithm uses the patient and treatment data which are input and saved in a specific database. For every patient the radiation doses are systematically calculated for the 151 points from every treatment beam weighted for its participation in the total dose, then for every course of radiotherapy.

Dos_EG had been validated using several comparison studies with available published data, and with doses measured in Alderson-Rando phantom, and the agreement was rather good(4-6).

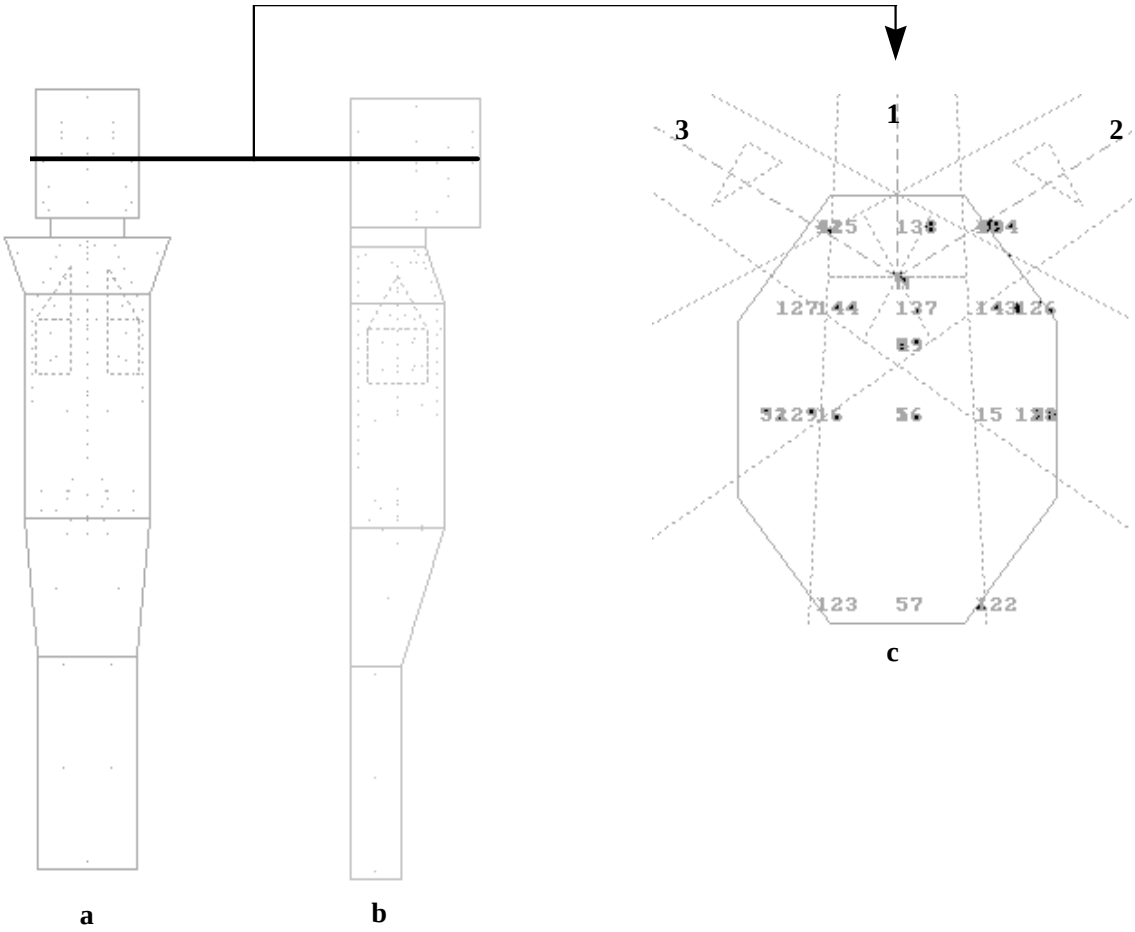

Figure 1 : Frontal(a), lateral(b), and transverse (c) views of a 4 years old girl as simulated by Dos_EG, c show's the treatment ^{60}Co beams: an anterior (1) and two oblics(2,3) with compensating wedges, and digital representation of anatomic points within the central axis plane.

ICTA

The ICTA model is devoted to evaluate doses received from radioactive sources applied on skin lesions and interstitial implant(brachytherapy).

Simulation of patient

The ICTA model simulates the patient using a real human model and the auxological data. The human model has been constructed from a set of real CT slices for a male adult (7). These data include 51 slices of the head and 78 slices of the neck, trunk and the upper part of the lower limbs. We have completed the remaining transverse slices of the lower limbs by modelling the outlines of frontal and lateral images from an anatomy atlas. All together, 137 transverse slices, are combined to produce a 3D representation of the human body (Figure 2). The coordinates of 165 anatomic points(151 of them are similar to those identified in the Dos_EG phantom) are then determined. These images are all stored in the image bank of ICTA, the final total storage capacity of the image files is about 8 MB. The phantom is adjusted to the patient dimensions, when the target-source distance is calculated for dose evaluation. This procedure starts by linking data in the image bank and the basic auxological tables, using the pixel-cm transfer. The 12 parameters listed in Table 1 could be used, if available, to fit better the patients geometry. The relative position and volume of each organ are considered to vary linearly with growth of the part of the body in which they are located(8).

Treatment simulation

Treatment simulation starts by positioning the applicator on the frontal and lateral images respectively, then adjusted on the transverse slice. The outline shape of ICTA phantom permit a better adaptation to the morphology of the actual patient, allowing, therefore a better treatment simulation. The applicators are the radioactive sources used for skin hemangioma treatment, e.g. Ra-226 flat sheets, needles, tubes, P-32 flat

applicators, S-90/Y-90 discs, and Y-90 needles. Their characteristics (activity, geometry, filtration, etc.) were collected from technical documents and literature and stored in a database, available for the treatment simulation and dose calculation (Table 3). The duration of application of the radium source, which is needed for dose calculation, is input according to the treatment records. The relative co-ordinates in pixel and the specification of each source and the 165 anatomic points are saved in the treatment database.

Table 3 Characteristics of the radioactive sources and irradiation considered by ICTA.

Source	Applicator form	Filter	Irradiation	Energy mean (max)
Ra-226	Needles, Tubes, Sheets	0.5-1.5 mm Pt	γ	0.8 MV (2.45)
Sr-90/Y-90	Discs	0.1 mm Ag	β	0.2 MeV (0.546)
P-32	Sheets		β	0.8 MeV (1.71)
Y-90	Needles	0.1 mm stainless steel	β	0.9 MeV(2.28)

Dose calculation

At this stage, the ICTA model is adapted to calculate the γ dose from radium applicators and β doses from the pure β emitter sources, and the integration of γ dose from ^{192}Ir sources is in progress. Its design allows integrating all necessary data and calculation models for internal dose estimation with nuclear medicine sources.

Calculation of γ dose from radium sources

The model adopts the well known quantization method and the required dosimetric parameters are :

Characteristics of the sources (geometry, filtering material and thickness, and radioactivity or radium quantity), and duration of application which are available in the treatment database.

Attenuation and scattering in the medium are considered using the effective transmission factor φ(r) which we have modelled using several Monte Carlo simulations. Our model is valid for any distance from the source up to 180 cm. It considers the semi-infinite nature (lack of scattered radiation) for the superficial points, and this correction is important for skin surface applications and superficial target points

The distance target-source is calculated after individualization of the phantom. The lung tissue and air portions, on the photon path length, are separately estimated, accordingly density corrections are made for dose evaluation(9).

The dose calculation algorithm do not consider the β participation in doses from radium sources, because the most commonly used radium plaques, needles and tube containers with their support materials insured beta filtration.

Calculation of doses from pure β sources

The β particles emitted by the sources used for skin hemangioma treatment are stopped in the immediate vicinity of the applicator. The dose calculation algorithm uses the simple exponential apparent attenuation of dose in the skin layers. Among the published dosimetric parameters we have selected those which permit to fit the exponential attenuation curve to available experimental data. Doses are calculated at different depths of the skin(2, 5,7,10 mm) and for all anatomic points located within 1 cm from the β applicator. Beyond this distance the β dose falls to a negligible level and the bremsstrhalung participation for such treatment conditions is negligible.

The dose calculation can be made for all or selected patients defined in a specific file, and for selected target points or all the 165 points.

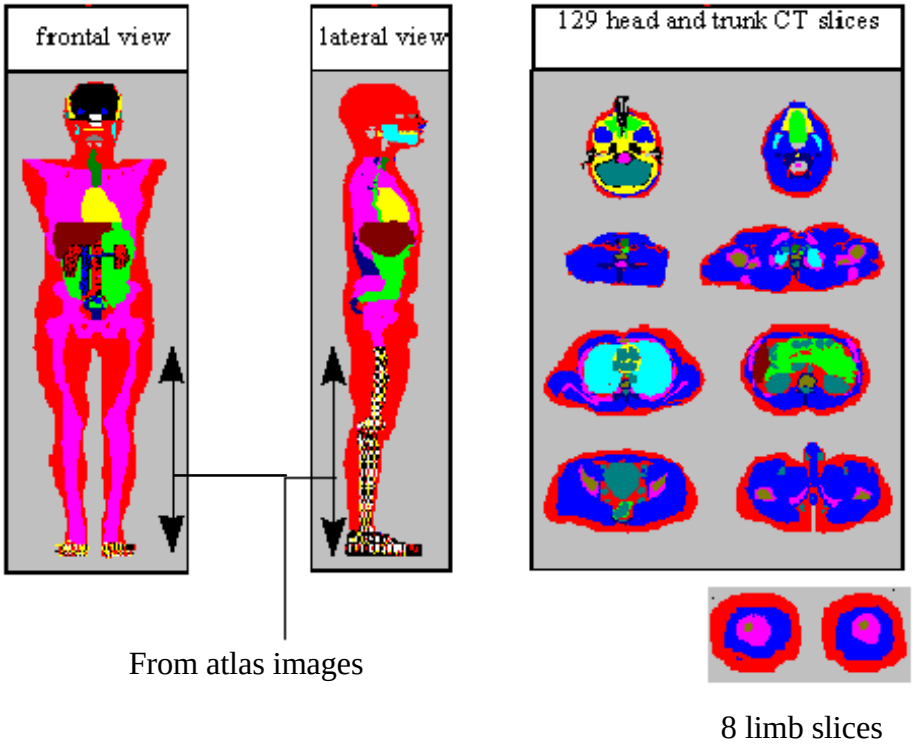

Figure 2 Frontal, lateral and selected transverse views of ICTA phantom representing a standard male adult.

CONCLUSIONS

Both models are adapted for personalised dosimetry in large epidemiological studies, and are easily handled. They both allow for further improvement and extends**.**

The out-off both models data include, dose values and the date of starting of each treatment course, permitting, thus, to select the radiation doses received before the diagnostic of the late effect(a new tumour) as a correlated dose to that effect. The dosimetric data provided by Dos_EG model had been used in radio-induced risk studies, mainly the temporal relationships between the local dose and the risk of solid cancers and leukemia after radiotherapy in childhood(10-14). The risk study of cancer incidence and mortality following radium therapy for a skin hemangioma in childhood, is being started using the dosimetric data provided by ICTA model.

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