OPTIMUM X-RAY ENERGY IN DIAGNOSTIC RADIOLOGY: MONTE CARLO SIMULATION STUDIES

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INTRODUCTION

Diagnostic X-ray examinations are the principal source of population exposure to ionizing radiation. ICRP recommends the limits in dose equivalent that are based on the risk estimates for each organ and tissue. For this reason a realistic knowledge of dose values to the organs involved in X-ray examinations and more efficient methods for dose reduction and image optimization are necessaqry. In this work a new methodology is proposed to correlate organ dose with irradiation photon energy and image quality. To recognize the influence of inhomogeneities on energy deposition in the body due to low energy photon exposure the new sex specific heterogeneous mathematical phantoms, GSF Adam and Eva,(1) have been used. A Monte Carlo method has been applied to the mathematical models to calculate organ doses and to evaluate the quantity of photons impinging on radiographic plane in diagnostic radiology under conditions of partial body irradiation. The technical parameters for a typical radiographic technique have been reproduced. External irradiation with monochromatic photon energies have been considered in the range 20-100 keV. Organ dose values have been normalised to the number of photons transmitted without interactions on radiographic plane. The doses so obtained against photon energy have been considered as ones necessary to produce the same useful diagnostic information. Moreover the ratio between the number od scattered and transmitted photons on radiographic plane have been calculated. Finally a discussion on the optimum photon energy for every organ has been carried out comparing these data.

MATHEMATICAL EXPOSURE MODEL FOR PHOTONS

Mathematical heterogeneous phantoms have been applied to calculate organ doses in diagnostic radiology under conditions of partial body irradiation. They are very similar (2) to GSF Adam and Eva and comprise 24 internal organs each of which is characterized by quadratic equations as shown in figure 1. This mathematical exposure model combines a Monte Carlo technique to the anthropomorphic heterogeneous phantoms. The physical processes treated are limited to the photoelectric and Compton effect since X-ray photon energies in diagnostic radiology range are generally less than 150 keV. Photon history are determined using linear attenuation coefficients, for each organ and tissue, calculated applying White and Fitzegerald (3) polynomial coefficients. The geometrical condition of a radiographic examination can be reproduced in particular the field size in the plane of image receptor, the focus to skin distance and the direction of incident photons. The radiation beam is considered uniformely distribuited and the source as point source. It is possible to use any radiation quality. The principal restriction associated with this exposure model is the rigidity of the phantoms that cannot consider special position used during X-ray examinations.

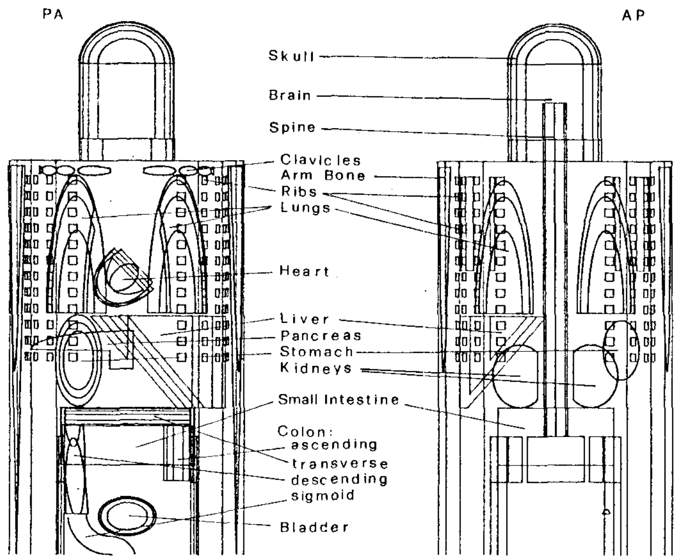

Fig.1 Two dimensional plot for defined vertical planes through the male phantom.

MONTE CARLO METHOD

The Monte Carlo method was applied to follow the transport of each photon through the phantom determining scattering angle, absorption site and to record the resulting energy depositions at the site of physical interaction. The Monte Carlo program used in this study is based on similar principles of ORNL code. The potential side of an interaction is chosen by the usual procedure of taking the distance traversed as:

$$d = (-\ln R)/\mu_0 \qquad (1)$$

in which R is a random number (0-1) and μ_0 is the attenuation coefficient of skeletal tissue. Determined the region of interaction one then plays a game of change with probability μ_i/u_0 where μ_i is the total attenuation coefficient of region i. An internal cavity is regarded as an organ with zero cross section. A new energy and direction are chosen on the basis of Klein-Nishina differential cross section formula. In particular Compton polar angle is chosen with Kahn algorithm and azimuthal angle with Neumann algorithm. Absorption due to photoelectric interaction is simulated by reduction of the statistical weight that is expressed by:

$$W_n = W_{n-1} (1 - \mu_\tau / \mu) \qquad (2)$$

where μ_τ and μ are the attenuation coefficients respectively for photoelectric and total process before the nth collision. The total flight history of a photon is termined if it is escaped from the phantom or if its energy falls below 1 keV or if its weight falls below 10-4 (in our calculations). In the latter two cases the energy was considered as locally absorbed. The energy deposition for the nth interaction E_n is:

$$E_n = W_{n-1} \left[\frac{\mu_\tau (E_{n-1})}{\mu (E_{n-1})} E_{n-1} + \frac{\mu_c (E_{n-1})}{\mu (E_{n-1})} (E_{n-1} - E_n) \right]$$

RESULTS AND DISCUSSION

Using the mathematical phantoms and the exposure model described above the geometrical conditions of external irradiation as in a diagnostic X-ray examination were accurately reproduced in the simulation. Furthermore the photons that passing through the phantom with or without interactions and impinge on radiographic plane were also recorded. To analyze the influence on organ doses of photon energy incident on the phantom, a simulation with monochromatic energies was carried out for a lungs PA examination. For each monochromatic energy the organ doses were normalised to the number of photons transmitted on radiographic plane without interactions with the phantom. This procedure allows to analyze the organ doses under equal conditions of radiological informations of the image. In this analysis image differences due to the contrast and energy response of image detector system were neglected for simplicity. Figures 2 and 3 show the results of this analysis. The organ dose values are compared with the curve A that represents the ratio between the number of scattered photons and transmitted without interaction on radiographic plane in function of photon energy. The doses to the lungs, the spine and the spleen have a maximum between 25-40 keV, that probably represents the optimum photon energy, then the doses decrease with photon energy. For the lungs and the spleen, down to 60 keV, the dose is independent on photon energy. For the other organs analyzed the doses increase with the photon energy, in particular for the heart where the dose increases as the scattered radiation on radiographic plane. These preliminary results are interesting because they shown that the variation of organ doses with photon energy can be foreseen with difficulty. In particular the decreasing of the dose with the increasing of photon energy is not absolutely true.

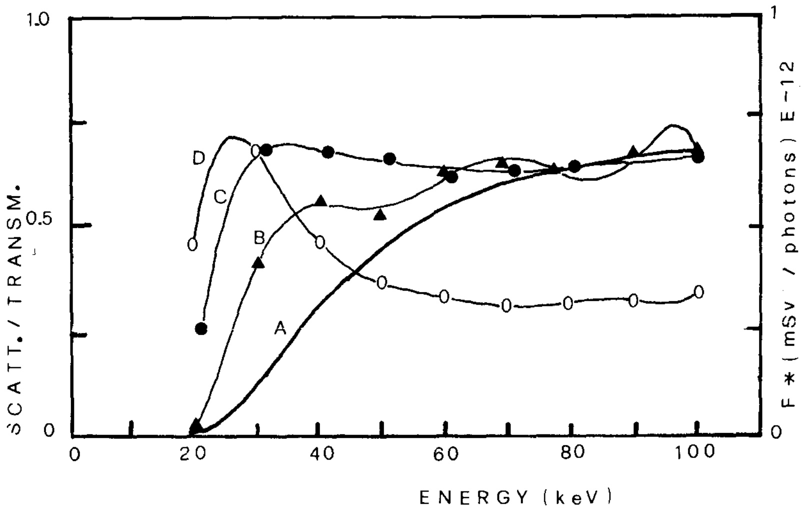

Fig.2 Lungs PA projection. Organ doses vs incident photon energy. Lungs (curve D);liver (curve C); pancreas (curve B); ratio between scattered and transmitted photons (curve A). F is a normalization factor.

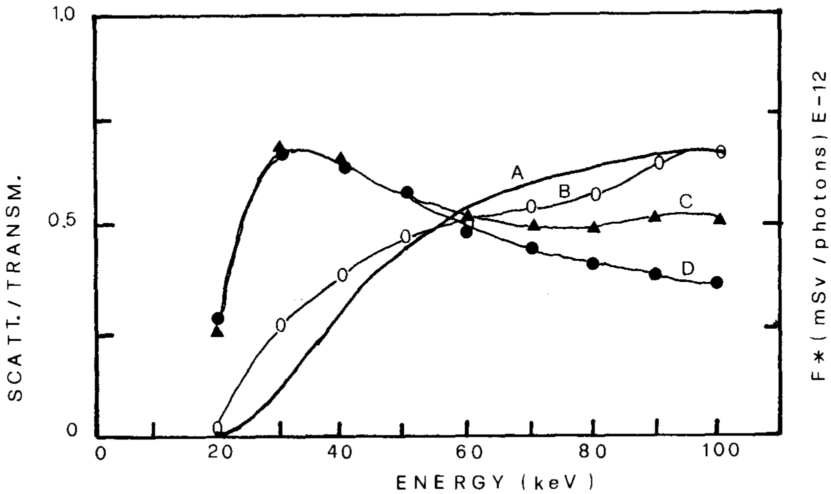

Fig.3 Lungs PA projection. Organ doses vs incident photon energy. Spine (curve D);spleen (curve C); heart (curve B); ratio between scattered and transmitted photons (curve A). F is a normalization factor.

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