Measurement of irradiation doses secondary to bedside radiographs in a medical intensive care unit

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Abstract. The authors prospectively studied the radiation doses to radio-sensitive organs secondary to bedside radiographs in intensive care patients and in a control phantom. Dosimeters were taped on different organs during each bedside X-ray. The mean radiation doses, expressed in 10^{-5} Gy (m-rad), for an "average patient" who was hospitalized 9 days and had 6 chest X-rays were respectively: 292 to the sternal bone marrow; 239 to the thyroid gland; 3 to the testes; 1 to the ovaries; 605 to the eye for 2 maxillary sinus X-rays. No diffused irradiation was measured during a 2-month period in the intensive care unit nor on dosimeters worn by four nurses.

Key words: X-rays – Thermoluminescence – Radioprotection – Intensive care

It has been recommended [8] that critically ill patients undergoing mechanical ventilation have frequent bedside chest radiographs in order to detect changes in cardio-pulmonary anatomy and confirm the position of invasive devices frequently used in such patients. Repeated X-rays are performed, submitting radio-sensitive organs to unknown radiation doses. The radiation doses and risks of various standard diagnostic radiological procedures have been extensively studied [5, 7], but no study has been performed to our knowledge on the secondary irradiation from bedside radiographs in an adult intensive care unit (ICU); studies have been conducted in pediatric ICUs [2, 12, 17]. We therefore decided to perform a prospective study in our medical ICU to evaluate the radiation doses to radiosensitive organs, consequent upon repeated bedside radiographs.

Material and methods

Patients

Forty unselected patients admitted for various illnesses to our ICU were included in the study; they were divided into two groups: Thirty-five patients, 21 men and 14 women, mean age 58 years (22 – 86 years) had chest X-rays only, either to monitor the position of invasive devices such as endotracheal or tracheostomy tubes, central venous and pulmonary arterial catheters and/or to follow cardiopulmonary changes. The mean duration of hospitalization was 9 days, ranging from 1 day in a 22-year-old man admitted for a drug overdose to 28 days for a 52-year-old man with post-operative peritonitis. The 35 patients had 197 chest X-rays, a mean of 6 X-rays per patient (Fig. 1) and an average of 1 X-ray each day and a half. The extremes ranged from 1 X-ray in the patient who stayed 1 day to 21 X-rays in the patient who stayed 28 days.

Five patients, all men, mean age 51 years (19 – 82 years), had both chest and maxillary sinus X-rays, to investigate acute sinusitis. The mean duration of hospitalization was 11 days (9 to 13 days). These pa-
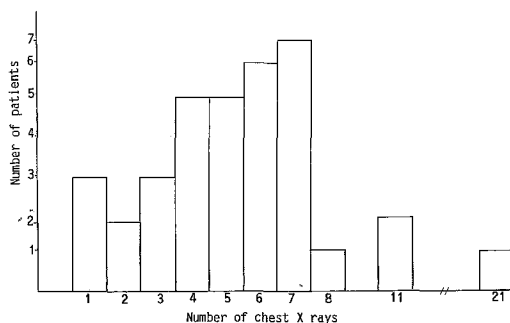

Fig. 1. Number of chest X-rays per patient. Total: 35 patients; 197 X-rays
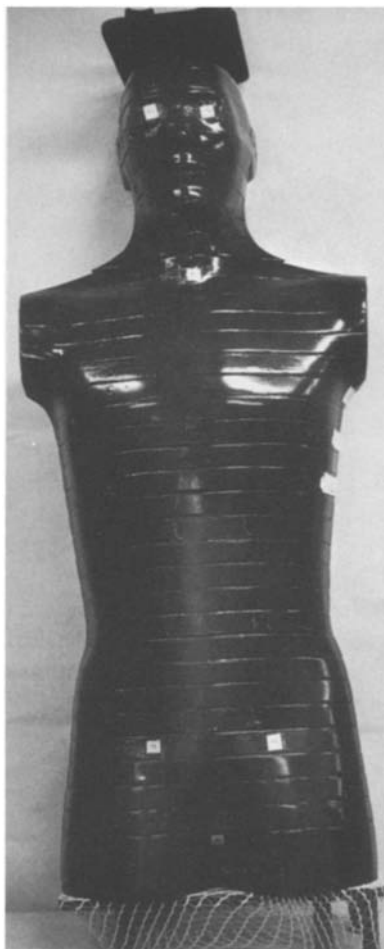
Fig. 2. The control phantom with position of dosimeters during X-rays

tients had a mean of 6 chest X-rays (range 4 to 10) and 2 maxillary sinus X-rays.

Control

An R-T Humanoid Phantom (Humanoid Systems, Humanetics Inc, Carson, California, USA) was used as a control for in vitro measurements (Fig. 2). This phantom is molded about a natural human skeleton, selected to correspond with an external body size of height 5 ft 9 in and weight, 162 lb. It reproduces exact body anatomy, including air spaces and lung density, and is made of tissue-equivalent material (urethane). The phantom had a combination of 6 chest X-rays and 2 maxillary sinus X-rays as this was the mean number of X-rays per patient.

X-ray tube

All bedside radiographs were performed with a portable type Practix apparatus (Philips Medical Systems, Eindhoven, Netherlands), using 36 × 43 cm films with a standard screen. The mean radiological

parameters were 76 kv, 15 mAs, 2 mm Al filter and source to skin distance was 1 m.

A quality control of the X-ray beam showed a 2.4 mm Al half-value layer within a wide beam and a 27 keV mean energy, measured according to published recommendations [15].

Dosimeter disks

During each bedside radiograph, solid-state lithium fluoride thermoluminescent dosimeters (Teledynes Isotopes, D. LIF 7 − 0,4; Physics Systems, Rambouillet, France), were taped on the following parts of the body:

1. during chest X-rays: on the thyroid gland; the xyphoid process (sternal bone marrow); on the gonads: testes in men: ovaries in women (2 cm above the pubis, 5 cm to the left of the median line); in 5 patients, who had 5 to 7 X-rays, on the eyelids.
2. during maxillary sinus X rays (MSR): on the eyelids.

   The dosimeters were taped in the same positions on the phantom for control measurements (Fig. 2) and were calibrated directly within the X-ray beam used for the bedside radiographs, enabling adjustment of the calibration of the disks to the true quality of the X-ray beam itself.

Dosimeters were also taped on the walls of the ICU (12 beds, 300 m²): 2 inside patient's rooms, 2 outside the rooms, 1 in the hallway and 1 in the monitoring control room; they remained for 2 consecutive periods of 1 month. During this same period, 4 nurses wore a dosimeter; the nurses remained in the hallway while X-rays were being taken.

384 X-rays were performed during this 2-month period, including chest-, abdominal-, and maxillary sinus-X-rays in 62 patients, an average of 6 X-rays per patient.

Analysis of dosimeters and dose evaluation

The dosimeters were analyzed on a model 654 RTL Toledo apparatus (Pitman Instr. Weybridge, Surrey, UK) coupled to a type 3021 Yew graphic plotter (Yokogawa Electric Works, Yokogawa, Japan). This analysis was performed when the patient left the ICU; the other dosimeters were analyzed after each 1-month period in order to avoid loss of sensitivity due to prolonged utilization.

The dosimetric calculation was performed according to the principle and standards of thermoluminescence [10]. Under our standard operative procedures, the accuracy of measurement is ± 10% for doses in the range of 10^{-5} Gy (mrad) and ± 2% for doses in the range of 10^{-2} Gy (rad). Two types of

Table 1. Chest X-rays: radiation doses to radio sensitive organs in 35 patients and in the control phantom

		Bone marrow (Xyphoid)	Thryoid gland	Testes ($n = 21$)	Ovaries ($n = 14$)
Patients	Mean dose per patient $n = 35$	292	239	⩽3	1
	(range)	(17 – 1127)	(14 – 1042)	(⩽1 – 7)	⩽1 – 8)
	Mean dose per X-ray $n = 197$	49	40	⩽1	⩽1
	(range)	(13 – 126)	(13 – 82)	(⩽1 – 3)	(⩽1 – 2)
Control Phantom	Total dose for 6 X-rays	294	216	⩽1	⩽1
	Mean dose per X-ray	49	36	⩽1	⩽1

Doses are expressed in 10^{-5} Gy (mrad)

measurements were made: firstly the dose to skin within the X-ray beam itself and secondly we established the relative depth absorbed dose curve in tissue-equivalent material. We then calculated the real dose to each radiosensitive organ according to its mean depth under the skin using the previous results; this real dose to organs is expressed in 10^{-5} Gy (mrad), the standard unit of absorbed radiation dose. Values shown as ⩽1 are not measurable. All values are rounded up to the closest unit.

Results

1. Table 1 shows the radiation doses to radiosensitive organs in the 35 patients who had only chest X-rays and in the control phantom.
2. The radiation doses to the eye are the following: in the 5 patients who had only chest X-rays, the mean dose per patient was $27 \cdot 10^{-5}$ Gy (range 1 to 54) and the mean dose per X-ray was $4.5 \cdot 10^{-5}$ Gy (range ⩽1 to 8); in the 5 patients who had both chest- and maxillary sinus-X rays, the mean dose per patient was $605 \cdot 10^{-5}$ Gy (range 446 to 842); in the control phantom the total dose was $504 \cdot 10^{-5}$ Gy.

An "average patient" can thus be defined: he remained 9 days in the ICU and had 6 chest − and 2 maxillary sinus − X-rays. The mean radiation doses delivered to radiosensitive organs are shown in Table 2.
3. The radiation dose on the dosimeters which were taped on the walls of the ICU and which were worn by four nurses during 2 consecutive months was not measurable in either case.

Discussion

The utilization of a control phantom for in vitro measurements, the calculation of real doses to radiosensitive organs and the study of doses to the eye in case of

maxillary sinus X-rays considerably improved the evaluation of irradiation doses compared to our preliminary results [1]. Doses in patients and in the control phantom are not significantly different.

Our results call for several comments: The wide variation of doses per chest X-ray is most probably due to the conditions under which bedside X-rays are performed. The intrinsic variations due to the output of capacitors of the portable apparatus are unavoidable since they are independant of human control. But the precision of the collimation of the irradiation field, which can be achieved with more rigourous attention, is an important factor in reducing unnecessary irradiation to nearby organs [7]. The irradiation undergone by patients calls for different conclusions according to the organ considered:

1. The radiation dose to the gonads is negligible, certainly because they are not in the irradiation field. Thus no radioprotective measure is necessary, except of course in case of suspected or proven pregnancy.
2. The mean dose to the thyroid gland and to the sternal bone marrow are noteworthy since they represent, delivered over a very short period of time, one and a half time the annual natural irradiation in Brittany, a granitic region with an important natural radioactivity, 150 to $200 \cdot 10^{-5}$ Gy [14]. Is protection therefore justified? The stochastic risks of a radiation induced leukemia or thyroid gland malignancy are respectively $5 \cdot 10^{-4}$ Sv^{-1} and $2 \cdot 10^{-3}$ Sv^{-1} accordingly

Table 2. Mean radiation doses to radiosensitive organs in an "average example patient": 6 chest − 2 and maxillary sinus − X-rays

To the eye	$605 \cdot 10^{-5}$ Gy
To the thyroid gland	$239 \cdot 10^{-5}$ Gy
To the bone marrow (lower part of the sternum)	$292 \cdot 10^{-5}$ Gy
To the gonads	
Testes	$3 \cdot 10^{-5}$ Gy
Ovaries	⩽$1 \cdot 10^{-5}$ Gy

to the IRCP [6]. Also it has been demonstrated that doses as high as $60 \cdot 10^{-2}$ Gy delivered with iodine 131 therapy did not increase the incidence of malignant thyroid disease over a 13 year survey period [3], doses considerably more important than the $1,04 \cdot 10^{-2}$ Gy maximal thyroid dose in our patient who had 21 chest X-rays. Therefore the doses received by our patients are in all cases negligible with regard to possible carcinogenic risk; no special thyroid radioprotective measure is necessary.

3. The mean dose to the eye due to 2 maxillary sinus X-rays must be considered, especially in patients over 50 years old, a usual situation in an ICU. The risk of radiation-induced cataract [9] and retinopathy [16] is well known, especially after radiotherapy of maxillofacial malignancies. Even though the doses received in the ICU are considerably smaller, no one knows their long-term effects. Therefore we suggest putting lead eye glasses on the patients during maxillary sinus X-rays.

The absence of measurable irradiation in the ICU, over a long period, in the patient's rooms as well as in the technical rooms, makes it unnecessary to incorporate specific radioprotective measures in the planning of ICUs. The absence of measurable irradiation on the dosimeters worn by 4 nurses during the same period of time also proves that ICU personnel are not at risk from irradiation, provided they leave the room in which an X-ray is being taken; radiographers must of course wear lead protection.

The average annual whole body dose rate due to medical usage has been estimated to be 73.10^{-5} Sv per year per individual [5]. Acutely ill patients are submitted to higher radiation doses of multiple radiological procedures not only in the ICU. The risk of low level radiation is considered to be very conservative [5, 11], even though it is difficult to determine the long term effect of repeated small doses; moreover there is no linear relationship between small range doses and tissue effects [11]. Therefore the medical radiation-induced risk must not be a subject of unreasoned public fear.

However, reducing medical irradiation must still be an aim. Technical improvements such as special screens or filters [7] and practical measures such as adequate collimation of the irradiation field [7] are important. Our proposal of a leaded eye protection during maxillary sinus X-rays may be of interest in people over 50 years old. However the main effort must be to limit repeated bedside radiographs if they are not essential [4 – 13].

References

1. Boles JM, Manens JP, Boussert F et al. (1984) Radiographies pulmonaires faites au lit en réanimation: évaluation de l'irradiation secondaire. Presse Med 13:1005
2. Boussert F, Manens JP, Dagorn Ch, Combot Y, Bellet M (1985) Etude dosimétrique des radiographies réalisées en réanimation néo-natale chez les nouveau-nés de un à trente jours. J Radiol (Paris) 66:219
3. Holm LE, Lundell G, Walinder G (1980) Incidence of malignant thyroid tumors in humans after exposure to diagnostic doses of iodine 131. II Estimation of thyroid gland size, thyroid radiation dose and predicted versus observed number of malignant thyroid tumors. J Natl Cancer Inst 65:1221
4. Greenbaum DM, Marschall KE (1982) The value of routine daily chest X-rays in intubated patients in the medical intensive care unit. Crit Care Med 10:29
5. Gregg EC (1977) Radiation risks with diagnosis X-rays. Radiology 123:447
6. ICRP publication 26 (1977) Recommandations of the International Commission on Radiological Protection. Ann ICRP 1:3
7. Laval-Jeantet M (1982) La situation actuelle de l'irradiation de la population dûe à la pratique du radiodiagnostic médical. Rev Epidemiol Sante Publique 30:183
8. Martz KV, Joiner J, Shepherd RM (1979) Management of the patient-ventilator system. A team approach. CV Mosby, St Louis
9. Merrian GR, Szechter A, Focht EF (1972) The effect of ionizing radiation on the eye. Radiat Ther Oncol 6:346
10. Robertson MEA (1981) Identification and reduction of errors in thermoluminescence dosimetry systems. Pitman Ltd, Weybridge
11. Sinclair WK (1981) Effects of low-level radiation and comparative risk. Radiology 138:1
12. Smith WL, Gresham E, Berg R, Hobson L, Franken EA, Smith JA (1979) A practical method for monitoring diagnostic radiative dosage in the newborn nursery. Radiology 132:189
13. Strain DS, Kinasewitz GT, Vereen LE, George RB (1985) The value of routine daily chest X-rays in the medical intensive care unit. Crit Care Med 13:534
14. Tubiana M (1981) Les risques posés par l'irradiation du malade lors de procédures diagnostiques: mythes et réalités. J Radiol (Paris) 11:609
15. Wachsmann F, Drexler G (1976) Graphs and tables for use in radiology, 2edn. Springer, Berlin Heidelberg New York
16. Wara WM (1979) Radiation retinopathy. Int J Radiat Oncol Biol Phys 5:81
17. Wesenberg RL, Rossi RP, Mendee WR (1977) Radiation exposure in radiographic examination of the newborn. Radiology 122:499

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