Patient doses and risks from diagnostic radiology in North-east Italy

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ABSTRACT

A study has been conducted to asses the impact of radiological practice in 1983 in Friuli-Venezia Giulia, a region of North-east Italy with 1 250 000 inhabitants. The design involved three phases: (i) a regionwide frequency survey; (ii) dosimetric measurements on patients in all public X-ray facilities; (iii) derivation of organ doses from those measurements. Frequencies by type, age and sex and values of the main technical parameters of radiological examinations are presented. Organ doses, effective dose equivalents and risk estimates are given for 14 selected examinations. The annual per-capita effective dose equivalent and the genetically significant dose are estimated at 0.848 mSv and 0.253 mSv, respectively. From these values, collective risks have been predicted by using the risk factors given in the International Commission on Radiological Protection Publication 26. The results indicate that 14 persons risk induced malignancies and 2.5 persons risk genetic detriment.

In 1977 the International Commission on Radiological Protection (ICRP) issued new recommendations on radiation protection (ICRP, 1977) and laid down a system of dose limitation to implement these recommendations, which included three elements: the justification of the practice, the optimisation of radiation protection, and the limits of individual dose equivalent. The application of these concepts to patient protection in medical radiology was then detailed in ICRP Publications 33 and 34 (ICRP, 1982a, 1982b). The present work is concerned with the first two elements of the system of dose limitation. It aims to provide a sufficiently accurate database to evaluate both the individual and collective impact of medical radiological practice in Friuli-Venezia Giulia (FVG), a region of North-east Italy with 1 250 000 inhabitants. Furthermore, these data may provide information to justify particular practices, to assess the health detriment to the population due to medical radiation, and to identify both the types of examinations where dose reduction is reasonably achievable and the methods to accomplish it without impairment of diagnostic value. At present, no exhaustive information is available on the current level of diagnostic exposure in Italy. Only a tentative estimate of the genetically significant dose was made in 1974 (Benassai et al, 1977) on the basis of film consumption and doses recorded in the literature.

This is the first estimate of frequencies, individual and collective doses and associated risks of radio-graphic examinations in Italy. The results can be properly compared with those of the National Radiological Protection Board (NRPB) in Great Britain and the Centre d'Etude sur l'Evaluation de la Protection dans le Domaine Nucleaire (CEPN) in France, since common dosimetric methods were adopted.

In this work the frequencies, the age and sex distributions, and the main technical parameters of radiological examinations have been determined by a statistical survey in all the X-ray departments and offices of the region. Entrance skin doses, as well as doses to superficial organs of interest, were measured directly with thermoluminescent dosemeters (TLDs) in a sample of patients undergoing 14 selected examinations. Entrance doses were converted to organ doses using Monte Carlo conversion factors calculated at the NRPB (Jones & Wall, 1985). The effective dose equivalent was calculated for each of the selected examinations. The frequency and organ-dose data were combined to derive two indices of the collective detriment due to diagnostic radiology, the genetically significant dose (United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 1972) and the per-capita effective dose equivalent (ICRP, 1977). Finally, risk estimates have been made using the nominal risk factors recommended in the ICRP Publication 26 (ICRP, 1977).

METHODS

The assessment of the radiation exposure due to diagnostic radiology in FVG involved three phases: statistical data collection, dosimetric measurements and estimation of organ and collective doses.

In the first phase, a regionwide survey was carried out during 2 weeks in 1983 to collect information on frequency and types of examinations, and on the sex and age of those exposed. Questionnaires were sent to all the facilities to record details on every examination, including patient sex, age, weight, height, number and size of radiographs, and use of fluoroscopy and gonadal shielding. The reply rate was about 100%, with the exception of the private dental offices, whose reply rate was about 11%.

Detailed data concerning 35 800 examinations were collected. The annual number of each type of

R. Padovani, G. Contento, M. Fabretto, M. R. Malisan, V. Barbina and G. Gozzi

examination was estimated by correcting the number per week obtained from the survey with a factor accounting for seasonal variations in the examination rate. The correction factor was estimated from a sample of radiology workloads reported in the 1983 annual returns to the regional health service.

The collected data were entered into a computer and checked on input. Checks were carried out for plausible patient age and sex for the examination, plausible patient size with regard to age and sex, and for consistent values of technical parameters for the examination.

The subsequent analysis allowed the estimation of the relative frequency of each examination, the age and sex distribution, the mean number of radiographs, film area and fluoroscopy screening time, and the percentage use of gonad shields.

The survey frequency data combined with the values in the literature for examination doses identified which examinations contributed most to the collective doses of the population. These were then the object of the measurements in the second phase. Fourteen examinations were selected, which contributed 95% of the genetically significant dose (GSD) and 86% of the per-capita effective dose equivalent (EDE).

The minimum size of the sample of measurements necessary to achieve a given level of confidence for the collective doses was determined a priori on the basis of frequencies of, and expected doses from, the 14 examinations (Fabretto, 1984).

Measurements were performed at all the X-ray facilities of the region's public health service, which account for more than 80% of the total radiological workload in FVG, and concerned 1620 randomly selected patients. Before measurements were started on a particular piece of equipment, the correspondence between the control setting and the effective potential difference of the tube was checked using a step-wedge penetrameter. The total filtration was then determined from measurement of the first half value layer (HVL) at 60 kVp.

For practical purposes, examinations were divided into two categories, "simple" and "complex", according to the technique used. For "simple" examinations (head, chest radiography and photofluorography, shoulder, abdomen, pelvis, hip/femur, cervical spine, thoracic spine, lumbosacral spine, full spine, intravenous urography), measurements were made with TLDs (LiF TLD-100, Harshaw, USA) attached to the patient's skin to determine the entrance skin dose per radiograph and the doses to the compact organs close to the surface of the body, i.e. thyroid, breast and testes (Fig. 1).

For "complex" examinations (barium meal and barium enema), which involve a considerable amount of fluoroscopy and variations in beam direction and field size, entrance skin dose cannot be conveniently measured with TLDs. The exposure–area product for the complete examination was recorded with a flat, transparent ionisation chamber (Diamentor, PTW, Germany), attached to the tube housing. The Diamentor reading was then used to assess the equivalent total entrance dose for a suitable field (abdominal region for a barium enema and the kidney region for a barium meal). Doses to the patient were also measured with TLDs, as for simple examinations. Two TLDs were attached to the patient's back at breast level for the estimation of lung dose. Four additional TLDs monitored the geometry of irradiation at ovary level (Fig. 2).

The dosimetry system had had preliminary tests: doses down to 0.1 mGy could be measured with a standard deviation (SD) of less than 8%, while at 1 mGy the SD was between 3% and 4% of the mean. The minimum detectable dose was about 0.02 mGy. Dosemeter response varied by less than 5% over the range of diagnostic X-ray qualities, so no correction was made for energy dependence.

Calibration of the chamber in terms of $R\,cm^2$ was carried out for all X-ray equipment: exposure was measured with a 35 ml ionisation chamber in conjunction with a Farmer electrometer (Nuclear Enterprises, Great Britain) calibrated against a secondary standard.
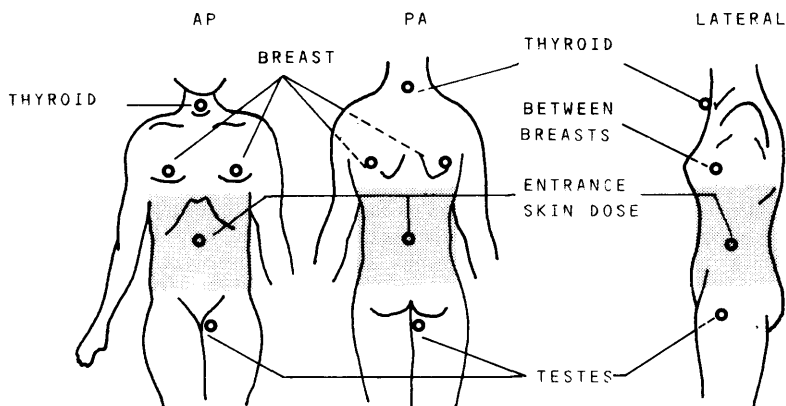

FIG. 1.

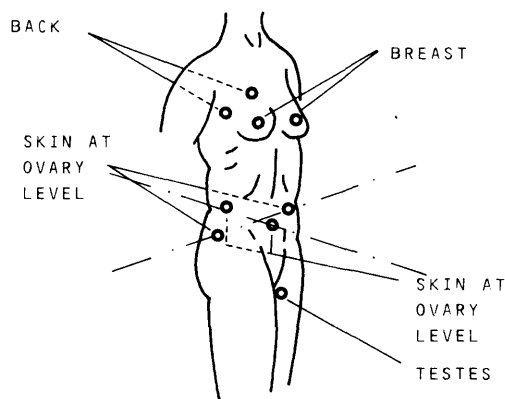Arrangement of TLDs on patients during "simple" examinations.

FIG. 2.

Arrangement of TLDs on patients during "complex" examinations.

An estimate of the beam area in the plane of the ionisation chamber was determined from the film exposure.

In the third phase, organ doses were derived from entrance doses for every examination of the sample. Thyroid and testes doses were estimated directly from TLD responses, while breast TLD measurements were converted to mean breast dose using factors to account for attenuation in the breast and the different composition of breast and muscle. Attenuation correction factors were 0.7 for the antero-posterior (AP) projections, 1.9 for the postero-anterior (PA) projections and 1.4 for the lateral (LAT) projections. Breast tissue composition was assumed to be a 50:50 mixture of water and fat, resulting in a further correction factor of 0.7. For complex examinations, lung dose was derived by taking the average response of the four TLDs at breast level.

Doses for other organs were derived from TLD measurements of entrance skin dose or from the exposure–area product for each examination of the sample, using the Monte Carlo conversion factors calculated at the NRPB (Jones & Wall, 1985). These factors relate the doses to 20 organs of an anthropomorphic phantom to the entrance skin dose for a set of 22 exposures covering the range of conditions found in the selected diagnostic procedures. The actual conversion factor for each exposure of the sample was derived by interpolating the NRPB conversion factors according to the corrected value of the voltage and the measured total filtration of the tube.

For complex examinations, a weighted combination of AP and PA Monte Carlo conversion factors was used, with weightings given by front and back TLD readings, respectively.

Doses to an individual patient were calculated for the organs recommended in ICRP 26 (lung, ovaries, bone, red bone marrow) and for the "remainder", which includes the five organs or tissues receiving the highest

doses during an examination. Examinations on children (under 15 years) could not be treated separately, but they represented only 8% of all examinations.

Estimates of organ doses for the other examination types were derived from the literature (Flatby et al, 1974; US Department of Health, Education and Welfare (DHEW), 1976; Wall et al, 1979, 1980; Hashizume et al, 1981; Beentjes & Glas, 1984; Drexler et al, 1984; Jankowski, 1984).

How representative the sample measurements are is shown by a comparison of the mean number of radiographs taken per examination in both the frequency survey and the measurement sample. Assuming that the mean dose is proportional to the mean number of radiographs per examination, a better estimate of the "true" mean doses can be obtained by correcting the sample mean doses with the ratio (number of films per examination of the statistical survey)/(corresponding value of the sample). The value of this ratio was close to unity for most examinations, the major exceptions being the abdominal and full spine examinations, found to have correction factors of about 1.4.

The estimation of the annual GSD to a population requires information on the age and sex distribution of the population, together with data on the child expectancy of the exposed individuals. Estimates of these data for the population of FVG were made from the regional health service's database. The population was divided into groups according to age and sex, and the mean mortality rate and the maternity/paternity rate were derived for every group (Padovani et al, 1985). The child expectancy for the population of FVG in 1983 was then calculated on the assumption that the mortality and fertility rates will not change significantly in the future. Moreover, the child expectancy of an exposed individual was taken to be equal to that of an average individual of the same age and sex. Results are given in Table I.

TABLE I

CHILD EXPECTANCY BY AGE AND SEX FOR THE POPULATION OF FVG IN 1983

Age band (years)	Male	Female
0	1.00	1.12
1–4	1.01	1.12
5–9	1.01	1.13
10–14	1.01	1.13
15–19	1.01	1.10
20–24	0.97	0.93
25–29	0.76	0.60
30–34	0.47	0.30
35–39	0.23	0.12
40–44	0.09	0.03
45–49	0.03	0.01
50–54	0.01	0.00
>55	0.00	0.00

R. Padovani, G. Contento, M. Fabretto, M. R. Malisan, V. Barbina and G. Gozzi

TABLE II

NUMBER OF DIAGNOSTIC RADIOLOGICAL EXAMINATIONS IN FVG IN 1983

	No. (thousands) of non-dental X-ray examinations (SE)	No. (thousands) of dental X-ray examinations (SE)	No. (thousands) of all X-ray examinations (SE)
Male	477 (13)	63 (46)	540 (48)
Female	451 (13)	85 (46)	536 (48)
Totals	928 (18)	148 (65)	1076 (67)

SE = standard error.

RESULTS

Frequency survey

The total number of examinations is shown in Table II. The annual rate, inclusive of dental examinations, was 864 examinations per 1000 population. This rate is comparable with about 1000 examinations per 1000 population in developed countries (UNSCEAR, 1982). Males underwent a slightly greater number of examinations (887 per 1000) than females (807 per 1000).

The frequency distribution of examinations by age and sex is shown in Fig. 3 as the number of examinations per 1000 population in a given age–sex group. It indicates that the probability of undergoing an X-ray examination increases gradually with age. The lowest frequency is observed in children under 2 years, for whom it is one-third of the mean value for the entire population, while in the male group aged 60 years or more, it reaches the maximum, with a value 1.5 times higher than the average. People older than 50 years, who are 36% of the FVG population, underwent 45% of all the examinations.

The age distribution of the examined population varies markedly with the examination type: the number of head examinations hardly varies with age; heart and femur examinations are performed frequently for older individuals; full spine and extremity examinations have a peak frequency in teenagers, while abdomen, pelvis and urographic examinations are relatively frequently performed on neonates.

The relative frequencies of various types of examinations are reported in Table III. Chest examinations account for 37% of all examinations; dental and extremity examinations each account for 14% of the total. Computed tomography accounts for 1.5% of all
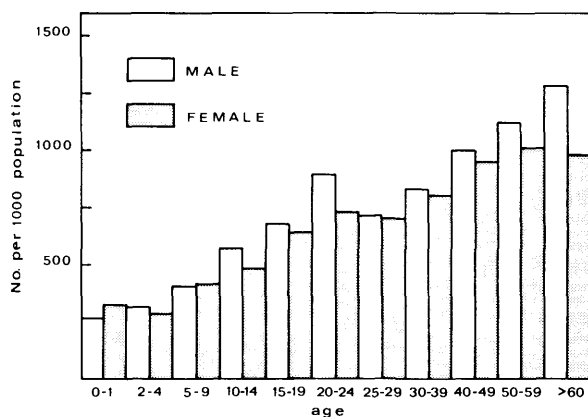

FIG. 3.

Frequency of X-ray examinations performed in FVG in 1983 as a function of age and sex. Each value represents the annual number of examinations per 1000 population in a given age–sex group.

TABLE III

DISTRIBUTION BY TYPE OF DIAGNOSTIC RADIOLOGICAL EXAMINATIONS IN FVG IN 1983

Type of examination	Male (%)	Female (%)	Male and female (%)
Head	4.66	5.07	4.86
Dental radiography	11.63	15.86	13.74
Chest, heart	30.34	25.53	28.12
Chest photofluorography	10.57	8.07	9.33
Mammography	0.00	1.50	0.75
Abdomen	2.54	2.44	2.49
Barium meal	2.71	2.88	2.78
Barium enema	1.06	1.28	1.17
Cholecystography	0.77	1.42	1.10
Cholangiography	0.29	0.47	0.34
Intravenous urography	1.77	1.21	1.49
Pelvis	2.12	3.51	2.81
Full spine	0.96	1.58	1.27
Cervical spine	2.44	3.70	3.07
Thoracic spine	1.29	1.71	1.50
Lumbosacral spine	3.77	4.73	4.25
Shoulder, clavicle	2.27	2.14	2.20
Upper extremities	6.86	4.44	5.66
Hip, femur	1.60	2.13	1.87
Lower extremities	8.69	7.54	8.12
Head CT	0.92	0.88	0.90
Body CT	0.66	0.56	0.62
Angiography	0.43	0.21	0.31
Other	0.82	0.84	0.83
Totals	100	100	100

Patient doses and risks from diagnostic radiology in North-east Italy

TABLE IV

MEANS AND MEDIANS OF THE NUMBER OF EXPOSURES AND RADIOGRAPHS PER EXAMINATION

Type of examination	No. of exposures		No. of radiographs	
	Mean	Median	Mean	Median
Head	3.9	3	3.5	3
Dental, orthopantomography	1.0	1	1.0	1
Dental, intraoral	2.2	1	2.2	1
Angiography, head	54.6	24		
Chest, radiography	1.7	1	1.7	1
Chest, photofluorography	1.0	1	1.0	1
Heart	2.3	2	2.3	2
Ribs	3.3	3	3.2	3
Mammography	5.3	6	5.0	5
Cardiac angiography	29.7	21		
Abdomen	2.1	2	2.0	2
Barium meal (swallow)	11.7	9	5.8	5
Barium meal (stomach, duodenum)	15.0	14	8.5	8
Barium meal (follow-through)	19.2	16	10.9	9
Barium enema	10.5	10	9.4	9
Cholecystography	4.4	4	2.9	3
Cholangiography	8.8	9	6.9	7
Intravenous urography	10.2	10	9.8	10
Cystography	9.1	9	7.0	6
Angiography, abdomen	24.0	13	12.6	
Pelvis	1.8	1	1.6	1
Full spine	5.8	6	5.2	5
Cervical spine	2.8	2	2.5	2
Thoracic spine	2.5	2	2.3	2
Lumbosacral spine	3.4	3	3.0	3
Myelography	13.2	10	10.1	8
Operative cholangiography	3.0	2	2.8	2
Shoulder, clavicle	2.2	2	2.1	2
Arm	2.2	2	1.9	2
Elbow	2.3	2	1.8	2
Forearm, wrist and hand	2.3	2	1.6	1
Hip, femur	2.3	2	2.2	2
Knee	3.0	2	2.6	2
Lower leg and foot	2.7	2	2.2	2
Angiography, peripheral	26.7	7		
Others	8.9	7	7.3	5
All	3.1	2	2.6	2

examinations (13 per 1000 population), with about 60% of the total concerning the head. The examinations are almost equally divided between males and females, the major exceptions being mammography and cholecysto-graphy. Examinations concerning the respiratory organs, the gastrointestinal tract (with the exception of barium enema) and the urogenital organs are more frequent in males, while spine, pelvis and hip examinations are more frequent in females.

The mean number of exposures and of radiographs for each type of examination are shown in Table IV. The total mean number of exposures per examination is 3.1, whereas the total mean number of radiographs is 2.6, consistent with other countries' results (Fig. 4).

Angiography involves the greatest number of exposures (55 for angiography of the head). Of the most frequent examinations, a great number of exposures (10–20) are taken during barium meal, urographic and barium enema studies.

Estimates of the percentage of cases where tomo-grams are taken are also made for the various types of examinations: cholangiography and urography are the only examinations that significantly involve tomo-graphic procedures (in 48% and 41% of cases, with a mean number of five and four exposures, respectively), while other examinations make use of tomography in less than 2% of cases.

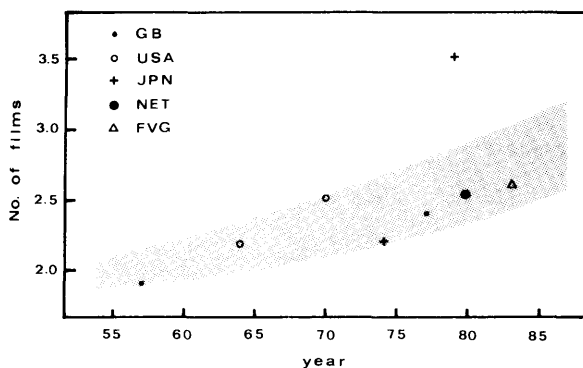About 8% of all examinations involve fluoroscopy.

R. Padovani, G. Contento, M. Fabretto, M. R. Malisan, V. Barbina and G. Gozzi

FIG. 4.

Mean number of radiographs per examination in FVG (△) in 1983 compared with the values assessed in other national studies. Data are drawn from ○ DHEW, 1973 (USA); ● Kendall et al, 1980 (Great Britain); + Hashizume, 1981 (Japan); ● Beentjes & Glas, 1984 (Netherlands).

Most angiographic studies and all cardiac catheterisation, barium meal and barium enema examinations involve fluoroscopy. In almost all of these examinations radiographs are also taken. The mean screening time is 3.5 min.

The use of gonad shields is reported in only 2.1% of examinations. There is a variation in the percentage use with the age of the patient: for children under 10 years, a 10% use is reported for males and 16% for females, while for people of reproductive age it falls to 2.1%. Gonad shields seem to be used properly in few cases: 10% of examinations where the use of a gonad shield is desirable compared with 9% in those where it is less important. The examinations on children most commonly associated with the use of gonad shields are urography, full spine, head, lower extremities and chest.

Dosimetric measurements

Table V shows the results of measurements of entrance skin dose during the commonest radiographic projections of the 12 simple examinations for a random sample of 1367 patients. Table VI shows the Diamentor measurements of total exposure–area product made during the two complex examinations. Mean values of the number of radiographs and applied potential for each examination are also given in the tables. The values of applied potential show a small coefficient of variation, from 8% for chest PA photofluorography to 23% for AP projections of lumbosacral spine examination. Entrance skin doses span very wide ranges, with the extremes covering an overall mean factor of 40 (from 6 for chest photofluorography to 270 for chest PA radiography). They are influenced by several factors, such as body size, examination method, equipment performance and personnel training. Distributions are often very skew, with a few strongly deviating observations which heavily influence the mean

and the standard deviation values, so that the mean only approximately locates the dose distribution.

Mean doses in various body organs for the 14 selected examinations are given in Table VII for each type of examination. In the second column, the ratio of the average exposure numbers assessed in the statistical survey to those in the sample gives the magnitude of the corrections made on the sample doses.

For some organs (thyroid, breast, testes and lungs) Monte Carlo doses derived from skin entrance dose are compared with doses measured with TLDs. It can be seen that the remainder dose is often the highest dose to an organ during an examination. This happens every time there are some of the remaining organs in the useful beam, as in the examinations of abdomen, pelvis and lumbosacral spine, and intravenous urography (IVU) and barium meal and barium enema studies.

The overall highest mean dose per examination to an organ (excluding the remainder) is the dose to the thyroid measured during the examination of the thoracic spine (16.4 mGy), followed by that to the ovaries recorded during barium enema examination (15.3 mGy). The highest doses to the testes, breast, red marrow, lungs and bone are delivered, respectively, by examinations of the pelvis, IVU, and barium enema and barium meal examinations.

The spread of doses between individuals is very large, with coefficients of variation greater than 100%. Dose distributions vary with the examination type and exhibit a positive asymmetry, with the median between 40% and 75% of the mean. Highest positive asymmetries pertain to the distributions of measured doses to the organs situated at the border of the radiation field. For instance, in an abdominal examination, the mean doses to the breast and testes are heavily influenced by a few high doses delivered when the organs are in the useful radiation beam and the medians are, respectively, 23% and 19% of the mean, while entrance skin doses have a median 75% of the mean for females and 86% for males.

The comparison between the doses measured with TLDs and Monte Carlo doses is interesting, as it demonstrates the limitations of the Monte Carlo method in simulating actual irradiation. Coefficients were calculated for a set of radiographic parameters (focus-to-skin distance, projection, field size and position) selected to represent the typical conditions for a given examination, but these parameters vary considerably, so that the method often underestimates the complete range of doses received in practice, as the deviations from the normal distribution of the measured doses indicate.

Table VIII shows the contribution of each examination type to the collective organ dose per 1000 population. Generally, the resultant collective dose to an organ cannot be attributed to one dominating type of examination. For a given organ, we can identify two examinations which contribute together over 50% to the collective dose, namely pelvic examinations and

Patient doses and risks from diagnostic radiology in North-east Italy

TABLE V

MEANS AND STANDARD DEVIATIONS OF ENTRANCE SKIN DOSES MEASURED DURING THE COMMONEST RADIOGRAPHIC PROJECTIONS OF THE "SIMPLE" EXAMINATIONS ON A RANDOM SAMPLE OF 1367 PATIENTS

Examination	No. of observed examinations	No. of radiographs per examination (SD)	Projection	No. of obser- vations	Applied potential (SD) (kV)	Entrance skin dose per radiograph (SD) (mGy)
Head	93	3.08 (1.27)	AP	58	71.4 (8.2)	4.10 (2.90)
			PA	71	73.0 (6.7)	4.62 (2.86)
			LAT	111	64.6 (8.0)	2.62 (1.86)
			OBL	46	76.3 (7.1)	4.61 (3.40)
Chest radiography	454	1.54 (0.62)	AP	83	64.2 (9.0)	1.27 (1.68)
			PA	395	74.4 (16.3)	0.53 (0.74)
			LAT	207	87.8 (14.1)	2.66 (2.80)
Chest photo- fluorography	127	1.00 (0.00)	PA	127	73.2 (6.2)	2.64 (0.91)
Shoulder	61	2.36 (0.86)	AP	113	62.3 (7.6)	1.40 (1.59)
			OBL	25	62.4 (9.1)	2.55 (3.17)
Abdomen	93	1.45 (0.55)	AP	79	75.4 (9.0)	8.09 (4.70)
			PA	24	74.1 (12.9)	6.56 (3.14)
Pelvis	93	1.43 (0.80)	AP	118	67.4 (9.0)	10.6 (12.4)
Hip, femur	46	1.85 (0.76)	AP	66	68.7 (9.4)	3.69 (2.73)
			LAT	19	62.1 (6.0)	4.53 (3.73)
Cervical spine	87	3.07 (1.04)	AP	88	73.8 (10.7)	1.82 (1.89)
			LAT	92	72.2 (10.7)	1.58 (1.31)
			OBL	81	82.3 (17.3)	1.67 (1.18)
Thoracic spine	34	2.24 (1.39)	AP	44	75.0 (17.0)	10.8 (16.7)
			LAT	32	72.5 (8.2)	18.7 (16.8)
Lumbosacral spine	124	3.15 (0.88)	AP	210	77.6 (17.9)	9.53 (8.29)
			LAT	122	85.3 (16.4)	28.3 (24.9)
			LSJ	58	93.3 (17.2)	24.9 (18.9)
Intravenous urography	130	10.13 (3.48)	AP (kidney)	565	71.4 (8.1)	9.15 (6.19)
			AP (abdomen)	430	72.2 (7.4)	6.91 (4.55)
			AP (bladder)	161	76.4 (11.0)	7.16 (6.63)
			PA (kidney)	21	85.1 (10.7)	5.81 (1.68)
			PA (abdomen)	39	70.6 (6.6)	5.53 (2.59)

SD = standard deviation.

IVU for testes; barium enema and lumbosacral spine examinations for ovaries; IVU and chest radiography for breast; barium meal and barium enema for red marrow and total bone; barium meal and chest radiography for lungs; thoracic and cervical spine examinations for thyroid; and barium meal and lumbosacral spine examinations for the remainder.

Mean annual individual doses to the various organs

TABLE VI

MEANS OF THE DIAMENTOR MEASUREMENTS OF TOTAL EXPOSURE–AREA PRODUCT MADE DURING THE "COMPLEX" EXAMINATIONS ON A RANDOM SAMPLE OF 253 PATIENTS

Examination	No. of observed examinations	No. of radiographs per examination (SD)	Screening time (SD) (s)	Applied potential (SD) (kV)	Exposure–area product (SD) (R cm²)
Barium meal	153	13.9 (7.6)	337 (410)	88.8 (18.1)	4377 (3055)
Barium enema	100	9.8 (3.8)	239 (206)	100.1 (18.6)	4765 (3485)

SD = standard deviation.

R. Padovani, G. Contento, M. Fabretto, M. R. Malisan, V. Barbina and G. Gozzi

TABLE VII

MEAN ORGAN DOSES (MGY) BY EXAMINATION TYPE

Examination	Correction factor	Mean dose received (% coefficient of variation) (mGy)											
		Testes		Ovaries	Breast		Bone marrow	Lung		Thyroid		Bone	Remainder
		TLD	MC	MC	TLD	MC	MC	TLD	MC	TLD	MC	MC	MC
Head	1.27		*	*		*	0.17 (89)		0.01 (117)	1.61 (177)	0.30 (116)	0.99 (85)	0.42 (73)
Chest radiography	1.10		*	*	0.29 (112)	0.45 (224)	0.12 (164)		0.45 (156)	0.34 (265)	0.11 (290)	0.25 (161)	0.17 (79)
Chest photofluorography	1.00		*	*	0.14 (7)	0.15 (66)	0.26 (41)		0.91 (39)	0.07 (26)	0.08 (48)	0.59 (38)	0.23 (22)
Shoulder	0.93		*	*	0.40 (168)	0.01 (125)	0.02 (123)		0.06 (123)	1.18 (195)	0.02 (125)	0.07 (127)	0.01 (118)
Abdomen	1.45	2.33 (177)	0.43 (97)	2.33 (87)	0.90 (213)	0.03 (95)	0.64 (83)		0.09 (88)		*	0.82 (76)	3.63 (43)
Pelvis	1.26	8.09 (104)	10.54 (102)	2.38 (100)	0.04 (106)	*	0.34 (103)		*		*	0.63 (101)	3.75 (47)
Hip, femur	1.24	5.68 (113)	1.80 (106)	0.51 (114)	0.02 (77)	*	0.07 (116)		*		*	0.22 (114)	0.59 (58)
Full spine	1.38	2.82 (191)	0.04 (100)	2.27 (88)	3.13 (117)	0.52 (163)	1.24 (74)		2.32 (112)	7.76 (87)	2.73 (142)	2.34 (54)	3.53 (38)
Cervical spine	0.91		*	*		*	0.03 (122)		0.02 (118)	4.00 (98)	1.16 (151)	0.15 (119)	0.02 (94)
Thoracic spine	1.12		*	*	0.68 (133)	0.59 (168)	0.73 (114)		2.63 (106)	16.45 (288)	2.38 (183)	1.79 (115)	0.97 (69)
Lumbosacral spine	1.08	1.71 (262)	0.06 (98)	3.85 (83)	0.47 (300)	0.08 (93)	1.07 (79)		0.34 (92)		*	1.36 (79)	5.03 (39)
Intravenous urography	1.01	7.57 (134)	2.27 (131)	5.05 (90)	8.79 (16)	0.22 (99)	1.44 (77)		0.66 (101)		*	2.34 (77)	12.64 (41)
Barium meal	1.27	0.15 (120)	*	1.51 (96)	1.85 (177)	0.63 (104)	4.81 (57)	9.79 (123)	2.71 (77)	0.73 (114)	*	7.36 (57)	22.61 (52)
Barium enema	1.07	2.26 (152)	2.33 (112)	15.34 (91)	0.50 (267)	0.19 (111)	6.65 (57)	2.39 (173)	0.69 (85)	0.11 (85)	*	7.18 (59)	17.53 (53)

*Represents doses lower than 0.01 mGy. TLD doses to testes and breast have been measured only for males and females, respectively, whereas Monte Carlo (MC) doses have been calculated for every patient, irrespective of sex.

from all the selected types of examinations are given in Table IX. By using the risk factors suggested by the ICRP for these organs, the approximate number of fatal cancers in these organs induced by 1 year's practice of these 14 examinations in the FVG region can be estimated. These risk estimates are very crude, as the risk factors are an average for both sexes and for all ages and probably lead to overestimation of the likely number of effects. With the population standing at 1 246 000, the expected fatal malignancies are estimated to be one cancer in lung, one in breast, and about one case of leukaemia. The high value of the remainder dose would predict 8.6 cases of cancer, but for the purpose of risk estimation, more realistic and specific factors for these organs are required, rather

than the same ICRP factor of 10^{-3} Sv^{-1} for every organ.

The effective dose equivalent and the annual per-capita effective dose equivalent per examination are given in Table X for all types of examination. The annual per-capita effective dose equivalent in 1983 from diagnostic radiology in FVG is 0.848 mSv, of the same order as the annual contribution from natural radiation sources.

These doses may provide an approximate prediction of the likelihood of malignancy induction and genetic detriment by using the nominal total risk factor of 1.65×10^{-2} Sv^{-1} suggested by the ICRP. The collective effective dose equivalent to the FVG population for diagnostic radiology in 1983 is about 1056 man.Sv.

Patient doses and risks from diagnostic radiology in North-east Italy

TABLE VIII

COLLECTIVE ORGAN DOSES PER 1000 POPULATION BY EXAMINATION TYPE FROM THE 14 EXAMINATIONS SELECTED FOR THE DOSIMETRIC MEASUREMENTS

Examination	No. of examinations per 1000	Collective organ dose (man.mGy per 1000 population)							
		Testes	Ovaries	Breast	Bone marrow	Lung	Thyroid	Bone	Remainder
Head	42	< 0.4	< 0.4	< 0.4	7.0	0.3	67.6	41.5	17.6
Chest radio- graphy	222	< 2.2	< 2.2	64.2	26.6	100.5	75.0	56.4	37.7
Chest photo- fluorography	80	< 0.8	< 0.8	11.2	20.8	72.8	5.6	47.2	18.6
Shoulder	19	< 0.2	< 0.2	7.6	0.3	1.2	22.4	1.4	0.1
Abdomen	22	50.1	50.0	19.3	13.7	1.9	< 0.2	17.6	78.0
Pelvis	24	196.6	57.9	1.0	8.2	< 0.2	< 0.2	15.2	91.1
Hip, femur	16	91.0	8.2	0.3	1.2	< 0.2	< 0.2	3.5	9.4
Full spine	11	31.1	25.0	34.4	13.6	25.5	85.4	25.7	38.8
Cervical spine	27	< 0.3	< 0.3	< 0.3	0.9	0.5	106.1	4.0	0.6
Thoracic spine	13	< 0.1	< 0.1	8.8	9.4	33.9	212.1	23.1	12.5
Lumbosacral spine	37	62.9	141.4	17.4	39.4	12.4	< 0.4	49.8	184.5
Intravenous urography	13	97.6	64.9	113.4	18.3	8.4	< 0.1	29.7	163.1
Barium meal	24	3.5	36.4	44.4	115.4	235.0	17.5	176.6	542.9
Barium enema	10	22.8	154.9	5.1	67.2	24.1	1.1	72.5	177.1
Total	559	556	539	327	342	517	593	564	1372

The collective organ doses for the whole population in FVG are 1246 times the doses per 1000 population. Collective doses to gonads and breast do not take into account the sex distribution of the patients undergoing a given examination. The totals do not include the upper dose limits (marked <), which would contribute less than 1% to the collective doses.

Within the limits already expressed, the associated risk is estimated to be about 17 cases of serious late injury. Excluding the genetic detriment, the number of X-ray-induced malignancies is about 14, which is to be compared with an estimated annual incidence of malignant diseases of 4000 cases (3777 deaths from cancer have been registered in FVG in 1978 (Istituto Centrale di Statistica (ISTAT), 1978), corresponding to a rate of 303 deaths per 100 000 population).

TABLE IX

MEAN ANNUAL ORGAN DOSE PER INDIVIDUAL AND CASES OF FATAL INJURY FROM EXPOSURE TO THE 14 SELECTED X-RAY EXAMINATIONS IN FVG IN 1983

Organ	Dose (mGy)	ICRP risk (10^{-4} Sv^{-1})	No. of cases in FVG
Testes	0.56	40	2.7
Ovaries	0.54		
Breast	0.33	25	1.0
Red bone marrow	0.34	20	0.9
Lungs	0.52	20	1.1
Thyroid	0.59	5	0.4
Total bone	0.56	5	0.4
Remainder	1.37	50	8.6

Collective risk estimates indicate that the greatest risk is due to the barium meal examination, with an associated risk of 4.6 cases from 1 year's diagnostic practice. Equal risks (1.9 cases) are carried by lumbosacral spine examinations, IVUs and barium enemas, followed by the examination of the lungs (radiography and photofluorography) and of the pelvis, with 1.2 cases each.

In Table X, the risk estimates per examination performed, calculated by using the ICRP total risk factor, are also given. Barium meal, barium enema and IVU examinations carry the highest risks, with more than 100 cases per million examinations, while examinations of the head, chest, shoulder and cervical spine carry a risk of 2–4 cases per million. Other examinations are associated with a risk of 10–50 cases per million, comparable with the risk of 50 per million associated with the recommended annual dose limit for members of the public in ICRP Publication 26.

Genetically significant doses have been determined separately for males and females, so they are not directly additive (Table X). Examinations of the pelvis, hip and femur, and IVU, in that order, contribute more than 50% to the GSD for males, while for females an analogous contribution is given by lumbosacral spine, barium enema and full spine examinations. The annual GSD to the population is 0.253 mSv compared with a mean gonadal dose of 0.547 mSv. This

R. Padovani, G. Contento, M. Fabretto, M. R. Malisan, V. Barbina and G. Gozzi

TABLE X

GENETICALLY SIGNIFICANT DOSE (GSD), EFFECTIVE DOSE EQUIVALENT (H_E), ANNUAL PER-CAPITA EFFECTIVE DOSE EQUIVALENT (EDE), INDIVIDUAL RISK AND COLLECTIVE RISK PER EXAMINATION BY TYPE OF EXAMINATION

Examination	GSD (μSv)		H_E (μSv)	EDE (μSv)	Risk per examination ($\times 10^{-6}$)	No. of cases in FVG
	Males	Females				
Head	< 0.2	< 0.2	224	9	4	0.2
Chest radio-graphy	< 0.9	< 0.9	181	40	3	0.8
Chest photo-fluorography	< 0.3	< 0.3	250	20	4	0.4
Shoulder	< 0.1	< 0.1	109	2	2	0.0
Abdomen	26	20	1919	41	32	0.8
Pelvis	77	25	2325	56	38	1.2
Hip, femur	50	2	879	14	15	0.3
Full spine	27	28	2878	32	47	0.7
Cervical spine	< 0.1	< 0.1	137	4	2	0.1
Thoracic spine	< 0.1	< 0.1	1343	17	22	0.4
Lumbosacral spine	31	65	2509	92	41	1.9
Intravenous urography	46	28	7074	91	117	1.9
Barium meal	2	14	9266	222	153	4.6
Barium enema	5	30	8968	91	148	1.9
Others	10	18		115		2.4
Total	253			848		17.4
Standard error	17			18		

The ICRP total risk factor of 165×10^{-4} Sv^{-1} has been used. The total GSD does not include the upper dose limits (marked <), which would contribute less than 1%.

value is of the same order as those recently estimated in industrialised countries, ranging from 0.120 mSv for Great Britain (Darby et al, 1980) to 0.420 mSv for Sweden (Bengtsson et al, 1978).

By using the risk factor of genetic injury suggested by the ICRP (10^{-2} Sv^{-1}) for the first two generations and an additional equal risk for all the succeeding generations, the resultant risk at equilibrium is estimated to be 2.5 cases per year. For comparison, it is estimated that, of babies born in FVG per year, about 200 suffer from congenital malformations (Mastroiacovo et al, 1982).

CONCLUSION

This survey has assessed the impact of radiological practice in FVG, through the determination of frequencies, doses and risks of examinations.

The frequency results indicate that medical radiology in FVG compares with that of other developed countries. The distribution of procedures shows that the role of complex examinations, e.g. CT procedures, becomes more and more important, photofluorography in mass chest procedures is increasingly replaced by radiography, and mammography appears to be still a clinical rather than a screening examination.

The spread of individual patient doses is quite large, usually two orders of magnitude or more, suggesting that a relevant dose reduction can be readily achieved with available techniques. Moreover, the main efforts for collective dose reduction should mainly concern a few types of examinations. Further indications for dose reduction may arise from a close comparison with analogous surveys in other countries.

Risk estimates, even with the associated large uncertainties, indicate that, at the moment, neither individual nor collective risks constitute any contra-indication to clinically indicated examinations. Nevertheless, it is felt that radiation protection of the patient is still far from optimal and the introduction of a code of practice for dose limitation in medical exposure (by far the largest component of collective dose from man-made radiation sources) should be considered.

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