Findings of a Survey of X-Ray Units

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A FIELD survey of X-ray units used by all types of practitioners for diagnostic work was made in Oregon during 1958 and 1959 as part of the State's recently developed radiological health program. Results of this survey, along with a summary of the efficacy of steps that can be taken to protect the population from unnecessary exposure, are presented in this paper. Administrative and technical details of the survey have been published (*1,2*).

The survey sample included approximately 25 percent of the facilities used by an estimated 3,000 physicians, dentists, chiropractors, veterinarians, osteopaths, and chiropodists in Oregon. With the assistance of professional biostatisticians, the sample was picked to be representative of the State on a geographic and community-size basis.

Little if any systematic geographic variation was found in protection standards, nor did community size influence the findings in a predictable way. However, we did note that certain medium-size communities where local radiologists had made a special effort to improve protection appeared to be above the average.

The number of physicians of each type contacted and estimates of their caseloads are shown in table 1. In the absence of registration in Oregon, lists of practitioners were compiled from professional society registers and from the classified telephone books. We then picked a series of representative communities and called on every practitioner in the community. During each visit we asked for an estimate of caseload, categorized as adult and pediatric patients, X-rays and fluoroscopy, X-ray pelvimetry studies, and other examinations. The data from hospitals were usually confirmed by examination of the daily workbook, but in many other offices we relied on estimates provided by the practitioner or technician. The average weekly caseloads for some practitioners seem surprisingly small, but at present there does not seem to be any way of verifying the number. In some areas it may be possible to obtain data on total sales of X-ray film.

Because of the comparatively small number of radiologists' offices outside of hospitals, we have included them within the category of "hospitals and radiologists." Hospitals (or oftentimes larger clinics in outlying communities), where the X-ray work was not supervised by a radiologist, are tabulated separately.

Protective Practices

Table 2 offers a statistical summary of protective practices observed.

In regard to "Operator and assistants well protected during fluoroscopy," we found quite reasonable protection. The hospitals and radiologists were uniformly good on this point. In some of the smaller offices with fluoroscopes, gloves or aprons or both were unavailable. We also evaluated leakage around the unit or through the viewing glass and the presence of assisting personnel in connection with this item. Grossly dangerous fluoroscopic units were rarely encountered, such as one that produced 65 r a minute at the tabletop in air and was used without an apron and with cloth (nonleaded) gloves.

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It does not appear that there are many offices today where exposure is grossly in excess of present-day occupational standards, though there are a few where protective action is urgently needed. Film badges should be used much more widely to provide accurate documentation of all potentially exposed individuals and also to serve as a protection for the owner in case of legal action at a later date. We found rather widespread interest in personnel protection, although some older technicians and practitioners still consider it superfluous.

The item "Personnel shielding available" was evaluated with cognizance of stated caseload, giving some consideration to any probable increase in work during the next year or two. In an office using the X-ray unit for only a few limb or chest exposures a week, for example, special added personnel protection devices might not be considered necessary. The low level of exposure under these conditions has been substantiated by experience with film badges as reported in the literature (*3–5*). Thus, the high score attained by certain classes of practitioners may reflect the lack of need for such devices rather than the actual availability of personnel shielding.

The third item "Personnel dosimetry provided" appraised the actual documentation of exposure in offices, even where exposure was suspected to be negligible. From the practical standpoint, this was interpreted to mean that film badges should be used to document personnel exposures, but not necessarily on a continuous basis. Occasionally, in hospitals, pocket ionization chamber dosimetry was encountered and considered acceptable. As is seen from table 2, documentation of exposure is inadequate except in hospitals. Use of dental films for personnel monitoring was considered to fulfill the criteria for this item in some cases, but dental films are not really satisfactory for personnel monitoring.

Patient Exposure

The data on patient exposure were chosen out of a large and complex mass of information. "Satisfactory collimation in routine use" was evaluated with consideration of the types of examinations done in the office, the size of cones, their number, presence of diaphragms or variable aperture collimators plus correct use of equipment. The mere presence of three cones in an office, of course, is not enough to assure "satisfactory coning." They must be used at all times, and they must be exactly the right size. The more convenient variable aperture collimators were found in many hospitals and radiologists' offices and in a few other offices.

Table 1. X-ray users, machines, and estimated weekly caseload, Oregon survey, 1958–59

Item	Hospitals and radiologists' offices	Hospitals and clinics without radiologists	Physicians other than radiologists	Dentists	Osteopaths	Chiropractors	Veterinarians	Total
Total number of potential users [1]	58	10	331	244	60	21	26	750
Portland	40	2	199	144	41	13	16	455
Salem	7	0	97	60	10	6	4	184
Smaller towns [2]	11	8	35	40	9	2	6	111
Total number of machines studied	81	10	107	170	44	7	22	441
Portland	56	2	62	85	32	6	16	259
Salem	14	0	26	52	4	0	3	99
Other towns	11	8	19	33	8	1	3	83
Estimated radiographic examinations per week [3]	4, 400	170	2, 800	7, 500	([4])	[4] 150	--------	15, 000
Estimated fluoroscopic examinations per week [3]	700	30	840	--------	([4])	([4])	--------	1, 600

[1] Represents nearly 25 percent of the estimated total of X-ray units in the State.
[2] Smaller towns included Oregon City, The Dalles, Bend, Burns, Seaside, Woodburn, and others.
[3] The best estimates of actual weekly caseload in the entire State are 50,000–60,000 radiographic examinations per week and 5,000–6,000 fluoroscopic examinations per week.
[4] Inadequate data.

For dentists, the criterion was a field size 2¾ inches or less in diameter at the tip of the pointer. For veterinarians, we thought it desirable to have some coning to limit scatter, but this was not considered critical as to size. For chiropractors, we used the same criteria as were applied to physicians.

The next item appraises filtration for radiographic work. The criteria used, 2.5 mm. total aluminum equivalent filtration for medical units and 1.5 mm. for dental units, are the values required by the NCRP standards and widely advised in the pertinent literature (*6–9*). Some dental units, particularly certain new models, need no added filter because of adequate inherent filtration. Veterinarians' units were subjected to the usual filtration standards so as to decrease scatter and other operator exposure.

Film processing was routinely evaluated. We frequently encountered 2–3½-minute development times, especially in dental offices. Special consideration was given to instances where the developer was normally kept at a higher temperature than 68° F. and where, therefore, full processing might occur in a shorter time. Occasionally 3½-minute development was considered acceptable for offices with small caseloads and where temperatures were actually measured and normally found to be above 68° F.

The kilovoltage used by Oregon practitioners was appraised. It must be stressed that this tabulation does not deal with true high kilovoltage technique, which means exposure in the range of 90 kilovolts and above for all thick parts. We obtained uniform data on the kilovoltage used for a posteroanterior projection of the chest and for a lateral projection of the lumbar spine which serve as two important typical exposures. The kilovoltage was judged "medium" if it was above 70 for the chest film and above 75 for the spine film. These figures were chosen on the basis of experience and consultation with radiologists. We found that many of the older machines are used at lower values. Some of them cannot be operated in the 75–90 kilovoltage range, which we recommend for all thick parts, but much more commonly the kilovoltages in use were simply taken from old exposure charts provided with the unit.

In connection with kilovoltages, it is pertinent to study table 3, which gives exposures associated with an ordinary A-P film of the pelvis.

Dose Rates

For fluoroscopy we used a criterion of less than 10 r per minute for the table-surface dose rate, as set by the NCRP (*9*). Substantially

Table 2. Percentage of X-ray users fulfilling protection criteria, Oregon survey, 1958–59

Protection criteria	Hospitals and radiologists' offices (81 units)	Hospitals and clinics without radiologists (10 units)	Physicians other than radiologists (107 units)	Dentists (170 units)	Osteopaths (44 units)	Chiropractors (7 units)	Veterinarians (22 units)
Operators and assistants well protected during fluoroscopy	97	84	82	--------	--------	66	23
Personnel shielding available	95	50	80	40	68	70	32
Personnel dosimetry provided	93	50	20	43	11	0	68
Satisfactory collimation used routinely	84	25	39	22	32	14	18
Adequate filtration for roentgenography [1]	91	50	38	38	29	0	9
Satisfactory development of films	68	50	56	18	39	57	5
Kilovoltage in medium range	80	50	33	4	18	0	0
Fluoroscopic dose rate below 10 r/min	97	66	62	--------	--------	--------	50
Fluoroscopic filtration equal to 2.5 mm. aluminum	88	50	46	--------	--------	--------	-------

[1] 1.5 mm. aluminum total equivalent, the standard established by the U.S. National Bureau of Standards in Handbook No. 60, was the criterion used for dental machines, and 2.5 mm. total filtration was considered satisfactory for medical radiographic machines.

lower exposures are possible and practical. The dose rate was measured with a condenser roentgen meter. Not many dose rates above 20 r/min. were found, but a fair number fell into the 10–20 r per minute range. On the other hand, satisfactory results were being obtained by many radiologists and some internists at 1–3 r/min. The recorded dose rate depends on the milliamperage used at the time of the measurement, and there is some variation in this parameter in practice. Most hospitals and radiologists had low fluoroscopic dose rates with satisfactory filtration. Units used by physicians other than radiologists were much less satisfactory in this regard.

Fluoroscopic dose rates were sought for veterinarians because of possible exposure to hands during animal examinations.

About a dozen pediatric fluoroscopes were encountered in the survey, most of which were used by several pediatricians practicing together in a clinic. The average dose rate was close to 10 r a minute and shuttering mechanisms were frequently unsatisfactory. Extensive recommendations were made on all these machines (often specially built from old X-ray parts), and in several places they were taken out of use entirely when the pediatricians learned of the exposure hazard. It is believed that a single pediatric fluoroscopy can equal or exceed the 10 r value which is suggested as the limit for the average 30-year gonadal exposure of the population (*10*). We found it exceedingly difficult to obtain satisfactory data on the frequency of pediatric fluoroscopy.

The table does not include data on local shielding, partly because it was found so infrequently. Plain lead strips were available in many hospitals and radiologists' offices, but we have not been able to judge how frequently they are used as gonadal shields. Lead strips or sheets were rarely found in any other types of offices. Because of the limitations of coning, we feel it is most important to recommend careful gonadal shielding for all persons under 40. Gonadal shielding must, in our opinion, be provided as an adjunct to coning for the most critical abdominal and pelvic examinations.

Table 3 shows the effects of a series of modifications on the doses of radiation a patient would receive in an ordinary X-ray of the pelvis (*7*, *8*, *11–13*). It should provide some perspective on the importance of protective recommendations. Added filtration and higher kilovoltage have somewhat the same effect in

Table 3. Effects of technical improvements on radiation doses received from anteroposterior projection of the pelvis [1]

Kilovoltage	Added filter (mm. Al)	Altered parameter	Air dose		Depth dose at 8–9 cm.	
			Roentgens	Percentage of original value	Roentgens	Percentage of original value
60	None	Original conditions [2]	4.0	100	0.36	100
60	None	Full 5-minute development.	2.4	60	.22	60
60	0.5	Minimal filtration	1.8	45	.22	60
60	3.0	Full filtration	.5	12	.11	30
85	None	Increase kilovoltage	1.2	30	.22	60
85	3.0	Increase kilovoltage and full filtration.	.3	8	.11	30
85	3.0	Fast film	.2	5	.07	19
85	3.0	Fast film and cassette screens.	.13	3	.05	14
100	3.0	High kilovoltage technique.	.08	2	.03	8
		From commonly found technique to good modern technique.	Change of 4.0 to 0.13 r at skin.	Decrease to about 3 percent.	Change of 0.36 to 0.05 r at ovaries.	Decrease to about 14 percent.

[1] Based on data in references 7, 8, 11, 13. All numerical estimates have been rounded off and are subject to some variation from machine to machine.

[2] Underdevelopment at 3 minutes, standard speed film, par-speed cassette screens.

that they "harden" the X-ray beam and reduce the skin dose relative to the exit dose. The usual exit dose for ordinary radiography is in the order of 25 to 50 mr, indicating that most of the radiation is absorbed by the body. Use of 85 kilovolts and 3.0 mm. of aluminum filter reduces the skin dose to about 12 percent of that received at 60 kilovolts without a filter. The depth dose changes less because of the filtration effect of the preceding soft tissues themselves, but nonetheless decreases as much as 50 percent. Addition of fast film and fast cassette screens to the above results in a drop to about 5 percent of the original dose at the skin and about 25 percent of the original dose at the approximate depth of the ovaries. If faulty development was also present initially, the reduction by improved film processing is to about 3 percent and 14 percent respectively. These reductions in exposure do not decrease film quality; in fact, there is usually an improvement. For the scrotum, in an A-P view, the decrease in gonadal dose approaches that in air dose, because of the relative absence of intervening tissue.

The effect of coning is not considered in table 3 because collimation of any sort would not adequately protect the gonads during a pelvic X-ray examination. Local shielding, however, may be of help if used properly. In general, exclusion of the gonads from the direct beam will decrease gonadal exposure by at least 90 percent and often even more (*14*). Therefore, coning and local shielding are of critical importance and heavy stress should be placed on them in control work.

Genetic Exposure

To appraise fully the steps advisable to protect patients from genetic damage, it is necessary to know their age and reproduction probabilities. It is also necessary to know what classes of practitioners are making the radiation exposures. Such information is not presently available, though many carefully conceived approximations have been made (*10*, *15*, *16*). Since reproduction is generally considered to be 50 percent complete by about 30 years and 90 percent complete by about 40 years, the genetic exposures of healthy individuals should be carefully considered up to age 40, rather than 30.

In general, available data indicate that a small percentage of examinations, those of the lower trunk, contribute the great majority of gonadal exposures. For example, in a study of the entire population of Oak Ridge (*17*) it has been reported that 5 percent of all examinations contributed 80 percent of exposure to the gonads. The most significant procedures include views of the hips, pelvis, lower spine and sacrum, large bowel, genitourinary system, and full spine. In the Oak Ridge study, chest X-rays constituted 80 to 85 percent of all X-rays but contributed only about 17 percent to the total gonadal exposure. All the remaining views made up the small remaining percentage of examinations. The study did not evaluate pediatric X-rays or X-rays in chiropractic offices, nor give full breakdown by age, but nonetheless it is probably representative.

Somatic Exposure

It is very difficult to appraise the potential somatic hazards of radiation exposure at the present time. Integral body dose computations are more precise in some respects, but are critically dependent on the tissue exposed. Much recent literature evaluates gonadal and integral bone marrow doses as the two most important general criteria for probable biological damage (*16*). It may be noted that trunk X-rays or fluoroscopies which irradiate the gonads also tend to give heavy (though local) bone marrow doses.

At present there is inadequate information on the percentage of these critical examinations done on patients in various age categories. The available information suggests that their frequency is at least 2 to 3 times higher in those over 30 years than among younger persons.

Recommendations

On the basis of the above findings we advocate the following approach. Primary attention should be focused on all pediatric fluoroscopy and childhood X-rays involving the trunk, chest X-rays of all types, X-rays of the lower trunk region in individuals under 40 or in anyone with a reasonably high reproductive potential. X-ray pelvimetry and other exposures of mother and fetus are particularly important because they heavily expose the sensitive fetus or embryo and the maternal and fetal gonads. On the other hand, less detailed attention needs to be given X-rays of extremities or head or both and to unusual special procedures, such as angiography, which are done on sick persons; also to X-rays of a type done predominantly on older persons. For instance, a large percentage of male genitourinary studies are done with patients past the age of 40 for whom local shielding is less important. The value of having these considerations clearly in mind is that one can make a more reasonable request of the practitioner, namely, that he use the cumbersome and bothersome local shielding only where it is distinctly indicated.

The complex situation discussed above demonstrates that all types of practitioners will have to give their full cooperation to produce a real reduction in genetically significant radiation exposure. A single spinogram (full-length X-ray of spine) may produce a higher dose to the gonads than dozens of other radiographic examinations. A single pediatric fluoroscopy can easily produce exceptional gonadal exposure. Routine X-ray pelvimetry may offset the radiation safety efforts of radiologists and general practitioners not engaged in obstetrics. It appears clear that serious consideration should be given to any and all measures which may discourage or prevent the particular exposures which are of overriding importance.

We should like to make some comments at this point on the problems of field studies devoted to the magnitude of X-ray exposure of large populations. Such a project was considered but not actually attempted in Oregon. Because of the great individual variations in technique, particularly in coning and local shielding, we believe that the only accurate way to estimate gonadal dose associated with a given exposure of a patient is to measure it, using a standard phantom in the office where the X-ray was actually taken.

If attempting such a study, we would proceed as follows, in the light of what we have learned.

An entire medium-size community would be appraised in the manner of our survey, but in addition, direct-beam and scatter measurements would be made in each office for several representative views, such as X-rays of the chest, abdomen, hips, and knee, using the phantom. Special measurements would be taken with dental units, pediatric fluoroscopes, and chiropractic units used for spinograms.

After all units were examined in this way, a sample of the population would be chosen for a detailed anamnestic study of all sources of radiation exposure during the preceding year. With prior measurements on hand, it would then be possible to make a good guess as to gonadal exposures associated with a given X-ray taken on a given unit. The problem here is the probable and understandable reluctance of practitioners to allow measurements in regard to any specific patient. On the basis of field experience, the application of extensive tables designed to derive gonadal doses from stated exposure conditions is subject to serious errors due to inaccuracies and variations in kilovolt and milliampere settings, and most particularly because of difficulties in defining the extent of coning. In actuality, the only practical way coning can be defined with any assurance is to study the radiation field itself, either with fluorescent screens or instruments. We do not believe it is practical to expect "cone cuts" on all films at the present time. Rather unexpected vagaries have been found even in some variable aperture collimators, for example, nonuniform fields in which the intensity falls off at different rates in different directions (*14*). The effects of local shielding, when used, would also be extremely difficult to predict accurately. Field measurements with a phantom would no doubt be subject to many errors also, but they appear the best hope for getting a more nearly accurate estimate of gonadal exposure.

Summary and Conclusions

1. The Oregon survey included approximately 25 percent of all users of diagnostic X-ray units in the State. Little geographic variation was found in regard to patient or personnel radiation exposures.

2. Radiologists and hospitals in which the

X-ray work is under the direction of radiologists had much higher scores than most other groups surveyed on a majority of the items pertinent to radiological protection.

3. Personnel exposure appears to be fairly well under control though film badges should be used much more widely for documentation of exposure.

4. Patient exposure can be reduced by a number of techniques, all of which should be considered. However, on the basis of the experience in Oregon, and considering practical field problems, we recommend that control measures be listed in the following order: (*a*) coning, (*b*) added filtration, (*c*) full-film processing, (*d*) fast film, (*e*) local shielding, (*f*) fast-intensifying screens, and (*g*) higher kilovoltage technique. In most instances, collimation should be combined with local shielding, which is essential to obtain gonadal protection in most abdominal and pelvic shots.

5. Existing data reveal that only a certain few X-ray examinations contribute most of the gonadal doses.

6. Because of the large radiation doses associated with such procedures as spinograms, well-baby fluoroscopy, and routine pelvimetry, such exposures should be curtailed.

7. Our experience suggests that the successful application of the cited techniques on a wide scale will reduce population gonadal exposure to one-half and perhaps to as little as one-fifth of present exposure. There is no question that this will be a long, complex effort requiring much educational activity as well as further improvements in the technical aspects of X-ray work.

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