THE GENETICALLY SIGNIFICANT DOSE DUE TO MEDICAL X–RAY EXAMINATIONS IN THE NETHERLANDS

by J.A. Koen and J. Weber
Interuniversitair Reactor Instituut

Summary

Recent in situ measurements of the gonadal doses of 2500 male patients in seven Dutch hospitals make a reappraisal of the genetically significant dose (GSD) due to X-ray examinations in the Netherlands possible.
It was found that the gonadal doses of nearly all examination types in all hospitals form a log normal distribution with a standard deviation of the same order of magnitude as the mean doses.
The mean doses differ largely between the hospitals. Measurements in many hospitals will be necessary to obtain a reliable national mean dose for each examination type.
The number of examinations for each type varies appreciably per district and needs careful consideration. The child expectancy, which did change drastically during the last 4 years, did not influence the GSD.

Introduction

The Genetically Significant Dose (GSD) due to X-ray examinations in the Netherlands was estimated by Beekman [1] over 1959 and by Beentjes [2] over 1967. The former estimation resulted in a GSD of 7 mrem, the latter in different values, ranging from 19 - 40 mrem.
Beekman used a set of relatively low gonadal doses obtained from phantom measurements with minimum beam size. In this respect her result is a minimum value. The number of examinations was obtained from the registers of all medical services in the city of Leiden and surroundings. For this confined population the total number of examinations was 0.55 per year in 1959, dental radiography and mass survey excluded. Beentjes used different sets of doses obtained from the literature and the phantom measurements of Beekman. The frequency of examinations was obtained from health insurance companies operating in different districts and covering 9 million people out of a total population of 13 million. The number of examinations per caput per year varies per district from 0.25 to 0.45 with a mean of 0.37. Dental radiography and mass radiography are excluded. The latter would add 0.21. Since no in situ dose measurements were available in our country we decided to perform a survey in the hospitals in order to obtain dose values as they really occur. The preliminary results from measurements on male patients now available permit some conclusions about the procedure to be followed for gonadal dose measurements and their influence on the GSD estimate. They will be discussed in this paper.

Methods

We used thermoluminescent dosimeters, consisting of three extruded lithium fluoride ribbons (1/8 x 1/8 x 0.035 inch) from Harshaw, wrapped up in plastic film. Up to this moment we performed measurements on male patients only. The dosimeter is attached to the scrotum during the X-ray examination. The measured exposure permits to calculate the testis dose if the following factors are properly taken into account.

a) The difference between the skin exposure and the testis exposure is estimated to be about +5% in the direct beam and −5% in scattered radiation.
b) A conversion from testis exposure to absorbed dose, chosen as 0.91 rad per röntgen.
c) The sensitivity of LiF for diagnostic X-rays compared with 0.662 MeV ^{137}Cs radiation is estimated to be between 1,25 and 1.38.

The absorbed dose can be obtained from the exposure (calibrated with ^{137}Cs) through division by an overall correction factor, deduced from a, b and c between 1.55 and 1.40 for direct radiation and between 1.40 and 1.30 for the scattered radiation. An arbitrary value of 1.4 was chosen.

Results of the measurements

The results of the measurements on about 2500 male patients in seven Dutch hospitals are given in table 1.

The mean gonadal dose d_{ij} of each examination type (i) is indicated separately for each hospital (j) with the number of patients n_{ij} and the standard deviation s_{ij} of the doses. The X-ray departments of the hospitals have slightly different characters. They comprise one academic hospital, one military hospital and five peripheral hospitals in different cities. The hospitals numbered 3 and 4 did not use lead shielding at all, while hospital 2 always used lead shielding for the examination types IVP, lumbo-sacral region, pelvis and hip. In hospital 5 an image intensifier was consistently used for examinations (fluoroscopy and radiography) of the lower gastro-intestinal tract.

For each examination type and hospital the distribution of the measured doses proved to be log normal. An example is given in fig. 1 and 2.

The standard deviation (s_{ij}) is often larger than the mean dose (d_{ij}). Since the accuracy of each measured dose is better than 10 % (except of measurements at the edge of the direct beam where the localisation is uncertain) this standard deviation reflects the real difference between the individual doses. The relative standard deviation of the mean dose (d_{ij}) is

$$\frac{s_{ij} \cdot 100}{d_{ij}\sqrt{n_{ij}}} \%\ ,$$

and it is used to calculate an upper and lower confidence limit of the doses (95 % confidence) obtained in each hospital.

The mean gonadal doses for one examination type differ significantly between the hospitals. Local circumstances influence the doses to a large extend. For each examination type (i) the mean $\bar{d}_i$ of the doses d_{ij} obtained in the 7 hospitals is calculated, together with its standard deviation s_i. From table 1 we see that s_i has the same order of magnitude as $\bar{d}_i$.

Calculation of the GSD

The measured gonadal doses make a reassessment of GSD possible.

Our first measurements happened to be in the hospitals 3 and 4 where relatively high doses were obtained. These results gave us the impression that the doses of Penfil and Brown [3] are appropriate for the Netherlands. However, further measurements, performed in the other hospitals, make this conclusions doubtful. It appears that the data out of a restricted number of hospitals are subject to such a large variation that this causes one of the major sources of error in the estimation of the GSD, as follows also from the calculated standard deviation s_i of $\bar{d}_i$.

For the calculation of the GSD due to the examination of male patients we used the mean of the doses d_{ij} weighted according to the number of measurements performed in each hospital (see table 2, column 3). The frequency of examinations of each type is taken from Beentjes and the child expectancy over 1971 is used. At the bottom of the table a correction of 10% per year for the increase of the number of examinations during the years 1967-1971 is given [4]. The resultant value of the GSD, 28 mrad, is subject to a large error for the following reasons.

1e. The influence of errors in the doses d_{ij} on the GSD is estimated with the 95% confidence limits of the mean doses. The deviations of the contribution to the GSD of the eight examination types proved to be plus or minus 36%.

2e. A much larger error is to be expected due to the restricted number of hospitals used in the calculation, as is already mentioned. The standard deviation of the mean $\bar{d}_i$ indicated that measurements in about hundred hospitals should be necessary to obtain this figure accurately, unless the hospitals can be classed into groups, for instance academic and peripheral hospitals. In order to study this point a calculation of the GSD was made with, for each examination type, the maxima and the minima of the mean doses d_{ij} found in all hospitals. The resultant GSD for the eight examination types was 19.8. and 1.2 mrad respectively for male patients over 1967. It seems unlikely that for male patients further dose measurements will lead to a higher GSD than 32 mrad over 1971, which is the maximum calculated in this way (table 2, column 4-7).

3e. The frequency of examinations of each type is not precisely known and influences the GSD to a large extend. Beentjes calculated the GSD on the basis of frequencies found in six different districts. For each examination type the contribution to the GSD in the six districts varies with a standard deviation between 30 and 40%.

We conclude that an estimate of the GSD for the whole country, obtained by multiplication of the mean doses with the mean number of examinations can lead to large errors.

Table 1. **Gonadal doses of male patients per examination type (i) and hospital (j). Doses in mrad.**

d_{ij} = mean gonadal dose $\bar{d}_i$ = mean of the mean doses for examination type i
s_{ij} = standard deviation s_i = standard deviation of d_i
n_{ij} = number of patients

i / j	Intravenous pyelography			Lower gastro-intestinal tract			Lumbosacral region			Abdomen (general)			Pelvis			Hip			Femur			Stomach		
Hospital no.	d_{ij}	s_{ij}	n_{ij}	d_{ij}	s_{ij}	n_{ij}	d_{ij}	s_{ij}	n_{ij}	d_{ij}	s_{ij}	n_{ij}	d_{ij}	s_{ij}	n_{ij}	d_{ij}	s_{ij}	n_{ij}	d_{ij}	s_{ij}	n_{ij}	d_{ij}	s_{ij}	n_{ij}
1	228	346	71	761	1154	15	204	324	290	65	164	45	893	901	53	–	–	–	560	630	12	6	5	100
2	86	216	238	107	104	90	30	111	127	–	–	–	99	168	8	36	24	17	23	36	6	24	30	9
3	1262	2560	102	367	728	134	–	–	–	136	264	46	–	–	–	–	–	–	–	–	–	24	28	134
4	1580	1871	64	106	71	56	1048	855	93	184	350	17	807	797	20	350	453	5	–	–	–	–	–	–
5	322	670	81	48	122	35	460	950	33	58	32	5				347	636	20	113	97	3	2	6	70
6	167	269	83	133	44	13	156	279	18	482	421	12	–	–	–	–	–	–	–	–	–	4	7	92
7	205	416	211	59	46	5	36	31	63	164	373	6	–	–	–	–	–	–	56	61	3	–	–	–
mean $\bar{d}_i$	550			226			322			182			536			244			188			12		
standard deviation s_i	606			259			388			156			377			180			251			11		
number of measurements n_i			850			348			624			131			101			42			24			405

Table 2. **Different estimations of the GSD over 1971. GSD in mrad per year, gonadal doses in mrad.**

Examination type.	Measured gonadal doses						Gonadal doses of Penfil and Brown 3)		Gonadal doses of Beekman 1)		
	mean doses		set of highest doses		set of lowest doses						
	Gonadal dose	GSD	Gonadal dose	GSD	Gonadal dose	GSD	Gonadal dose	GSD	Gonadal dose	GSD child exp. '67	GSD child exp. '71
Hip	223	0.27	350	0.43	36	0.044	1064	1.29	3323	4.06	4.04
Femur	307	0.67	560	1.22	23	0.050	96	0.21	91	0.20	0.20
Pelvic region	793	2.91	893	3.27	99	0.363	717	2.63	157	0.58	0.58
Lumbosacral region (lumbar spine and abdominal aortography included)	290	1.84	1048	6.69	30	0.191	2268	14.46	60	0.32	0.32
Intravenous urography (retrograde urography and urethro cystography included)	411	1.43	1580	5.51	86	0.299	2091	7.29	640	2.11	2.10
Abdomen (general)	148	0.29	482	0.94	58	0.112	254	0.49	92	0.18	0.18
Lower gastrointestinal tract	229	0.49	761	1.63	48	0.102	1585	3.39	45	0.10	0.10
Stomach and duodenum (oesophagus included)	11.2	0.09	24	0.19	2	0.016	137	1.10	4.8	0.03	0.03
Total		7.99		19.88		1.177		30.86		7.58	7.55
Other examinations		2.01		2.01		2.01		2.01		0.03	0.03
Total GSD for males		10.00		21.89		3.19		32.87		7.61	7.58
Total GSD for females		9.13						8.88			9.13
Total		19.13						41.75			16.71
Total corrected for increase of number of examinations '67 - '71		28						61			24

4e. In our country the child expectancy is decreasing rapidly during the last years. In order to get an idea of the influence of this factor we made two calculations of the GSD (male patients), one with the child expectancy over 1967 and one over 1971. The estimations were calculated following the method of Beentjes; for both years the set of doses reported by Beekman and the frequency of examinations of Beentjes was used. Although there is a strong shift in the number of live births and child expectancy in all age classes (see table 3), the resultant differences in the calculated GSD are insignificant (7.58 and 7.55 mrad for male patients over 1967 and 1971 respectively).

Table 3.
Male child expectancy in the Netherlands

age	1967	1971
−0.75 - 0	2.644	2.232
0	2.676	2.255
0 - 4	2.720	2.307
5 - 9	2.742	2.314
10 - 14	2.748	2.319
15 - 19	2.745	2.309
20 - 24	2.564	2.071
25 - 29	1.921	1.405
30 - 34	1.080	0.809
35 - 39	.494	0.294
40 - 44	.186	.100
45 - 49	.056	.028
50 - 54	.014	.005
55 - 59	.002	–
60 +	–	–

Deduced from tables of the Netherlands Central Bureau of Statistics.

Conclusion

In spite of 2500 gonadal dose measurements and intensive efforts to obtain the frequency of each type of examination per year the estimation of the GSD is still unreliable. Improvement is only possible if an appreciable number of measurements in many hospitals is available. Relatively large statistical errors in the dose measurements may be tolerated due to the large standard deviation in the dose distributions. In our country the rather important changes in child expectancy did not influence the GSD of the male patients significantly.

References

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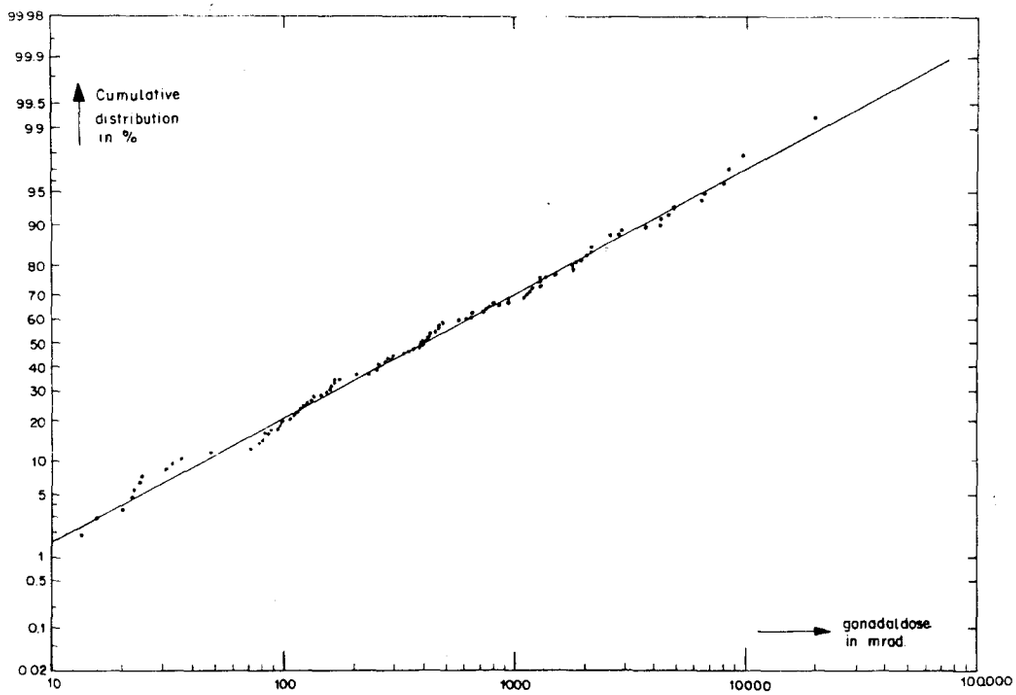

Fig. 1. Cumulative distribution of male gonadal doses from intravenous pyelography; hospital no. 3; $d_{ij} = 1300$ mrad; $s_{ij} = 2600$ mrad; median= 370 mrad; 102 patients.

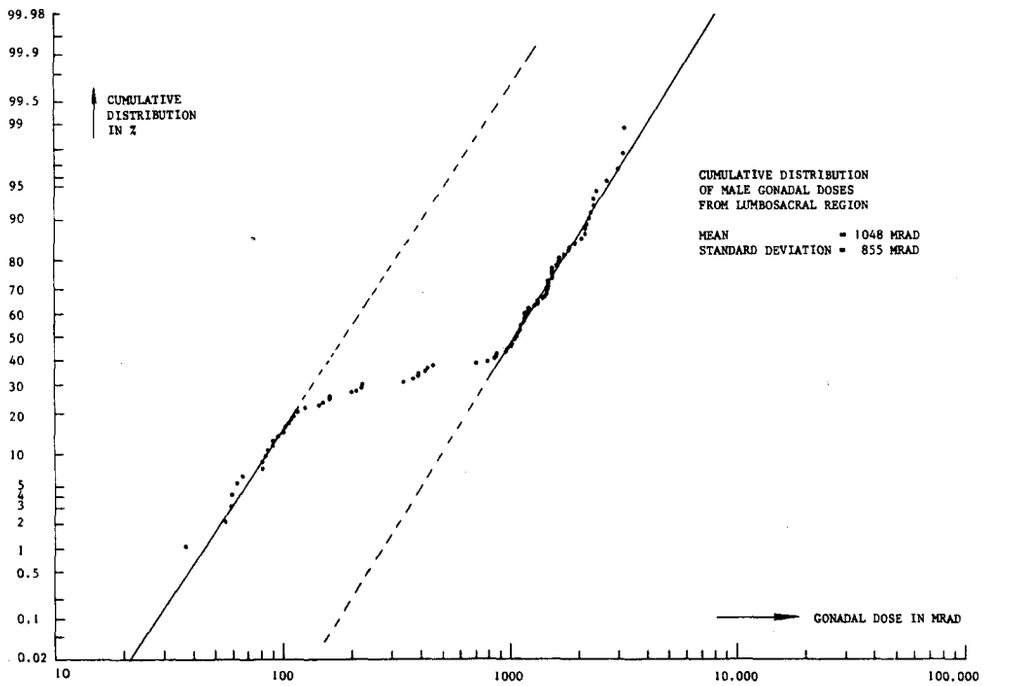

Fig. 2. Cumulative distribution of male gonadal doses from intravenous pyelography; hospital no. 4; $d_{ij} = 1048$ mrad; $s_{ij} = 855$ mrad; median = 1079 mrad; 93 patients. This examination type forms the unique exception on the log normal distribution found in all other types.