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REFERENCE MAN IN DIAGNOSTIC RADIOLOGY DOSIMETRY

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Abstract — Patient size and shape are considered in patient dose evaluations in diagnostic radiology. The size, shape and constitution of the patients are shown to relate exponentially to the energy imparted during examination of the trunk. The equivalent cyclindrical diameter of the patient body is used as the independent variable. Exponential functions are created by linear regression. A method is suggested by which coordinate transformations reduce data to a base line defined by Reference Man. It is shown that the method reduces the range of energy imparted during X ray examinations of the trunk. Resulting data constitute a finer instrument for intercomparisons between hospitals for the same examination. Reference Man, stripped of 10 kg subcutaneous adipose tissue, is used as the non-fat standard. The suggested method is used to estimate the fraction of energy imparted to vital organs only.

INTRODUCTION

Reference Man concept was given by the ICRP as a 'well defined reference individual for estimation of radiation dose in health physics'. The hope was that this individual 'should be used by health physicists in comparing and checking their results without tedious enumeration of assumptions obscuring the basic agreement or disagreement of their results'. Although ICRP does not claim Reference Man to be predictive for any individual or randomly chosen population on this planet, they admit that the typical values selected often were average or median values of existing populations.

This work is an attempt to use Reference Man for simplification of patient dose evaluation within diagnostic radiology dosimetry.

MATERIALS AND METHOD

Transmission ionisation chambers were used during a time span of three years. The chambers were moved between laboratories with about a two months interval. They were calibrated on site at each X ray tube in terms of area air kerma ($Gy.m^2$) using a standard ionisation chamber ($30\ cm^3$) applying air kerma factors from the National Dosimetry Laboratory in Stockholm.

The voltage (kV) and filtering were checked on all equipment using dedicated, commercial, computerised equipment (Digi-X, ORTIGO).

Special efforts were made to collect data concerning the shape of the patients. The weight (W) and the height (H) were measured for each individual. The staff filled in charts with the following data: sex, height, weight, age, typical dimensions of target area, type of examination, equipment, grid, number of films, rejected number of films, projections, field size, cassette size, kV, mA.s, focus–film distance, focus–skin distance, film–screen combination, tube output, developer, and special comments if needed.

The energy imparted to each patient was computed by means of Monte Carlo tables.

The outer dimension of the trunk is not particularly well correlated with the energy imparted to the body as it does not include any information about the density. The body weight will take the average density into consideration but does not include the shape. Figure 1 depicts the concept of the equivalent cylinder. The patient is approximated by a cylinder having the same height (H in cm) and weight (W in g) as the body. The equivalent cylindrical diameter (D_e) takes the average (unit) density into consideration and it has some information about the shape of the body. $D_e = 2\sqrt{(W/H\pi)}$.

RESULTS

In Figure 2(a), the total energy imparted for urography examinations is plotted as a function of D_e. Each cross shows the total energy imparted to the patient's body, film exposure and fluoroscopy combined. The diagram depicts a surprisingly good fit.

By normalising to the number of films and to the fluoroscopy time used, the body size influence becomes even more obvious. This was done in a slightly smaller sample of patients. Figure 3 shows the normalised energy imparted per film, Figure 4 the corresponding fluoroscopy energy imparted per minute. The regression coefficients are the same

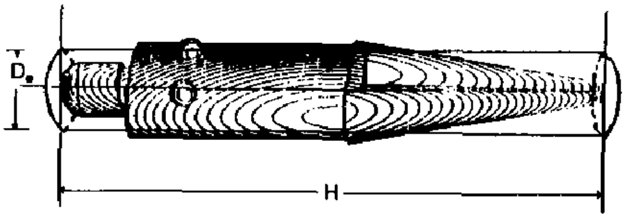

Figure 1. Equivalent cylinder.

as before but the standard deviation is considerably reduced.

Judging from these diagrams, it is obvious that it would not be adequate just to compute the average value and the standard deviation, and use these data for intercomparisons or for estimates of organ dose and dose equivalent. For instance in Figure 2(a) the mean of all data is 190 mJ with a standard deviation of 100%, whereas the standard deviation of the regression line is only 47%. The body size, shape and constitution play such a great part in the energy consumption that it really must be taken into consideration.

It should be possible to choose some level along

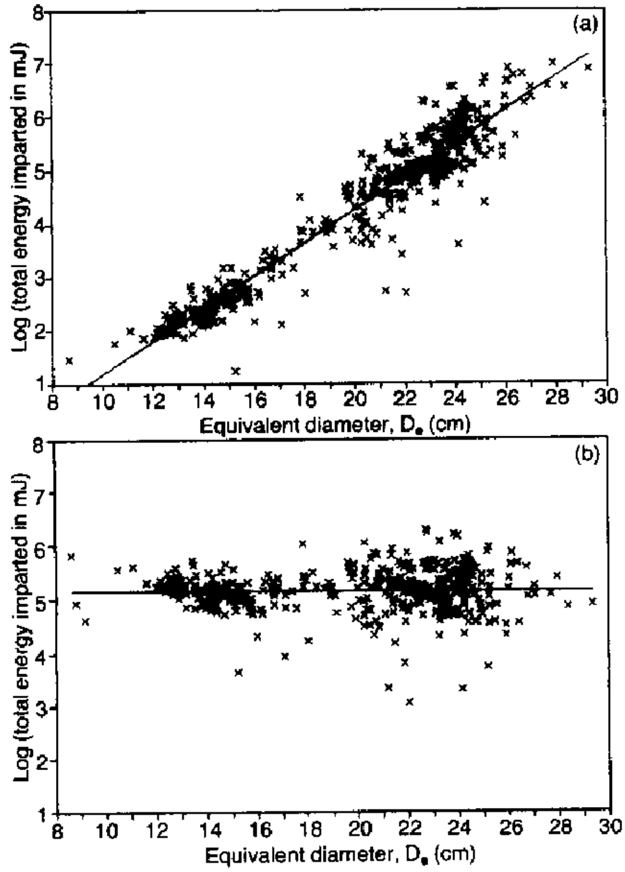

Figure 2. (a) Total energy imparted in urography examinations (film and fluoroscopy) for a normal population. Solid line = regression line, crosses are original data. (b) As (a) for Reference Man. Solid line is reference level, crosses are original data.

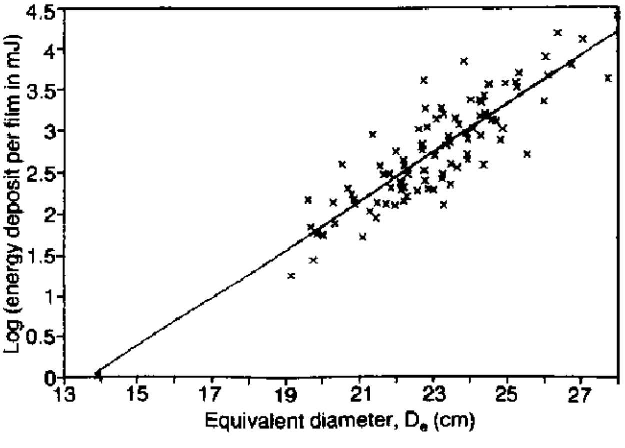

Figure 3. Normalised energy imparted per film. Solid line = regression line, crosses are original data.

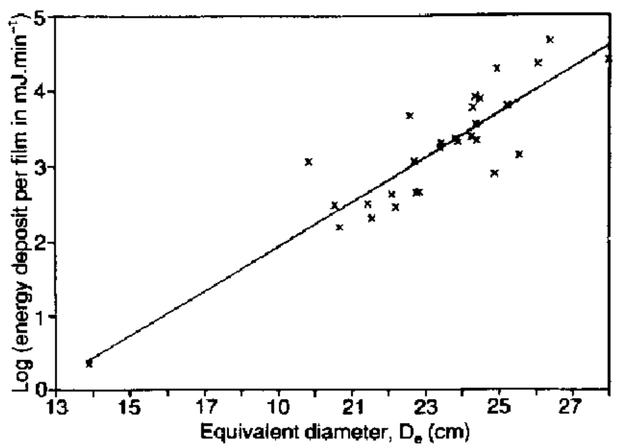

Figure 4. As Figure 3 for fluoroscopy examinations.

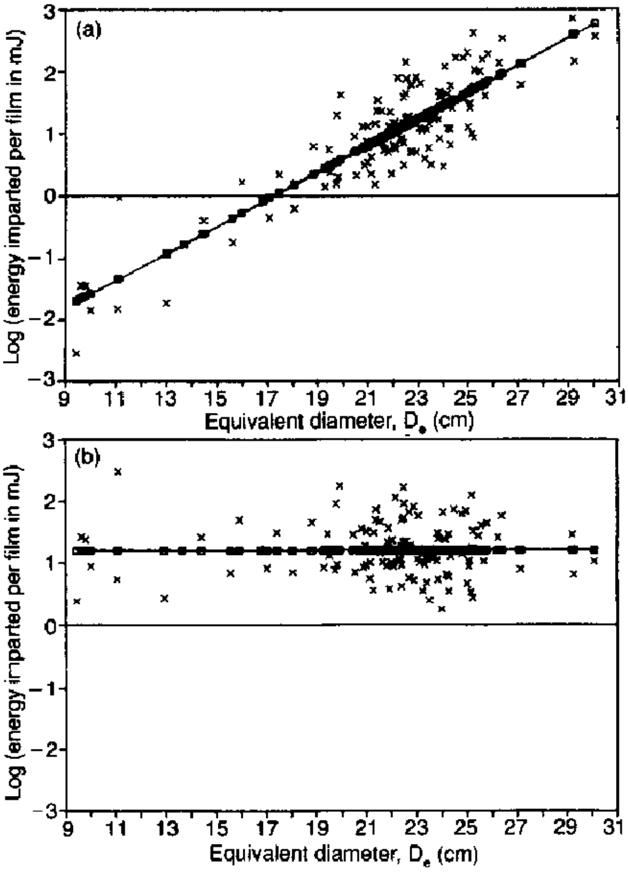

Figure 5. Heart and lung normalised film exposure for (a) normal population, and (b) Reference Man. (❑) regression line, (x) original data.

the regression line as the standard of reference; perhaps using Reference Man. The Reference Man has an equivalent cylindrical diameter of 22.9 cm (70 kg, 1.70 m). Using this diameter as a typical dimension for reference, the reference level of energy imparted can be read directly from the regression lines for each type of examination.

By rotating the regression lines clockwise around the point of reference, until parallel with the abscissa, the data are brought to a 'Reference Man level'. Mathematically this can be done simply by a coordinate transform. Collectively, this could be interpreted as reducing the energy imparted, i.e. the energy that the patients should have received, had they all been of the Reference Man size.

Figure 2(b) shows the urography data compressed to the Reference Man size. The maximum value 1060 is reduced to 540 mJ. The standard deviation is reduced from 100% to 41%. The reference value is 180 mJ. Similarly, Figures 5(a) and (b) show heart and lung normalised film exposure for a normal population and Reference Man, respectively.

Table 1 summarises the parameters of interest for interpreting the physics of the data reduction. The upper part of the table shows six typical examinations, mean energy imparted in mJ, standard deviation, maximum and minimum values, ratio max/min and, in the last column, the number of patients involved. The lower half of the table is for colon and urography examinations normalised to the number of films and time, respectively. Table 2 shows the same data after reduction to the Reference Man size. The energy level and the range are considerably reduced.

Data reduction is not the same as reduction of dose in real terms. However, realising that the energy imparted to fat is of minor interest for detrimental effects of ionising radiation, one would like to interpret the algorithm used in terms of anatomy. The body content of adipose tissue must be related to the equivalent cylindrical diameter. According to the ICRP, the body content of fat increases almost linearly with the total body weight. Different age groups have slightly different levels. The weight of fat as a function of body weight can be drawn in parallel lines for various ages, highest age at the top line. Although fat is unevenly distributed, it is represented all over the body, particularly in a subcutaneous layer that covers the whole body. Wherever radiation penetrates a body, some part of the energy is bound to be absorbed in adipose tissue. Thus, presuming that the body content of fat is a constant fraction of the body weight, then, subtracting this fraction from the weight of an adult, the remaining mass will represent other vital organs. Collectively, this could be considered as the consequence of the mathematical algorithm.

The same reasoning applies to skin dose measurements, or any other kind of dose measurement, because of the inherent feedback mechanisms of the radiology procedures. Firstly, the automatic exposure control guides the exposure until the density of the target pattern on the film is sufficient. Secondly, the examination continues until the operators and the doctors are satisfied. The more adipose tissue the beam has to go through, the more energy is needed.

According to ICRP, the Reference Man content of adipose tissue is 17 kg. Of this, 10.3 kg is non-essential subcutaneous fat which should be deducted. Consequently, the reference diameter should be less than 22.9 cm. Excluding 10 kg from the weight of Reference Man results in the equivalent diameter 21.2 cm.

Table 1.

Normal population	Total energy imparted (mJ)					
Examination	*Mean*	*SD*	*Max*	*Min*	*Ratio*	*Number of patients*
Heart and Lung	3.8	3.1	17	0.1	220	112
Lung	4.5	3.1	19	0.4	42	204
Urography	191	192	1061	3.4	310	289
Lumbar spine	31	16	75	4.3	17	72
Colon	423	238	1906	72	27	316
Thorax spine	73	51	254	1.7	149	27
					Sum:	1020
Normalised						
Colon (mJ/film)	19	11	97	3.9	25	137
Colon (mJ.min^{-1})	53	45	322	6.6	49	138
Urogr (mJ/film)	19	14	81	1.0	80	96
Urogr (mJ.min^{-1})	32	24	104	1.4	73	29
					Sum:	400

Table 2.

Reference Man. D_e = 22.9 cm.	Total energy imparted (mJ)					
Examination	Mean	SD	Max	Min	Ratio	Ref. level
Heart and Lung	3.8	1.9	12	1.3	9	3.4
Lung	4.5	2.2	13	1.2	11	4.0
Urography	193	78	536	21	25	176
Lumbar spine	30	9.0	54	13	4.2	29
Colon	410	175	1257	108	12	379
Thorax spine	79	50	213	23	9	66
Normalised						
Colon (mJ/film)	19	6.6	40	5.5	7	17
Colon (mJ.min^{-1})	54	43	288	11	25	40
Urogr (mJ/film)	16	5.3	37	7.2	5	15
Urogr (mJ.min^{-1})	23	9.2	51	10	5	22

Table 3 shows the resulting data after reduction to Reference Man stripped of almost all subcutaneous adipose tissues. The energy imparted is considerably reduced and so is the range.

The relative reduction is summarised in Tables 4 and 5.

DISCUSSION

To a certain extent, the equivalent cylindrical diameter (D_e) could be used in medicine as a measure of the total body fat mass. Fat has very little bearing on the detriment of radiation and it is not included in the calculation of the effective dose equivalent. Clearly, a considerable fraction of the energy absorbed in bodies having a D_e larger than 21.2 cm will be imparted to fat. Consequently, the parameter D_e should be accepted as the independent variable of choice in standardising dose data. However crude this measure may seem, it probably renders a more adequate anatomical realism in patient dose studies than just presenting the average dose, not reduced.

Table 3.

No adipose tissue. $D_e = 21.2$ cm

Examination	Total energy imparted (mJ) Mean	SD	Max	Min	Ratio	Ref. level
Heart and Lung	2.6	1.3	8.3	0.89	9	2.4
Lung	3.1	1.5	9.0	0.80	11	2.7
Urography	113	47	318	13	25	105
Lumbar spine	21	6.4	39	9.1	4	20
Colon	294	125	902	78	12	272
Thorax spine	48	30	129	14	9	40
Normalised						
Colon (mJ/film)	14	5.4	29	4.0	7	13
Colon (mJ.min^{-1})	44	34	232	9.2	25	33
Urogr (mJ/film)	10	3.2	23	4.3	5	9.1
Urogr (mJ.min^{-1})	14	5.6	31	6.3	5	13

Table 4.

	(a) Reference Man Relative reduction (%)				**(b) No adipose tissue** Relative reduction (%)			
	Dose	SD	Max value	Ratio Max/min	Dose	SD	Max value	Ratio Max/min
Heart and Lung	11	39	30	96	38	58	52	96
Lung	10	28	28	73	39	51	51	73
Urography	7	59	50	92	45	76	70	92
Lumbar spine	9	42	28	76	35	59	48	76
Colon	10	27	34	56	36	47	53	56
Thorax spine	9	1	16	96	45	40	49	94
Normalised					**Normalised**			
Colon (per film)	7	32	59	71	33	51	70	71
Colon (min^{-1})	24	5	11	48	39	23	28	48
Urogr (film)	22	62	54	94	53	77	72	94
Urogr (min^{-1})	33	62	51	93	60	77	70	93

According to a Swedish estimate, diagnostic X rays induce about 110 malignant cancers or genetic injuries annually. In Europe, 2000 cancers per year have been estimated. These estimates are based on internationally accepted risk factors and average values of dose measurements. If the same estimates were made after reduction of data according to the described algorithm, the result will be between 10 and 40% fewer. At the same time, the standard deviation will be reduced in the range 30–80% and the high/low ratio in the range 60 to 100%, which all serves to relieve the fear of diagnostic radiation.

CONCLUSIONS

Standardising according to body shape and weight along the lines shown here may be useful in diagnostic radiology, for relative comparisons of exposure, in setting limits for dose reduction, and in estimating organ dose based on Monte Carlo calculated tables valid for a standard body shape or a standard phantom.

All new X ray equipment should be supplied with permanent large-area transmission ion chambers and an area–dose display at the operator's desk. Alternatively, a calculated dose display based on technique factors should be provided. The staff should be given lists of acceptable area–dose values for all types of examinations for a patient of reference dimensions. Added to this list should be a list of correction factors for weight and height other than the reference size. In this way, it is assured that the staff know how much to expect for a heavy patient. The dose level will not come as a surprise. But even more important, for small people, like children, the staff will make sure that they are not given an unreasonably high dose for their size. A small body should have less energy imparted, and the present method immediately shows when children or infants, are overexposed.

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