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Dose to patients in CT examinations.
Results and consequences from a field study
in the Federal Republic of Germany

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Abstract
At 122 facilities for the four most current examinations there, the doses per single scan free in air on the axis of rotation were measured and data (tube voltage, filtration, mAs-product, slice width, number of slices) essential for the estimation of dose to patient and quality control was collected. On the basis of these results average organ doses were determined for examinations in the various body regions. Due to the findings of the field study a detailed and reliable estimation of embryo dose would be necessary in nearly half of the cases when pregnant patients undergo CT-examination of the pelvis. In such cases embryo dose must be determined on the basis of measurements performed at the respective facility.

Dose to patients in CT examinations. Results and consequences from a field study in the Federal Republic of Germany

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The aim of the field study was to obtain a general view of the state of the art of CT examinations with regard to dose to patients and some aspects of quality control. To this end at 122 facilities (representing about one fifth of all installations operated in the country) for the four most current examinations there doses per single scan, free in air on the axis of rotation were measured and data essential for estimating dose to patients and also related to quality control was collected.

Method

The participants who joined voluntarily in the field study were sent by mail five capsules (Fig. 1), each containing 12 LiF TL-dosemeters (3x3x0.8 mm) and a simple, adjustable holder to locate the capsules in the center of rotation for a single scan irradiation. LiF can be considered as an energy independent dosemeter material in the energy range covered by computer tomography. All the LiF chips were calibrated individually inside the capsules by means of an ionisation dosemeter. During the calibration they were rotated to simulate the circular irradiation at the CT machines.

The decision to measure absorbed dose free in air for a single scan was made out of the following reasons:

- No patientlike phantoms were involved on which the participants would have had to perform complete examinations.
- At least for thin slices information on the real slice width was achievable.
- On the basis of the dose D_a free in air on the axis of rotation organ or tissue doses D_i can be easily calculated, following the relation:

$$D_i = f_i \cdot D_a \qquad (1)$$

Values for f_1, resulting from Monte Carlo calculations using mathematical human reference phantoms exist already for various types of CT examinations /2, 3/ and can also be prepared for further ones.

After irradiating four of the capsules (the fifth was added just for control) they were sent back for evaluation together with a filled-in questionnaire. In this form data on dosemeter irradiation (tube voltage, mAs-product, filtration, slice width, scan angle, examination which typically is performed under these conditions)
and general data (producer and type of machine, year of purchase, number of slices per examination, slice distance) was collected.

Results and conclusions

The field study revealed that exclusively rotate-only systems are in use and that examinations are most often performed in the 360° scan mode in adjacent slices. The high uniformity of these examination parameters later on will facilitate the determination of organ doses and the presentation of the results.

From the number of slices per examination and the slice width used for this examination the length of the scanned body region can be determined. Table I shows these values for the various types of examinations. It indicates that half of the values lie within a comparatively narrow range around the mean value but the other half is scattered over a very wide range, thus restricting the applications of average or typical values, because those might differ remarkably from the "true" values in a special situation under question.

Fig. 2 shows an example for a measured dose profile from a single scan free in air on the axis of rotation. The correct value to be used for D_a in formula (1) would be the CT-Dose Index (CTDI) taking into account also contributions from neighbouring slices due to discrepancies between nominal and real slice width and/or extrafocal radiation (or a lack of radiation if in case the nominal slice width is larger than the real one). However, in most of the cases it was not possible to determine the whole dose profile because the TLD staple (length 9.6 mm) was too short or the capsule was not adjusted exactly in the beam. So in the field study the plateau value D_s was determined. The error introduced thereby can be described by:

$$f_E = CTDI / D_s \qquad (2)$$

In about 150 cases the whole beam profile could be analysed and the values for f_E are listed in Table II. It turned out that for 1 mm and 2 mm slices a considerable dose enhancement can occur, due to poor adjustment of the collimating system.

The values found for D_s for the various types of examinations are presented in Table III. The large fluctuations are not surprising at a first sight because all tube voltages, filtrations, mAs-products and focus to axis distances are included. More surprising, however, are the results displayed in Fig. 3. It shows the distribution of values for D_s normalised to 100 mAs and a focus to axis distance of 76 cm. The large deviations from dose values from the literature /1, 5, 8/ in Table IV and the large range might be due to discrepancies between nominal and real values for tube voltage, filtration and mAs-products (as assumed and recorded by the participants). Also the expected dependence of X-ray output from tube voltage and filtration is completely masked by these effects. As a consequence it is to state that reliable estimations of doses to individual patients (e.g. embryo doses) must not rely only on the informations from the users and that dose measurements must become part of Quality Control programs in computer tomography.

On the basis of findings of the field study, the mean values for the length of the scanned body region (Tab. I) and the mean values for the dose free in air on the axis of rotation (Tab. III) for the various types of examinations average organ doses were calculated using female and male mathematical phantoms /3/ (Tab. V). The high doses to the eyelenses on both the skull projections are due to the fact that the calculation cannot simulate situations in which the axis of the scanned body region is not parallel to the axis of rotation. So in both projections they come to lie within the scanned region. Apart from this inconsistency the results demonstrate:

- Doses to patients from CT examinations are in the most often cases by an order of magnitude higher than in conventional X-ray diagnosis (last column of Tab. V). The results also confirm an earlier statement by Stieve and Schmidt /7/ that dose to patient from a single CT scan is in the same order of magnitude like the dose from a conventional examination of the respective body region.

- The impact of the phantom chosen and the assumed radiation quality is very small compared to the variability of the values for the length of the scanned region (Tab. I) and dose on the axis (Tab. III).

- Whenever a pregnant patient underwent a CT examination of the pelvic region a reliable estimation of embryo dose based on dose measurements at the respective facility becomes necessary. Because in 50% of all cases an investigation level of 20 mGy (to make sure that no values of 50 mGy or more fail to be noticed) which exists for this purpose in Germany /4/ is exceeded.

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Table I: Length of the examined body region

Examination	Length (cm)			
	Mean	1. Quartile	3. Quartile	Range
Skull	12	8	16	2 - 26
Thorax	24	20	27	10 - 40
Abdomen	30	21	36	5 - 40
Pelvis	20	16	24	5 - 40
Spine	7.5	6	8.6	4 - 12

Table II: Values for f_E

Slice thickness	P_E			
	Mean	1. Quartile	3. Quartile	Range
1 mm	-	-	-	1.5 - 3.7
2 mm	1.37	1.19	1.71	1.0 - 2.26
4 mm	1.04	0.97	1.27	0.88 - 2.22
5 mm	0.97	0.93	1.08	0.90 - 1.19

Table III: Dose values free in air on the axis of rotation

Examination	Dose (mGy) Mean	1. Quartile	3. Quartile	Range
Skull	45.4	26.3	52.0	7 - 208
Thorax	32.9	16.3	38.8	7 - 91
Abdomen	36.6	16.2	38.5	6 - 168
Pelvis	35.8	14.5	38.8	7 - 161
Spine	53.7	32.0	63.6	13 - 162

Table IV: Values from the literature for the dose free in air in 76 cm distance normalized to 100 mAs

Tube voltage kV	Filtration mm	Dose mGy
100	2.2 Al + 0.25 Cu	7.3 /5/
120	5.0 Al + 0.50 Cu	6.7 /1/
120	6.0 Al	14.0 /8/
120	6.0 Al	14.8 /5/
125	2.2 Al + 0.25 Cu	12.8 /5/
125	2.2 Al + 0.40 Cu	9.6 /5/
125	2.2 Al + 0.40 Cu	11.0 /1/

Table V: Average organ doses calculated on the basis of the results of the field study using female (f) and male (m) adult mathematical phantoms

Region: Organ	Organ dose (mGy) A f	A m	B f	B m	C f	C m	Convent. diagn. /2, 6*/
Skull (top):							(ap)
Bone marrow	3.66	3.27	4.08	3.63	3.05	2.72	0.16*
Brain	29.1	26.9	32.2	29.9	24.3	22.4	0.67
Eyelense	37.3	34.5	37.8	36.7	34.8	32.1	4.00
Thyroid	1.23	0.69	1.41	0.83	0.96	0.51	0.42*
Skull (base):							
Bone marrow	2.76	2.65	3.11	2.80	2.26	2.18	
Brain	15.3	15.7	17.1	13.9	12.7	12.9	
Eyelense	37.4	35.9	38.8	37.6	40.0	33.4	
Thyroid	8.31	5.04	8.94	5.77	6.95	4.11	
Thorax:							(pa)
Lungs	23.5	22.4	25.5	24.4	20.0	19.2	0.15*
Bone marrow	5.17	4.80	5.79	5.36	4.28	3.95	0.04*
Breast	25.9	-	27.1	-	23.5	-	0.09*
Thyroid	2.87	2.47	3.06	2.82	2.26	1.93	0.02*
Abdomen:							(ap)
Bone marrow	8.56	7.5	9.66	8.53	6.88	6.07	0.40*
Uterus	17.9	-	20.1	-	14.7	-	2.90*
Upper L.I.	24.2	22.2	26.7	24.7	20.0	18.6	2.34
Lower L.I.	12.2	9.55	13.5	10.8	10.1	7.87	1.14
Pelvis:							(ap)
Bone marrow	7.02	6.05	7.88	6.87	5.62	4.87	0.18*
Uterus	19.4	-	21.9	-	16.1	-	1.70*
Upper L.I.	9.27	7.30	10.3	8.23	7.52	6.09	2.03
Lower L.I.	17.7	15.9	19.8	18.0	14.6	13.1	1.58

A: 125 kV, 2.2 mm Al + 0.25 mm Cu
B: 125 kV, 2.2 mm Al + 0.40 mm Cu
C: 120 kV, 6.0 mm Al

Fig. 1: Arrangement of capsule in the beam

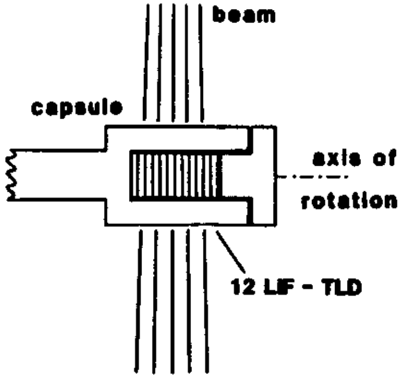

fig 1

Fig. 2: Typical dose profile for a 4 mm - single scan free in air on the axis of rotation

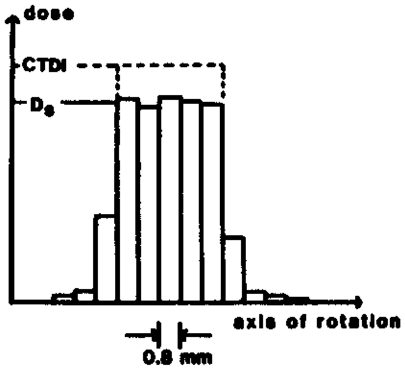

fig 2

Fig. 3: Distribution of normalised dose values for a single scan free in air on the axis of rotation (100 mAs, 76 cm focus to axis distance)

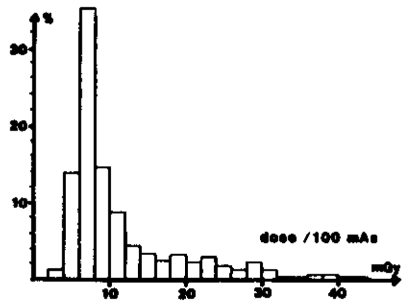

fig 3