Equivalent dose to organs and tissues in Hysterosalpingography calculated with the FAX (*F*emale *A*dult vo*X*el) phantom

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Abstract. Hysterosalpingography (HSG) is a radiological examination indicated for investigating infertility or uterine and tubal pathologies. Women who undergo HSG are relatively young, typically between 20 and 40 years, and equivalent doses to the ovaries are usually reported to be around 4 mSv per examination. A review of studies on patient dosimetry in HSG revealed that almost all absorbed doses to organ and tissues had been calculated with conversion coefficients (CCs) based on hermaphrodite versions of MIRD5-type phantoms. The CCs applied had been taken from data sets for abdominal or pelvic examinations because CCs for HSG examination were not available. This study uses the FAX (*F*emale *A*dult vo*X*el) phantom in order to calculate equivalent doses to radiosensitive organs and tissues especially for exposure conditions used in HSG. The calculations were also performed for the MIRD5-type EVA phantom to demonstrate the influence of anatomical differences on organ equivalent dose. The results show organ and tissue equivalent doses as function of the variations of the exposure conditions. With 4.56 mSv the ovarian equivalent dose calculated for the FAX phantom is about 21% greater than the average ovarian equivalent dose reported in the literature, which reflects the anatomical differences between the FAX and the MIRD5-type phantoms.

Introduction

Hysterosalpingography (HSG), a radiological examination which delivers relatively high equivalent doses to the ovaries and the uterus, is used to examine the uterine cavity and the patency of the Fallopian tubes. Common indications for HSG are primary and secondary infertility, assessment of tubal patency following reversal of sterilization, of tubal blockage following a difficult sterilization and of the uterine cavity following division of an intrauterine septum.

Reference	ESAK [mGy]	Ovarian Dose [mSv]	OD / ESAK Sv /Gy	Av. Voltage [kVp]	Field size [cm x cm]
Fife et al [1]	13.3	2.8	0.21	82	24 x 30
Fernandez et [2]	23.4	4.6	0.20	80	24 x 30
Gregan et al [3]	13.1	3.1	0.24	78	24 x 30
Calicchia et [4]	24.6	4.6	0.19	72	24 x 30
Khoury et al [5]	19.2	2.9	0.15	70	30 x 24
Average	18.7	3.6	0.20		

Table 1. Entrance air kerma and ovarian equivalent doses reported in references 1-5

Equivalent doses to the ovaries from HSG examinations are usually around 4 mSv, which triggered a series of investigations on patient dosimetry and on possibilities for the reduction of patient exposure. Table 1 summarizes typical values for the entrance surface air kerma (ESAK), which includes the contribution from backscattered radiation, and the equivalent dose to the ovaries reported in recent publications [1, 2, 3, 4, 5], in which the equivalent dose to the ovaries was calculated by multiplying the ESAK by a conversion coefficient (CC), which had been determined by Monte Carlo methods for hermaphrodite MIRD5-type phantoms, i.e. male bodies with female organs like ovaries, uterus and breasts [6, 7, 8].

However, during the last decade in radiological protection the mathematical MIRD5-type phantoms have inceasingly been replaced by tomographic or voxel-based phantoms, which are a true to nature representation of the human body. The recently developed FAX (*F*emale *A*dult vo*X*el) phantom [9], together with the traditional MIRD5-type EVA phantom [10], have been selected to simulate HSG examinations in order to see the influence of the different anatomies on organ and tissue equivalent doses, and also to demonstrate the effect of varying exposure parameters, like tube voltage, filtration, field size, field orientation, focus-to-film distance, and projection on these doses.

Materials and methods

The phantoms

The recently developed FAX (*F*emale *A*dult vo*X*el) phantom has been segmented from CT images of patients [9]. Organ and tissue masses correspond to the anatomical specifications recommended by the International Commission on Radiological Protection (ICRP) in its Publication 89 for the female reference adult [11], while tissue compositions and densities are based on data published by the International Commission on Radiation Units (ICRU) in its report No.44 [12].

The EVA phantom has been developed from the first hermaphrodite MIRD5 phantom, which had already ovaries and a uterus, by scaling down the male body to the height of the female reference adult from ICRP Publication 23, and by introducing female breasts [10]. Tissue compositions and densities of the EVA phantom have been taken from an early MIRD5 publication [13].

The EGS4 Monte Carlo code

The EGS4 Monte Carlo code [14] simulates coupled electron-photon transport through arbitrary media. The default version of EGS4 applies an analogous Monte Carlo method, which was used for the calculations of this investigation. Rayleigh scattering has been taken into account, but secondary electrons have not been transported. With respect to the simulation of radiological examinations a special user code has been developed, which outputs absorbed dose to radiosensitive organs and tissues normalized to the ESAK. The X-ray spectra have been taken from the IPEM spectra catalogue [15].

Exposure conditions

Based on a review of the exposure conditions reported in references [1–5], the following representative irradiation parameters have been identified for the simulation of the HSG examination:

X-ray generator:	constant potential
Target:	tungsten, 17^0
Voltage:	70 kV – 120 kV
Filtration:	2.0 – 4.0 mm Al
Projection:	anterior – posterior (AP), posterior-anterior (PA)
Field size:	18cm x 24cm, 24cm x 30cm in the detector plane
Field position	Centered on uterus
FSD	70cm, 80cm, 90cm (focus-to-skin distance)
FFD	100cm, 110cm, 120cm (focus-to-film distance)

Figures 1 and 2 show silhouettes of the FAX and the EVA phantoms with X-ray beams, field sizes and FFDs, the uterus in grey and the ovaries in black, respectively.

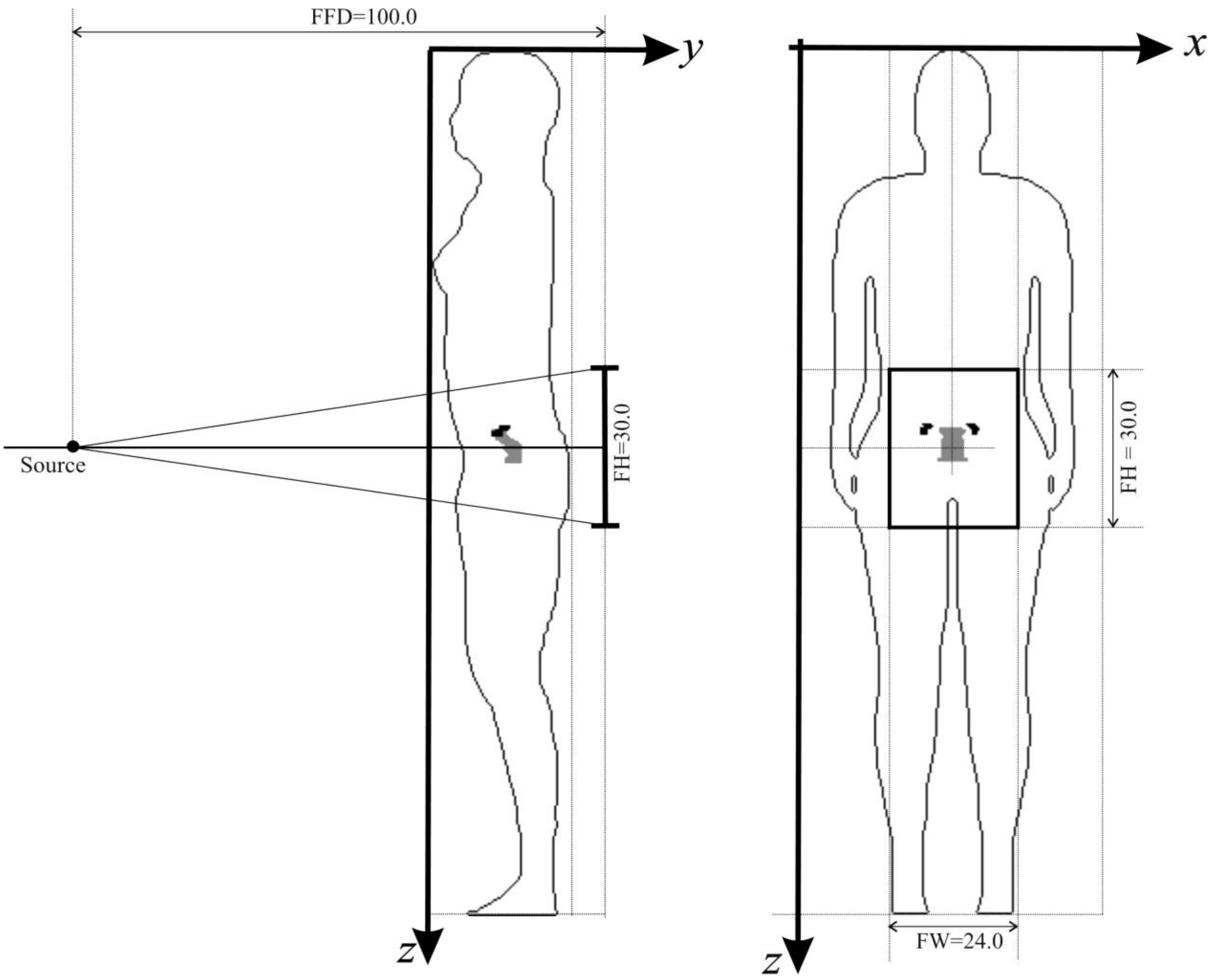

Figure 1. The FAX phantom: HSG exposure set-up for field = 24cm x 30cm and SDD = 100cm

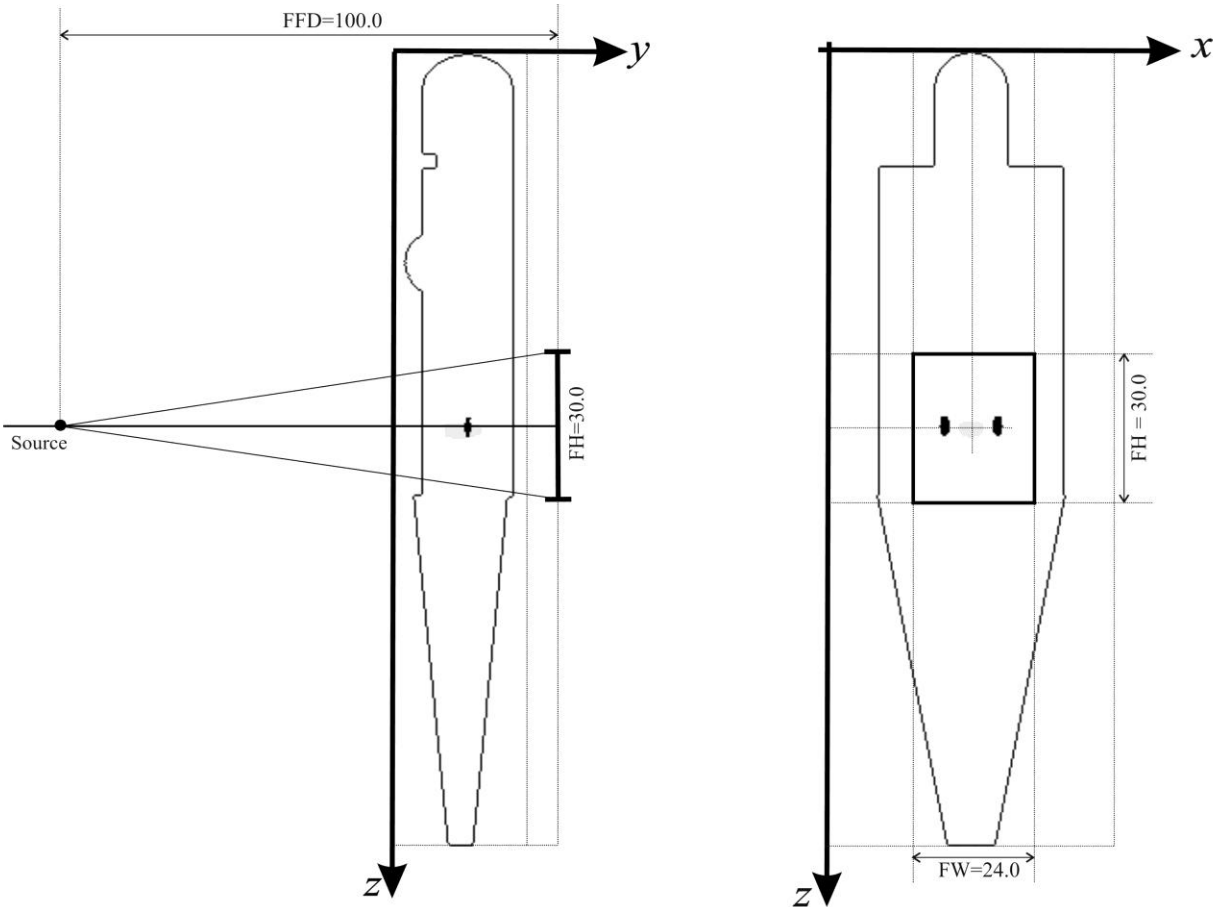

Figure 2. The EVA phantom: HSG exposure set-up for field = 24cm x 30cm and SDD = 100cm

Results

The results will be presented as CCs between organ equivalent doses and the ESAK as function of the tube voltage and the filtration. ESAK stands for *E*ntrance *S*urface *A*ir *K*erma, and refers to the center of the radiation field at the surface of the patient's body. As tube voltage and filtration increase, so do the CCs. However, the absolute value of the equivalent dose to organs will decrease, because increasing the tube voltage or the filtration reduces the mAs necessary for constant exposure to the detector system.

Conversion coefficients

Tube voltage

Figure 3 shows equivalent dose to the ovaries of the FAX and the EVA phantoms normalized to the ESAK as a function of the tube voltage for field sizes of 18cm x 24cm, and 24cm x 30cm, respectively. For the whole range of tube voltages for the smaller field size the FAX ovarian equivalent dose is ca. 25% greater than the EVA ovarian equivalent dose, while for the large field this number is about 18%. The reason for this differences are the different depths at which the ovaries are located in the two phantoms: Beginning at 6.5cm depth in the FAX phantom, and beginning at 8.3cm depth in the EVA phantom.

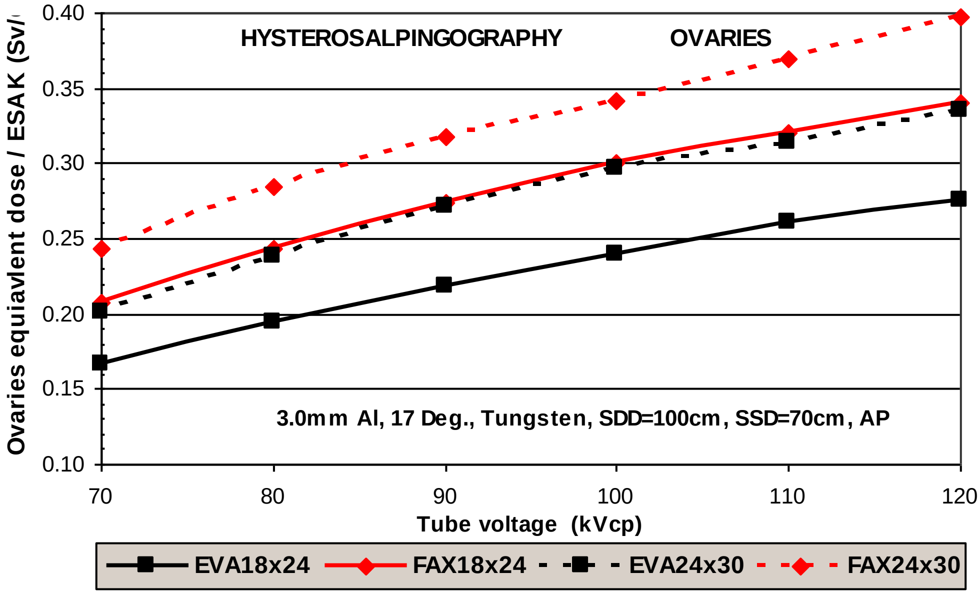

Figure 3. Conversion coefficient between equivalent dose to the ovaries and entrance surface air kerma as function of the tube voltage for field sizes of 18cm x 24cm, and 24cm x 30cm

The average CC between ovarian equivalent dose and ESAK in table 1 for references 1-3 is 0.22, and for references 4-5 it is 0.17. This should be compared with the CCs for the EVA phantom in figure 3 for a 24cm x 30cm field, for 80 kVp and 70kVp, respectively. For the EVA phantom one finds CCs of 0.24 for 80 kVp, and of 0.20 for 70 kVp. These EVA CCs agree reasonably well with the CCs from table 1 if one takes into account differences between the real HSG examination and its simulation not known here, like position of the ovaries, patient thickness, X-ray generator, filtration, etc. When the tube voltage increases from 70 kVp to 120 kVp, the CCs in figure 3 increase by ca. 65% over this range of tube voltage.

Figure 4 presents CCs for the uterus as function of the tube voltage for both phantoms and the two field sizes already mentioned. The uterus equivalent dose of the EVA phantom is ca. 36% greater than the equivalent dose to the uterus of the FAX phantom over the whole range of photon energies. Again the explanation comes from different depths at which the uteri are located in the two phantoms: Beginning at 4.7cm depth in the EVA phantom, and beginning at 6.8cm depth in the FAX phantom.
When the tube voltage increases from 70 kVp to 120 kVp, the CCs in figure 3 increase by ca. 55% over this range of tube voltage.

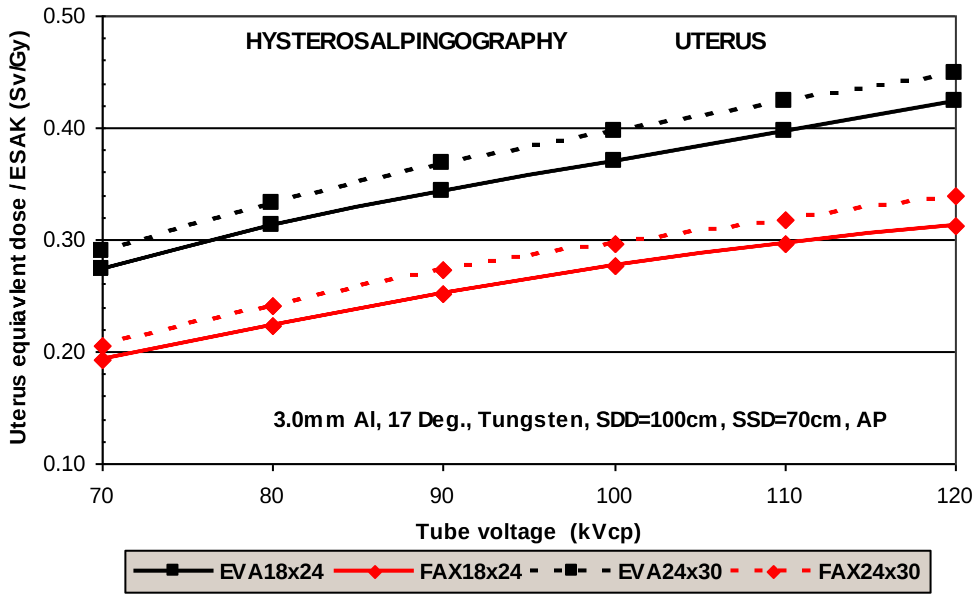

Figure 4. Conversion coefficient between equivalent dose to the uterus and entrance surface air kerma as function of the tube voltage for field sizes of 18cm x 24cm, and 24cm x 30cm

Filtration

Figure 5 shows CCs for the ovaries for the two phantoms as function of the filtration for the two field sizes. When the filtration increases from 2.0mm Al to 4.0mm Al the CCs in figure 5 increase by ca. 20% over this range of filtration.

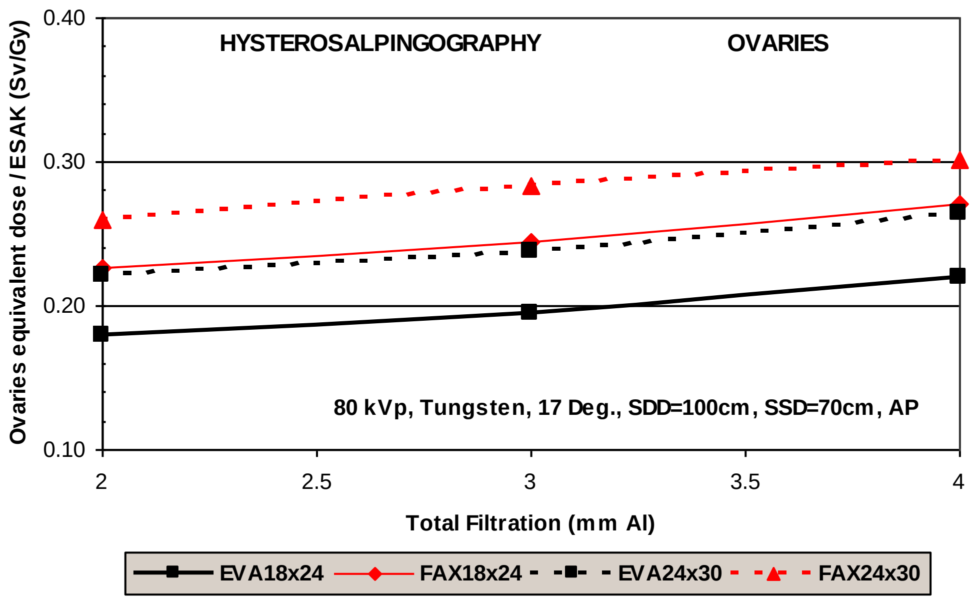

Figure 5. Conversion coefficient between equivalent dose to the ovaries and entrance surface air kerma as function of the filtration for field sizes of 18cm x 24cm, and 24cm x 30cm

Field orientation

If one understands the dimensions of the field given as width times height, then one can see from table 1 that HSG examinations in Recife/Brazil are usually made with the larger field side representing the width, while the opposite is the case for the other references cited. In order to get an idea what the effect of the field orientation on the organ equivalent doses would be, the calculations shown so far have been repeated with the larger field side representing the field width. For the radiation fields A1 = 24cm x 18cm, A2 = 18cm x 24cm, B1 = 30cm x 24cm, and B2 = 24cm x 30cm the following results have been found for the range of tube voltages between 70 and 120 kVp:

Uterus

No change of the uterus equivalent dose has been found for changing the field orientation from A2 to A1, or from B2 to B1.

Ovaries

For the FAX phantom an increase of the ovarian equivalent dose has been found between 5 and 8%, and between 2 and 4% for changing the field orientation from A2 to A1, and from B2 to B1, respectively.
For the EVA phantom an increase of the ovarian equivalent dose has been found between 13 and 16%, and between 4 and 6% for changing the field orientation from A2 to A1, and from B2 to B1, respectively.

Source-to-skin distance (SSD)

Variations of the SSD between 100cm and 120cm did not change significantly the equivalent dose to the ovaries and the uterus.

Equivalent doses per radiograph

Although the CCs shown in figure 3 and 4 increase with the tube voltage, the absolute equivalent dose per radiograph usually decreases with increasing tube voltage, because for constant exposure to the detector system the ESAK decreases with increasing tube voltage.

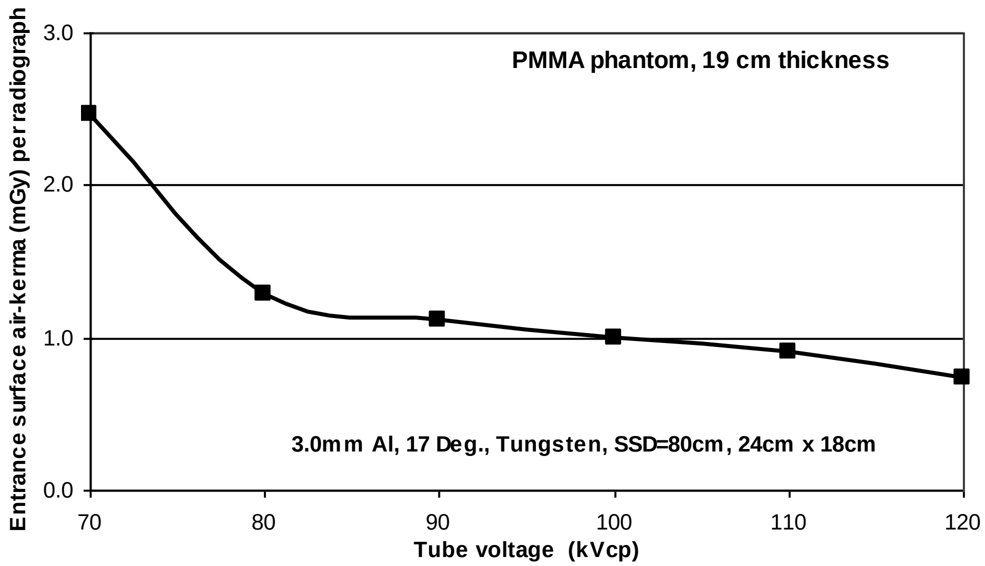

Figure 6. Entrance surface air kerma per radiograph measured with a homogeneous PMMA phantom as function of the tube voltage

Figure 6 shows the ESAK measured with a PMMA phantom as a function of the tube voltage. The reduction is about 50% when the tube voltage increases from 70 to 80 kV, while for voltages above 80kV the reduction is about 10-15% per 10 kV increase.

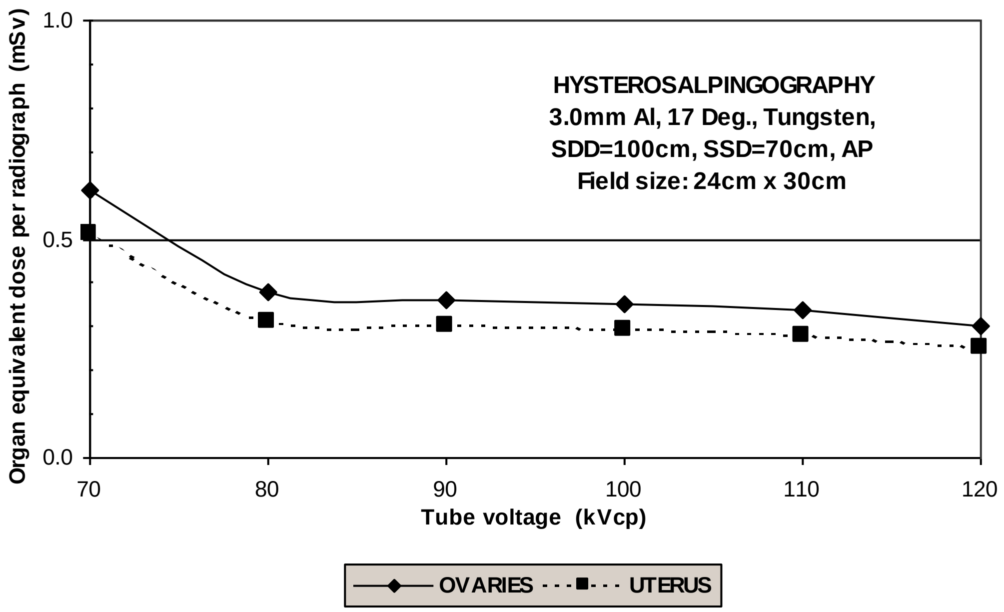

Figure 7. Ovarian and uterus equivalent dose per radiograph in HSG as function of the tube voltage

Application of the ESAK data from figure 6 to the CCs from figures 3 and 4 provides the organ equivalent doses per radiograph shown in figure 7, which confirm the reduction of exposure to the patient with increasing tube voltage by up to 50%.

The influence of the projection on organ equivalent dose

In the HSG studies cited in table 1, anterior-posterior (AP) was the most frequently used projection. However, in some countries under couch X-ray tubes are more prevalent than overcouch ones, i.e. that here posterior-anterior (PA) projections dominate the HSG examinations. Therefore some of the calculations reported above for the FAX phantom have also been done for PA projection. Figure 8 presents ratios between equivalent doses for PA and AP projection for the ovaries and the uterus.

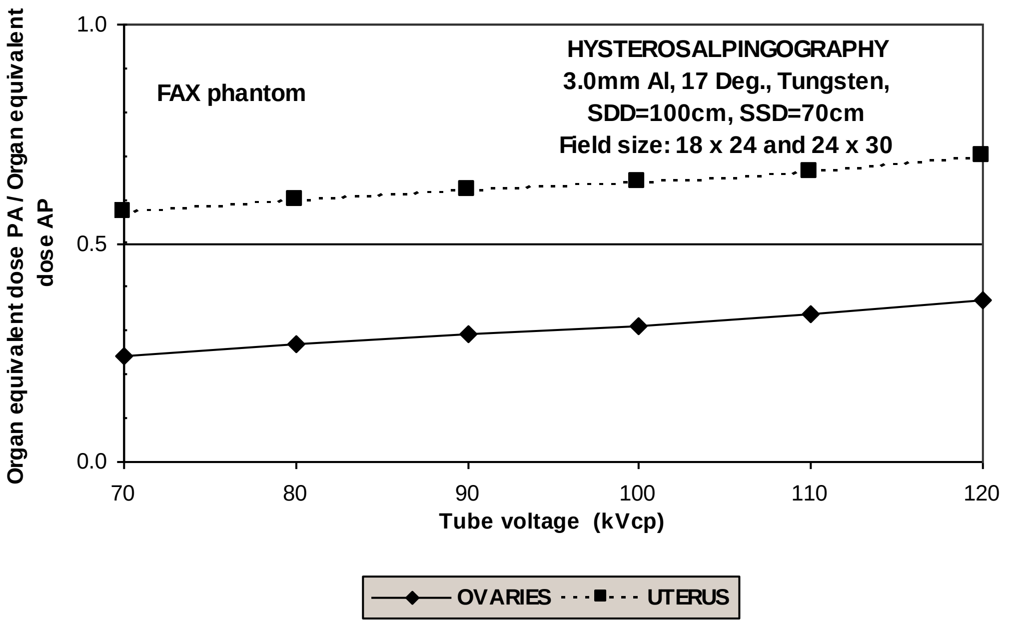

Figure 8. Ratios between organ equivalent doses for PA and AP projection as a function of the tube voltage

The ratios show that using the PA projection can lead to significant equivalent dose reductions compared to the application of the AP projection. The main reason is the presence of the pelvis in the radiation field, which shields internal abdominal organs, like the ovaries and the uterus from the incident photon radiation. The position of the ovaries in the frontal part of the FAX abdomen causes additionally a reduction of equivalent dose because for PA incidence the ovaries are located at a greater depth. For both field sizes used in this study the effect of equivalent dose reduction is about 60-75% for the ovaries, and about 30-43% for the uterus between 70 and 120 kVpc tube voltage.

Equivalent dose per HSG examination with AP projection

The results of the previous sections have shown that the CCs change with the variations of the exposure parameters. However, a tube voltage of 80 kVp, a filtration of 3.0mm Al, a field size of 24cm x 30cm, a SSD of 100cm and AP projection can be considered typical for a HSG examination. For these settings one finds for the FAX phantom in figures 3 and 4 the following CCs:

Ovaries: 0.244 Sv/Gy
Uterus : 0.205 Sv/Gy

From table 1 one can find an average ESAK of 18.7 mGy. In absolute terms this means that for a typical HSG examination of the FAX phantom one gets:

Equivalent dose to the ovaries: 4.56 mSv

Equivalent dose to the uterus : 3.83 mSv

The average ovarian dose for the MIRD5-type phantom from table 1 is 3.6 mSv, i.e. 21% less than the value for the FAX phantom, which is in agreement with the findings of figure 3.

Conclusion

Equivalent dose to the ovaries and to the uterus calculated with the FAX/EGS4 exposure model for HSG examinations as function of the tube voltage, the filtration, and the SSD. The results have been compared with similar data for the MIRD5-type EVA phantom, which was often used in recent studies.

The data have shown that ovarian equivalent doses are 18-25% greater in the FAX phantom compared to the corresponding values for the EVA phantom due to a 2cm difference between the locations of this organ below the surface in the two phantoms.

For similar reasons the uterus equivalent dose of the EVA phantoms was found to be 36% greater than the corresponding value for the FAX phantom.

As for the variation of the exposure parameters the calculations revealed an increase of 65% of the ovarian CC, and of 55% of the uterus CC for an increase of the tube voltage from 70kVp to 120 kVp. But as demonstrated the absolute values of ovarian and uterus equivalent dose are decreasing by up to 50% when the tube voltage increases. Therefore, increasing the tube voltage is usually recommended as step to reduce the exposure to the patient. This applies also to the increase of the filtration, although in absolute terms this effect was not shown here, and especially also to the choice of the PA projection.

Finally it has to be pointed out that the orientation of the field with regard to width and height can cause differences between 2 and 15% for the organ equiavlent doses discussed in this presentation.

The CCs presented can serve as a tool for patient dosimetry. If the ESAK, tube voltage, filtration, and field size are known one can multiply the ESAK with the appropriate CC from figures 3 – 5 to get an idea about the equivalent dose to the ovaries or to the uterus.

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