BIOKINETICS OF INTERNAL EMITTERS AND ABSORBED DOSE TO THE HUMAN FETUS

H.D.Roedler, A.Erzberger, A.Kaul
Institut für Strahlenhygiene des Bundesgesundheitsamtes,
8042 Neuherberg, Federal Republic of Germany

1 Objectives

In the medical use of radiopharmaceuticals as well as in the unintentional intake of radionuclides, e.g. by emission from nuclear power plants, incorporation-caused radiation exposure of the fetus as compared to that of the adult may be of particular interest. Therefore, as a research project, biokinetic data of selected radionuclide compounds were extracted from literature references on investigations in man and animal with the purpose to provide the basis for comparative assessments of fetal and adult radiation dose from incorporated radionuclides.

2 Methods

A comparative assessment of internal radiation exposure of fetal and adult tissues requires that the factors determining absorbed dose be known. In case of a tissue dose being mainly determined by the activity in this tissue, the assessment is based on the value of the proportion of fetal (f) and adult (a) tissue doses as follows:

$$\frac{D_f}{D_a} = \frac{(A_{o,f}/m_f) \cdot T_f \cdot \phi_f}{(A_{o,a}/m_a) \cdot T_a \cdot \phi_a} \qquad (1)$$

D	mean absorbed dose in respective tissue (Gy or rd)
A_o	maximum tissue activity (Bq or μCi)
m	mass of tissue (kg or g)
T	effective half-life (s or h)
ϕ	absorbed fraction

Accordingly, the following proportions should be considered for fetal and adult tissues: activity concentrations, effective half-lives and mean absorbed fractions.

There are only some radionuclides for which biokinetic data (activity concentrations and effective half-lives) measured in *human* fetuses and newborns are available that are suitable for a comparative assessment of fetal and adult radiation exposure. These are iodine 131 and iron 59 from medical use as well as strontium 90, caesium 137 and again iodine 131 from fallout due to nuclear weapons' tests. Literature references on the above radionuclides were evaluated as to activity concentrations and half-lives in total body or organs in order to perform absorbed dose calculations.

The evaluation of literature references on *animal* studies was made for activity concentrations in fetuses and mother animals as follows: summary of methods used, compilation of measured results from authors, evaluation of measurement results for ratios of activity concentrations in fetal and adult tissues, discussion of activity concentration ratios, conclusions and list of references evaluated.

---

*) Financially supported by the Bundesminister des Innern of the Federal Republic of Germany

Uniform total body distribution			
Ratio of activity concentrations in fetus and mother or reference man:			
Humans:			~1
Animals:	0.3 – 0.6		
Effective half-lives			
Human fetus:		no data	
Assumption:		50 d (equal to maternal)	
Newborn:		15 d	
Adult:	male:	110 d	
	female:	80 d	
	pregnant:	50 d	
Ratio of half-lives in fetus and mother:			~1
Ratio of total body doses to fetus and mother:			~1
Ratio of total body doses to fetus and reference man:			~0.5

Table 1: **Data and assumptions for estimating the total body dose to fetus and mother or reference man from caesium 137**

Organ with highest radiation exposure				Liver
Activity concentrations in the liver				
Fetus:	11th week:	0.319 %/g		
	22th week:	0.150 %/g		
	mean value:	0.230 %/g		
Adult:		0.0067 %/g (12%/1800g)		
Ratio of activity concentrations in fetus and adult				34
Effective half-lives, corrected for growth				
Fetus:	(0.12 x 20 d) + (0.88 x 2.4 d)		= 4.5 d	
	storage	erythropoesis		
Adult:	$T_{eff} = T_{phys}$		= 45 d	
Ratio of half-lives in fetus and adult				0.1
Liver doses per kBq (μCi)				
Fetus:	11th week:	61 mGy (165 mrd)		
	22th week:	39 mGy (104 mrd)		
Adult:		33 mGy (89 mrd)		
Ratio of liver doses in fetus and adult				1.2 – 1.9

Table 2: **Data and assumptions for estimating the liver dose to fetus and adult from iron 59**

Organ with highest radiation exposure			thyroid
Ratio of activity concentrations in fetus and mother (8 values)			1.7
Effective half-lives, corrected for growth			
Fetus:	17th week:	1.9 d	
	birth:	4.6 d	
Mother:		7.5 d	
Ratio of effective half-lives in fetus and mother:			0.25 – 0.60 (17th week – term)
Absorbed fraction of emitted β-energy			
Fetus:	⩽1		
Mother:	1		
Ratio of thyroid doses			0.43 – 1.0

Table 3: **Data and assumptions for estimating the thyroid dose to fetus and mother from iodine 131**

Organ with highest radiation exposure			bone
Ratio of activity concentrations in fetus and adult (from fallout-measurements during 1957–1966)			
– based on pCi/g Ca			~2 – 4
– based on pCi/g bone (wet)			~0.5 – 1
Effective half-lives			
Fetus:	6 months	21 d	
	9 months	97 d	
Infant:	1 year	350 d	
	2 years	600 d	
Adult:	several thousand days (power function)		
Ratio of half-lives in fetus and adult (conservative assumption: adult half-life ≈ 1000 d)			0.02 – 0.1
Absorbed fraction of energy emitted			
Fetus:	6 months	65 %	
Infant:	1 year	80 %	
Adult:		93 %	
Dose commitment per kBq(μCi)			
Fetus:	for intake at 6 months	0.22 Gy (0.6 rd)	
	for intake at 9 months	0.67 Gy (1.8 rd)	
Adult:		2.2 Gy (6.0 rd)	
Ratio of bone doses to fetus and adult:			0.1 – 0.3 (6 months – 9 months)

Table 4: **Data and assumptions for estimating the bone dose to fetus and adult from strontium 90**

3 Results

The biokinetic data from measurements in *humans* and the assumptions used for estimating the fetal and adult radiation exposure after intake of caesium 137, iron 59, iodine 131 and strontium 90 are summarized in Tables 1 – 4.

Based on *animal* experiments, the ratios of activity concentrations in fetal and adult tissues were derived for antimony, cerium, cobalt (chloride and vitamin B 12), manganese, nickel, niobium, technetium (pertechnetate, albumin, iron complex, polyphosphate, pyrophosphate, sulfur colloid, sulfur colloid albumin particles) and zinc (chloride, citrate, sulfate), whereas fetal retention data are practically non-existent. These ratios are of considerable variability, in some cases up to three orders of magnitude. This is not only due to different experimental conditions and metabolic characteristics of different species, but also due to the authors' selection of measuring times not necessarily representing the maximum fetal and adult activity concentrations.

4 Discussion

Ideally, for a comparative assessment of fetal and adult radiation dose, the activity concentrations versus time in the tissues of fetal and adult animals should be known. As an approximation, these can be replaced by the maximum activity concentrations and mean half-lives. For the total body of mother or mother animals this maximum is equal to the mean activity concentration immediately after administration and can be calculated as ratio of the administered activity and body weight. For the fetal total body, the measurements performed at selected times may not include the maximum activity concentration, even if measurements are performed at different times after administration. For organs, the interpretation of ratios of activity concentrations in fetal and adult tissues is even more difficult due to the different retention functions and the delay during diaplacental transfer, since the measurements refer only to selected times and the retention function, especially in relation to its maximum, is generally not known.

Furthermore, for a comparative assessment of the mean total body or organ dose to the human fetus, the fetal growth must be considered which, at an assumed constant total body or organ activity, leads to a decrease of the mean activity concentration. With a fetal weight of approximately 100 g at the 16th week of pregnancy and of about 3.300 g at the 40th week, this implies a purely growth related decrease of the mean activity concentration with a mean half-life of about 5 weeks. This decrease was included in the above calculations.

5 Conclusions

For those radionuclides where results from investigations in man are available (caesium 137, iron 59, iodine 131, strontium 90), a significantly higher radiation exposure of the fetus in comparison to that of the adult is not to be expected: the ratio of estimated absorbed doses to the fetus and adult is approximately in the range of 0.1 – 1.9.

Due to the scarcity and variability of relevant data on animal experiments from literature references, it appears necessary to perform studies on fetal and adult biokinetics that are particularly designed for comparative dose calculations. This concerns mainly niobium, nickel and vitamin B 12, but also technetium and zinc.

Acknowledgements

Thanks are due to Mrs. R. LeMar for assistance in translation and Mrs. I. Zeitlberger for typesetting the manuscript.