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Radiation Absorbed Dose Estimates to the Embryo from Some Nuclear Medicine Procedures

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Abstract. Using the specific absorbed fractions reported by Smith and Warner, the radiation doses absorbed by the embryo in early pregnancy were calculated for various radiopharmaceuticals used in the diagnostic procedures of nuclear medicine. Radiopharmaceuticals are considered which are excreted predominantly through urine and cause the doses to the embryo to be 40% – 90% higher than gonad doses. Also discussed are large differences of doses reported by various authors to the embryo by ^{99m}Tc-pertechnetate.

Introduction

A large number of women of childbearing age are investigated using radiopharmaceuticals in the routine practice of nuclear medicine. Sometimes the radioactive drug is administered to a woman at the beginning of her pregnancy before she is aware of her condition.

In early pregnancy the embryo is particularly sensitive to irradiation. The dose to the embryo is caused by penetrating radiation from the radioactivity in surrounding tissues as well as by radiation from the radioactivity distributed in the embryo. In the literature it is usually assumed that the dose to the embryo is similar to or equal to the gonad dose (Sear, 1974; Ellis et al., 1977).

In our paper we deal with the calculation of the radiation dose to the embryo by various radiopharmaceuticals and with the assumption that the dose to the embryo can be approximated by the gonad dose (dose to the ovaries).

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Materials and Methods

Our calculation of the dose to the embryo in the period of the organogenesis, i.e., 10–41 days after conception, is based on the specific absorbed fractions calculated by Smith and Warner (1976) for the phantom of a standard hermaphrodite weighing 70 kg. We shall review shortly the basic assumptions made by Smith and Warner The uterus is not enlarged in early pregnancy and the presence of a placenta could be neglected. The calculation does not take into account the dose resulting from the placental transfer of radioactivity to the embryo. The embryo is not irradiated by particulate radiations except when radioactivity is uniformly distributed in the whole body. The bladder is assumed to contain 200 ml of urine.

We calculated the absorbed dose to the embryo as follows:

$$\bar{D} = \sum_{k=a}^{n} \tilde{A}_k S_k + \tilde{A}_{\text{rem}} S_{\text{TB}}$$

Where $\tilde{A}_k$ is the cumulated activity in the k-th source organ, S_k, the values of the absorbed dose to the embryo per unit of cumulated activity in the k-th source organ, and S_{TB}, the absorbed dose to the embryo per unit of cumulated activity in the whole body. The cumulated activity $\tilde{A}_{\text{rem}}$ is calculated as:

$$\tilde{A}_{\text{rem}} = \tilde{A}_{\text{TB}} - \sum_{k=a}^{n} \tilde{A}_k$$

Where $\tilde{A}_{\text{TB}}$ is the cumulated activity in the whole body, *a, b, c, d, ... n* denotes the source organs.

The calculation of absorbed doses was performed by computer. The constants S_k for 6 radionuclides, ^{99m}Tc, ^{111}In, ^{113m}In, ^{123}I, ^{131}I, and ^{133}Xe, are given in a paper by Smith and Warner (1976) For other radionuclides, we calculated the values of S_k using the constants A_i from tables by Dillman and Von der Lage (1975) and the interpolated absorbed fractions from a table by Smith and Warner. The cumulated activity in individual organs and in the total whole body were taken from a report by McEwan (1974), MIRD Reports (1973, 1975, 1976), and the MIRD study by Lathrop et al. (1972).

For calculating the embryo dose we also used the more complicated equation derived by Roedler and Kaul (1975), but the results obtained differed only slightly from those yielded by the simple equation given above.

The specific absorbed fractions for the first three months of pregnancy were also calculated by Cloutier et al. (1976) We did not attempt to use them in our calculations, although a comparison with those of Smith and Warner would be interesting.

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Results and Discussion

The results of our dose calculations are summarized in Table 1, together with the gonad dose taken from the literature (McEwan, 1974, MIRD Reports 1972, 1973, 1975, 1976). For a given radiopharmaceutical, the same cumulated activity as that used for the calculation of the gonad dose was also employed to calculate the dose to the embryo.

If the calculation includes the cumulated activity in the bladder, besides that in individual organs such as the stomach, large intestine, spleen, liver, and thyroid gland, then the dose to the embryo is significantly higher than the gonad dose. This is the case for ^{99m}Tc-pertechnetate, ^{99m}Tc-polyphosphate, ^{99m}Tc-gluconate, ^{113m}In-DTPA. This phenomenon, characteristic of radiopharmaceuticals excreted predominantly in the urine, can be easily explained by Smith and Warner model (1976) which takes into account the closer proximity of the embryo to the bladder in comparison with the proximity of the ovaries. With regard to all the uncertainties concerning the calculations, the difference between the gonad dose and the dose to the embryo in early pregnancy is not too great, but it should be taken into account.

The doses to the embryo recorded in Table 1 are calculated under the assumption that the embryo contains no activity. In the event that radiopharmaceuticals cross the placenta, the doses to the embryo would be higher than those given in Table 1. However, no human data are available on the activity contained in the embryo in early pregnancy. Some information can be gained from animal experiments performed on rats (Hahn et al., 1977, 1978) and rabbits (Mahon et al., 1973). From these experiments it follows that the concentration of some radiopharmaceuticals (^{67}Ga-citrate, ^{99m}Tc-polyphosphate, and similar radiopharmaceuticals for bone scanning, albumine particles labeled with ^{99m}Tc) in the embryo is almost zero. If we assume that this finding also holds true for humans, the dose to the embryo due to such radiopharmaceuticals will be approximately the same as that given in Table 1.

Unlike the radiopharmaceuticals mentioned, ^{99m}Tc-pertechnetate was found to cross the placenta in experimental animals. On the basis of the measurement of activity in mouse embryos, Lathrop et al. (1976) estimated the dose to be approximately 1 rad in the human embryo after administration of 10 mCi $^{99m}TcO_4^-$. It is not clear whether these authors also considered the irradiation of the embryo due to the activity in surrounding organs. If they did not, the dose to the embryo must be higher than what they calculated. Hahn et al. (1977, 1978) measured the content of ^{99m}Tc-pertechnetate in early rat embryos and estimated the dose to the human embryo to be 23 mrad/mCi. Table 2 shows that there are large differences in the doses given by various authors. It is only possible to assume that the dose to the embryo, after the administration of 10 mCi $^{99m}TcO_4^-$, probably lies somewhere in the range of 0.2–1.3 rad. Further experimental data on the passage of ^{99m}Tc-pertechnetate into the embryo are needed in order to assess the dose more accurately.

The reliability of the doses stated in Table 1 depends, of course, strongly on the cumulated activity $\tilde{A}_k$ in individual source organs used for the calculation. Unfortunately, the cumulated activities are only rarely reported and the data on the biologic distribu-

Table 1. The calculated doses to the embryo after administration of some radiopharmaceuticals. Biological data on ^{99m}Tc-polyphosphate reported by Subramanian et al. (1975) suggest that the dose to the embryo from this radiopharmaceutical could be about 400 mrad/10 mCi of administered activity. An even higher dose results from ^{99m}Tc-EHDP or ^{99m}Tc-MDP

Radiopharmaceutical	Typical administered activity (μCi)	Gonad dose (mrad)	Dose to the embryo (mrad)
^{99m}Tc-pertechnetate[a]	10,000	180	270
^{99m}Tc-polyphosphate[b]	10,000	180	250
^{99m}Tc-DTPA[b]	10,000	190	350
^{99m}Tc-sulfur colloid[b]	2,000	12	14
^{99m}Tc-gluconate[b]	2,000	36	68
^{67}Ga-citrate[c]	2,000	520	500
^{113m}In-DTPA[b]	10,000	200	350
^{75}Se-methionine[d]	250	1,250	950
^{131}I-iodide[e]	5	0.7	0.75

[a] MIRD (1976), [b] McEwan (1974), [c] MIRD (1973), [d] Lathrop et al. (1972), [e] MIRD (1975)

Table 2. The gonad dose and the dose to the embryo after the administration of 10 mCi ^{99m}Tc-pertechnetate according to various authors. There is a difference between our calculation and that of Smith and Warner because we did not use the same cumulated activity in the bladder

Author	Gonad dose (mrad)	Dose to the embryo (mrad)
Our calculation according to Smith and Warner	–	270
Smith and Warner (1976)	–	390
Lathrop et al. (1976)	–	1,000
Hahn et al. (1977, 1978)	–	230
Publication HEW 77-8035	180	–
Roedler and Kaul (1975)	200	–
ICRP publication 25	200	–
Mian et al. (1977)	167	–

tion and the excretion of some radiopharmaceuticals are incomplete making their estimation impossible. On the other hand, the difference between the dose to the embryo and the gonad dose, existing for radiopharmaceuticals excreted predominantly in the urine, will remain approximately the same as that in Table 1, even when other values of cumulated activity are used.

It should be remembered that the calculation presented assume the contents of the bladder to be a fixed volume equivalent to 200 g. The dose to the embryo and the gonad dose vary substantially, depending on the daily urinary output, frequency of voiding, bladder volume at the time of voiding, and on other factors.

In conclusion, our results show that the radiation dose to the embryo cannot be approximated by the dose to the ovaries in early pregnancy. Since the uterus lies in contact with the bladder, the dose to the embryo may be significantly higher than that the ovaries receive because some radiopharmaceuticals are excreted predominantly through urine. This fact may help to evaluate the risk of nuclear medicine procedures performed on pregnant women and may have some implications for the use of the 10-day rule.

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References

Cloutier, R.J., Watson, E., Snyder, W.S.. Dose to the fetus during the first three months from gamma sources in maternal organs. In: Radiopharmaceutical Dosimetry symposium. Proc. Symp. Oak Ridge, HEW Publication (FDA) 76-8044 Rockville: U.S. Department of Health Education and Welfare 1976

Dillman, L T., von der Lage, F.C : Radionuclide decay schemes and nuclear parameters for use in radiation dose estimation. MIRD Pamphlet No. 10. New York: Society of Nuclear Medicine 1975

Ellis, R E., Nordin, B.E.C., Tothill, P., Veall, N. The application of the 'ten-day rule' in radiopharmaceutical investigations. Br. J. Radiol **50**, 200–202 (1977)

Hahn, K., Brod, K.H., Wolf, R., Eissner, D.: Untersuchungen zur Strahlenbelastung des Feten bei nuklearmedizinischen Untersuchungen von Graviden. In: Nuklearmedizin. Qualitätskriterien in der Nuklearmedizin Stuttgart-New York. F.K Schattauer 1977

Hahn, K., Wolf, R., Eissner, D.: Die Strahlenbelastung des Foeten bei nuklearmedizinischen Untersuchungen von Graviden. Vortrag beim Inter. Röntgenkongress, Rio de Janeiro 1978

ICRP Publication 25. The handling, storage and disposal of nonsealed radionuclides in hospitals and medical research establishments. Annals of the ICRP **1**, No. 2 (1977)

Lathrop, K.A., Gloria, I.V., Harper, P.V : Response of mouse foetus to radiation from Na $^{99m}TcO_4$ In: Biological and Environmental effects of low-level radiation. Proc. Symp. Chicago, Vol. II, pp. 211–221. Vienna: IAEA 1976

Lathrop, K.A., Johnston, R E., Blau, M., Rotschild, E.O.: Radiation dose to humans from ^{75}Se-L-selenomethionine. J. Nucl. Med. **13**, Suppl. No. 6 (1972)

Mahon, D.F., Subramanian, G., McAfee, J.G.: Experimental comparison of radioactive agents for studies of the placenta J Nucl. Med. **14**, 651–659 (1973)

McEwan, A.C.: Patient radiation doses from radiopharmaceuticals. Report NRL 1974/3. Christchurch National Radiation Laboratory 1974

Mian, T.A., Suzuki, H.J., Haynie, T.P., Meistrich, M L.: Radiation damage to mouse testis cells from ^{99m}Tc-pertechnetate. J. Nucl. Med. **18**, 1116–1122 (1977)

MIRD/Dose estimate report No. 2. Summary of current radiation dose estimates to humans from ^{66}Ga-, ^{67}Ga-, ^{68}Ga-, and ^{72}Ga-citrate. J. Nucl. Med. **14**, 755–756 (1973)

MIRD/Dose estimate report No. 5 Summary of current radiation dose estimates to humans from ^{123}I, ^{124}I, ^{125}I, ^{126}I, ^{130}I, ^{131}I and ^{132}I as sodium iodide. J. Nucl. Med. **16**, 857–860 (1975)

MIRD/Dose estimate Report No. 8. Summary of current radiation dose estimates to normal humans from ^{99m}Tc as sodium pertechnetate. J. Nucl. Med. **17**, 74–77 (1976)

Roedler, H.D., Kaul, A.: Radiation absorbed dose from medically administered radiopharmaceuticals. In: Biomedical dosimetry. Proc. Symp. Vienna, pp. 655–665 Vienna: IAEA 1975

Sear, R.. Radioisotopes and the '10-day rule'. Br J. Radiol **47**, 822 (1974)

Smith, E.M., Warner, G.G.: Estimates of radiation dose to the embryo from nuclear medicine procedures J. Nucl. Med **17**, 836–839 (1976)

Subramanian, G., McAfee, J.G., Blair, R.J., Kallfelz, F.A., Thomas, F.D.· Technetium-99m-methylene diphosphonate – a superior agent for skeletal imaging: comparison with other technetium complexes. J. Nucl Med. **16**, 744–755 (1975)

The developing role of short-lived radionuclides in nuclear medicine. HEW Publication (FDA) 77-8035 Rockville: U.S Department of Health, Education and Welfare 1977

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