

Absorbed ^{18}F -FDG Dose to the Fetus During Early Pregnancy

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We describe a rare case of a woman who underwent ^{18}F -FDG PET/CT during early pregnancy (fetus age, 10 wk). The fetal absorbed dose was calculated by taking into account the ^{18}F -FDG fetal self-dose, photon dose coming from the maternal tissues, and CT dose received by both mother and fetus. **Methods:** The patient (weight, 71 kg) had received 296 MBq of ^{18}F -FDG. Imaging started at 1 h, with unenhanced CT acquisition, followed by PET acquisition. From the standardized uptake value measured in fetal tissues, we calculated the total number of disintegrations per unit of injected activity. Monte Carlo analysis was then used to derive the fetal ^{18}F -FDG self-dose, including positrons and self-absorbed photons. Photon dose from maternal tissues and CT dose were added to obtain the final dose. **Results:** The maximum standardized uptake value in fetal tissues was 4.5. Monte Carlo simulation showed that the fetal self-dose was 3.0×10^{-2} mGy/MBq (2.7×10^{-2} mGy/MBq from positrons and 0.3×10^{-2} mGy/MBq from photons). The estimated photon dose to the fetus from maternal tissues was 1.04×10^{-2} mGy/MBq. Accordingly, the specific ^{18}F -FDG dose to the fetus was about 4.0×10^{-2} mGy/MBq (11.8 mGy in this patient). The CT scan added a further 10 mGy. **Conclusion:** The dose to the fetus during early pregnancy can be as high as 4.0×10^{-2} mGy/MBq of ^{18}F -FDG. Current dosimetric standards in early pregnancy may need to be revised.

Key Words: fetal dosimetry; ^{18}F -FDG PET/CT; Monte Carlo simulation

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Several million ^{18}F -FDG PET examinations are performed annually worldwide, yet dosimetry reports of ^{18}F -FDG PET examinations accidentally performed during pregnancy are still exceptional (1).

Although the photon component of the fetal dose, coming from maternal tissues, can be reliably estimated from phantom measurements, the intensity of fetal tissue

uptake—which is essential for deriving the self-dose from positrons—is poorly known.

We describe in the present article a rare case of a woman who underwent ^{18}F -FDG PET/CT while pregnant. The total fetal dosimetry was calculated by taking into account the fetal ^{18}F -FDG self-dose, dose coming from the maternal tissues, and CT dose.

MATERIALS AND METHODS

A 30-y-old woman (weight, 71 kg) underwent ^{18}F -FDG PET/CT for the follow-up of Hodgkin lymphoma. The lymphoma had been treated by chemotherapy and radiotherapy. The last chemotherapy ended 1 mo before the scan. The scan was required to verify the absence of residual disease.

The patient was examined using a Discovery ST (GE Healthcare) PET/CT hybrid scanner, starting at 1 h after the injection of 296 MBq of ^{18}F -FDG. Imaging was obtained from the base of the skull to the mid-thigh level. The PET scan, acquired in 3 dimensions, lasted about 20 min (7 table positions, 3 min per position). The images were reconstructed with an iterative (ordered-subset expectation maximization) algorithm using unenhanced CT data for attenuation correction (CT parameters: 140 keV, 80 mAs, and 5-mm section thickness). Coregistered images were displayed on a Xeleris workstation (GE Healthcare).

In the institution where the examination was performed, patients with child-bearing potential are informed that PET/CT cannot be performed in the case of pregnancy. They are asked about the date of their last menstruation, use of contraceptive devices, and other factors. The patient had been in amenorrhea since the end of the chemotherapy. However, she was fully confident that she was not pregnant, because she had an intrauterine device (well visible on the CT images). Therefore, a serum pregnancy test was not done before imaging.

The pregnancy was first suspected at review of imaging. The fetus was at about 10 wk of gestational age on the day of PET/CT examination.

The fetal self-dose, photon dose coming from maternal tissues, and CT dose were independently assessed.

Self-Dose

We first calculated the weight-based maximum standardized uptake value (SUV_{max}), using circular regions of interest drawn around the fetus on multiple slices, encompassing the entire fetal volume. Then, we derived the total number of disintegrations per

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unit of injected activity. Because the cumulated activity in the fetus is not known, we assumed an instantaneous tracer uptake and no biologic removal.

We considered that the fetus, on the day of the ^{18}F -FDG study, had the average dimensions of a normal fetus at 10 wk (2). The fetus was thus represented by a cylinder capped with hemispheres, with a total length of 6 cm and a diameter of 1.13 cm (volume, 21 cm³).

Monte Carlo analysis, performed with GATE (3), was used to derive the positron and the photon self-dose. In a previous case report (1), the photon self-dose was neglected because the fetus in that case was smaller (4.8 cm³). The pregnancy was more advanced in the present case, and photons needed to be considered.

Photon Dose

We calculated an average photon dose to the fetus using the 3-mo pregnant woman anthropomorphic phantom included in the OLINDA software (4). Because we did not know the pharmacokinetics in maternal tissues for this specific patient, we used published average data on the pharmacokinetics of ^{18}F -FDG (5).

CT Dose

We calculated the CT dose using the whole-body volumetric CT dose index, as displayed on the operator's console. The volumetric CT dose index is a close estimation of the fetal dose in early pregnancy (6,7).

RESULTS

On the PET images, the fetus was visualized in the middle of the uterine cavity (Fig. 1). It was seen as a C-shaped structure—which evokes the idea of the classic fetal position—several centimeters in length and with one end bigger than the other (the head and the feet, respectively).

The fetus, as compared with maternal tissues, showed a high ^{18}F -FDG uptake. The SUV_{max} in the fetus, found in 2 successive slices in the region of the head, was 4.5. We thus used this value to derive the total number of disintegrations occurring in the fetus. Low variability of SUV_{max} across the different fetal slices, with a mean of 4.1 ± 0.4 , was observed. However, given the poor spatial resolution of PET machines, the radioactivity distribution was likely to be more heterogeneous than it appeared on PET images. Thus, our study did not address the possibility of heterogeneous dose distribution at a microscopic level.

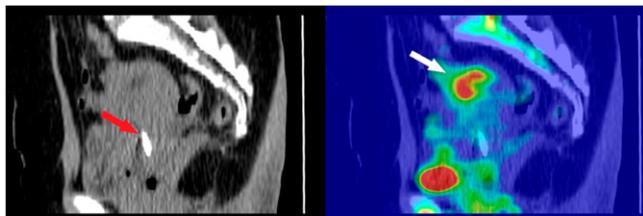


FIGURE 1. Sagittal CT (left) and fused ^{18}F -FDG PET and CT (right) slices through uterus. Fetus is indicated by white arrow. Red arrow points to portion of intrauterine device visible in this CT slice.

The PET scan did not show any pathologic focus that could be linked to the lymphoma. The patient has been disease-free since the time that this scan was obtained (4 y before publication of this report).

Fetal Self-Dose

The total number of disintegrations occurring in the fetus was 12,623,000/MBq injected to the mother. Monte Carlo simulation showed that the total energy released and absorbed in fetal tissues was about 3.9×10^6 MeV/MBq injected, composed of 3.5×10^6 MeV from positrons (2.7×10^{-2} mGy/MBq) and 3.8×10^5 MeV from photons (0.3×10^{-2} mGy/MBq). Thus, the total fetal self-dose was 3.0×10^{-2} mGy/MBq (90% from positrons and 10% from photons).

Photon Dose

The photon cross-dose to the fetus, coming from maternal tissues, was 1.04×10^{-2} mGy/MBq.

In total, the average dose to the fetus per unit of ^{18}F -FDG activity administered to the mother was estimated at about 4.0×10^{-2} mGy/MBq (11.8 mGy in this patient, who received 296 MBq).

The CT acquisitions added a further 10 mGy. Thus, the final absorbed dose for this fetus was 21.8 mGy.

DISCUSSION

The present case is, to our knowledge, only the second ever reported in the literature. Our results suggest that the dose received by a 10-wk-old fetus is about 4.0×10^{-2} mGy/MBq of ^{18}F -FDG injected to the mother. This figure is higher than currently reported standard values for early pregnancy (2.2×10^{-2} mGy/MBq) (8). These standard values were extrapolated from PET images of monkeys in late pregnancy, which showed a similar ^{18}F -FDG uptake between maternal and fetal tissues (9).

The present case showed a much higher ^{18}F -FDG uptake in human fetal tissues. One likely explanation, besides species differences, is that early pregnancy is characterized by rapid cell proliferation (10), which is generally associated with high glucose consumption.

The fetal absorbed dose in the present case was also higher than that of the previously reported case (at a different institution), which had an estimated fetal absorbed dose of 3.3×10^{-2} mGy/MBq (1). This difference could be due not only to the normal interindividual variability but also to the larger dimensions of the fetus in the present case, so that the SUV_{max} was less influenced by partial-volume effect.

Because the measure of radioactivity concentration in the fetus is likely to be influenced by partial-volume effect, we chose to use the SUV_{max} as the most accurate and conservative value to represent the average concentration in the fetus. Moreover, it is possible that even the SUV_{max} underestimates the real activity concentration, because at

this age the fetus still has nonnegligible mobility inside the uterine cavity.

In the previous case (11), the placenta was seen as a thin layer of activity lining the inner portion of most of the uterine wall. However, in the present case, we did not observe any placental ^{18}F -FDG uptake. Data from other case reports are needed to clarify this issue.

After the discovery of this unplanned pregnancy, the woman chose to abort.

CONCLUSION

In agreement with a previously published case report (1), ^{18}F -FDG fetal uptake in early pregnancy is higher than current dosimetric standards, mainly because of a high positron self-dose. Current dosimetric standards in early pregnancy may need to be revised.

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