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Construction of Pregnant Female Phantoms at Different Gestation Periods for Radiation Dosimetry

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Abstract - Medical imaging procedures, including CT, PET, and SPECT, involving the use of ionizing radiation, are nowadays playing a pivotal role in clinical diagnosis, staging and restaging, and treatment monitoring of a number of diseases. Due to the high radiosensitivity of the embryo/fetus, the concerns of possible radiation-induced cancers from medical and non-medical exposures of the pregnant female continue to grow, thus stimulating the need for accurate fetal radiation dose estimation at the organ level from common nuclear medical procedures. Methods: To obtain realistic biological and physical representations of the pregnant female body and embedded fetus, we constructed a series of hybrid computational pregnant female phantoms including the fetus at 8, 10, 15, 20, 25, 30, 35 and 38 weeks post-conception ages. We evaluate the S-values of F-18 as well as the absorbed dose and effective dose for six F-18 labeled radiotracers using realistic anthropomorphic computational phantoms at 8 different gestation periods, and the most recent biokinetic data available. The Monte Carlo N-Particle eXtended (MCNPX) general purpose Monte Carlo code was used for radiation transport simulation. Results: The masses of most fetal organs in the developed hybrid pregnant female phantoms match the reference data at corresponding gestation periods. For ^{18}F-FDG, the estimated absorbed dose and effective dose to the 8-week fetus are 0.032 mGy/MBq and 0.033 mSv/MBq, respectively. Conclusion: The generated computational pregnant female phantoms can be exploited to estimate the radiation dose delivered to pregnant patients and fetus from various radiation sources used in clinical and research settings. The generated dosimetric data can be used to assess the radiation risks to pregnant woman and fetus undergoing PET studies involving the administration of ^{18}F-FDG or other tracers.

Index Terms - Pregnant female model, radiation dosimetry

I. INTRODUCTION

Pregnant females represent a critical subpopulation for which absorbed doses from radiologic imaging procedures must be evaluated to make critical decisions regarding fetal health. Over the period 1997-2006, the number of radiologic examinations performed in the US in general and those involving pregnant patients in particular, have increased by 121% and 89%, respectively [1]. The impact on health of fetal radiation exposure depends on the gestation period at the time of exposure and the absorbed dose level. At fetal doses below 50 mGy, the primary risk for the fetus is childhood cancer, an organ-specific disease with no demonstrated dose threshold. Accurate assessment of fetal absorbed dose following exposure to ionizing irradiation requires the use of reliable computational phantoms representing the physiological and anatomical characteristics of the developing fetus and maternal body. In this work, we constructed a series of pregnant female models based on existing available pregnant female, fetus and newborn models. Monte Carlo simulations were then used for the calculation of S-values in different organs/tissues of pregnant female at different gestation periods for F-18 as well as fetal/maternal absorbed doses and effective doses from six F-18 labelled radiotracers.

II. METHODS

A. Pregnant female phantoms

The Rensselaer Polytechnic Institute (RPI) pregnant female phantom series [2], the Fetal and Mother Numerical Models (FEMONUM) of Telecom ParisTech [3], the Katja phantom (24 weeks-gestation) of Helmholtz Zentrum [4] and the UF-NCI newborn model [5] were used to construct representative fetus and reference pregnant woman models. The maternal body and most maternal organs of the developed phantoms were obtained from the RPI phantoms [6]. The uterine wall, placenta, umbilical cord, amniotic fluid, vesicule vitelline and fetal body contour of 8 and 10 weeks gestation were obtained from 8 and 10 weeks FEMONUM phantoms. The fetal skeleton and fetal bone marrow of all phantoms were scaled from RPI 9-months phantoms to match the reference values of ICRP 89 [7]. The fetal esophagus, fetal thyroid, fetal salivary gland, fetal LI, fetal SI, fetal UB and fetal testis were scaled from the UF-NCI newborn phantom with the same ratios as the fetal skeleton. The fetal spinal cord was constructed as a pipe model along the spine. The fetal brain, eyes, lungs, heart, stomach, gall bladder of 8-20 weeks gestation, 25-35 weeks gestation and 38-week gestation were scaled from corresponding fetal tissues of Katja model, FEMONUM models of 26, 30 and 35 weeks and UF-NCI newborn model, respectively. The fetal kidneys and fetal liver of 8-30 weeks gestation models and 35-38 weeks gestation models were scaled from Katja model and UF-NCI newborn model, respectively. The ICRP reference organ masses were set as the target mass during the organ scaling procedure. The breast, maternal abdomen, maternal LI and SI and maternal bladder were manually adjusted at each gestation period using the Rhinoceros™ package.

B. Dosimetry calculations

The MCNPX code was used for Monte Carlo simulations of F-18 sources in 54 identified maternal and fetal organs. The MIRD formalism was adopted to calculate S-values of F-18 and to estimate radiation absorbed dose delivered to fetal and maternal organs from six F-18 labelled radiotracers. An equal average activity concentration was assumed in maternal and fetal tissues for all considered radiotracers.

III. RESULTS

A. Computational phantoms

Figure 1 shows the constructed computational pregnant female phantoms at 8-, 10-, 15-, 20-, 25-, 30-, 35- and 38-weeks gestation. Figure 2 shows the embedded computational fetus phantoms at corresponding gestation periods. The body contours and organ volumes of pregnant female and fetus were adjusted to match the reference mass of the ICRP publication 89 at different gestation periods.

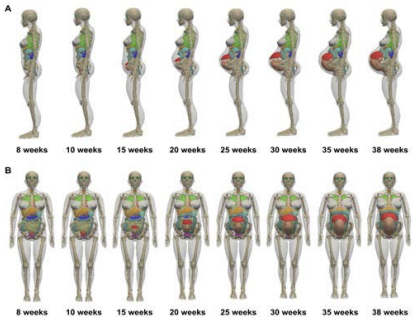

Figure 1. (A) Side view and (B) front view of the developed pregnant female phantoms at different gestation periods.

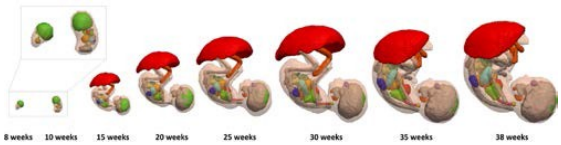

Figure 2. 3D visualization of the embedded fetus phantoms

B. S-values for F-18

Figure 3 shows the self-absorbed S-values for representative fetal organs from F-18. For all fetal organs, the self-absorbed S-values decrease with gestation age as the fetal weight increases.

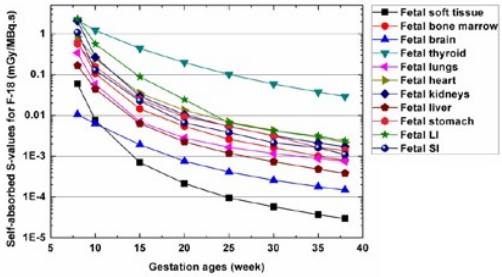

Figure 3. Self-absorbed S-values of F-18 for fetal organs

C. Absorbed dose and effective dose from radiotracers

The fetal and maternal absorbed dosed and effective dosed from ^{18}F-Amino acids, ^{18}F-Brain receptor substances, ^{18}F-FDG, ^{18}F-L-dopa, ^{18}F-FBPA and ^{18}F-FDOPA were calculated. For ^{18}F-FDG, the estimated absorbed doses to the fetal total body are 0.032 mGy/MBq, 0.026 mGy/MBq, 0.021 mGy/MBq, 0.017 mGy/MBq, 0.016 mGy/MBq, 0.015 mGy/MBq, 0.014 mGy/MBq and 0.013 mGy/MBq at 8, 10, 15, 20, 25, 30, 35 and 38 weeks gestation, respectively. The effective doses per unit administered activity to the fetus and pregnant female from ^{18}F-FDG were compared in Figure 4.

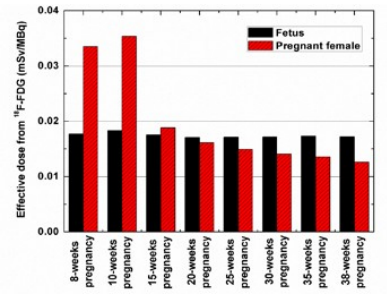

Figure 4. Effective dose per unit administered activity (mSv/MBq) to the fetus and pregnant female from ^{18}F-FDG.

IV. CONCLUSION

The generated hybrid computational pregnant female phantoms can be exploited to estimate the radiation dose delivered to pregnant patients and fetus from various radiologic examinations used in clinical and research settings. The generated dosimetric data of F-18 can be used to assess fetal radiation risks from various ^{18}F-labelled radiotracers.

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