Construction of a computational model of pregnant patients with twins for radiation dosimetry

Tianwu Xie [1], Paolo Zanotti Fregonara[2,3] and Habib Zaidi [1,4*]
[1] Department of Medical Imaging and Information Sciences, Geneva University Hospital, CH-1211 Geneva 4, Switzerland
[2] Department of Nuclear Medicine, University Hospital of Bordeaux, Bordeaux, France
[3] Houston Methodist Research Institute, Houston, TX, USA
[4] Department of Nuclear Medicine and Molecular Imaging, University Medical Center Groningen, Groningen, Netherlands
*Corresponding author: Habib.Zaidi@hcuge.ch

***Abstract*—Objectives: The radiation dose delivered to the fetus during radiological imaging procedures of pregnant patients raises health concerns because of the high radiosensitivity of the developing embryo and fetus. To assess the diagnostic benefits considering the radiation risks, the radiologist requires reasonably accurate and detailed estimates of the fetal dose from radiological imaging procedures. We present here a case of pregnant patient with twins who received PET/CT scan. To produce realistic biological and physical representations of pregnant patients and embedded fetus, we developed a patient-specific voxel-based computational model based on existing standardized hybrid pregnant female phantoms and fetus model and estimated the maternal absorbed dose and fetal organ dose from ^{18}F-FDG. The N-Particle eXtended (MCNPX) general purpose Monte Carlo code was used for radiation transport simulation. The normalized fetal absorbed dose are 0.018 and 0.02 mGy/MBq for the two fetus, respectively. The fetus brain receive an absorbed dose of 0.024 mGy/MBq and 0.016 mGy/MBq, respectively. The fetal organ dose is affected by the fetal position. The methodology for construction of personalized computational models can be exploited to estimate patient-specific radiation dose.**

***Index Terms*—twins; computational model; pregnant patient; radiation dose; ^{18}F-FDG**

I. Introduction

Pregnant females represent a critical subpopulation for which absorbed doses from radiologic imaging procedures must be evaluated to make critical decisions regarding the outcome of the developing fetus. At fetal doses greater than 50 mGy, the potential hazard effects of radiation on the fetus include embryonic death, intra-uterine growth limitation, average intelligence quotient (IQ) loss, mental retardation, organ malformation, and small head size. [1] Stochastic effects, such as cancer and organ-specific disease might also occur at fetal doses below 50 mGy. [2,3] The fetal nervous system exhibits a longer period of sensitivity to ionizing radiation than other fetal tissues and is also known to be affected by radiation exposure above 5 mGy.

Accurate estimation of fetal absorbed dose in diagnostic radiological procedures is highly desired owing to the high radiosensitivity of developing fetal organs and constitutes an enormous challenge owing to the difficulties associated with direct measurement of energy deposition in the fetal body. Different approaches have been followed to estimate the fetal dose, including Monte Carlo simulations using computational anthropomorphic models and measurements using physical phantoms with embedded dosimeters. [4-7] However, in this case, to their knowledge, the computational pregnant female model of twins has never been reported before. Therefore, in this work, we constructed a computational fetus model of twins and propose a methodology for the construction of patient-specific computational models based on image segmentation and registration methods and previously developed standardized hybrid computational phantoms of pregnant female series.

II. Methods

A. Patient-specific Computational Models

Standerlized ICRP-based pregnant female computational phantoms were developed based on the Rensselaer Polytechnic Institute pregnant (RPI) female phantom series, the Fetal and Mother Numerical Models (FEMONUM) of Telecom ParisTech and the Katja phantom of Helmholtz Zentrum. The developed standerlized phantoms were used as anchor models for the construction of patient-specific models. Figure 1 shows the constructed twins model. Figure 2 shows the standerlized ICRP-based pregnant female computational phantoms with twins at 35- and 25-week gestation.

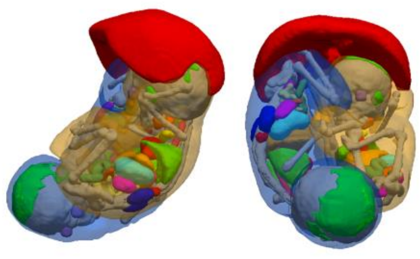

Figure 1. Constructed twins model.

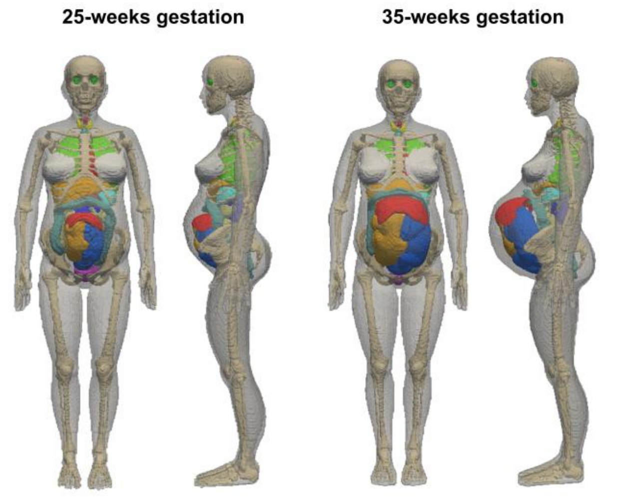

Figure 2. Standerlized ICRP-based pregnant computational phantoms with twins at 35- and 25-week gestation

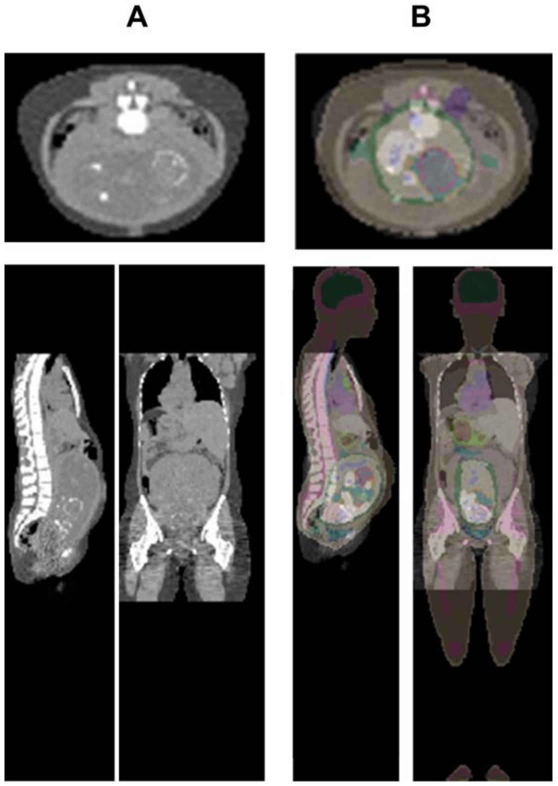

Figure 3. Representative slices showing transverse (top), sagittal (bottom and left) and coronal (bottom and right) views of two examples of the (A) original CT images of patient and (**B**) registered computational model with patient image.

CT images of patient were segmented and utilized for the construction of regional voxel-based models. The developed anchor models were registered to regional patient-specific voxel-based models using a 3-D deformable registration algorithm to produce new personalized pregnant phantoms with well-defined anatomical structures, matching patient images obtained from CT examinations. Image registration was performed using the Insight Toolkit (ITK, https://itk.org/ItkSoftwareGuide). (As shown in Figure 3) The personalized voxel-based pregnant phantoms were used as input for MCNPX-based Monte Carlo calculations of CT radiation dose to the fetus and maternal body.

B. *Monte Carlo Simulations*

The developed computational pregnant female phantoms were imported to the MCNPX code for radiation transport simulations. S-values of uniformly distributed positron-emitting sources in all identified maternal and fetal tissues were calculated. Absorbed dose and effective dose delivered to fetal and maternal body organs from ^{18}F-FDG were calculated based on biokinetic data reported in ICRP publications.

III. RESULTS

The normalized fetal absorbed doses are 0.018 and 0.02 mGy/MBq for the two fetuses, respectively. The fetus brain receive an absorbed dose of 0.024 mGy/MBq and 0.016 mGy/MBq, respectively. The absolute difference of absorbed organ dose between the two fetus ranges from 37% to 54%.

IV. CONCLUSION

The fetal organ dose is affected by the fetal position. The methodology for construction of personalized computational models can be exploited to estimate patient-specific radiation dose.

ACKNOWLEDGMENT

This work was supported by the Swiss National Science Foundation under Grant SNSF 31003A-149957.

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