Fetal Phantom Construction of Real-World Pregnant Patients Who Underwent Radiotherapy

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INTRODUCTION

Radiation risks for the fetus are a major concern for pregnant patients who undergo radiation therapy or diagnostic imaging [1,2]. The number of patients undergoing radiation therapy has increased because of the vast improvement in cancer detection, treatment, and survival for patients. However, these patients are at higher risk for secondary malignancies due to their radiation exposure [3]. These concerns extend to the fetus if the mother is treated with radiation during pregnancy. The AAPM Radiation Therapy Committee Task Group 36 (TG-36) reported that up to 4,000 pregnant women in the United States receive radiotherapy treatment every year [4]. Cancer is the number one cause of death in women aged 35 to 54 years. The most common invasive cancer types in pregnant women are breast cancer, cervical cancer, lymphoma, malignant melanoma, and thyroid cancer [5,6].

26% of breast cancer in pregnant women [6]

26% of cervical cancer in pregnant women [6]

15% of leukemia cancer in pregnant women [6]

PURPOSE

To develop a series of realistic computational human fetal phantom model sets derived from human pregnant patients at different gestational ages to accurately estimate the radiation dose to the fetal organs for a pregnant patient undergoing radiation therapy or diagnostic imaging.

METHODS

Three computational phantom models were obtained using de-identified good quality Computed Tomography (CT) and Magnetic Resonance (MR) imaging data for each fetus to construct a complete anatomically accurate fetus, gravid uterus, and placenta. All radiological images in DICOM format were anonymized under an approved IRB protocol to conduct this study. The fetal organs were outlined from radiological images using the Velocity Treatment Planning System (TPS) (Figures 1&2) and imported into 3D modeling software Rhinoceros [7] for further reconstruction and combining with the revised adult ICRP phantom (Figure 3). All fetus organ (total 34) and adult female organ (total 34) masses were accurately adjusted to match the reference data described in ICRP-89 [8]. Since radiotherapy is typically avoided during the first trimester of pregnancy, our fetal model series includes 20, 31, and 35 weeks of pregnancy.

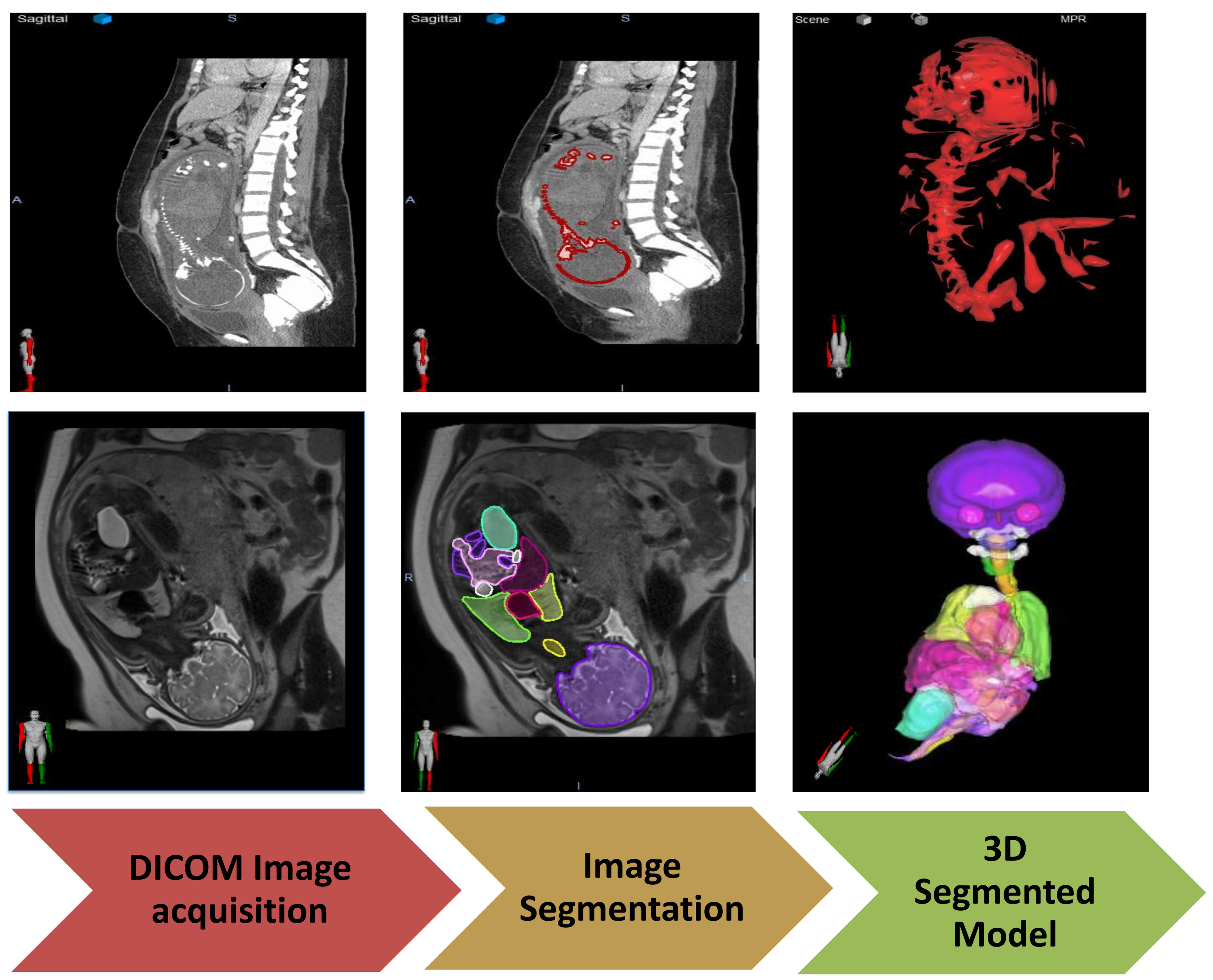

Figure 1: Sagittal CT (top raw) and MRI (bottom raw) images of a pregnant patient at 35 weeks of gestation, demonstrating segmentation using Velocity Software (TPS) and the 3D model for export in DICOM-STRUCTURE format.

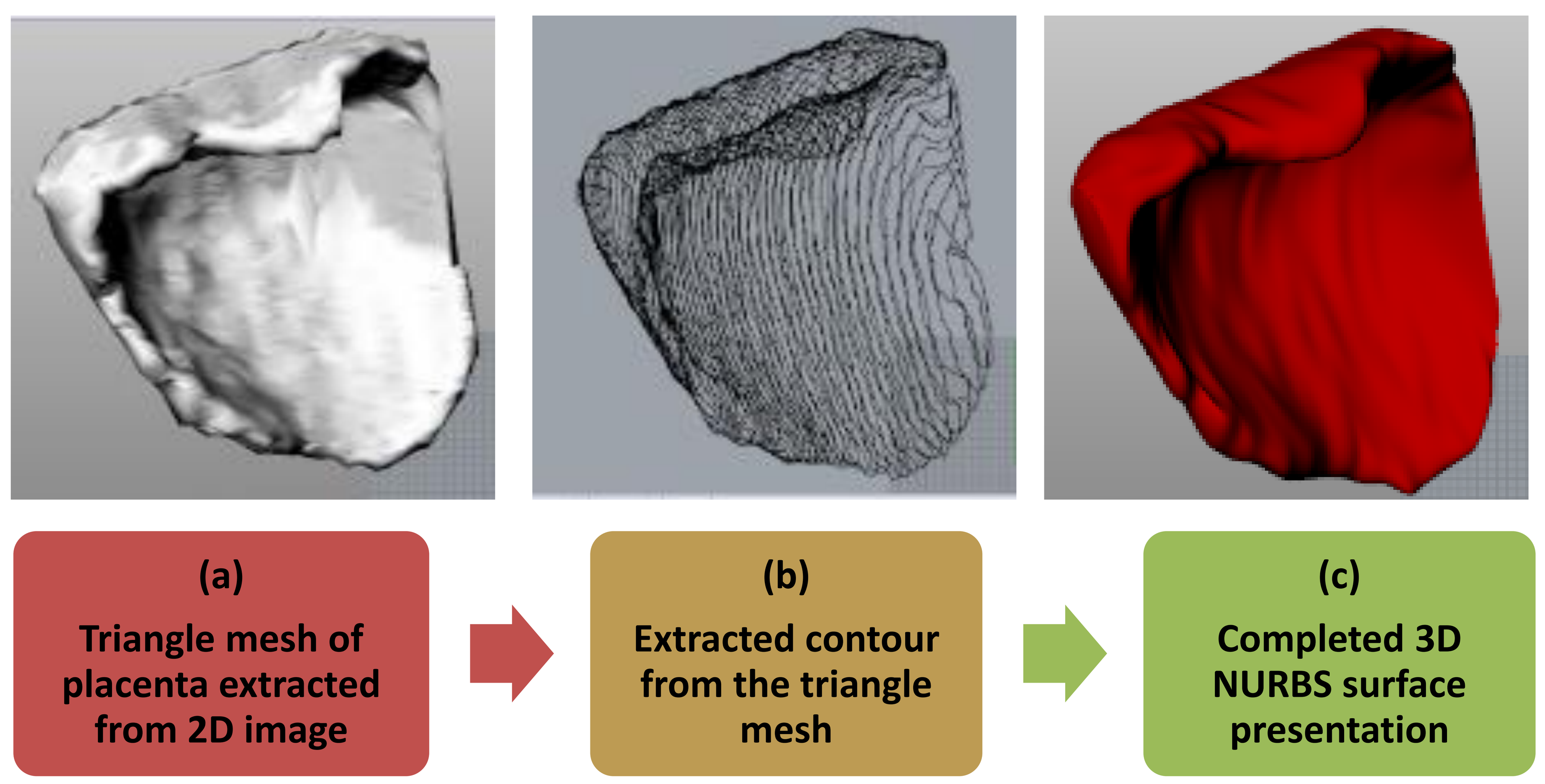

Figure 2: An example of model development, in this case the placenta. (a) The original triangle mesh model extracted from 2D MR imaging. (b) The extracted contours from the original model. (c) The completed 3D Non-uniform rational basis spline surface (NURBS) representation of the placenta model.

RESULTS

The fetal organs were accurately converted to NURBS-surfaces including the brain, heart, kidneys, liver, lungs, pancreas, spleen, stomach, thymus, trachea, gall bladder, skeleton, urinary bladder, pituitary gland, thyroid gland, tongue, tooth buds, and umbilical cord. The maternal uterus and placenta were also completed. Eyes and lenses were replaced with spheroid and ellipsoid objects that match the initially segmented organs. The total fetal organ masses were matched to ICRP-89 data for dosimetry study [8].

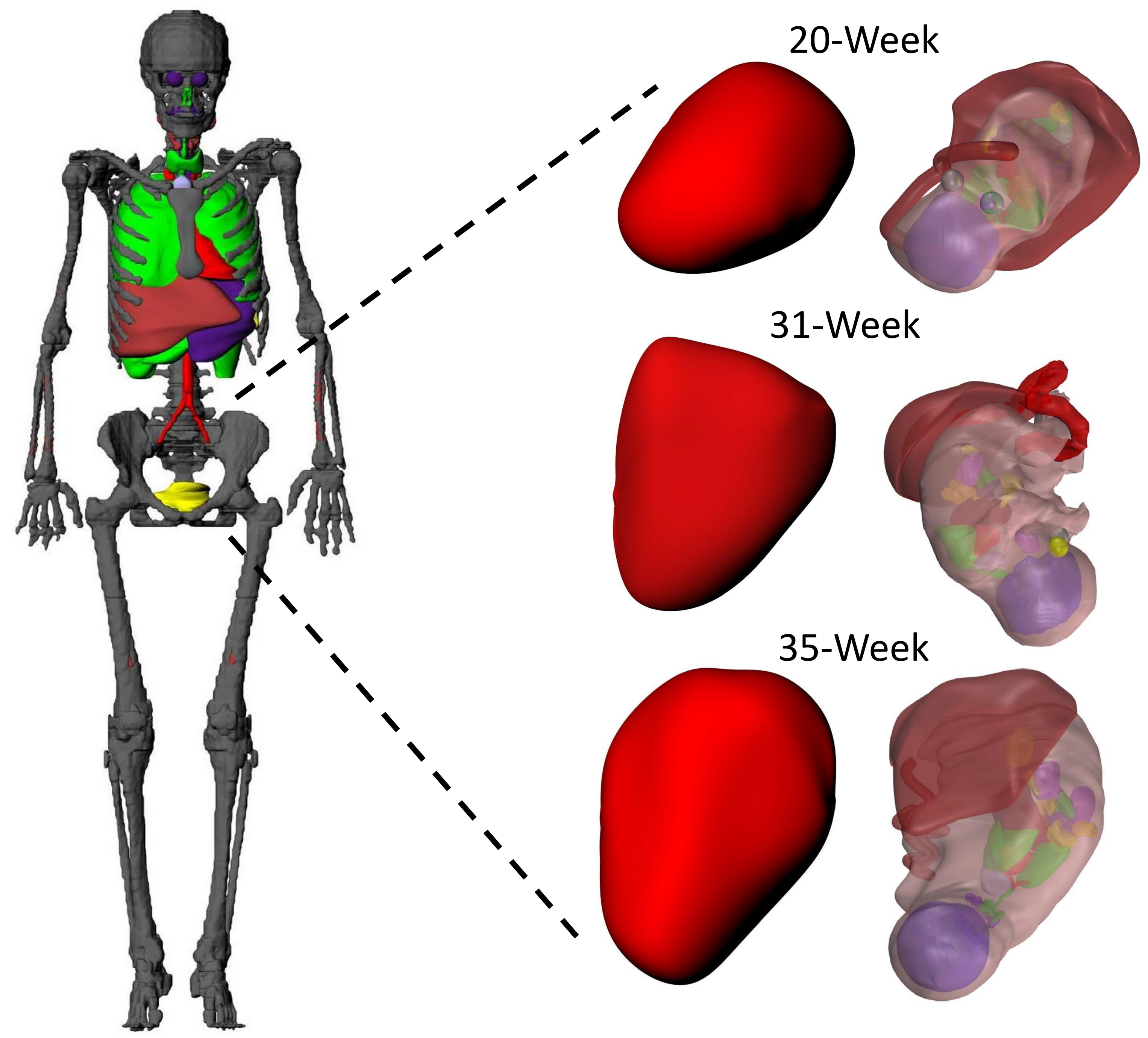

Figure 3: Three dimensional representations of NURBS-surfaces pregnant female model with her fetus models at 20, 31, and 35 weeks of gestation.

CONCLUSION

These newly developed fetal computational models at different gestation ages based on real-world imaging of pregnant patients will be useful in evaluating radiation dose to the fetus and ultimately risk assessment for the pregnant patient seeking radiotherapy or diagnostic imaging.

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