

Investigation of Fetal Radiation Dose Estimation Methods

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Introduction

- Pregnant patients receive radiation from necessary computed tomography (CT) scans
- *In utero* doses greater than 100mGy may cause miscarriage or cancer induction
- Impossible to measure direct fetal radiation dose
- Accurate dose estimation is difficult
 - Several methods have been published
- Study purpose: compare four fetal radiation dose estimation methods
 - Secondary objective: identify sources of variability

Method

- Database of 40 CT scans of pregnant patients
 - Scans acquired between 2007 and 2017
 - Mean maternal weight: 78 ± 18kg
 - Mean gestational age: 159 ± 63 days
 - Seven 1st trimester, nineteen 2nd trimester, and fourteen 3rd trimester
 - Abdomen (n=10) or abdomen/pelvis (n=30) scans
- Manual measurements by two observers:
 - Fetal depth
 - Maternal circumference
 - Maternal diameter
- Volumetric CT dose index (CTDIvol) and Dose Length Produce (DLP) obtained
- Four estimation methods were studied:
 - Classic calculation
 - Updated calculation
 - iPad app
 - Commercial dose tracking software (Radimetrics)
- Summary statistics, regression, and Bland-Altman analysis

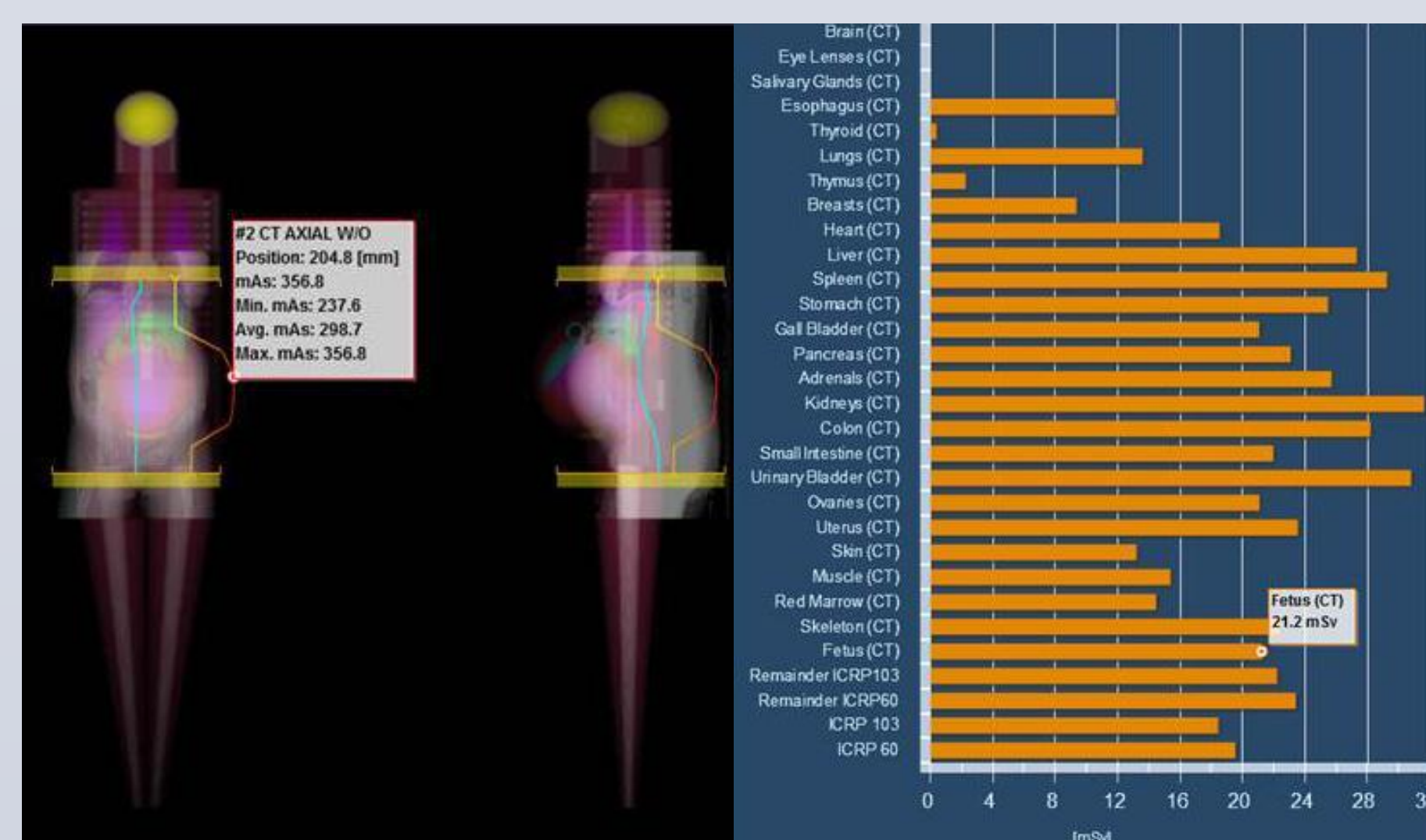


Fig 1. Radimetrics output demonstrating digital phantom with CT localizer overlay. Note the slight misregistration (misalignment) between the computational phantom and localizer in both the lateral and anteroposterior directions. Currently there is no method to manually correct the registration.

Results

- Fetal radiation dose range: <1mGy to 32mGy
 - Differences between methods were significant ($p < 0.05$), but generally small (<10mGy)
- Bias between methods was less than 5mGy and 95% Confidence Intervals (CI) were $< \pm 15\text{mGy}$
- Regression had typical slopes between 0.8 and 1.2
 - Coefficient of determination (R^2) values between 0.3 and 0.8
- Violating method assumptions such as tube voltages other than 120kV, differing trimester, and differing scanner models increased variability
 - If limited, both bias and CI were cut by 50% or more
- Measurement variability between observers generally resulted in fetal dose estimate changes of <10mGy
- Incomplete maternal circumference on CT for 75% of patients causes fetal dose overestimation
- Radimetrics system demonstrated large variability (~20mGy) depending on the patient model selected in the first trimester

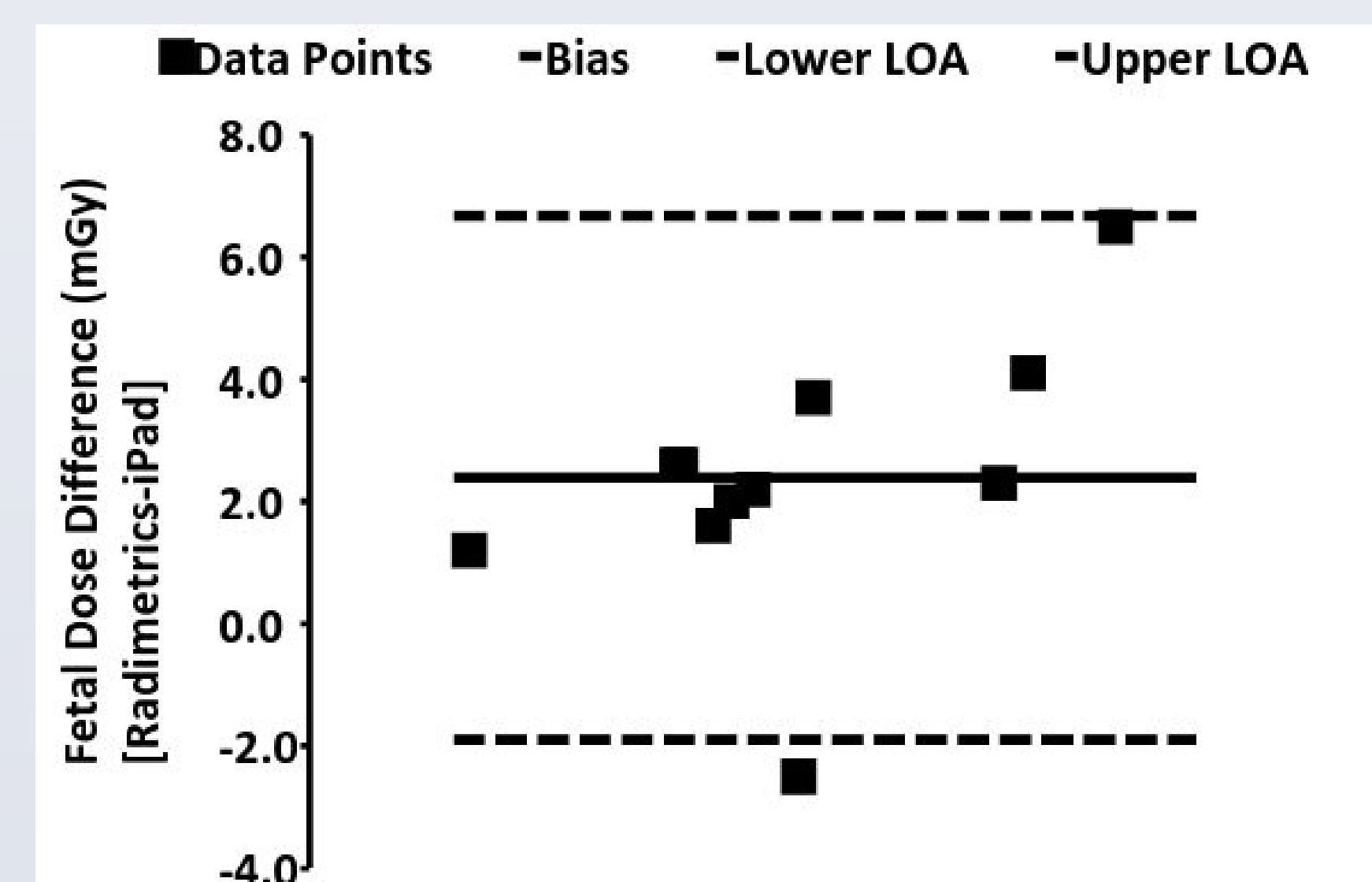


Fig 2. Bland-Altman Plot comparing Radimetrics and iPad app on a subset of the data. Radimetrics is ~2.2mGy higher on average and 95% CI is ~ 8mGy.

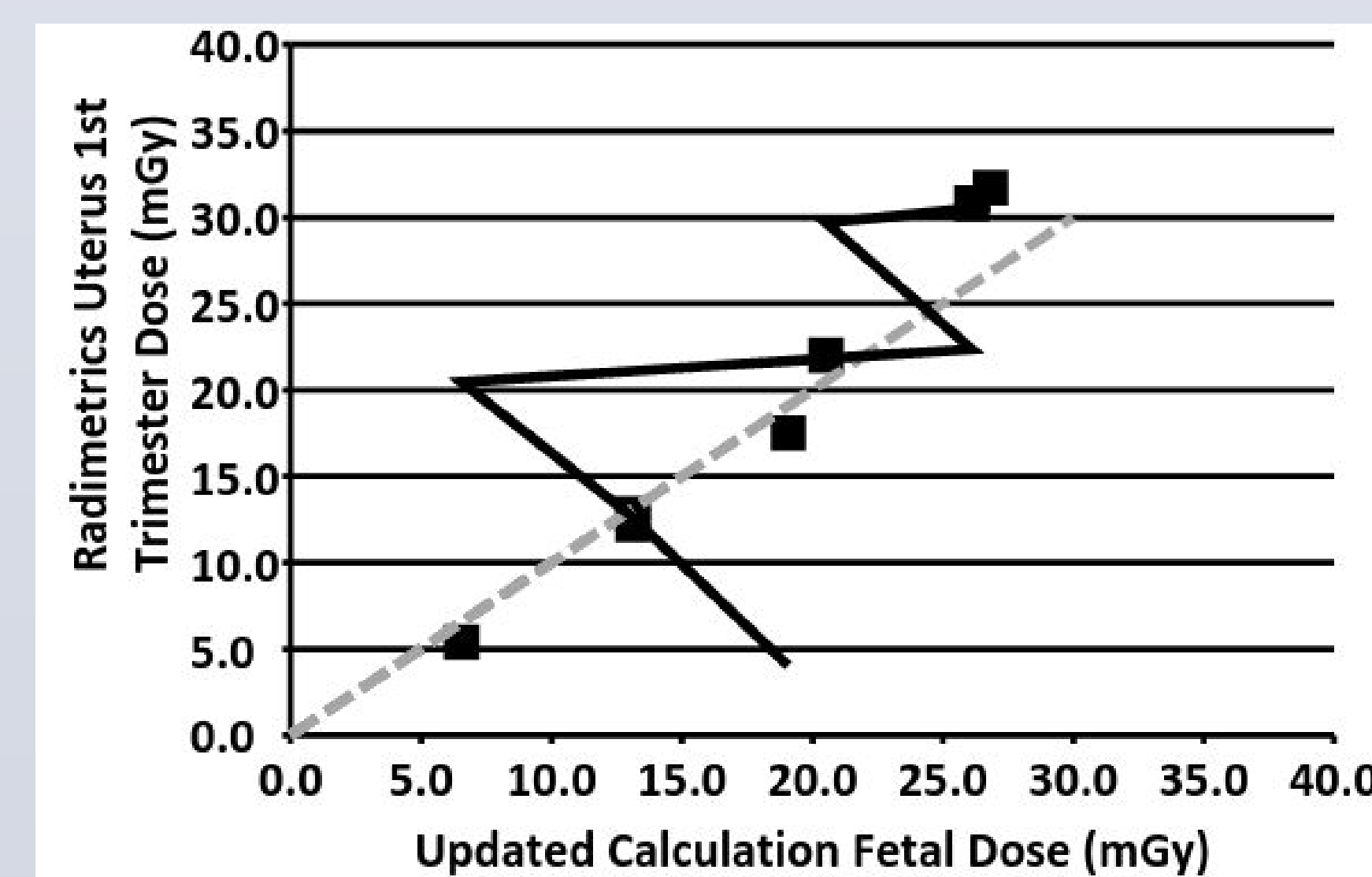


Fig 4. Regression between Radimetrics and the updated calculation method. Energies and scanners not modeled by the updated calculation method (model violations) have been removed. Note the slope and R^2 values are nearly ideal. Gray dashed line represents perfect agreement between methods.

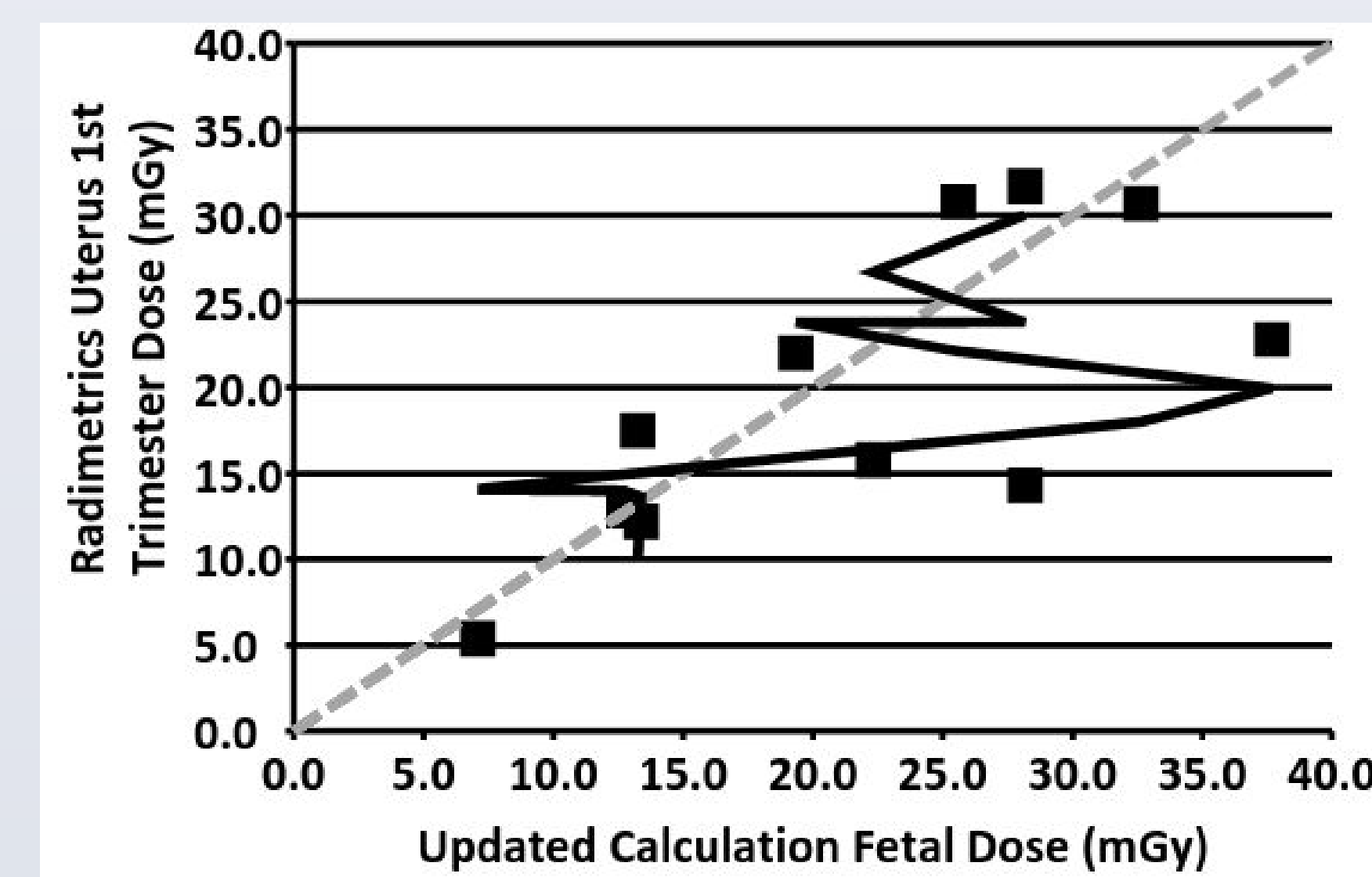


Fig 3. Regression between Radimetrics and updated calculation methods. This data subset included scanners and energies not originally modeled in the updated calculation method (model violations). Note slope and moderate R^2 . Gray dashed line represents perfect agreement between methods.

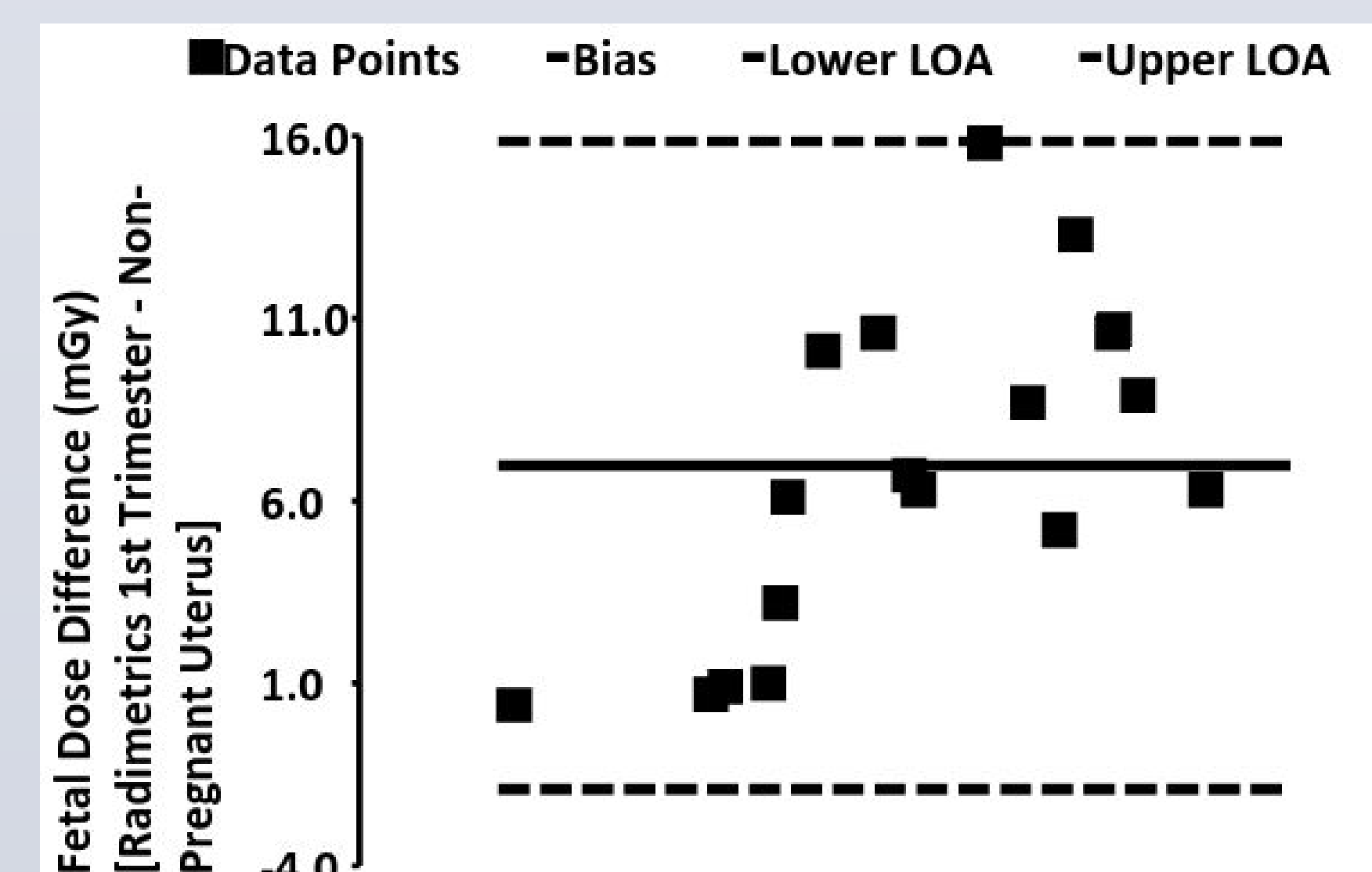


Fig 5. Bland-Altman Plot comparing Radimetrics when different patient models are selected. Here models selected were uterus dose (not pregnant) and uterus dose for a 1st trimester pregnant woman. Note that uterus dose is typically when the embryo/fetus is not visible (as is common in the early 1st trimester). A user would typically need to make this choice for a woman in the first week of pregnancy. Note that the pregnant uterus is ~7mGy higher on average with a 95% CI of ~20mGy.



• Fig. 6 Axial CT section of a pregnant patient. The arrows indicate a portion of the maternal circumference is missing from the images resulting in an artificially low measurement of maternal circumference and diameter. Since the maternal tissue shields the fetus, this likely results in an increased dose estimate for some methods.

Discussion

- Good agreement among the four methods
 - Variability and outliers noted
 - Recommend selecting a default method and limiting model variations
- No dose approached the 100mGy limit
- Variability could become important for dose tracking if estimates exceed the threshold considered acceptable
- Qualified medical physicists should review dose estimates
- Fetal dose estimation methods generally agree, but variability and outliers can cause substantial differences

References

1. Felmlee JP, et al. Estimated fetal radiation dose from multislice CT studies. *AJR* 1990 154: 185-90.
2. Angel E, et al. Radiation dose to the fetus for pregnant patients undergoing multidetector CT imaging. *Radiology* 2008 249(1): 220-27.
3. Sahbaee P, et al. Patient-based estimation of organ dose for a population of 58 adult patients across 13 protocol categories. *Medical Physics* 2014 41(7): 1-12.
4. ImPACT Group (www.impactscan.org/ctdosimetry), London, UK; St George's Hospital.
5. Huda W, et al. Embryo dose estimates in body CT. *AJR* 2010 194: 874-80.
6. Huda W, et al. In-patient to isocenter KERMA radios in CT. *Medical Physics* 2011 38(10): 5362 - 69.
7. Goldberg-Stein SA, et al. Radiation dose management: Part 2, Estimating fetal radiation risk from CT during pregnancy. *AJR* 2012 198: W352-6.