# Monitoring of fetal radiation exposure during pregnancy

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*Background:* **One unique concern of vascular surgeons and trainees is radiation exposure associated with increased endovascular practice. The safety of childbearing is a particular worry for current and future women in vascular surgery. Little is known regarding actual fetal radiation exposure. This multi-institutional study aimed to evaluate the radiation dosages recorded on fetal dosimeter badges and compare them to external badges worn by the same cohort of women.**
*Methods:* **All women who declared pregnancy with potential radiation exposure were required to wear two radiation monitors at each institution, one outside and the other inside the lead apron. Maternal (external) and fetal monitor dosimeter readings were analyzed. Maternal radiation exposures prior to, during, and postpregnancy were also assessed to determine any associated behavior modification.**
*Results:* **Eighty-one women declared pregnancy from 2008 to 2011 and 32 had regular radiation exposure during pregnancy. Maternal whole-body exposures ranged from 21-731 mrem. The average fetal dosimeter recordings for the cohort rounded to zero. Only two women had positive fetal dosimeter recordings; one had a single recording of 3 mrem and the other had a single recording of 7 mrem. There was no significant difference between maternal exposures prior to, during, and postpregnancy.**
*Conclusions:* **Lack of knowledge of fetal radiation exposure has concerned many vascular surgeons, prompting them to wear double lead aprons during pregnancy, and perhaps prevented numerous other women from entering the field. Our study showed negligible radiation exposure on fetal monitoring suggesting that with the appropriate safety precautions, these concerns may be unwarranted. (J Vasc Surg 2013;58:710-4.)**

Over the past decade, the number of endovascular procedures performed by vascular surgeons has increased exponentially. At present 50%-75% of all vascular interventions have endovascular components requiring fluoroscopy, and the cases are becoming increasingly complex. The annual number of endovascular abdominal aortic aneurysm procedures, for example, has increased 600% since 2000.[1] While this growth in endovascular surgery has certainly had a positive impact on patient well-being and the patient's accessibility to care, it has brought with it a new and important concern over radiation exposure to both patients and vascular surgeons.

The risks associated with radiation exposure and importance of safety measures have been highlighted in recent vascular surgery publications.[2-4] Although radiation exposure concerns both men and women; women, particularly those of childbearing age, assume the unique responsibility of the potential for fetal exposure. A developing human embryo/fetus is particularly sensitive to ionizing radiation. Fetal exposures greater the 10 rem can lead to miscarriage, neurologic defects, mental retardation, and childhood cancers.[5] The fear of fetal exposure has led many female interventionalists to adopt the practice of wearing double or even triple lead aprons. This practice is uncomfortable and significantly increases the occupational hazards for these pregnant women. Fetal monitors, which are under-lead dosimeter badges, serve to demonstrate the amount of exposure penetrating the standard protective lead gowns. There is little published information on fetal exposure attributable to occupational maternal exposure.

Our study aimed to assess the fetal radiation exposure in pregnant women exposed to occupational radiation in the hospital setting. This multi-institutional retrospective review analyzed radiation dosages recorded on fetal dosimeter badges and compared them with maternal (external) badges worn by the same cohort of women.

## METHODS

We reviewed radiation safety records at three academic institutions, including Stanford University Hospitals and affiliated Palo Alto Veterans Affairs Medical Center, Hershey Medical Center, and Brigham and Women's Hospital. We analyzed maternal (external) dosimeter readings as well as fetal (under-lead) dosimeter readings. The dosimeter badges contain three filters that record exposure at different depths. The deep dose equivalent estimates whole body exposure at a tissue depth of 1 cm, the shallow-dose

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equivalent estimates skin exposure at a tissue depth of .007 cm, and the eye dose equivalent, which measures radiation at a depth of .3 cm.

The minimum detectable radiation dose for the dosimeter badges was 1 mrem for two of the institutions and 5 mrem for one of the institutions. Badge readings were performed on a monthly basis and were reviewed by radiation physicists at each institution.

There were 81 declared pregnancies between 2008 and 2011; of those, only 32 women had greater than zero maternal dosimeter readings for more than 2 months. Of the 32 women, 14 were interventionalists, which included interventional radiologists, cardiologists, urologists, and vascular surgeons. The noninterventionalist group (n = 18) mainly included computed tomography and general radiology techs. Because of the small numbers of pregnant vascular surgeons alone cohort in three institutions, we compared interventionalist and noninterventionalist groups. Maternal radiation exposure recordings prior to, during, and after pregnancy were evaluated. Overall, there was an average of 11 months of prepregnancy radiation dosimetry data, 6 months of during pregnancy data, and 10 months of postpregnancy data.

The interventionalist group and noninterventionalist group were compared using an unpaired Student *t*-test and radiation exposures pre-, during, and postpregnancy were compared using an analysis of variance. A *P* value of .05 was considered significant.

## RESULTS

A total of 670 records were reviewed. Average maternal exposure at the deep dose equivalent was 75 mrem before pregnancy, 69 mrem during pregnancy, and 71 mrem after pregnancy. Average maternal exposure at the eye dose equivalent was 87 mrem before pregnancy, 76 mrem during pregnancy, and 78 mrem after pregnancy. Average maternal exposure at the shallow dose equivalent was 91 mrem before pregnancy, 79 mrem during pregnancy, and 81 mrem after pregnancy. Only two women (both were interventional radiologists in the interventionalist group) had greater than background fetal radiation exposures. One had a recording of 7 mrem over the period of 1 month and another had a 3 mrem recording over 1 month. Fig 1 demonstrates maternal radiation exposure at all three depths as well as fetal exposure. Overall, the monthly average fetal radiation exposures above background rounded to zero. There was no significant difference between the various tissue depths or between any of the time periods.

When comparing the interventionalist to the noninterventionalist group, there was a statistically significant difference between the two groups in their overall relative exposures before (188 mrem vs 38 mrem; $P = .003$), during (136 mrem vs 6 mrem; $P < .001$) and after pregnancy (147 mrem vs 19 mrem; $P = .005$) (Fig 2). Once again, fetal monitor radiation exposures above background rounded to zero in both groups. Among interventionalists, there was no significant difference between the various tissue depths nor among the before, during, and after pregnancy time periods.

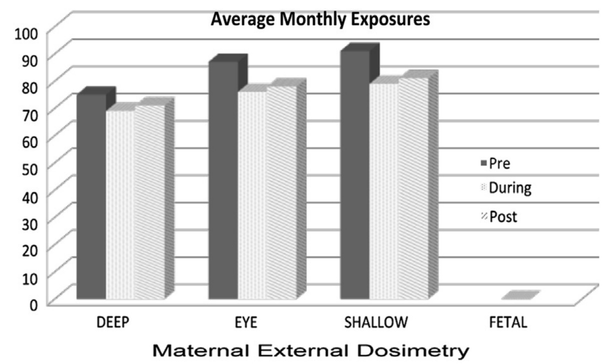


**Fig 1.** Total average monthly exposures: maternal and fetal. Average monthly exposures from maternal (external) dosimetry badges and fetal badges. Maternal exposures pre-, during and post-pregnancy are depicted. The deep dose equivalent estimates whole body exposure at a tissue depth of 1 cm, the shallow dose equivalent estimates skin exposure at a tissue depth of .007 cm, and the eye dose equivalent measures radiation at a depth of .3 cm.

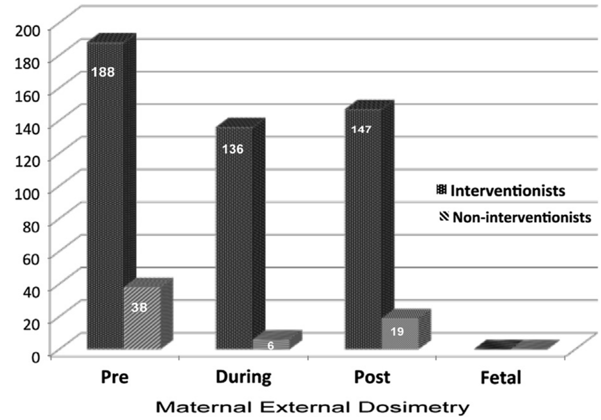


**Fig 2.** Average monthly exposures: interventionalists vs noninterventionalists. Statistically significant differences in radiation exposure during and after pregnancy exists between interventionalists and noninterventionalists. Fetal monitor radiation exposures above background continued to round to zero in both groups.

When the radiation dose was examined at various tissue depths during pregnancy, the DEEP dose equivalent monthly exposure for interventionalist was 115 mrem as opposed to 12 mrem for noninterventionalist ($P = .026$). There were similar statistically significant differences in monthly exposure during pregnancy between interventionalists and noninterventionalist at the EYE dose equivalent (146 mrem vs 4 mrem; $P = .012$) and the SHALLOW dose equivalent (148 mrem vs 3 mrem; $P = .013$).

## DISCUSSION

Occupational exposure to radiation among vascular surgeons during endovascular procedures is a growing concern as this diagnostic and therapeutic modality becomes more commonplace.[6-9] In addition, as more complicated interventions are attempted, longer fluoroscopy times will be encountered leading to even greater radiation exposure. Prolonged exposure to radiation raises safety issues for both patients and health care providers. Because radiation dose is cumulative, there is an understandable interest in the degree and accumulation of exposure. Such concern over occupational radiation exposure applies to both men and women. Pregnant women or those of childbearing age bear the unique concern for potential fetal exposure and injury.[6] We, for the first time, objectively demonstrated minimal under-lead fetal radiation exposure despite non-negligible maternal radiation exposure during pregnancy. This multi-institutional study underscores the minimal to no risk in pregnancy among active female interventionists as long as appropriate precautions are upheld.

There are an increasing number of women who fall into this category in medicine today. Over 50% of all medical students are women.[10,11] Despite the growing numbers of women in medicine, there has not been an analogous increase in women joining procedural specialties—particularly those involving endovascular procedures. As of 2010, less than 20% of vascular surgery trainees were women, and only 7.8% of practicing vascular surgeons were women.[10,11] While many factors likely contribute to this discrepancy, concern over radiation exposure and the ability to start a family are documented fears that contribute to decision making during career planning. According to a survey of vascular surgery applicants, concern over being past prime childbearing years affected 79%, the ability to have children bothered 53%, and 31% were specifically worried about radiation exposure.[10]

Concern over radiation exposure to the fetus is not unfounded. The human embryo/fetus is particularly sensitive to ionizing radiation, especially between 8 and 15 weeks gestation.[3] According to a United Nations Scientific Committee and the National Radiological Protection Board, the risks can include decreased mental capacity, severe mental retardation, and childhood cancer.[5] An increased risk of miscarriage has also been observed among flight attendants exposed to radiation during long international flights, although radiation has not been definitively identified as the source of this risk.[12]

Given these risks, there is an understandable fear of fetal radiation exposure. This fear often leads to practices above and beyond standard safety mechanisms that may not necessarily be protective and could potentially be detrimental. Double leading increases the weight burden to the practitioner two-fold, which could lead to back injuries, with a paltry <1% increase in protection.[13] Avoiding cases and minimizing exposure is certainly one approach but could potentially carry a negative career impact. Surveys of interventional cardiologists and vascular surgeons demonstrated that up to 65% of cardiologists avoided the catheterization lab during pregnancy as opposed to only 18%-32% of vascular surgeons.[6,14]

To attempt to mitigate the risk to the fetus, the National Council on Radiation Protection and Measurement has published recommended limits to occupation exposure of expectant mothers at <500 mrem total and <50 mrem/mo.[5,15] These limits are based on a review of available scientific literature and are designed to provide an adequate margin of protection for the embryo/fetus. If this dose limit is not exceeded, the total lifetime risk of cancer and non-cancer impacts to the embryo/fetus are negligible. To adequately ensure compliance with these regulations, monthly monitoring of the radiation exposure under-lead at waist level is typically recommended. This radiation monitoring is done in addition to the standard "over lead" or external badge and the dose should be assessed monthly during pregnancy. These under-lead or "fetal" dosimeter badges serve to monitor the amount of exposure penetrating the standard protective lead apron, but not all institutions mandate their use.

Our study is the first to directly look at the amount of radiation exposure to the fetus as recorded by fetal monitor occurring in pregnant women exposed to occupational radiation exposure. We found negligible radiation exposure to the fetus, as the exposure recorded on the fetal monitors rounded to zero throughout the pregnancies of the participants. Other studies have looked at under-lead dosimeter readings, although not specifically in pregnant women. Marx et al looked at exposure among 30 interventional radiologists over a 1-year period. They also found that the majority of under-lead exposure was less than the minimum detectable. Overall, the mean yearly radiation dose under-lead for the group was 0.9 mSv (90 mrem), which is even less than annual environmental exposures.[16] Lipsitz et al found total effective annual body doses under-lead to be slightly higher at 152 mrem, and a group from Hong Kong found a significantly lower under-lead dose of approximately 20 mrem/y.[17,18] One possible explanation is that pregnant women are more conscious in radiation exposure and, therefore, take additional measures, such as stepping away from the X-ray tube during digital subtraction angiography and using overhang lead screen during procedures. That being said, there was no statistically significant difference in maternal exposure pre, during, and postpregnancy in all levels (eye, shallow, and deep) despite a trend of lesser maternal radiation dosages during and post-pregnancy. Importantly, all of these findings demonstrated that under-lead dosing was consistently below the recommendations set forth by the International Commission on Radiological Protection.[19]

While under-lead dosimeter readings are reassuringly low in our study as well as several others, external readings are not negligible. The table demonstrates some comparisons between our findings and well-documented annual exposures and published national radiation exposure limits. Given the minimal detectable limitations of radiation dosimetry (for example, one of our sites had a minimal detectable limit of 5 mrem), we used an exaggerated level of 60 mrem for our potential maximum annual fetal exposure.

**Table.** Average annual exposure comparisons (millirems)

| | |
|---|---|
| NCRP: maximum permissible occupational | 5000 |
| Mountain areas of Brazil | 1250 |
| Study cohort-maternal | 828 |
| NCRP: maximum permissible for expectant mothers | 500 |
| Background level environment | 240 |
| Seven round-trip transcontinental flights | 100 |
| Study cohort-fetal[a] | <60 |

*NCRP,* National Council on Radiation Protection and Measurement.
[a]Estimated maximum exposure of current study cohort.

Even at this conservative level, it is quite striking to see that fetal exposures are far less than the maximum permissible for expectant mothers and much less than the background environmental radiation exposure of 240 mrem/y.[20] Maternal annual exposures were much less than maximum permissible occupational exposure and even less than areas of high natural background environmental exposure such as mountainous Brazil where annual background radiation is 1250 mrem. Maternal exposure was, however, greater than the maximum exposure permitted for expectant mothers of 500 mrem total despite nearly zero fetal radiation dose.[20] It is not clear how to interpret these findings; one may surmise that maternal exposure need not be as limited during pregnancy, but likely these pregnant women took precautions to minimize radiation. Importantly, with our encouraging results in mind, we believe, focus should continue to be made on overall strategies to minimize both over- and under-lead occupational radiation exposure. Strategies such as collimating carefully, minimizing digital subtraction angiography runs, and stepping away from the fluoroscopy table when appropriate can have a significant impact on the amount of radiation exposure experienced by surgeons.[21]

Our study has several limitations. This is a retrospective study of small size. More importantly, the data reviewed was information provided to the radiation safety committee at the various hospitals, thus, no details regarding protective mechanisms used (such as the presence or absence of double or triple leading), procedure details, or types of machines used are known. All of these variables could potentially make a significant difference in terms of the degree and amount of radiation exposure. Interestingly, there was no significant decrease seen in radiation exposure during the months of pregnancy compared with before and after. We believe that wearing fetal badges may have contributed to this by decreasing some of the anxiety of radiation exposure in pregnant women. Thus, we believe women should be encouraged to disclose their pregnancies and wear fetal badges.

In summary, we have demonstrated negligible radiation exposure on fetal monitoring of pregnant health care workers exposed to occupational radiation. Certainly, every effort should still be taken to minimize exposure to all operators. Ultimately, this study should serve to diminish the concerns of associated radiation exposure as long as standard safety principles are upheld. At the very least, we hope that potentially harmful measures such as "double leading" will be further examined, as they are likely unnecessary.

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## AUTHOR CONTRIBUTIONS

Conception and design: WZ, VC
Analysis and interpretation: WZ, VC, DB
Data collection: VC, CD, AR, PS, DB
Writing the article: WZ, VC
Critical revision of the article: WZ, VC, CD, AR, PS, DB
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## DISCUSSION

**Dr Eva Rzucidlo** (*Lebanon, NH*). It seems that we are doing a good job of protecting the fetus, but we are not doing a good job of protecting the mother. And so that is a problem for not only women but for men. Do you have any recommendations for that?

**Dr Venita Chandra.** Certainly, actually when looking at some of the previous studies in this area, overall radiation exposures during the past few years have decreased. I believe this is evidence that we are doing a good job of understanding and focusing on safety mechanisms. Some important ones include wearing appropriate lead, stepping away from the digital subtraction angiography during the digital subtraction angiography runs, using the other protective mechanisms around, and minimizing as much as you can the amount of fluoroscopy time used.

**Dr John Ricotta** (*Washington, DC*). A follow-up to that last comment. In the three institutions, is there a formal radiation safety course? How much actual training are the surgeons, and particularly the fellows, getting in terms of how to prevent radiation exposure or reduce radiation exposure?

**Dr Chandra**. There are not actually many formal training or formal guidelines for this, which is quite shocking to me. I certainly hope that bringing this up in a national forum will lead to more formal discussion and decision making on guidelines and a potential curriculum.

Interventional cardiologists do have such a curriculum apparently, but not many places in vascular surgery do.

**Dr Amy Reed** (*Hershey, Pa*). I will just follow-up with that. Currently the state of Pennsylvania requires 8 hours of safety training and then an annual review. So it is different from state to state.

One of the things we are going to try to do at the program directors' level is to try and incorporate more of the radiation safety training so that when our trainees come out, no matter what state they go to they should have documented training.

Currently, our interventional cardiology fellows training programs are recognized by most states as having adequate radiation safety training. So it is certainly something that I think we need to provide for all of our trainees.