

In-Flight Radiation Exposure During Pregnancy

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During high-altitude flight, the cosmic radiation dose rate in an airliner is greater than it is at ground level. For a casual traveler, the impact on pregnancy from cosmic radiation exposure during flight is trivial. Pregnant frequent flyers, pilots, and flight attendants can, however, receive exposures that exceed current recommended values if they do not appropriately modify their work schedules. In addition to the galactic cosmic-ray background that is the source of this radiation, severe disturbances on the sun may cause eruptions that significantly raise radiation levels at airliner altitudes for brief periods, possibly having an impact even on casual travelers. This article will help obstetrician-gynecologists provide advice to their pregnant patients about in-flight radiation risks. That advice should be influenced by an understanding of recommended radiation exposure limits and a perspective on how those limits relate to the potential for real harm. Resources provided by the U.S. Federal Aviation Administration and others to help pregnant women and their physicians make informed decisions about the acceptability of this type of exposure are described. (Obstet Gynecol 2004;103:1326-30. © 2004 by The American College of Obstetricians and Gynecologists.)

Radiology departments generally post notices that advise women who are receiving an X-ray examination to inform the physician or X-ray technician if they are, or may be, pregnant. Some even mandate pregnancy testing for any woman considered to be of childbearing age. Such testing provides information about the patient's pregnancy status that might lead to an alternative form of testing or the postponement of a radiological examination until a less sensitive stage of the pregnancy is reached. Institutional guidelines are generally in place to discriminate between those procedures that should be of concern and those for which the risk is trivial. There is a considerable difference in radiation risk between the radiograph of an extremity and, for example, a computed tomography examination of the abdomen and pelvis. In all cases, the benefit to be derived from the examination is weighed against the risks of the radiation exposure.

The nuclear processes of our sun and other stars in the galaxy produce cosmic radiation. On earth, these cosmic

rays are an important component of the natural background radiation environment in which we live. At airliner altitudes, cosmic radiation levels are greater than at sea level because the earth's atmosphere absorbs much of the radiation before it reaches the ground. At an altitude of 6 or 7 miles, there is much less atmospheric shielding between occupants of an airliner and the galactic and solar radiation sources.

Should pregnant women generally be advised against flying because the fetus is more susceptible to harm from this radiation than an adult? How does this issue impact pregnant pilots, airline flight attendants, and frequent travelers? Some "storms on the sun" can very significantly increase the usual radiation dose at airliner altitudes and possibly cause levels of radiation that might be of concern to a pregnant passenger. Media reports of such solar storms can elicit questions from a woman to her physician about their significance with respect to her travel plans.

It is the purpose of this paper to elaborate on the subject as it specifically applies to pregnant airline passengers and crew members, with the expectation that obstetrician-gynecologists will be better able to provide advice to these women when questioned. The health issues discussed here are only those that relate to the conceptus, not to the mother.

RADIATION LEVELS AT AIRLINER ALTITUDES

The United States Federal Aviation Administration (FAA) has been involved in the issue of in-flight radiation exposure since the 1960s when the subject was examined with respect to development of a supersonic transport that would travel at very high altitudes. The Concorde aircraft, which were in service until late 2003, incorporated radiation monitoring as part of the routine data acquired on every flight. In 1980 the FAA began to produce a body of literature specifically addressing expected radiation exposures during flight and the associated risks.^{1,2} Members of the radiation protection community showed that aircrews were among those occupational groups with the highest exposures.³ The FAA developed a publicly accessible computer program that can be used to calculate the radiation exposure received during a flight, assuming the altitude changes along the route are known (CARI-6; Federal Aviation Administration. Radiobiological Team web site. Available at: <http://jag.cami.jccbi.gov./cariprofile.asp>. Retrieved February 6, 2004). The results of the FAA dosimetric analysis of a number of selected short- and long-haul routes have been published.¹ The analysis used the CARI-6 computer program.

The magnitude of in-flight exposure depends strongly on altitude; there is a weaker correspondence between

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magnitude of exposure and latitude. There is also a variation in the exposure level as a function of the approximately 11-year solar sunspot cycle. Thus, there is a considerable difference in radiation dose (more than a factor of 100) received on short-haul, low-altitude flights (such as between Seattle, Washington, and Portland, Oregon) and long-haul intercontinental flights at high altitude. For the purposes of this commentary, we will take as "worst case" examples the highest round-trip intercontinental and transcontinental exposures that appear on published FAA lists. These values are approximately 150 microsievert ($150 \mu\text{Sv} = 15 \text{ mrem}$) for travel between New York and Tokyo on transpolar flights and $60 \mu\text{Sv}$ (6 mrem) for travel between New York and Seattle (see box for definitions of radiation terms).

RADIATION RISKS DURING PREGNANCY

The risks of exposure to ionizing radiation are generally described as either *stochastic* or *nonstochastic*. *Stochastic risk* describes those health effects for which the probability of occurrence in an exposed population (rather than the severity in an affected individual) is a direct function of dose; they are commonly regarded as having no threshold. Cancer and hereditary effects fall into this category. *Nonstochastic risks* are those for which the severity of the effects is a function of dose. There may or may not be a dose threshold below which no injury is possible. This category includes miscarriage (spontaneous abortion), mental retardation (neurobehavioral effects), congenital malformations, and growth restriction.

Most experts in the field of radiation research agree that there are no definitive data showing fetal harm at dose levels below about 20 millisievert ($20 \text{ mSv} = 2 \text{ rem}$).^{4,5} An exposure of considerably less than that amount might result in an increased risk of death for the embryo if it occurred during the first day of development, but it is unlikely that a woman would even be aware of her pregnancy at that stage.⁶ It is possible that repeated loss of embryos, as a result of many such early-stage exposures, could be misinterpreted as infertility.

The nonstochastic risks described above, ie, miscarriage, mental retardation, congenital malformations, and growth restriction, generally are accepted to have dose thresholds greater than 20 mSv. The levels for single round-trip flights given above, ie, $150 \mu\text{Sv}$ for the intercontinental trip and $60 \mu\text{Sv}$ for the transcontinental route, amount to only 0.75% and 0.30%, respectively, of that dose. So, under ordinary flight conditions, in-flight radiation exposures will not reasonably be expected to ever reach values that have been proven "harmful."

One could simply stop there and say that in-flight radiation exposure is generally inconsequential. But, for radia-

tion exposure during pregnancy, the stochastic risk of cancer later in childhood still remains a matter of concern. In a recent study of this subject, the existence of a threshold for childhood cancers, particularly leukemia, could not be either confirmed or ruled out.⁷ In the case of all such stochastic risks, those organizations responsible for making policy with respect to radiation assume the existence of a linear no-threshold model for the specific endpoints and, on that basis, recommend exposure limits.

RISK VERSUS RECOMMENDED LIMITS

The discussion of what to tell a woman about radiation risk to a conceptus at the levels of in-flight exposure must therefore be conducted with an understanding of the standards and regulations that are in place for radiation safety of members of the general public and for radiation workers. In the United States, the National Council on Radiation Protection and Measurements recommends values of annual and long-term maximum permissible exposures for specific groups of individuals. The council's recommendations are usually adopted into law or policy by federal and state agencies that regulate radiation produced by traditional ground-based industrial or medical facilities. In Europe and other parts of the world, a related organization, the International Commission on Radiological Protection provides similar guidance. At present, both bodies recommend a maximum annual exposure limit of 1 mSv (100 mrem) for members of the general public.^{8,9} The limits for the conceptus of an exposed member of the public are identical to that of the woman herself, ie, 1 mSv, but over a 40-week pregnancy. The 2 high-dose trips discussed earlier would give only 15% and 6%, respectively, of this generally permitted maximum exposure. Although these numbers look significantly different from the trivial percentages presented earlier relating to the likelihood of a real biological effect (a factor of 50 times greater), they are easily defensible by an obstetrician-gynecologist wishing to allay the fears of a pregnant patient concerned about taking a trip or two during pregnancy.

Regarding the increased risk of childhood and adult cancer, in their article "What Commercial Aircraft Crewmembers Should Know About Their Occupational Exposure to Ionizing Radiation," which can be found at the web site of the FAA Radiobiology Research Team,² the authors apply the linear no-threshold model to develop a table of increased risk for a fatal cancer for a child as a result of prenatal exposure. That table is reproduced here as Table 1. It should also be noted that, in addition to the lifetime risk of all cancers represented in this FAA table, an exposure of 1 mSv would (again assuming that the linear model is valid) possibly lead to an increase in



Table 1. Increased Lifetime Risk of Fatal Cancer Because of Prenatal Exposure to Ionizing Radiation*

mSv	Risk	mSv	Risk	mSv	Risk
1.0	1 in 10,000 (0.01%) [†]	1.6	1 in 6,300 (0.02%)	4	1 in 2,500 (0.04%)
1.1	1 in 9,100 (0.01%)	1.7	1 in 5,900 (0.02%)	5	1 in 2,000 (0.05%)
1.2	1 in 8,300 (0.01%)	1.8	1 in 5,600 (0.02%)	6	1 in 1,700 (0.06%)
1.3	1 in 7,700 (0.01%)	1.9	1 in 5,300 (0.02%)	7	1 in 1,400 (0.07%)
1.4	1 in 7,100 (0.01%)	2	1 in 5,000 (0.02%)	8	1 in 1,300 (0.08%)
1.5	1 in 6,700 (0.01%)	3	1 in 3,300 (0.03%)	9	1 in 1,100 (0.09%)

mSv = millisievert(s).

* In the general population of the United States (all ages), approximately 23% of all deaths are from cancer. The lifetime risk of fatal cancer for a working-age population (20–64 years) from occupational radiation exposure is estimated to be 4 in 100,000 per millisievert.

[†] A risk of 1 in 10,000 at a dose of 1 mSv means 1 expected death from radiation-induced cancer for every 10,000 concepti receiving a dose of 1 mSv.

the background rate of childhood leukemia from about 36 per 100,000 to 37 per 100,000, ie, a change from only 0.036% to 0.037%, but a relative increase of about 3%.¹⁰

So although there is no demonstrable harm at these exposure levels, it may well be prudent for a physician to advise a patient to generally restrict radiation exposure during pregnancy to the recommended 1-mSv limit. For the casual travel during pregnancy, where it would take a minimum of 7 of the highest-dose trips to exceed that value, it would be unreasonable to ever deter a pregnant patient from vacations or family visits using air travel because of radiation concerns, even when considering the most distant destinations.

OCCUPATIONAL EXPOSURES

Physicians may also have female patients who are exposed to this source of radiation through their occupation. The International Commission on Radiological Protection recommends a dose limit of 1 mSv (100 mrem) to the conceptus, essentially considering it to be a member of the general public that happens to inhabit the body of an occupationally exposed person.¹¹ In their most recent publication on exposure of pregnant members of aircrews, the FAA has adopted the International Commission's value when analyzing the acceptability of typical work schedules.¹ Again, using the exposures of 150 μ Sv and 60 μ Sv for the 2 highest-dose trips and calculating that the 1-mSv limit would be exceeded with 7 of the intercontinental trips and 17 of the transcontinental journeys, it can be concluded that, for a pregnant flight crew member who works on long-haul, high-altitude flights, a significant modification in work schedule (ie, keeping her out of the air) would often be required to keep her exposure within these occupational limits. The FAA agrees with this assessment.¹ Presently, a major difference now exists between the United States and Europe in this regard. In countries of the European Union, the 1 mSv limit on fetal exposure has been

embodied into law. In the United States, the FAA documents on this subject are only advisory, not regulatory.

This, of course, raises the issue of patients who are frequent flyers. The only difference between the exposure of a pregnant passenger and a pregnant crew member is the amount of time that each might spend in the air. It can be reasonably argued that business frequent flyers are occupationally exposed.³ So, a woman with frequent business travel will need to keep track of her in-flight exposures during pregnancy if she is to keep her exposure below 1 mSv.

SOLAR PROTON EVENTS

The doses calculated by the FAA CARI computer program are based on normal variations in solar output. There is, however, an irregular phenomenon that might significantly change the radiation dose received while in flight. These solar energetic-particle events (sometimes called solar flares) can occur with very little warning. In July 2000, there was a solar-particle event that raised the dose rates to 200 μ Sv (20 mrem) per hour. The FAA dose estimate for that event, based on travel at an altitude of 40,000 ft (12,000 m) at high latitude, is 630 μ Sv (63 mrem) for a 3-hour flight, 735 μ Sv for a 5-hour flight, and 832 μ Sv for a 10-hour flight. If a pregnant flyer's radiation dose in the weeks and months before and after the event were added to the dose received during the event itself, the total dose could easily have been greater than 1 mSv.

It is important to note that these proton events are generally of short duration and that postponing a flight for a few hours may be all that is needed to avoid the high-dose period. Real-time data on proton intensity as a result of a satellite-based monitoring program is available online from the Space Environment Center of the National Oceanic and Atmospheric Administration.¹² The FAA and the Space Environment Center have recently introduced an alert system that sends airlines a warning



at the start of a significant proton event. Observations from the satellites operated by the National Oceanic and Atmospheric Administration are sent to the Civil Aerospace Medical Institute of the FAA for analysis. The institute recommends a maximum flight altitude to keep the dose rate below 20 μSv in an hour. This alert system is specifically intended to limit the radiation dose received by pregnant women who are already in the air.

The frequency of these proton events generally follows the approximately 11-year sunspot cycle. The current cycle peaked in 2001, but, at the time this paper was in preparation, a solar energetic-particle event on October 29, 2003 caused an alert to be issued. At one point, the maximum recommended flight altitude was only 25,000 ft (7,600 m). If the radiation warning is made known to the traveling public as well as to the air carriers, a pregnant traveler might briefly postpone her trip until normal conditions return. Whether a pregnant crew member will be able to opt out of a flight if a proton event is in progress at the time of departure may become an issue to be addressed by the airlines and their flight deck and cabin employees.

SUMMARY

Physicians can assure pregnant women who are concerned about radiation risks during flight that, for casual travel under normal solar conditions, the risk of direct harm from cosmic radiation is negligible. However, during some solar energetic-particle events, the dose rates at airliner altitudes may be significantly greater than usual. During these rare events, a pregnant woman should be advised to check the web site of the Space Environment Center of National Oceanic and Atmospheric Administration and to consider a brief postponement of her trip until the peak-dose period has passed. Alternatively, if airlines universally accept the new alert system of the FAA, the aircraft itself will be redirected to a safe altitude.

The situation warrants a more detailed analysis for those women whose occupations puts them into the air on a regular basis. This category includes pilots, flight attendants, air marshals, couriers, and business frequent flyers. These women can themselves calculate their in-flight dose on a trip-by-trip basis using software available from the FAA and accessible via the Internet. By referring to risk tables generated by that agency and with knowledge of the recommended dose limits from national and international organizations concerned with radiation safety, they can make an informed decision as to the amount of flying that they wish to do. They should understand that these dose limits are set well below levels at which real harm has been demonstrated. Obstetrician-gynecologists should be aware of the available tools, such as

the solar flare warning system of National Oceanic and Atmospheric Administration and the CARI radiation estimation software program and should be able to instruct their patients about how to access and use them.

TERMINOLOGY: RADIATION DOSE AND EXPOSURE

Radiation: The transport of energy through space.

Radiation can be either particulate or electromagnetic.

Electromagnetic radiation: Radiation that consists of a combined electric and magnetic field that travels through space as pure energy. Common examples are light, radio waves, microwaves, X-rays, and gamma rays.

Particulate radiation: Radiation in the form of particles having measurable mass. The particles may be electrically charged or they may be neutral. The most commonly encountered particulate radiations are the 3 atomic particles (neutrons, protons, and electrons) that have been liberated from their usual bonds.

Radiation dose: A way of describing the amount of energy transferred into a material that has been exposed to radiation. The unit of radiation dose in the SI system (le Systeme International d'Unites) is the gray (Gy). In the older centimeter-gram-second (CGS) system, it was the rad.

Gray (Gy): The unit of radiation dose in the SI system. One Gy represents the absorption of 1 joule (J) of energy by 1 kg of any material, ie, $1 \text{ Gy} = 1 \text{ J/kg}$

Rad (obsolete): The unit of radiation dose in the CGS system. One rad represents the absorption of 100 ergs of energy by 1 g of material, ie, $1 \text{ rad} = 100 \text{ erg/g} = 0.01 \text{ Gy}$; $100 \text{ mrad} = 1 \text{ mGy}$.

Dose equivalent: Different types and energies of radiation produce differing amounts of damage when they interact with the whole body or with specific organs. For example, a dose of high-energy neutrons will have a different biological effect than an equal dose of X-rays. By using an appropriate modifying factor, dose (energy deposited per unit mass, a strict physical definition) is expressed as a new quantity that allows meaningful comparisons of biological damage without regard to the radiation type. Regulatory limits on radiation exposure set by governmental agencies are expressed in units of dose equivalent. In the SI system, this unit is the sievert (Sv); in the older CGS system, it was the rem. Using as an example the radiations mentioned above, an absorbed dose of 1 Gy of high-



energy neutrons will be equal to a dose equivalent of 20 Sv. The same absorbed dose of X-rays, 1 Gy, will have a dose equivalent of only 1 Sv.

Sievert (Sv): The unit of radiation dose equivalent in the SI system.

Rem (obsolete): The unit of dose equivalent in the CGS system (1 rem = 0.01 Sv; 1 mSv = 100 mrem).

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Received December 30, 2003. Received in revised form February 6, 2004. Accepted March 11, 2004.

