

# *Embryologic Effects from Radiation*

---

**C28**

# *Objectives*

- Describe the stages of gestation: preimplantation, organogenesis, fetal
- Identify which stages are most radiosensitive and explain why
- Explain the effects of radiation on the embryo and fetus
- Describe stage-specific radiation effects:
  - Preimplantation: all-or-nothing, embryonic death
  - Organogenesis: malformations and congenital abnormalities
  - Fetal stage: growth, functional disorders, and cancer risk
- Summarize evidence from animal and human studies (Hiroshima, Nagasaki, Chernobyl)
- Identify major fetal risks: pregnancy loss, malformations, growth disturbances, and carcinogenesis
- Relate radiation dose and gestational age to risk level
- Apply radiation protection principles to minimize fetal exposure
- Recognize that dose and gestational stage determine effects and that radiosensitivity decreases with gestational age

# *Stages of Gestation*

## *Preimplantation*

0-9 days after  
conception

## *Organogenesis*

10 days- 6 weeks

## *Fetal Stage*

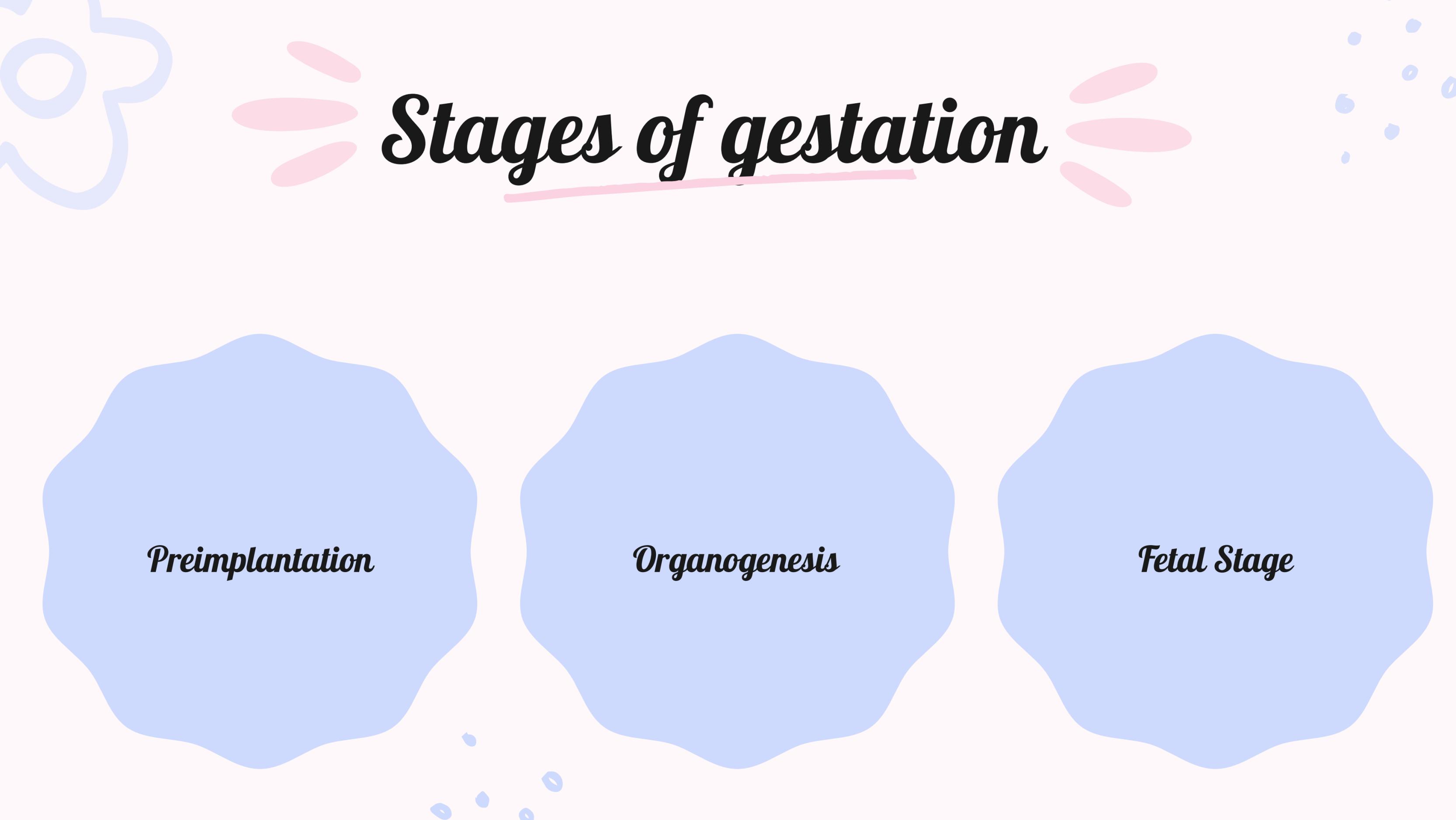
6 weeks - term

## *First Trimester*

Most crucial period  
as far as irradiation is  
concerned.

## *Second + Third Trimester*

Fetus is less sensitive  
to ionizing radiation



# *Stages of gestation*

*Preimplantation*

*Organogenesis*

*Fetal Stage*

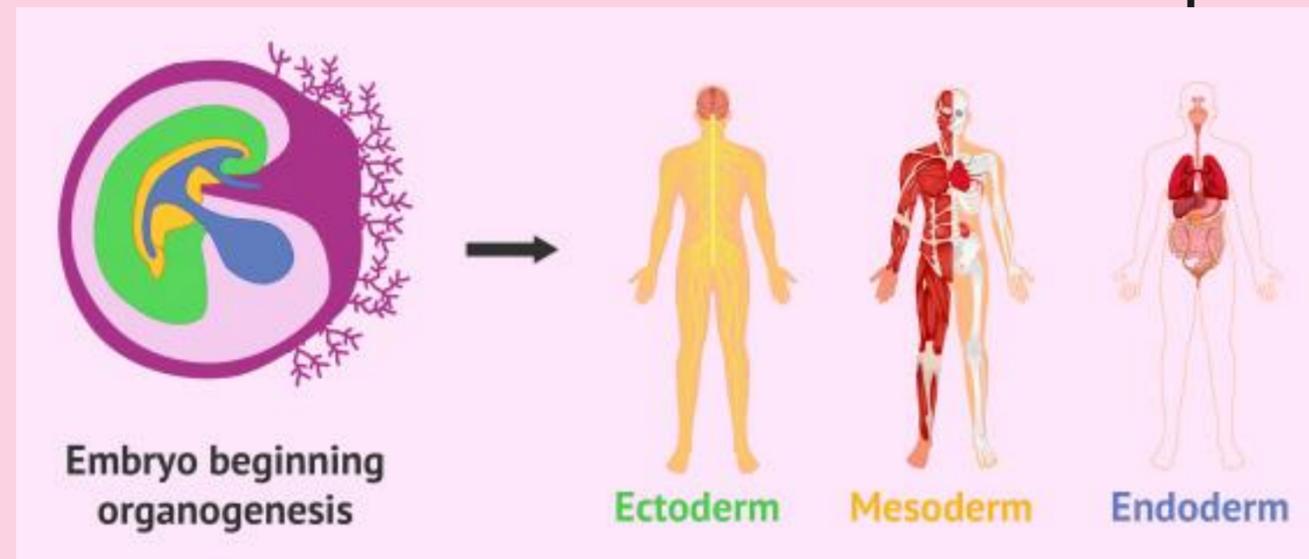
# *Preimplantation*

---

- Starts at fertilization and ends with implantation of the embryo when it attaches to the wall of the uterus around day 9
- The fertilized ovum goes through rapid cell division while it travels through the fallopian tube
- This is the most sensitive stage to the lethal effects of radiation

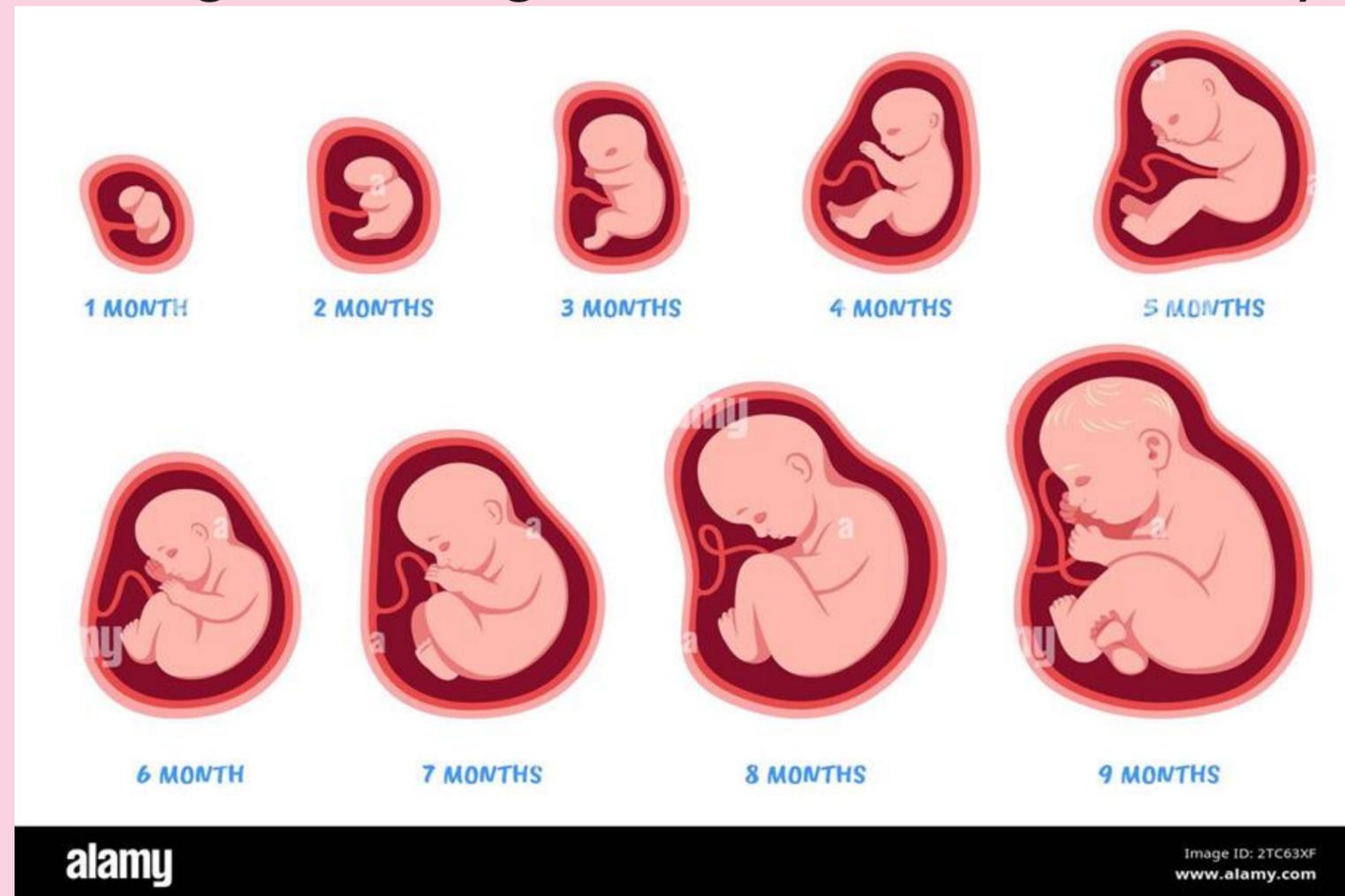
# *Organogenesis*

- This is the time period where the major organs are developed
- Cells are moving around to form 3 distinct layers
  - endoderm
  - mesoderm
  - ectoderm
- These layers will give rise to every cell type and organ
- This stage is very important when it comes to radiation exposure



# Fetal Stage

- This is the period during which the growth of the structures already formed take place



alamy

Image ID: 2TC63XF  
www.alamy.com



# ***Radiation exposure***

## ***during gestation***



***Preimplantation***

***Organogenesis***

***Fetal Stage***



## *Radiation exposure during Preimplantation*

- If irradiated with a dose of 0.05 to 1.5 Gy (*Hall & Giaccia, 2019*), embryonic death will occur
- Malformation does not occur at this stage
- All or Nothing Effect
  - If the embryo survives, it will grow normally in utero and afterwards
    - The number of cells is small and their nature is not specialized yet
  - Too many cell deaths = embryo death
  - Few cell deaths = one or two cell divisions can make itself normal again

## *Radiation exposure during Organogenesis*

- Fetus is most susceptible to radiation-induced congenital abnormalities
- Examples include growth inhibition, mental retardation, microcephaly, genital deformities, sense organ damage
- During late stages, presence of nonminor fetal abnormalities will cause death at birth
- Irradiation of the embryo-fetus during the first 12 weeks of doses above 200 mSv (20 rem) may result in fetal death or severe congenital abnormalities
- Skeletal damage from radiation occurs most often in week 3 to week 20
- Cancer and functional disorders during childhood are other possible effects of irradiation during this stage if there is not death at birth
- During this period the first morphologic evidence of an organ may be observed

*(Statkiewicz-Sherer et al., 2021; Hall & Giaccia, 2019)*

## *Radiation exposure during Fetal Stage*

- Cancer and functional disorders during childhood are effects of radiation during the fetal stage
- Growth of structures already formed during organogenesis are taking place during this stage
- This is where you would see more permanent effects of disturbances of growth
- It takes a much higher dose of radiation to kill the embryo at this point in time



# *Radiation During the First Trimester*



- Most crucial period as far as irradiation of the embryo-fetus is concerned due to rapid cell division and differentiation
- CNS and related sense organs are extremely radiosensitive as they contain a large number of stem cells
- If the embryo receives a high dose within approximately 2 weeks of fertilization, fetal death is the most apparent consequence, followed by spontaneous abortion
- Irradiation of the embryo during the first 8 weeks can result in death or congenital abnormalities
- The risk of developing childhood cancer is about 2.5 times greater than the third trimester.

*(Hall & Giaccia, 2019)*





# *Radiation During the Second & Third Trimester*



- Fetal radiosensitivity decreases as gestation progresses due to reduced cell differentiation
- Even in these later trimesters, congenital abnormalities and functional disorders can still be caused by radiation exposure
- There are many studies in recent years for radiation-induced congenital abnormalities in children exposed in utero during the atomic bomb detonations in Hiroshima and Nagasaki (*Hall & Giaccia, 2019*)
  - The risk is higher during the first trimester but still present in later trimesters

# *Medical Exposure*



0-3 weeks

Large doses (2.5 Gy) unlikely to result in abnormalities although a considerable number of embryos may be reabsorbed or aborted



4-11 weeks

Risk of severe organ abnormalities in multiple organs of children



11-16 weeks

A few eye, skeletal, and genital organ abnormalities; stunted growth, microcephaly, and mental retardation are frequently present



16-25 weeks

Mild degree of microcephaly, mental retardation, and stunting of growth



30+ weeks

Unlikely to produce gross structural abnormalities leading to a serious handicap in early life but cause functional disabilities



***Rat Study***

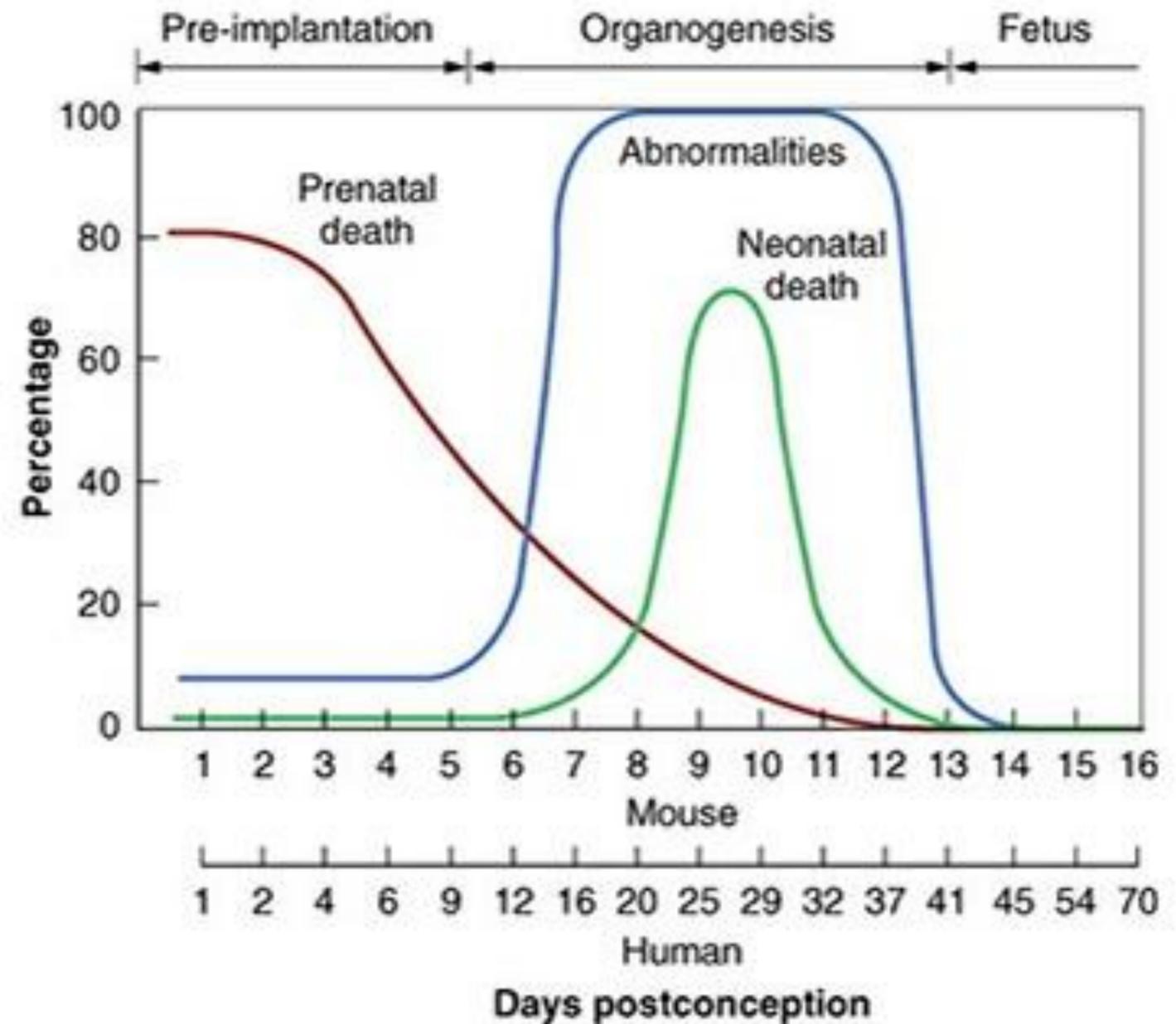


# Russel and Russel Rats

In mice, gestation is divided into preimplantation (days 0- 5), organogenesis (days 5-13), and the fetal period (day 13 to full term at ~20 days) In this experiment, 2 Gy of x-rays were delivered at various times after fertilization.

- About 80% of the time prenatal death occurred early in preimplantation and decreases during organogenesis
- Abnormalities appeared almost 100% of the time during organogenesis
- Neonatal death occurred about 70% of the time within organogenesis

(Radiology Key, 2016)

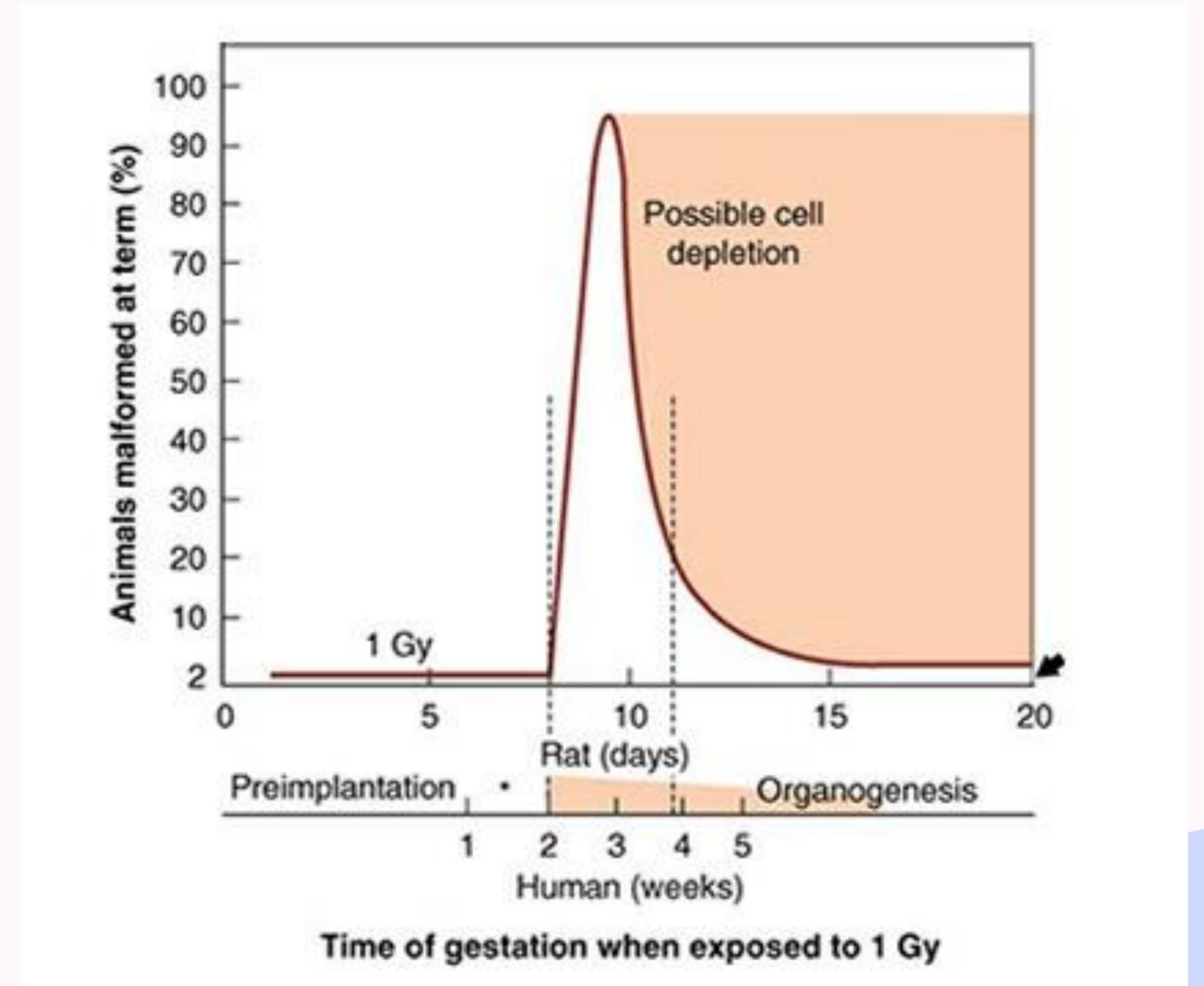


Note: From Radiology Key, 2016, June, <https://radiologykey.com/effects-of-radiation-on-the-embryo-and-fetus/>

# Brent and Ghorson Rats

The graph illustrates congenital malformation rates in rats after exposure to ~1 Gy of x-rays at different gestational stages. Control malformation rates are about 2%. Radiation exposure before day 8 shows malformation rates similar to controls, while exposure during early organogenesis results in nearly 100% malformations. As organogenesis progresses, malformations decrease. During the fetal stage, a 1 Gy dose leads to permanent cell loss, causing growth retardation that persists into adulthood.

*(Radiology Key, 2016)*



Note: From Radiology Key, 2016, June, <https://radiologykey.com/effects-of-radiation-on-the-embryo-and-fetus/>

# *Teratogenic Risks*

The effects of radiation on the embryo/fetus in utero depending on the fetal stage of development and the dose that it received.

- Decreased birth weight.
- Congenital malformations
- Increased stillbirths.
- Disturbances in growth and development.
- Embryonic, fetal, or neonatal deaths.
- Childhood malignancy and mortality.

*(Statkiewicz-Sherer et al., 2021)*

# ***Fetal Risks from Ionizing***

Potential risks are divided into four main categories  
***Radiation***



***Pregnancy Loss***



***Malformation***



***Disturbances of  
growth or development***



***Mutagenic or  
Carcinogenic effects***

# *Pregnancy Loss (Lethal Effects)*

In the first trimester, if the embryo receives a high dose of radiation within 2 weeks of fertilization, fetal death is the most seen negative consequence followed by spontaneous abortion. If this does not happen, the pregnancy will go to term possible with adverse effects or none at all. Lethal effects can occur because of radiation both before or immediately after the implantation of the embryo in the uterine wall.

(Hall & Giaccia, 2019)

# *Malformation*

Malformations result from high radiation doses during the first trimester, particularly during major organogenesis (10 days to 12 weeks after conception), when body structures are forming and cell division is most active. These abnormalities can arise from both genetic and environmental factors. By about 20 weeks, the fetus is fully developed, more resistant to radiation, and no more vulnerable than the mother when exposure levels are low.

(Hall & Giaccia, 2019)

# *Disturbance of growth or development*

- This effect can be induced at all stages of development, but normally occurs later during pregnancy.
- Follow up data from atomic bomb survivors showed permanent physical growth restriction with increasing radiation dose, significantly when doses were above 1 Gy.
- This was most obvious when the exposure occurred in the first trimester. A 3-4% decrease in height at age 18 was seen whenever the cumulative dose was higher than 1 Gy.
- Microcephaly can be a significant effect of radiation that results in decreased head size

(Hall & Giaccia, 2019)

# *Mutagenic & Carcinogenic effects*

Animal experiments show that carcinogenic effects are commonly seen during the late stages of fetal development. Risk of having childhood cancer, particularly leukemia, increases by a factor of 1.5 to 2 when exposed to 0.01 to 0.02 Gy levels of radiation in utero (*Kumar, 2023*)



Ionizing radiation may increase the frequency of naturally occurring genetic mutations; however it is hard to detect when the spontaneous mutations are already high, occurring at approximately 10%



# ***Mutations/Chromosome Rearrangements***

***Somatic***

Carcinogenesis



***Germline***

Heritable Genetic  
Effects



***Fetal***

Developmental  
Effects

# *Nuclear Accidents and Pregnancy*

## *Chernobyl*

- Of the 135,000 evacuees of the 18 mile radial zone, approximately 2000 were pregnant women
  - Each received an estimated total-body equivalent dose of 0.43 Sv
- No apparent abnormalities were observed in the 300 babies born by August 1987
- However, between 1987 through 1990, the ministry of health in Ukraine recorded and increased number of miscarriages, premature births, and stillbirths
- Also during this time the ministry record an increase of 3 times the average rate of deformities and developmental abnormalities in newborns

*(Hall & Giaccia, 2019)*

# Nuclear Accidents and Pregnancy

## Hiroshima & Nagasaki

- There is not much data on individuals exposed at the gestational age of less than 4 weeks as data would presumably represent the all-or-nothing effect that there is a high likelihood of fetal death
- Data found that embryos exposed closer than 1,500 meters from the hypocenter of the atomic bomb were typically shorter, weighed less, and had significantly smaller head diameters than those who were more than 3,000 meters from the hypocenter

(Hall & Giaccia, 2019)

**Table 12.1 Growth Retardation at Hiroshima from In Utero Irradiation<sup>a</sup>: Comparison of Those Exposed within 1,500 m<sup>b</sup> of the Hypocenter with Those More than 3,000 m from the Hypocenter**

Height	2.25 cm shorter
Weight	3 kg lighter
Head diameter	1.1 cm smaller

<sup>a</sup>80% of 1,613 children exposed in utero followed to age 17 years.

<sup>b</sup>Average kerma, 0.25 Gy.

# *Nuclear Accidents and Pregnancy*

## *UNSCEAR*

- Fetal effects such as mortality, malformations, intellectual disability, and childhood cancer were reviewed by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)
- This group proposed an upper-limit increased *combined radiation risk* for the fetal effects mentioned of 3 chances per 1000 children for each rem (0.01 Sv) of fetal dose
- With no radiation exposure, these fetal effects have an estimated *reasonable total risk* of 60 chances per 1000 children
- So with the reasonable total risk plus combined radiation risk if exposed to radiation, a total risk of 60 per 1000 children plus an additional 3 per 1000 children for each 0.1 Sv of fetal equivalent dose was indicated

# *First Report of Childhood Malignancy*

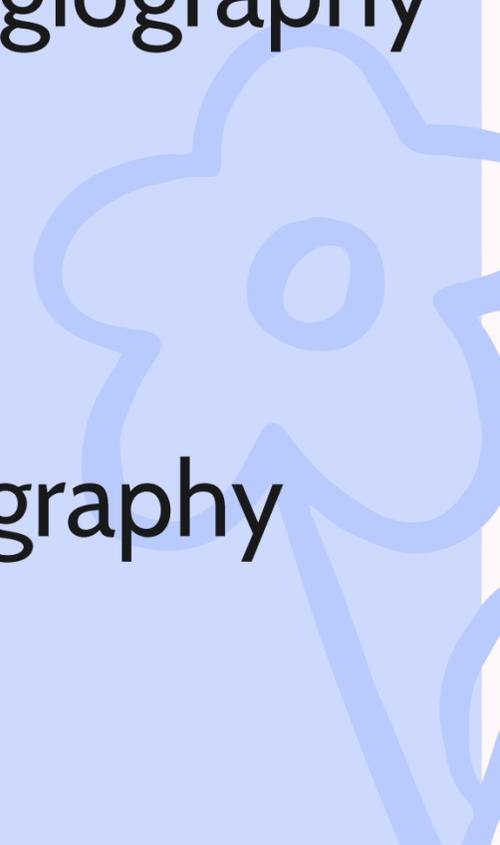
In context to prenatal diagnostic and assessment X-ray

- First reported in 1956
- A survey of childhood cancers showed that the risk of developing the cancers increased linearly with the amount of times a person was exposed
- The atomic bombing of Hiroshima and Nagasaki in 1945, became a defining study as it is the most extensive study of intrauterine radiation exposure

# *Ways to Minimize Fetal Exposure*



*(Statkiewicz-Sherer et al., 2021)*

- \* Non-abdominopelvic plain radiography
  - \* Abdominopelvic plain radiography
  - \* Fluoroscopy & Angiography
  - \* Nuclear Medicine
  - \* Computed Tomography Scan
- 

# *Non-abdominopelvic Plain Radiography*

- Wear lead apron
- Images that don't include the fetus in the field of view produce almost no scatter to the fetus
- Digital radiography helps with reducing cumulative exposure



# *Abdominopelvic Plain*

## *Radiography*

- Do a PA exposure
- Dose is reduced by 0.02-0.04 mGy
  - Collimate to reduce scatter
  - Use of grids reduces scatter
  - Avoid repeats

# *Fluoroscopy & Angiography*

A pink scribble consisting of several overlapping loops, located in the upper right corner of the blue background.

- Modify exposure time and amount of images
  - Limit beam size



# *Nuclear Medicine*

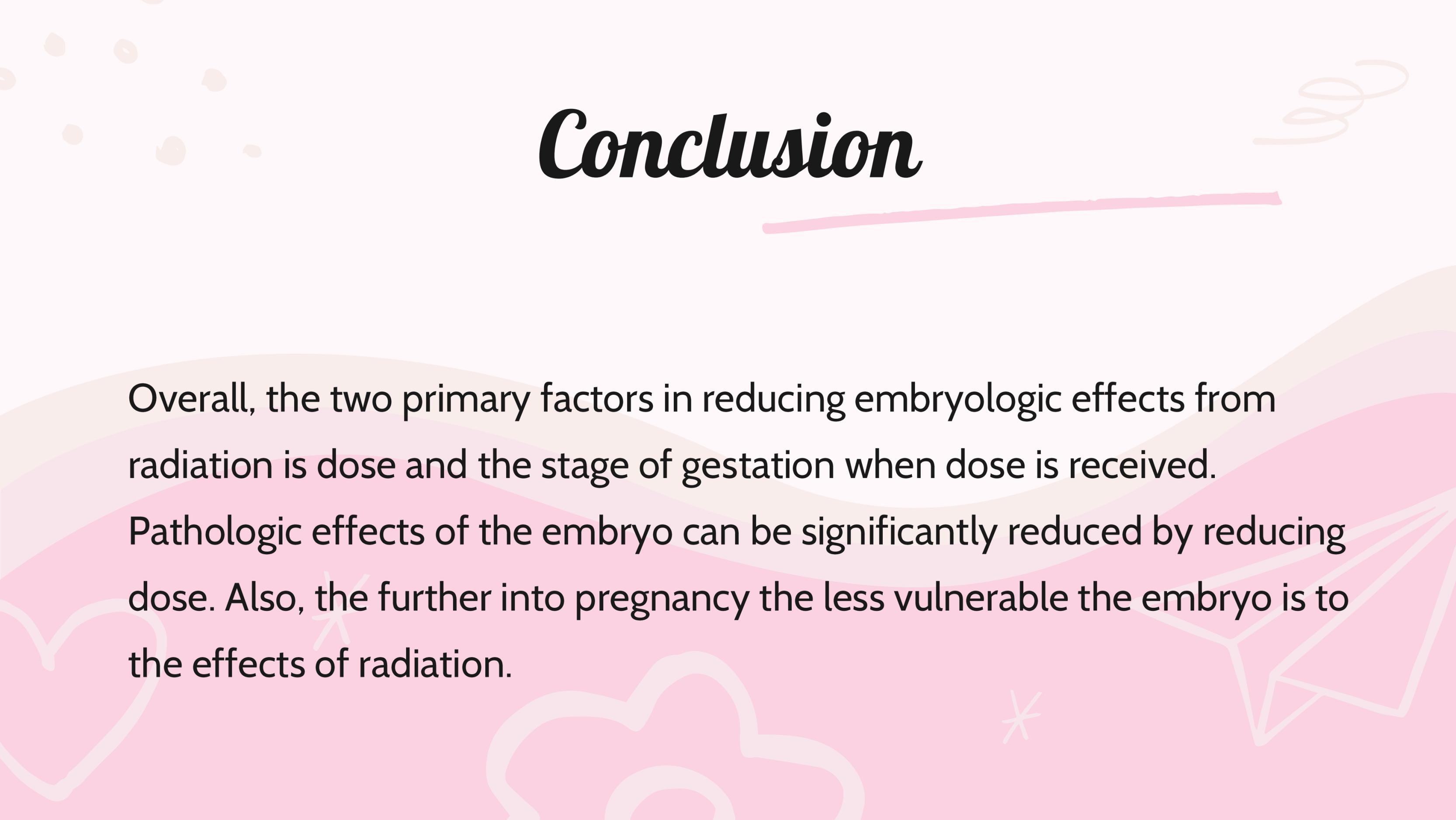


- Most procedures use short-lived radionuclides that do not expose the fetus to large doses of radiation
    - To reduce radionuclides exposure, maternal hydration and frequent urination helps to eliminate them
- 

# CT

- Use narrow collimation and a wide pitch
  - Slightly decreases image quality
  - Greatly reduces radiation exposure

# *Conclusion*



Overall, the two primary factors in reducing embryologic effects from radiation is dose and the stage of gestation when dose is received.

Pathologic effects of the embryo can be significantly reduced by reducing dose. Also, the further into pregnancy the less vulnerable the embryo is to the effects of radiation.



(Centers for Disease Control and Prevention, 2015)



*Thank you!*



# References

Alamy Limited, 2026, <https://www.alamy.com/stock-photo/fetal-development-stages.html?pseudoid=913187EB38CB4CE08C9CED92F4954425>

ASTRO. (2024, November 7). *Chapter 12 – Effects of Radiation on the Embryo and Fetus*. ASTRO.org; ASTRO

<https://www.astro.org/ASTRO/media/ASTRO/AffiliatePages/arro/Yuan%20Lecture%20PDFs/Chapter12.pdf>

Centers for Disease Control and Prevention (CDC). (2015, August 27). Prenatal Radiation Exposure. YouTube. <https://www.youtube.com/watch?v=1xalId8dHv4>

Hall, E. J., & Giaccia, A. J. (2019). *Radiobiology for the radiologist* (8th ed.). Wolters Kluwer.

[https://books.tarbaweya.org/static/documents/uploads/pdf/Eric%20J.%20Hall%2C%20Amato%20J.%20Giaccia%20-%20Radiobiology%20for%20the%20Radiologist%20\(2018%2C%20LWW\).pdf](https://books.tarbaweya.org/static/documents/uploads/pdf/Eric%20J.%20Hall%2C%20Amato%20J.%20Giaccia%20-%20Radiobiology%20for%20the%20Radiologist%20(2018%2C%20LWW).pdf)

Invitra, 2026, <https://www.invitra.com/en/wp-content/uploads/2019/04/organogenesis-570x242.png>

Kumar, R. (2023, August 23). *Radiation effects on the fetus*. StatPearls [Internet]. <https://www.ncbi.nlm.nih.gov/books/NBK564358/>

Radiology Key, 2016, June, <https://radiologykey.com/effects-of-radiation-on-the-embryo-and-fetus/>

Statkiewicz-Sherer, M. A., Visconti, P. J., Ritenour, E. R., & Haynes, K. (2021). *Radiation Protection in Medical Radiography* (9th ed.). Mosby.