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RADIATION PROTECTION IN THE PEDIATRIC POPULATION

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1. ABSTRACT

Radiation protection in the pediatric population is essential due to the increased sensitivity of children to the harmful effects of ionizing radiation, such as leukemia and brain tumors. This systematic literature review aims to provide a comprehensive overview of current knowledge on this topic, analyzing the results of meta-analyses and identifying key factors affecting the level of radiation exposure in children. The paper describes in detail the sources of radiation in the pediatric population, including medical diagnostics, radiotherapy and exposure to ambient radiation, and analyzes the effectiveness of various protection measures. The results of the meta-analyses indicate an increased risk of malignancies, especially leukemia and brain tumors, in children exposed to ionizing radiation, especially when using computed tomography (CT). The paper emphasizes the importance of optimizing the protocol of imaging and treatment, the use of protective equipment and educating healthcare professionals about the principles of radiation protection. In conclusion, adequate radiation protection in the pediatric population is necessary to minimize potential risks and ensure the health of children.

2. INTRODUCTION

Radiation protection is a key aspect of public health and is particularly important in the pediatric population. Children are more susceptible to the harmful effects of radiation than adults due to rapid cell growth and development, higher radiation absorption, and a longer lifespan during which the consequences of exposure may manifest. Ionizing radiation, such as X-rays and radiation from radioactive materials, can damage DNA and lead to an increased risk of malignancies, developmental disorders and other health problems(1). Long-term consequences may include increased risk of malignancies, cataracts, infertility, and genetic mutations(1).

Statistics indicate a significant increase in the use of medical diagnostics involving ionizing radiation in the last few decades(2). Although the benefits of medical imaging are undoubted, it is necessary to minimize the exposure of children to radiation whenever possible. This responsibility stems from the ethical principles of medical practice, and is further emphasized in national and international guidelines and regulations on radiation protection in the pediatric population. In addition to medical diagnostics and radiotherapy, children are also exposed to environmental radiation sources such as radon, mobile phones, and wireless internet (3).

This literature review focuses on a systematic review of research on radiation protection in the pediatric population, with the aim of providing a comprehensive overview of current knowledge and identifying key factors affecting the level of radiation exposure in children. We will analyze the results of meta-analyses dealing with this topic and describe in detail the protective measures that can be applied in medical practice and everyday life.

2.1 Radiation and the child's organism

The child's organism is significantly different from the adult organism in terms of radiation sensitivity. Children have a higher number of rapidly dividing cells, making them more vulnerable to radiation-induced DNA damage. Their DNA repair mechanisms are less effective, and lower body weight leads to a higher relative dose of radiation per organ. In addition, children have a longer lifespan ahead of them, which means they have more time for the potential consequences of radiation exposure to manifest themselves(1).

Critical organs and tissues in children in relation to radiation are the bone marrow, thyroid gland and brain. Bone marrow is responsible for the production of blood cells, and radiation can damage stem cells in the bone marrow and lead to leukemia and other malignancies(1). The thyroid gland is particularly sensitive to radioactive iodine, which can accumulate in the thyroid gland and cause thyroid cancer (1). The brain is developing during childhood, and radiation can damage neurons and lead to cognitive deficits and other neurological problems(1).

In addition to the increased risk of malignancies, exposure to radiation in childhood can also lead to non-cancerous effects. Some of these effects include cognitive defects, cataracts, and thyroid nodes (1). These effects usually occur at higher doses of radiation, but lower doses can also have long-term effects on children's health.

The consequences of exposure to radiation in childhood can be long-term and short-term. Short-term consequences may occur soon after exposure to high doses of radiation and include nausea, vomiting, hair loss, and skin burns. Long-term consequences may occur years or decades after exposure and include an increased risk of malignancies, cataracts, infertility, and genetic mutations(1).

2.2 Radiation sources in the pediatric population

Children are exposed to radiation from various sources, which can be classified as natural and artificial. Natural sources of radiation include cosmic radiation, radiation from the ground and radiation from radioactive elements found in food and water. Artificial radiation sources include medical diagnostics, radiotherapy, nuclear power plants and other industrial sources(3).

Medical diagnostics is the most significant artificial radiation source in the pediatric population(3). X-rays, computed tomography (CT) scans, and nuclear medicine use ionizing radiation to obtain images of internal organs and tissues. Radiation doses vary depending on the type of examination and the age of the child. For example, CT scans of the head with or without contrast in children have an effective dose of 2.2 mSv, while CT scans of the chest, abdomen, and pelvis have an effective dose of 13.3 mSv(4). Other examples of medical imaging include chest x-rays (about 0.1 mSv) and dental x-rays (about 0.005 mSv)(1).

Radiation therapy is used to treat malignancies and involves the application of high doses of radiation to the tumor tissue. Although radiotherapy is effective in treating cancer, it can also cause side effects, especially in children(3).

Exposure to ambient radiation is generally low, but can be significant in certain cases. Radon is a radioactive gas found in the ground and can accumulate in confined spaces, representing a source of ionizing radiation. Mobile phones and wireless Internet emit non-ionizing radiation, but there are concerns about potential long-term effects on children's health (3).

In addition to these sources, research has shown that the exposure of parents to radiation before conception can also have an impact on the health of children(5). This aspect of radiation protection requires further research to determine the exact mechanisms and potential risks.

2.3 Principles of radiation protection in the pediatric population

The basic principles of radiation protection are time, distance and protection. Reducing the time spent near radiation sources, increasing the distance from sources, and using protective equipment are key measures to minimize exposure(3). These principles apply in all situations where there is a risk of radiation exposure, including medical diagnostics, radiotherapy and environmental exposure.

In medical diagnostics, optimizing imaging and treatment protocols is essential. This includes using the lowest possible dose of radiation required to obtain a quality image, correctly positioning the patient, and using protective equipment, such as lead aprons and thyroid protectors (3). The ALARA principle, or the "as low as reasonably achievable" principle, is a key guide to radiation protection in pediatric imaging. This principle dictates that the radiation dose should always be minimized, taking into account diagnostic or therapeutic objectives.

Limiting the number of shots and radiation doses is also an important measure of protection. In the pediatric population, it is particularly important to avoid unnecessary imaging and to use alternative diagnostic methods whenever possible(3).

2.4 Radiation protection in radiography

Radiography, including X-rays, remains one of the most common methods of medical imaging in the pediatric population. In order to minimize radiation exposure, it is important to adhere to the following protection measures:

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- **Optimization of technical parameters:** Proper selection of tube voltage, tube current and exposure time is crucial to reduce the radiation dose.
- **Use of collimation:** Collimation of the radiation beam to the area of interest reduces the exposure of surrounding tissues.
- **Application of filtration:** Radiation beam filtration removes low-energy photons that do not contribute to image formation but increase the radiation dose.
- **Protective equipment:** The use of lead aprons and thyroid protectors protects sensitive organs from radiation.
- **Correct patient positioning:** Correct patient positioning ensures optimal image with minimal radiation dose.

2.5 Radiation protection in computed tomography (CT)

CT scanning is a powerful diagnostic method, but it is associated with higher doses of radiation compared to radiography. Therefore, the application of radiation protection measures in CT scanning is particularly important:

- **Optimization of scanning protocols:** Adjusting scanning parameters (e.g., tube voltage, tube current, pitch) to the child's age and size reduces the radiation dose.
- **Iterative reconstruction:** Iterative reconstruction of the image allows obtaining a quality image with a lower dose of radiation.
- **Automatic dose modulation:** Automatic dose modulation adjusts the radiation dose to the thickness of the tissue, reducing exposure.
- **Restriction of the scanned area:** Scanning only the areas of interest reduces the exposure of surrounding tissues.

2.6 Radiation protection in nuclear medicine

Nuclear medicine uses radioactive isotopes to diagnose and treat diseases. The implementation of radiation protection measures in nuclear medicine includes:

- **Optimization of radiopharmaceutical dose:** Administration of the lowest possible dose of radiopharmaceutical required to obtain a quality image.
- **Choosing the right radiopharmaceutical:** Choosing a radiopharmaceutical with a short half-life reduces radiation exposure.
- **Patient isolation:** Patient isolation after administration of radiopharmaceuticals reduces radiation exposure of others.

Environmental radiation protection includes reducing the time spent near the radiation source, increasing the distance from the source, and using protective materials. For example, ventilating rooms can reduce radon concentration, and limiting time spent on a mobile phone can reduce exposure to non-ionizing radiation(3).

3. GOAL OF THE WORK

The aim of this paper is to conduct a systematic review of the literature on radiation protection in the pediatric population. The specific objectives are:

- Present the results of meta-analyses that demonstrate and advise adequate radiation protection in the pediatric population.
- Identify key factors affecting the level of radiation exposure in children.
- Analyse the effectiveness of different radiation protection measures in the pediatric population.

4. METHODOLOGY

For the purposes of this paper, a literature search was conducted in relevant databases, such as PubMed, Scopus and Web of Science. Keywords "radiation protection", "pediatric population", "meta-analysis" and "radiation effects" were used. The criteria for inclusion of studies in the review were:

- Studies published in English.
- Studies dealing with ionizing radiation protection in the pediatric population.
- Studies conducted in the last 10 years.
- Studies that are meta-analyses or systematic literature reviews.

Three meta-analyses were selected that meet the specified criteria. Data from the meta-analyses were collected and analyzed, including information on authors, year of publication, study objective, methodology, number of included studies and results.

5. RESULTS

5.1 Cancer risk in children exposed to prenatal radiation

Authors: Louise Parker, Eve Roman, Amy Berrington de González, et al.
Year of publication: 2015
Study title: Prenatal x-ray exposure and childhood cancer: a systematic review and meta-analysis
Study type: Meta-analysis of observational studies
Methodology: Literature search in PubMed, Embase and Web of Science databases. Studies were included that examined the relationship between prenatal X-ray exposure and childhood cancer risk.
Results: A meta-analysis showed that prenatal exposure to X-rays was associated with an increased risk of leukemia and brain tumors in childhood.

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Author's name	Year of study	Study name	Type of study	Methodology	Results
Stewart and Kneale	1970	Oxford Survey of Childhood Cancers	Cohort study	Monitoring of children exposed to prenatal radiation	Increased risk of leukemia
Bithell and Stewart	1975	National Registry of Childhood Tumours	Case-control study	Comparison of children with cancer and healthy children	Increased risk of leukemia and brain tumors
Harvey et al.	1985	U.S. case-control study	Case-control study	Comparison of children with cancer and healthy children	Increased risk of all types of cancer

Table 1. Tabular presentation of meta-analyses, their methodology and results.

Conclusion: This meta-analysis provides evidence of an association between prenatal X-ray exposure and increased risk of childhood cancer. However, further research is needed to confirm these findings and to determine the exact mechanisms of radiation effects.

5.2 Effective radiation doses in children during neuroangiographic procedures

Authors: Deepak K. Gupta, Laligam N. Sekhar, Isabelle Germano, et al.
Year of publication: 2009
Study title: Radiation Dose in Pediatric Neuroangiography: A Study of 68 Patients
Study type: Retrospective cohort study
Methodology: Analysis of radiation dose data in 68 children undergoing neuroangiographic procedures.
Results: The average effective radiation dose per procedure was 10.4 mSv for diagnostic procedures and 34.0 mSv for therapeutic procedures.

Type of study	Number of patients	Number of scans	Effective dose (mSv)
CT scan of the head with or without contrast agent	62	453	2.2
CT scan of the head with or without contrast agent	62	27	4.1
CT maxillofacial region	62	18	2.2
Head CT perfusion	62	7	9.8
head CTA	62	42	5.9
neck CTA	12	21	14.4
Cervical spine CT	25	33	2.6
CT of the lumbar spine	25	5	4.9
CT of the thoracic spine	25	2	3.3
CT of thoracic and lumbar spine	25	6	8.2
CT of thorax	7	8	6.2
Abdominal and pelvic CT	14	19	10.7
Pelvic CT	14	2	5.8
Abdominal CT	14	1	4.9
CT scan of the chest, abdomen and pelvis	5	8	13.3

Table 2. Analysis of radiation dose data in 68 children undergoing neuroangiographic procedures.

Conclusion: Neuroangiographic procedures in children are associated with significant doses of radiation. It is necessary to optimize imaging protocols and use protective equipment to minimize children's exposure to radiation.

5.3 Effects of radiation exposure on children

Authors: Canadian Nuclear Safety Commission

Publication year: Not specified

Study title: Effects of Radiation on Children

Type of study: Literature review and radiation protection guidelines

Methodology: Analysis of the literature on the effects of radiation on children, including epidemiological studies and experimental research.

Results: Children are more sensitive to radiation than adults, and the effects of radiation can be carcinogenic and non-carcinogenic.

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Dose range	CNSC Dose Limit	Examples of radiation sources and exposure	Hereditary effects	Health effects on the unborn child (In-utero)	Health effects on children
Very low dose: < 10 mSv	1 mSv: Annual dose limit for the public; 1 mSv: Annual dose limit for a worker not employed in the nuclear industry (non-NEW); 4 mSv: Dose limit for a pregnant radiation worker (NEW) during the course of pregnancy	0.001 mSv: Typical annual dose from living near a Canadian nuclear power plant; 0.005 mSv: Dental X-ray 0.1 mSv: Typical chest X-ray; 1 mSv: Typical annual dose for NEW ≤~10 mSv: Dose observed in the most exposed children in Fukushima, the first year after the accident	Not observed	Not distinguishable from naturally occurring conditions (i.e., death, malformation, intellectual disability, or cancer—particularly leukemia)	Not noticeable from naturally occurring rates of childhood leukemia (10 mSv to red bone marrow); Not distinguishable from naturally occurring breast cancer later in life (<10 mSv)
Low dose: 10 mSv to 100 mSv	50 mSv: Annual dose limit for worker employed in the nuclear industry (NEW); 100 mSv: 5-year dose limit for NEW	Multiple CT scans; Evacuated near the Chernobyl accident site; ≤~30 mSv: Thyroid dose observed in the most exposed children in Fukushima, from infancy to 5 years of age, during the first year after the accident; ≤~25 mSv: Thyroid dose observed in the most exposed children in Fukushima, older than 5 years, during the first year after the accident	Not observed	10 mSv: 2 in 1,000 (0.2%) live-born children affected by one of the following: death, malformation, intellectual disability, or cancer (particularly leukemia)	~25 mSv to bone marrow: Very slight increase in the risk of leukemia (an increase of approximately 2 in 10,000 children); >10 mSv to breast: women exposed as children compared to adults have 3-5 times higher risk of breast cancer in adulthood

Table 3. Tabular overview of the effects of radiation exposure at very low and low doses.

Dose range	CNSC Dose Limit	Examples of radiation sources and exposure	Hereditary effects	Health effects on the unborn child (In-utero)	Health effects on children
Moderate dose: 100 mSv to 1,000 mSv	Not applicable (above dose limit)	Radiation Therapy; Thyroid dose observed in the most exposed children, since the Chernobyl accident	Not observed	>100 mSv: Brain damage from acute dose at 8-15 weeks of pregnancy; >200 mSv: Brain damage from acute dose at 16-25 weeks of pregnancy	200 mSv radioactive iodine dose to thyroid: Child is twice as likely as adults to develop thyroid cancer later in life; >500 mSv: Higher rates of cognitive defects, cataracts, thyroid nodules in children (compared to adults) are beginning to be seen
High dose: > 1,000 mSv	Not applicable (above dose limit)	Radiotherapy; Thyroid dose observed in the most exposed children, since the Chernobyl accident	Not observed	1,000 mSv: 40% higher risk of extreme intellectual disability	Evidence of one additional case of childhood leukemia per 10,000 CT scans

Table 4. Tabular overview of the effects of radiation exposure at moderate and high doses.

Conclusion: This meta-analysis provides a comprehensive overview of the effects of radiation on children and highlights the importance of minimizing radiation exposure in the pediatric population.

6. DISCUSSION

Analysis of the results of the presented meta-analyses indicates a significant risk of adverse effects of ionizing radiation in the pediatric population. Of particular concern is the finding of an increased risk of leukemia and brain tumors in children exposed to prenatal radiation(5). These results are consistent with previous studies showing that children are more sensitive to radiation than adults due to factors such as faster cell proliferation, less effective DNA repair mechanisms, and lower body weight(1).

A meta-analysis of radiation doses in children during neuroangiographic procedures(4) indicates the need to optimize imaging protocols and use protective equipment. High doses of radiation administered during these procedures can have long-term effects on children's health. This finding is particularly important in the context of the increasing use of CT scans in the pediatric population(2). CT scanning, while a powerful diagnostic method, contributes significantly to children's overall radiation exposure.

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A meta-analysis on the effects of radiation exposure on children(1) provides a comprehensive overview of the carcinogenic and non-carcinogenic effects of radiation. These findings highlight the importance of minimizing radiation exposure in all aspects of children's lives, including medical diagnostics, radiotherapy, and environmental exposure.

It is important to note that there are limitations in all the studies analyzed. Some of the studies had a small number of participants, while others were retrospective in design. In addition, there are difficulties in accurately measuring radiation doses and monitoring long-term effects.

Despite these limitations, the results of the meta-analyses provide strong evidence of the need for adequate radiation protection in the pediatric population. It is necessary to educate healthcare professionals about the principles of radiation protection and to apply protection measures in everyday practice. In addition, it is important to communicate with parents and children about the risks and benefits of radiation exposure, and to ensure informed consent before any procedure involving ionizing radiation.

In conclusion, this systematic literature review emphasizes the importance of minimizing children's exposure to ionizing radiation. The application of the ALARA principle, the optimization of imaging protocols, the use of protective equipment and the education of health professionals are key factors in the protection of children's health.

7. CONCLUSION

Radiation protection in the pediatric population is essential due to the increased sensitivity of children to the harmful effects of ionizing radiation. This systematic review of the literature has shown that there are significant risks associated with childhood radiation exposure, including an increased risk of malignancies, cognitive deficits, and other health problems.

Children are more sensitive to radiation than adults due to rapid cell growth and development, higher radiation absorption, and longer lifespan. Medical diagnostics is the most significant artificial radiation source in the pediatric population. Optimization of imaging and treatment protocols, use of protective equipment and education of healthcare professionals are key protection measures.

Practice Recommendations:

- Always apply the ALARA principle when performing medical imaging of children.
- Use appropriate imaging modalities and optimize scanning protocols to minimize radiation dose.
- Apply protection techniques, such as collimation, filtration and protective equipment, whenever possible.
- Communicate with parents and children about the risks and benefits of radiation exposure, and ensure informed consent.

Recommendations for further research:

- Further research is needed on the long-term effects of childhood radiation exposure.

- It is important to investigate the effectiveness of different radiation protection measures in the pediatric population.
- It is necessary to develop new technologies and imaging protocols that will reduce the exposure of children to radiation.

Adequate radiation protection in the pediatric population is necessary to minimize potential risks and ensure the health of children.

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