The Role Of Radiology In Pediatric Imaging And Radiation Safety Considerations For Children

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Abstract

Consensus guidelines are required for optimizing ionizing radiation doses in multimodality imaging techniques for kids with inherited and congenital heart disease (CAHD). These kids frequently suffer from intricate illnesses and may encounter a relatively substantial accumulation of ionizing radiation from medical imaging techniques, such as cardiac computed tomography, nuclear cardiology investigations, as well as fluoroscopically guided diagnostic and interventional catheterization and electrophysiology processes. While these imaging treatments are crucial for the treatment of children with CAHD and have significantly enhanced patient results, they come with the potential dangers of ionizing radiation exposure, which may lead to an increased lifelong risk of cancer. The objective of these guidelines is to promote the use of well-informed imaging techniques in order to obtain optimal research quality while minimizing radiation exposure as much as possible. Additional methods to enhance care are adopting a patient-centric approach to imaging, prioritizing education and well-informed decision making, and implementing programmatic measures to assure accurate dosage monitoring. In the future, it is necessary to establish a uniformity of dose measurements for different imaging techniques in order to promote comparable efficacy studies on the whole range of cardiovascular and heart disease in children.

Keywords: Radiology, imaging techniques, pediatric, congenital heart disease (CAHD), children.

1. Introduction

Children diagnosed with congenital and acquired heart disease (CAHD) are a group of patients who are more susceptible to harm and will likely need ongoing medical treatment throughout their lives. Accurate diagnosis and safe intervention in these youngsters need the use of ionizing radiation for cardiac imaging. Simultaneously, being exposed to ionizing radiation raises the chance of developing cancer (1–

3). Recent epidemiological studies have shown that childhood exposure to computed tomography (CT) scans is associated with an elevated lifetime relative risk of cancer (4–6). Nevertheless, these investigations, along with others, have emphasized the intricacies and lack of confidence in assessing the long-term dangers linked to low-dose ionizing radiation exposures often seen during medical imaging procedures. This has led to ongoing discussions and debates (7,8). There is still a significant amount of confusion among the general population about the hazards associated with radiation, which is frequently spread by the media. There is also confusion about which medical techniques use ionizing radiation.

Although the exact level of danger is unclear, there is a unanimous consensus that we should make every possible effort to minimize radiation exposure in medical imaging, as long as it does not compromise diagnostic accuracy and procedural safety (2). Education is a crucial approach to ensuring radiation safety in cardiology. This is often achieved by well-informed talks about the advantages and possible hazards of a certain operation. These discussions include patients, parents, caregivers, as well as healthcare workers specializing in clinical and imaging services (17). It is crucial to educate both the individuals who request research and those who carry out and analyze these investigations. The principles of radiation protection include two key aspects: justification and optimization. Justification involves assessing whether an imaging method is clinically essential and suitable.

Optimization, on the other hand, focuses on ensuring that radiation exposure is maintained at a reasonable level and minimized as much as possible. Optimization does not always mean reducing the dosage at all costs; abuse may happen when both too much and too little radiation dose is administered. Optimization in medicine may be defined as the effective control of the radiation dosage given to the patient, ensuring that it aligns with the specific medical objective. The primary objective of optimization in the medical field is to guarantee that the amount of protection is optimal given the current conditions, hence maximizing the margin of benefit over harm. This scientific statement aims to offer expert consensus recommendations for enhancing medical imaging procedures frequently conducted in children with CAHD, such as cardiac CT, nuclear cardiology studies, and fluoroscopically guided diagnostic and interventional catheterization and electrophysiology procedures.

The suggestions offered here concentrate on optimization strategies that, when correctly executed, will enhance the radiation safety for children with heart disease. This will be achieved without sacrificing the diagnostic information obtained from these vital investigations or any other elements of procedural safety. These considerations are given in the context of specific factors that need to be taken into account when caring for children with CAHD (19). This includes recognizing that the quality of diagnostic and image-guided interventional care may vary between different centers that specialize in pediatric care, such as children's hospitals and university practices, and community practices.

2. The Correlation Between Childhood Heart Disease And Ionizing Radiation

Congenital heart disease is the prevailing congenital anomaly, impacting about 1 million children residing in the United States (20,21). Cardiomyopathies and other types of heart disease that are acquired impact an extra 1 out of every 100,000 children and adolescents each year (22). Children diagnosed with Congenital Anomalies of the Heart and Great Vessels (CAHD) often needs intricate medical treatment. They often have extended periods of hospitalization and many require sequential or recurrent surgical procedures. Due to the intricate nature of their treatment, individuals often undergo a significant amount of diagnostic medical imaging procedures that include ionizing radiation. Alongside diagnostic imaging, image-guided interventional treatments have gained significant importance in patient care. There has been a notable overall rise in the average number of exposures per patient in the last 20 years (23). While diagnostic and therapeutic techniques have significantly improved the outcomes for children with CAHD, several studies have shown that these children may receive quite substantial cumulative doses of ionizing radiation (24,25).

There is a growing recognition of the possible detrimental impacts of being exposed to ionizing radiation from imaging techniques (1–3). Significant amounts of ionizing radiation may lead to tissue responses, formerly known as deterministic effects, such as skin ulceration and hair loss. On the other hand, even very small doses of radiation have been linked to stochastic effects like cancer. Tissue responses occur as a consequence of cell death or damage caused by radiation. These reactions are seldom seen in children since the doses they receive during medical procedures are usually below the limits that would elicit such reactions. In contrast, most expert panels have concluded that the available facts strongly suggest a linear, no-threshold relationship to ionizing radiation dosage for stochastic effects, which serves as the foundation for radiation protection.

Stochastic effects arise from mutations caused by ionizing radiation and are more prevalent in rapidly proliferating cells and in organs and tissues with a greater risk of cancer, such as the breast, bone marrow, stomach, colon, and lungs (2). While mutations may occur upon exposure, there is often a significant delay between exposure and the development of solid tumors, which may only be recognized several years later. Exposures that occur at younger ages are linked to an increased risk of cancer due to the fact that children have organs and tissues with cells that divide more quickly. Additionally, the longer expected lifetime after exposure provides more time for cancer to develop (1). Likewise, females have a higher risk mostly because of their increased susceptibility to breast malignancies. As awareness grows about the long-term dangers of being exposed to ionizing radiation, it is important to acknowledge the crucial role that medical imaging procedures using ionizing radiation play in diagnosis and treatment. Therefore, it is essential to optimize these procedures in order to achieve accurate diagnoses while minimizing radiation doses whenever feasible.

3. Optimization And Justification

The fundamental concepts of justification and optimization are the core ideas that underpin the guidelines for managing the dosage of medical imaging (26). Justification, in the context of an individual patient, implies that a medical operation is not just suitable but also that the expected therapeutic advantages outweigh all potential hazards, including the risk of radiation. In the field of adult cardiology, there are recognized criteria for determining the acceptable use of cardiac imaging investigations. However, a considerable number, ranging from around 5% to over 45%, of these studies have unclear rationale, depending on the specific research and imaging method used. There is a lack of established guidelines for the proper use of ionizing radiation in juvenile cardiac imaging treatments. It is uncertain how many medical imaging procedures would typically be regarded reasonable for these individuals. The ethical norms of nonmaleficence and beneficence make justification an essential component of radiation protection in children.

Optimization, as previously explained, refers to ensuring that the radiation dosage administered to the patient is appropriate for the intended medical goal, while avoiding any radiation that is clinically unneeded or unproductive (2). Irrespective of the kind of imaging technique used, the methods for improving the quality of the images usually differ based on the size or physical characteristics of the patient. Strategies aimed at optimizing dosage in adults are often not directly applicable to children. Practitioners involved in pediatric medical imaging treatments that include ionizing radiation must have a thorough understanding of the specific requirements of children and the difficulties in achieving optimal imaging results for pediatric patients ranging from preterm newborns to adolescent-sized adults.

4. Metrics for Dosage

Various measures are used to assess the radiation load of cardiovascular operations. These include both commonly used terms (2) and measures that are peculiar to a particular modality (35). All cardiovascular imaging procedures in children with CAHD should have one or more dosage metrics reported.

Ionizing radiation transfers energy to the human body, resulting in the formation of charged particles known as ionized tissue molecules. These particles have the ability to inflict harm to biological systems. The absorbed dose is a quantitative measure of the amount of energy that is deposited in a material. Due to the phenomenon of attenuation, where a large amount of energy is deposited in the superficial layers of tissue, a fluoroscopic x-ray beam carries less energy to deeper layers. Therefore, it is important to specify the location of the absorbed dose, such as the absorbed dose to a specific organ or tissue, the point of entry into the skin, the midline, or the exit plane.

Currently, the measurement of absorbed dosage is indicated using the International System of Units (SI) with the unit of grays. In the past, absorbed dose was measured using units of rads or mrads, where 1 mGy is equal to 100 mrad. The idea of equivalent dose is closely linked, since it takes into account the absorbed dosage and adjusts it to account for the particular kind of radiation's potential to cause biological harm. The weighting factor for x-rays and gamma-rays, which are the radiation types used in imaging children with CAHD, is 1. Therefore, absorbed and equivalent doses have identical values. Equivalent dosage is quantified using the International System of Units (SI) and is measured in sieverts (Sv) or millisieverts (mSv), rather than grays (Gy). The rem was the ancient unit of measurement, with a conversion factor of 1 mSv = 100 mrem (2).

Another universal measurement, applicable to different methods and enabling comparisons across methods, is the effective dosage. The effective dose is a comprehensive measure of radiation exposure to the whole body. It is calculated by summing the organ equivalent doses, which are weighted by tissue weighting factors that take into account the potential harm caused by radiation to each specific organ. The tissue weighting parameters are determined by international standards and are based on a comprehensive analysis of existing global radioepidemiological data (2). The current tissue weighting variables used to calculate effective dose are averaged values based on age and sex. This is a problem when trying to assess the individual stochastic radiation risk for a single patient, particularly in children. The concept of effective dose allows for comparisons across exposure situations in which various areas of the body are exposed to varying levels of radiation. It is measured in units of sieverts. A dosage measured in sieverts might refer to either an effective dose or an equivalent dose. Therefore, it is important to clearly indicate which kind of dose is being referred to. For instance, if an accurate dosage is mistakenly understood as a comparable dosage, the amount of radiation received by organs immediately exposed to it and the possible harm they may face from a diagnostic procedure might be greatly overestimated.

5. Computed Tomography Metrics

Multiple correlated CT dose index numbers are derived from dosimetric measurements conducted in a cylindrical Plexiglas phantom (35). These include the volume CT dose index (CTDIvol), the dose–length product (DLP), and the size-specific dose estimate (SSDE). CTDIvol, as determined by modern CT scanners, is derived from dosimetric measurements taken at both the periphery and center of a cylindrical phantom, together with the pitch used for a helical scan. The procedure may be conducted with a phantom with a diameter of either 32 or 16 cm. DLP, which is also documented in contemporary scanners, is determined by multiplying CTDIvol by the scan duration. It represents the overall radiation exposure during a scan, rather than simply the dose at one specific site. SSDE (36) is a newly established CT dose metric that has not yet been recorded by CT scanners. It adjusts the CTDIvol measurement to account for the size of the subject, specifically the effective diameter (36).

6. Optimization Techniques For Cardiac Computed Tomography

Cardiovascular computed tomography (CT) is becoming more widely used in infants with congenital heart disease (CAHD) (37–39). Contemporary cardiovascular multidetector CT (MDCT) scanner technology provides precise imaging of the structure of the heart in children with high heart rates (37). This technology minimizes the requirement for sedation, as opposed to magnetic resonance (MR) imaging (38) or cardiac catheterization. Additionally, MDCT scans can be conducted with effective doses of less than 1 mSv (40–42). The guidelines for advanced noninvasive cardiovascular imaging in children with CAHD do not provide specific recommendations for cardiovascular CT (43). However, it is essential for cardiac imagers to have expertise in radiation dose management strategies to minimize potential radiation risks for patients with cardiovascular disorders (44,45). Furthermore, the existing fluctuation in radiation dosage for cardiovascular CT scans in juvenile patients with cardiovascular diseases should be minimized by using radiation dose optimization strategies universally (46).

7. The Significance of Patient/Caregiver-Centered Imaging

Public, patient, and caregiver awareness of the hazards of ionizing radiation is frequently limited; certain patients and caregivers are unaware of the potential for detrimental effects, while others, often influenced by distorted media portrayals, perceive risks that are significantly exaggerated compared to the actual ones (9,10). According to a poll, the majority of parents whose children are having medical imaging treatments express a strong preference for being told about the potential dangers involved (10). Furthermore, the disclosure of risk is an essential duty of professionals, which includes respecting patient autonomy (47). To ensure family involvement in the decision-making process, we communicate the expected risks and benefits of the planned treatment, including addressing the potential dangers associated with radiation exposure when they are expected to be significant (48). The communication technique and level may be customized based on the risks and advantages of a specific imaging situation, such as the possibility of cognitive impairments resulting from general anesthesia utilized during MR examination in young children, or the use of intravenous contrast agents for either CT or MR (49). For operations with lesser dosages, offering written or electronic information may be enough. However, for treatments with larger doses, direct verbal communication, with or without formal written agreement, may be more suitable. Previously suggested radiation dosage criteria have been established for adult cardiac imaging to determine the degree of debate.

The recommendations, given by a group of experts supported by the National Institutes of Health–National Heart, Lung, and Blood Institute/National Cancer Institute, state that if the expected effective dose of a procedure is ≤3 mSv, then the procedure is considered to have very low risk and does not require detailed discussion or written informed consent. On the other hand, a projected dosage of ≥20 mSv is deemed to be at a threshold that requires either formal discussion or written informed consent. This publication does not include precise recommendations for dose cutpoints in pediatric cardiac imaging. However, there have been reports of doses above 20 mSv for some pediatric cardiac imaging techniques. Adult guidelines may be used as a reference point for these cases (24). It is crucial to recognize the significance of multidisciplinary communication, which involves the referring physician, imaging physician, and other members of the care team. It is crucial to ensure that the treatment is carried out for acceptable reasons with a thorough awareness of the risks and benefits (48).

8. Summary

The imaging techniques used in cardiac CT, nuclear cardiology, and fluoroscopically guided cardiac catheterization and electrophysiology span a wide range of hardware and software features and configurations. These techniques also include operator-dependent methods to imaging. If these recommendations are widely adopted by programs that care for children with CAHD, they could lead to substantial reductions in the overall exposure to ionizing radiation at a population level. At the same time, they would ensure that imaging procedures maintain high quality and do not compromise the accuracy of diagnoses or the safety of the procedures. Additionally, it is encouraged to implement other strategies such as actively including patients and caregivers in a well-educated decision-making process about medical imaging, as well as establishing comprehensive dose monitoring processes throughout the program. These approaches aim to enhance patient care and promote informed decision-making in the field of medical imaging. The advancement of contemporary cardiac imaging technology has transformed the field of cardiovascular medicine in children with CAHD by enabling enhanced diagnosis and less intrusive treatments. It is now the responsibility of the imaging community to optimize these techniques in order to provide the highest possible picture quality that is suitable for the patient's medical requirements, while minimizing the radiation dosage as much as possible.

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