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THE DIGITAL REVOLUTION IN PEDIATRIC RADIOLOGY: FROM ULTRASOUND TO AI-DRIVEN DIAGNOSTICS – A NARRATIVE REVIEW

Justyna Kącikowska *(Corresponding Author, Email: kacikowskajustyna@gmail.com)*
Dr. Anna Gostyńska Wolski Hospital, Marcina Kasprzaka 17, 01-211 Warsaw, Poland
ORCID ID: 0009-0007-1399-9553

Piotr Szczepański
University Clinical Centre of Medical University of Warsaw, The Infant Jesus Clinical Hospital, Lindleya 4, 02-005 Warszawa, Poland
ORCID ID: 0009-0007-1064-6947

Katarzyna Sordyl
Samodzielny Publiczny Zespół Zakładów Opieki Zdrowotnej w Wyszkowie, Komisji Edukacji Narodowej 1, 07-200 Wyszków, Mazovia, Poland
ORCID ID: 0009-0005-1438-154X

Oliwia Bolek
Centralny Szpital Kliniczny WUM, Stefana Banacha 1A, 02-097 Warszawa, Poland
ORCID ID: 0009-0006-2399-9808

Oliwia Grzelak
Mazowiecki Szpital Bródnowski, ul. Kondratowicza 8, 03-242 Warsaw, Poland
ORCID ID: 0009-0001-3649-1134

Krzysztof Rogulski
National Medical Institute of the Ministry of Interior and Administration, Warsaw, Poland
ORCID ID: 0009-0006-7091-0546

Maria Fengier
Medical University of Warsaw, Poland
ORCID ID: 0009-0002-9201-5703

Weronika Kuśmierczyk
Samodzielny Publiczny Szpital Kliniczny im. prof. W. Orłowskiego CMKP, Warsaw, Mazovia, Poland
ORCID ID: 0009-0000-5704-1485

Magdalena Majkowska
Medical University of Warsaw, Poland
ORCID ID: 0009-0001-7472-9537

ABSTRACT

Background: The rapid development in AI and imaging technologies has enabled pediatric radiology to become digital. The objective of modern diagnostic methods is to achieve balance between radiation safety and accuracy in diagnosis by adapting imaging techniques to the anatomical, physiological, and ethical requirements of pediatric patients.
Aim: The aim of this study is to summarize recent advancements in artificial intelligence applications across pediatric imaging modalities and to evaluate their impact on diagnostic accuracy, workflow efficiency, and patient safety.
Methods: Recent peer-reviewed studies in pediatric radiology and artificial intelligence were analyzed to conduct a narrative review. The primary focus included advancements in ultrasound, MRI, CT, and hybrid imaging systems, as well as AI-driven diagnostic applications, workflow optimization, and ethical considerations.
Results: Ultrasound remains the preferred choice, and quantitative tools like contrast-enhanced ultrasonography and elastography render it more valuable. Diffusion imaging, spectroscopy, and faster acquisition methods have made magnetic resonance imaging more accessible and less probable to require sedation. Thanks to advances in CT and PET/CT, often enhanced by iterative and AI-driven reconstruction, radiation exposure has declined considerably. Hybrid PET/MRI provides both molecular and structural details while minimizing radiation exposure significantly. Artificial intelligence is now an integral part of almost all subspecialties in pediatrics.
Conclusions: Integrating AI, radiomics, and hybrid modalities is altering theranostic processes in medicine and shows how crucial it is to monitor ethics, equitable access, and professional learning possibilities. To ensure worldwide equity, it's necessary to establish clear validation processes, collaborate across fields, and launch international initiatives.

KEYWORDS

Ultrasound Elastography, Contrast-Enhanced Ultrasound, Hybrid Imaging Techniques, Artificial Intelligence, Radiomics

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Introduction:

Pediatric radiology is one of the most complex areas of medical imaging. A precise diagnosis must be achieved while simultaneously guaranteeing that the child is the primary focus of care. All imaging decisions must be made with the child's unique anatomical, physiological, and psychological characteristics, as well as their increased sensitivity to radiation and anesthesia, in mind. The need for continuous diligence in the selection of protocols and the rationale for imaging is underscored by the fact that children are particularly susceptible to the stochastic effects of ionizing radiation and the potential neurodevelopmental consequences of anesthetic exposure (Don et al., 2013; Ng, 2022; Smith-Bindman et al., 2025). In this specific context, the "Image Gently" initiative has made a significant impact. It has argued in favor of prioritized ultrasound and MRI over other imaging modalities that utilize radiation, as well as for dose optimization and shielding (Don et al., 2013; Sammer et al., 2023).

Despite ongoing advancements in safety protocols, computed tomography (CT) continues to make a substantial contribution to the cumulative radiation exposure of children. This data suggests that the dosage levels are still in flux and that it is still necessary to standardize acquisition procedures on a global scale (Don et al., 2013; Smith-Bindman et al., 2025).

Ultrasound continues to be the most effective method for imaging minors because of its safety, affordability, and portability. This procedure is the initial assessment that is employed the most frequently for a variety of conditions (Brzewski, 2017; Davis et al., 2025). Technological advancements have significantly enhanced its diagnostic capabilities. Contrast-enhanced ultrasound (CEUS) is capable of conducting a comprehensive vascular assessment without the use of nephrotoxic agents or ionizing radiation, which is comparable to CT and MRI in the differentiation of benign from malignant hepatic lesions (Ajmal, 2021; Wang et al., 2021). In the same vein, shear-wave elastography offers a quantitative evaluation of the rigidity of soft tissues and the liver, which allows for the non-invasive staging of fibrosis and the identification of subtle liver changes during early chronic pediatric hepatopathies (Mărginean et al., 2020; Wiecek et al., 2022). MVI enhances the sensitivity of ultrasonography to detect very slow blood flow in microvessels without the use of contrast chemicals (Davis et al., 2025). The advent of CEUS, elastography, and MVI has revolutionized ultrasound, transforming it from a rudimentary screening tool into a multifaceted quantitative and functional diagnostic modality capable of enabling precise real-time assessments (Ajmal, 2021; Davis et al., 2025; Medyńska-Przęczek et al., 2024).

Due to its superior soft-tissue contrast and lack of radiation exposure, magnetic resonance imaging (MRI) continues to be essential for pediatric neuroimaging, cancer, and musculoskeletal assessment. Nevertheless, problems still remain, including the need for immobilization and the lengthy examination times, for which sedation is often required, which again can be detrimental to the child and the process. Acquisition times and sedation needs have also been considerably minimized with the latest developments, such as motion-correction algorithms, parallel imaging, and rapid-sequence protocols (Harrington et al., 2022; Jaimes et al., 2021). Supplementary behavioral strategies, including the presence of a parent or therapy animal, interactive preparation, and audiovisual distraction, enhance compliance and reduce fear, allowing younger children to endure an MRI without sedation (Harrington et al., 2022; Iwayama et al., 2025).

Computed tomography (CT) continues to be the preferred choice for critical and emergency situations, as it is highly reliable, holds a high spatial resolution, and operates within minutes. This technique is a vital component of trauma, pulmonary, and vascular imaging, where having the ability to make rapid decisions is essential for survival. The implementation of deep-learning iterative reconstruction, convolutional neural networks, and model-based algorithms has significantly enhanced CT by significantly reducing radiation dose—often by over fifty percent—while maintaining diagnostic quality (Brady et al., 2021; Greffier et al., 2015; He et al., 2025; Horst et al., 2025). On the other hand, tube-current modulation, developed especially for children, enables dosing in each patient to be tailored to his or her size and clinical needs (Greffier et al., 2015; Nagayama et al., 2018), while deep learning-based reconstruction enhances texture integrity and contrast resolution (Ng, 2022). These improvements contribute to CT being a more efficient and dose-conscious technique (Greffier et al., 2015; Ng, 2022).

Beyond conventional methods, hybrid and computational imaging are revolutionizing the diagnosis of medical conditions. The diagnosis of neuro-oncological, metabolic, and inflammatory conditions is facilitated by the integration of metabolic and anatomical data into PET/MRI, which uses less radiation than PET/CT (Pedersen et al., 2022). Simultaneously, pediatric imaging is being transformed by artificial intelligence (AI), which is improving workflow efficiency, automating segmentation, facilitating the evaluation of image quality, and aiding in the optimization of dosage and the prediction of outcomes (Laborie et al., 2023; Yan et al., 2025). Artificial intelligence in radiology is positioned to enhance clinical skill and judgment by facilitating the development of an accurate diagnosis tailored to a patient's unique needs.

With these new innovations come new challenges. The increased use of AI has made ethical oversight and global equity considerably more critical. Disproportionate distribution of advanced imaging resources geographically, data bias, and lack of transparency are ongoing problems (Brady & Neri, 2020; Laborie et al., 2023; Sammer et al., 2023; Yan et al., 2025). We should base the adoption of AI and hybrid technologies on the ethical principles of responsibility, explainability, and inclusivity. These principles would ensure that all children, irrespective of their socioeconomic or geographical conditions, can benefit from innovations (Alkhulaifat et al., 2023; Gallée et al., 2023; Salih et al., 2024).

This review covers the latest standards, new technologies, challenges, and future possibilities in pediatric radiography. It integrates data from peer-reviewed studies to provide insight into ethical and technological issues in this rapid-growth field. While it highlights the sensitive balance needed between safety and innovation, it also points to knowledge gaps that prevent the translation of revolutionary concepts into clinical practice and explores possible ways for cautious integration with traditional pediatric care using AI and hybrid imaging. The following sections describe enhancements to traditional approaches, how new technology influences diagnostic pathways, and ideas for the future that can serve to make pediatric radiology more efficient, safer, and equitable.

Methodology:

This narrative review was conducted in accordance with the Scale for the Assessment of Narrative Review Articles (SANRA) and established methodological standards for medical literature reviews to ensure transparency, comprehensiveness, and methodological rigor.

Search Methodology: A comprehensive search was performed in PubMed, which employed combinations of pediatric radiology, ultrasound, elastography, contrast-enhanced ultrasound, MRI, CT, PET/CT, PET/MRI, hybrid imaging, radiomics, artificial intelligence, machine learning, and deep learning in the search phrases. We also manually reviewed the reference lists of relevant review papers and meta-analyses to identify additional studies that met the requirements.

Criteria for Eligibility: The criteria for inclusion were as follows:

1. Published in English, original or review articles that have undergone peer review;
2. Research that concentrated on imaging in pediatric populations or diverse groups that comprise a designated pediatric subset;
3. Research that focuses on the efficacy of diagnostic imaging, quantitative biomarkers, radiation safety, AI-driven reconstruction, or process optimization;
4. The provision of a minimum of an abstract and methodological details that facilitate the evaluation of the study design.

Conference papers, letters, editorials, case reports that lacked imaging or AI components, and studies that were exclusively focused on adult populations were all included in the exclusion criteria.

Integration and Extraction of Data: The texts of qualifying papers were assessed to confirm their pertinence to digital technology and pediatric imaging. Data were collected from each study in relation to imaging modalities (ultrasound, MRI, CT, PET/CT, PET/MRI), clinical domains, cohort characteristics, computational or AI approaches, and documented diagnostic or workflow outcomes. The literature was qualitatively synthesized, and the results were narratively organized into thematic areas that corresponded to the sections of this review. To resolve discrepancies in the study's interpretation, consensus was implemented. Utilizing PubMed or official publisher databases, we verified the authenticity and traceability of all references.

Results:

1. Current Standards in Pediatric Imaging and Their Innovations

1.1. Ultrasound Imaging

Ultrasound continues to provide the most suitable technique of children's imaging, as it is inexpensive, easy to perform, and safe. Since it does not emit ionizing radiation, it is particularly suitable for newborns and children, who may be examined repeatedly without risk of excessive exposure. This advantage makes it very valuable in conditions requiring thorough observation, such as chronic diseases and congenital anomalies, and in pathologies requiring frequent and regular investigations. Ultrasound is primarily used for the examination of the abdomen and genitourinary system—it aids physicians in diagnosing biliary disease, hydronephrosis, vesicoureteral reflux, intussusception, pyloric stenosis, or appendicitis (Brzewski, 2017; Davis et al., 2025). Doppler techniques provide, in real time, hemodynamic disturbances, besides anatomical imaging, in both acute and chronic situations, by offering dynamic functional information about blood flow, tissue perfusion and vascular anomalies ((Brzewski, 2017; Davis et al., 2025; Kozyak et al., 2023).

Recently, point-of-care ultrasonography (POCUS) has become widespread inside emergency rooms and intensive care units. It is a fundamental tool for immediate decision-making in pediatric emergencies, since it is portable and can be used immediately. POCUS helps the physician determine the diagnosis of conditions related to abdominal pain, chest traumas, pleural effusions, or sepsis. It also offers real-time guidance on procedures, including the placement of lines and the drainage of abscesses (Kozyak et al., 2023; Lee et al., 2024; Lin-Martore & Kornblith, 2021). Structured POCUS training has become increasingly accessible to pediatricians, emergency physicians, and intensivists, which has facilitated its routine implementation. This data indicates that ultrasound competencies extend beyond radiology departments.

This article examines the significant advancements in ultrasound technology over the past few years. These developments have had significant impacts on making ultrasound diagnosis much more precise and valuable. One such major advance is the CEUS, allowing clinicians to assess the vascularity of lesions and organs without radiation. MVI is a novel Doppler technique that allows the detection of slow and subtle blood flow in small vessels, which normally is not possible to detect with standard color or power Doppler techniques. Elastography, on the other hand, helps figure out how stiff tissues are.

Ultrasonography is the most effective modality for pediatric imaging, as evidenced by these recent developments. A real-time instrument that incorporates data on structure, function, and blood circulation, it is radiation-free and versatile. As technology advances, ultrasound is transitioning from a diagnostic instrument to a comprehensive, patient-centered imaging solution in contemporary pediatric medicine (Kozyak et al., 2023; Lin-Martore & Kornblith, 2021).

1.2. Magnetic Resonance Imaging (MRI)

Due to its superior soft-tissue contrast and the absence of ionizing radiation, magnetic resonance imaging (MRI) continues to be the preferred method for examining the brain, spine, musculoskeletal system, and abdominal organs in pediatric patients (Daldrup-Link, 2017; Pedersen et al., 2022). This makes it indispensable in pediatric practice, where it is particularly important to reduce radiation exposure. Magnetic Resonance Imaging (MRI) is the modality of choice for the detection, staging, follow-up during treatment, and long-term follow-up of tumors in pediatric oncology. Multiparametric MRI techniques that incorporate both structural and functional sequences provide additional information about morphology, diffusion, perfusion, and metabolism. This allows for improved tumor characterization and therapeutic response. Quantitative biomarkers, including magnetic resonance spectroscopy (MRS), dynamic contrast-enhanced (DCE) perfusion, and apparent diffusion coefficient (ADC) mapping, facilitate the early evaluation of treatment response and the differentiation between post-therapeutic effects and tumor recurrence (Daldrup-Link, 2017; Inarejos Clemente et al., 2022). Diffusion-weighted imaging (DWI) and diffusion tensor imaging (DTI) facilitate the noninvasive assessment of microstructural integrity, thereby elucidating white matter architecture, ischemia, demyelination, and tumor cellularity. Resting-state functional magnetic resonance imaging (fMRI) has enabled the evaluation of brain connectivity and functional maturation without requiring active patient involvement, which is especially beneficial in adolescent populations (Zhou et al., 2024). Magnetic resonance spectroscopy (MRS) enhances structural MRI by showing how the metabolism of tissues changes, hence highlighting unique biochemical profiles that may be used to differentiate tumor types or to monitor treatment-related changes. Similarly, MR elastography offers a noninvasive approach to assess the stiffness of the parenchyma and liver tissues. The evidence indicates that the demand for a biopsy can be substantially reduced in cases of chronic liver disease and fibrosis (Trout et al., 2020).

Recent technological developments have made magnetic resonance imaging more accessible to children and adolescents by placing increased emphasis on convenience, rapidity, and accessibility. Techniques such as compressed sensing and parallel imaging have made it possible to carry out high-resolution experiments in fractions of the conventional time by reducing acquisition times. This development allows for no-sedation protocols and thus minimizes anesthesia-related complications and speeds up patient throughput, as noted in studies (Harrington et al., 2022; Jaimes et al., 2021). AI-assisted image reconstruction and automated protocol optimization enhance workflows by dynamically adjusting parameters to suit each patient's anatomy, reducing motion artifacts, and improving image quality (Calixto & Gee, 2025; Davendralingam et al., 2021). These new methods not only make radiologic procedures easier, but they also reduce stress, noise, and the need to keep children still during the exam.

1.3. Computed Tomography (CT)

Despite decades of concerns about exposure to radiation, CT remains a crucial imaging modality in pediatric care, particularly in the assessment of emergency, trauma, pulmonary, and vascular conditions. This is the effect of its widespread availability and unmatched spatial resolution, as well as speed (Ohana et al., 2018). Frequently, CT enables practitioners to take instantaneous treatment decisions for patients by offering them critical, conclusive, and current information. This feature makes it the most appropriate option to assess for life-threatening or time-sensitive conditions, like polytrauma, pulmonary embolism, or complex airway and vascular conditions. CT's ability to rapidly produce high-quality multiplanar reconstructions allows clinicians to promptly evaluate internal injuries and initiate appropriate treatment (Chandra et al., 2020).

However, the long-term risk of developing cancer from radiation exposure is increased by the heightened sensitivity to radiation and the expected longer lifespan of children who undergo CT scans. Therefore, we must exercise cautiously - it is imperative to adhere to the ALARA (As Low As Reasonably Achievable) guideline to ensure accurate diagnoses and minimize exposure (Regmi et al., 2022). The Image Gently campaign actively advocates for the ALARA approach to safe imaging practice. It ensures that every exam is indicated, provides consistent guidelines for pediatric doses, and enhances understanding about radiation. The repeated exposure to malignancy can significantly raise the lifetime risk for the patient (Regmi et al., 2022; Smith-Bindman et al., 2025). It implies that every CT scan should be clinically justified, appropriately optimized for patient size and clinical setting, and narrowly focused on the diagnostic question. Protocol refinement plays an important role in pediatric CT scans regarding their safety.

It is also important to carefully adjust acquisition parameters such as tube current, voltage, pitch, and slice thickness according to the size of the patient and diagnostic needs. Organ-specific shielding, automated tube-current modulation, and scan-range restriction are effective strategies for reducing exposure, particularly in sensitive organs like the thyroid, breast, and gonads (Brady et al., 2021; Gottumukkala et al., 2019; Greffier et al., 2015; Nagayama et al., 2018; Regmi et al., 2022). Dual-energy and spectral CT methods enhance tissue characterization, enable virtual non-contrast reconstructions, and enhance vascular imaging, all while minimizing radiation exposure (Gottumukkala et al., 2019). Modern CT systems are equipped with high-velocity gantry rotation and ultra-rapid detectors, which allow for the acquisition of thoracoabdominal images in less than one second. This rapidity is especially beneficial for infants and young children, as it substantially reduces motion artifacts and reduces the need for anesthesia (Gottumukkala et al., 2019).

Recent technical innovations have substantially improved the quality of images and the safety of pediatric CT. This page further elaborates on these modifications. Iterative reconstruction techniques have revolutionized dose reduction by allowing for significant reductions in radiation exposure while maintaining high diagnostic accuracy (Brady et al., 2021; Greffier et al., 2015; Nagayama et al., 2018). Deep learning image reconstruction (DLIR) renders this method superior by minimizing the dose, improving spatial resolution and contrast fidelity, and eliminating the noise along with other anomalies (Nagayama et al., 2018; Ng, 2022). AI-driven denoising networks have demonstrated immense utility in pediatric chest CT, enabling ultra-low-dose CT images without affecting diagnostic accuracy or clarity (Hultenmo et al., 2025).

The above developments illustrate the road of evolution that pediatric CT has taken—from a high-dose and limited-use tool to a safe, accurate, and modern diagnostic technique. CT imaging in pediatric patients stands at the threshold of attaining the two-fold objectives: radiation management and diagnostic superiority, facilitated by improvements in AI-driven optimization, detector efficacy, and reconstruction algorithms.

2. Emerging Technologies and Innovative Modalities with AI Integration

2.1. Ultrasound Elastography (UE)

Ultrasound elastography (UE) is a validated, noninvasive imaging technique that is capable of assessing tissue stiffness. This method yields essential diagnostic data while mitigating the risks and discomfort associated with biopsy (Davis et al., 2025). Elastography is a precise intermediary marker that maps the degree of fibrosis and parenchymal remodeling by measuring tissue displacement upon mechanical or acoustic challenge to assess the elastic properties of organs and soft tissues (Davis et al., 2025; Ferraioli et al., 2021; Medyńska-Przęczek et al., 2024). These capabilities thus allow to detect pathogenic changes early in the course of the disease before morphological changes are present, which increases disease surveillance and treatment planning.

Taken together, transient elastography (TE) and shear-wave elastography (SWE) have shown a high degree of correlation with histologic fibrosis staging and are thus very effective for the detection and assessment of liver fibrosis (Wiecek et al., 2022). SWE facilitates the evaluation of liver stiffness by allowing for the real-time visualization of shear wave propagation through tissue. It is particularly beneficial for children as it does not cause discomfort, is relatively fast to provide, and does not contain ionizing radiation. Its use indicates that patients who are exceptionally immature or uncooperative can utilize it safely without sedation (Ferraioli et al., 2021; Mărginean et al., 2020).

Ultrasound elastography is increasingly acknowledged as a clinical tool in pediatric hepatology. It aids physicians in the management of chronic liver conditions, including cystic fibrosis-related liver disease, cirrhosis, non-alcoholic fatty liver disease (NAFLD), viral hepatitis, and autoimmune hepatitis (Davis et al., 2025; Medyńska-Przęczek et al., 2024; Wiecek et al., 2022). It enables the longitudinal surveillance of therapy efficacy by facilitating the objective assessment of hepatic stiffness.

Shear-wave velocity shows close correlation with biochemical indicators of liver injury and with signs of portal hypertension in cystic fibrosis, which may signify early development (Medyńska-Przęczek et al., 2024). Several experts have recommended that the safety and reproducibility of elastography will warrant inclusion of this technique in the annual liver workup of patients with cystic fibrosis, with increased potential for early intervention and consequent improved long-term outcomes (Mărginean et al., 2020; Wiecek et al., 2022).

Elastography is being used rapidly on more organ systems than just the liver, reflecting its added value in pediatric radiology. In the spleen and kidneys, elastography measures parenchymal stiffness due to fibrosis, congestion, or reflux nephropathy. SWE is able to differentiate benign from malignant thyroid nodules due to significantly higher stiffness of malignancies; this further reduces unnecessary biopsies and increases diagnostic confidence. In the musculoskeletal system, elastography quantifies muscle stiffness and elasticity, thus making it a modality by which treatment response can be assessed, and neuromuscular diseases, such as Duchenne muscular dystrophy, can be monitored (Mentzel et al., 2022). These characteristics reveal that UE has grown into a valuable general-purpose diagnostic biomarker, making traditional ultrasound superior.

2.2. Contrast-Enhanced Ultrasound (CEUS)

One of the most significant developments in the field of pediatric imaging is contrast-enhanced ultrasonography (CEUS). This allows for the real-time visualization of microvascular flow and tissue perfusion without the use of nephrotoxic substances or ionizing radiation (Ajmal, 2021; Davis et al., 2025). The technique employs intravascular microbubble contrast compounds, which the lungs, not the kidneys, retain within the blood vessels and eliminate. CEUS is remarkably safe for children, particularly those with kidney disorders. The favorable safety profile, portability, and absence of anesthetic requirements of CEUS make it an appealing alternative to CT and MRI for the dynamic perfusion evaluation of children.

Contrast-enhanced ultrasound (CEUS) is crucial for detecting liver lesions in pediatric hepatology. It provides diagnostic accuracy similar to multiphasic MRI as it offers dynamic information about vascular enhancement patterns, thus enabling differentiation between benign and malignant lesions (Ajmal, 2021; Chen et al., 2023; Wang et al., 2021). Studies have shown a strong correlation of these findings with MRI and enable a quick, bedside alternative for follow-up studies (Davis et al., 2025). Perfusion kinetics can be quantitatively assessed, thereby offering a method of assessing the response of therapy and natural history.

CEUS has shown great advantages in imaging pediatric trauma by providing real-time assessment of organ perfusion and the detection of parenchymal injury to the spleen, liver, and kidneys. It assists in the rapid decision-making process during emergencies by identifying minor regions of ischemia or laceration without exposing individuals to radiation, as is the case with CT scans (Davis et al., 2025; Di Renzo et al., 2025; Zhang et al., 2022). CEUS is also widely utilized to monitor patients after surgery and transplantation—it evaluates blood flow in liver and kidney transplants, identifies vascular abnormalities, and compares quantitative perfusion indicators with kidney or liver function (Zhang et al., 2022). Due to these features, CEUS represents a very important tool in both diagnostics and follow-up planning in acute care.

This modality is beneficial in various pediatric medical domains. It enables the dynamic evaluation of testicular or ovarian perfusion in cases of torsion, trauma, or malignancy and distinguishes benign from malignant thyroid nodules in endocrine and genitourinary imaging (Davis et al., 2025). In gastrointestinal and inflammatory disorders, CEUS offers comprehensive imaging of the vascularity and perfusion kinetics of the intestinal wall, which enables the noninvasive evaluation of the activity of inflammatory bowel disease (Davis et al., 2025; Gokli et al., 2021). It has largely supplanted conventional fluoroscopic cystourethrography in the field of urology for the diagnosis of vesicoureteral reflux. This method offers equivalent diagnostic accuracy without exposing the patient to radiation. Combining CEUS with elastography and Doppler ultrasound creates a multiparametric approach that gathers both structural and functional information. The result provides a range of imaging biomarkers that can be utilized in the categorization of disorders and monitoring treatment advancement (Ajmal, 2021).

PET/CEUS and CEUS/MRI are examples of hybrid imaging techniques that are becoming increasingly prevalent. They combine real-time data on metabolism, molecules, and blood flow. Such integration establishes a link between molecular and functional imaging, creating theranostic applications that help doctors diagnose and monitor the treatment of pediatric conditions.

CEUS is a great example of the evolution of ultrasound from a morphology-viewing instrument to a quantitative, dynamic, and, very often, AI-enhanced diagnostic tool. This is part of modern pediatric imaging and stands at the forefront of the change toward personalized, precision-based care, given its outstanding safety profile, quite excellent diagnostic accuracy, and free from radiation.

2.3. Microvascular Imaging (MVI)

Microvascular imaging (MVI) is a revolutionary Doppler ultrasound technique that allows for visualization of slow and subtle blood flow in microvessels that regular color or power Doppler cannot capture. MVI differentiates real microvascular flow from tissue motion artifacts by using sophisticated adaptive congestion reduction algorithms along with high-frame-rate acquisition methods. The result is the creation of highly detailed images of perfusion at the capillary level without the need for contrast compounds (Davis et al., 2025; Ohno et al., 2017). This innovative method combines traditional Doppler and contrast-enhanced techniques to provide physicians a non-invasive but highly precise examination of tissue microcirculation.

MVI substantially improves diagnostic accuracy in pediatric radiology by facilitating the assessment of organ microperfusion in the liver, kidneys, gallbladder, thyroid, testes, and spleen. Given its ability to provide minute blood vessel visualization, it is especially well-suited for the examination of congenital defects, inflammatory diseases, and localized lesions. In hepatic and renal imaging, MVI yields microvascular flow patterns that differentiate normal parenchymal perfusion from conditions such as ischemia, tumor angiogenesis, or fibrosis. MVI reveals the organization of blood vessels and enables the identification of unusual or chaotic flow patterns linked to malignancies during the examination of localized lesions and tumors - this feature enables the real-time differentiation between benign and malignant lesions (Bayramoglu et al., 2020; Davis et al., 2025; Ohno et al., 2017).

The vascular index, a critical metric derived from MVI, represents the percentage of pixels within a selected region that exhibit detectable flow. This index has been used as a semi-quantitative biomarker of microvascular density and tissue perfusion, allowing for the long-term monitoring of disease activity or response to treatment (Bayramoglu et al., 2020; Davis et al., 2025; Ohno et al., 2017).

Alterations in vascular index values, before structural changes become apparent on standard imaging, may provide an early indicator of improvement after anti-inflammatory or anti-angiogenic therapy. This quantitative measure increases reliability and reduces operator dependency, long-standing limitations of conventional ultrasound assessments. What is more, microvascular imaging (MVI) is a significant non-contrast alternative, particularly for neonates and pediatric patients, where the administration of intravenous contrast may pose safety concerns or logistical challenges.

MVI serves as an essential preliminary tool for evaluating microcirculation prior to moving on to CEUS or MRI, exhibiting similar sensitivity in detecting minor vascular flow across diverse clinical contexts. Additionally, MVI is an excellent option for pediatric patients with chronic or progressive diseases, as it can be safely repeated for follow-up evaluations.

The incorporation of other modern ultrasound technologies is expected to improve MVI's ability to diagnose disorders in the future. The combined use of MVI and elastography allows for the simultaneous evaluation of tissue rigidity and vascularity, which enhances our understanding of inflammatory or fibrotic processes. Additionally, techniques for AI-driven noise reduction and motion correction are being developed to enhance image reliability and reduce reliance on operator proficiency. These developments will ensure that all institutions conduct examinations of the same quality. The visualization of individual capillaries and real-time dynamic perfusion maps may soon be possible due to the innovation of super-resolution ultrasound techniques that may surpass current spatial resolution constraints (Davis et al., 2025).

2.4. Functional and Accelerated MRI

Functional and quantitative imaging has been driving a paradigm shift in using MRI for the diagnosis of children. These new imaging techniques address the functionality and composition of tissues rather than their morphology—unlike routine sequences, which focus on anatomical structures. They intend to quantify biological and physiological processes at the cellular level. MR spectroscopy (MRS), perfusion imaging, diffusion-weighted imaging (DWI), diffusion-tensor imaging (DTI), and MR elastography are reliable techniques that yield biomarkers for the microarchitecture of tissues, metabolism, and hemodynamic status (Ahmad et al., 2018; Daldrup-Link, 2017; Inarejos Clemente et al., 2022). They contribute to making physiologically informed imaging possible, enabling doctors to identify a child's disease more rapidly and conduct follow-up on their therapy.

In the field of pediatric oncology, multiparametric MRI is crucial for further evaluation, staging, and diagnosis of tumors. As a result of integrating diffusion, perfusion, and metabolic data, these techniques provide a significant degree of uniformity in risk stratification and the monitoring of treatment (Inarejos Clemente et al., 2022; Pringle et al., 2022). ADC mapping shows significant correlation with histologic grade and therapeutic response, thus confirming its usefulness as a noninvasive biomarker of tumor aggressiveness

(Daldrup-Link, 2017). Diffusion–perfusion analysis can further help in differentiating malignant from benign lesions in various systems, including musculoskeletal, gastrointestinal, and renal malignancies, which is important to determine tumor vascularity, necrosis, and microstructural heterogeneity (Davendralingam et al., 2021). Spectroscopic metrics and quantitative perfusion may also serve as very early indicators of therapeutic response even before morphologic changes are apparent. Treatment can thus become more personalized and tailored to each patient based on this information.

Functional and diffusion-based MRI techniques have revolutionized our understanding of brain development and pathology in neurological imaging (Daldrup-Link, 2017; Nikam et al., 2022). DWI, DTI and tractography enable a comprehensive assessment of white matter integrity, hypoxic-ischemic injury, and functional connectivity networks related to neurodevelopmental disorders or epilepsy. These methods helped us identify important white-matter tracts that need to be kept intact for the brain to work correctly—especially advantageous when planning surgeries for epilepsy and tumor resections. Advanced quantitative techniques, including T1/T2 mapping, myelin imaging, and resting-state fMRI, offer noninvasive methods of assessing cerebral development in neonates and young children, while high-resolution diffusion imaging enhances the identification of microstructural changes (Zhou et al., 2024). These advancements have rendered functional MRI a crucial component of contemporary pediatric neuroimaging, as they create a linkage between neuronal understanding and structural evaluation.

New faster MRI techniques are making cardiac and body imaging more accurate and efficient. Real-time cine MRI assisted by artificial intelligence enables the fast acquisition of high-quality images of the heart, reducing the time used per scan by nearly half while continuing to diagnose accurately (Taylor, 2022). Quantitative methods, such as MR elastography, deliver additional information by assessing tissue stiffness, thereby generating radiation-free biomarkers for hepatic and cardiac fibrosis (Trout et al., 2020). These techniques facilitate early detection of diffuse hepatic or cardiac abnormalities in systemic conditions, thus reducing the necessity for invasive biopsies.

These innovative concepts highlight how functional and quantitative MRI, often enhanced by AI, is becoming increasingly valuable in the field of precision pediatric imaging. MRI is a dynamic, biologically informed approach to diagnosis in pediatric patients as it combines speed and repeatability with advanced tissue characterization.

2.5. Hybrid Imaging: PET/MRI and Long Axial FOV PET/CT

Hybrid imaging is an enormous advance in pediatric radiology, putting together in one examination, molecular and anatomic knowledge. PET/MRI combines the high metabolic sensitivity of PET with the excellent soft tissue contrast and radiation-free advantages of MRI, providing comprehensive, multiparametric visualization for both structure and function. This synergism is of particular benefit in pediatric settings concerning conditions involving oncology, epilepsy, and inflammatory disorders. Simultaneous assessment of metabolic activity with morphological changes is an ideal and important aspect that helps elucidate the mechanisms of the disease process with greater accuracy than was possible in the past (Gatidis et al., 2016; Pedersen et al., 2022; States & Reid, 2020).

PET/MRI has dramatically changed the landscape for neuro-oncological tumor imaging in children by allowing lesion detection, grading, and response evaluation beyond what is possible with either modality alone. Combining metabolic PET features with diffusion-weighted imaging enhances tumor delineation and facilitates more precise radiation planning, thereby reducing ambiguity in target volume definition (Pringle et al., 2022). The simultaneous acquisition of diffusion and metabolic data allows the relationship between cellular and metabolic activity to be seen in real time, reducing registration errors. PET/MRI helps in differentiating healthy tissue and post-treatment changes by identifying tumor heterogeneity and necrosis caused by treatment.

Neuroinflammatory disorders and epilepsy are two of the increasingly important indications for PET/MRI studies. It is capable of discovering early indications of microglial activation or demyelination and identifying epileptogenic foci before any changes in structure become apparent (Gatidis et al., 2016). This ability makes it possible to diagnose children with refractory epilepsy sooner and makes surgical or therapeutic interventions more accurate. PET/MRI offers numerous logistical advantages in clinical environments. The acquisition of functional and anatomical data simultaneously reduces the scan duration, sedation requirements, and radiation exposure by more than fifty percent compared to PET/CT. Additionally, MRI-based attenuation correction eliminates the necessity for CT (Gatidis et al., 2016; Pedersen et al., 2022).

The advantages of combining PET/MRI applications surpass those of neuroimaging applications. PET/MRI characterizes infectious, inflammatory disorders and malignancies in pediatric musculoskeletal and systemic diseases by integrating such techniques as diffusion, perfusion, and metabolic characteristics to understand the effect of lymphoma, sarcomas, and metabolic bone diseases on the bone marrow, soft tissues, and metastases to other regions of the body. PET's metabolic sensitivity and MRI's unique soft-tissue contrast make it easier to stage, monitor treatment, and check for residual illness. This process is accomplished without exposing the patient to additional radiation, which is especially important for children who require multiple follow-up imaging procedures (Davendralingam et al., 2021; Pedersen et al., 2022).

A substantial advancement in hybrid imaging is the Long Axial Field-of-View (LAFOV) PET/CT, which is also known as total-body PET/CT. The LAFOV devices are fitted with detectors that can cover an area of 194 cm and are capable of whole-body metabolic imaging in under one minute. They are also capable of recording dynamic physiological events that are occurring simultaneously in multiple organs. PET imaging is rendered safer and more feasible, even for neonates, due to the substantial reduction in tracer doses—by as much as 80% compared to conventional systems—resulting from the increased sensitivity. The technology improves temporal and spatial resolution, thereby reducing the need for anesthesia and motion artifacts (Dias et al., 2025).

3. Artificial Intelligence in Pediatric Radiology

Artificial intelligence is rapidly emerging from experimental research into widespread utilization to begin making significant impacts on pediatric radiology, enhancing workflow efficiency, diagnostic accuracy, and the ability for personalized decision-making. Applying AI to pediatric medicine is more demanding than to adults due to the unique ethical considerations pertinent to minors, distinct anatomical differences, and limited datasets. The inherent diversity of pediatric imaging data arises from variations in growth, physiology, and disease presentation. Therefore, it is vital to establish validation frameworks and algorithms that accommodate the age-related anatomical differences and limited sample sizes. Future solutions must prioritize children, clarify the ethical implications of AI technologies, and enhance their usability in routine tasks as they become more integrated into clinical settings to support radiologists without compromising their expertise (Salih et al., 2024).

3.1. Present Clinical Applications of AI Across Radiology Subspecialties

Artificial intelligence is currently having a huge impact on almost all areas of pediatric radiology, enhancing diagnostic accuracy, safety, and efficiency. Deep-learning models have achieved expert-level performances in the classification, lesion detection, and brain tumor segmentation tasks in neuroradiology. Advanced CNNs can differentiate between different types of posterior fossa tumors and link imaging features to genetic and histological classifications, which improves diagnostic precision and allows for the development of individualized, targeted treatment strategies (Huang et al., 2022). In pediatric patients with gliomas and medulloblastomas, non-invasive biomarkers are being developed for risk stratification, outcome prediction, and treatment response monitoring, using integrated radiomics and artificial intelligence (Daldrup-Link, 2019). AI-enhanced denoising algorithms and motion-resistant diffusion sequences make quantitative features more consistent and images better, especially in children who do not cooperate or are not sedated. This indicates that a reduced number of readings is required (Laborie et al., 2023; Lundervold & Lundervold, 2019).

AI models have been excellent at leveraging thoracic imaging for the diagnosis and staging of common respiratory conditions in children. Algorithms tested on large databases of chest radiographs can identify pneumonia with high accuracy similar to expert radiologists and thus permit rapid and reliable evaluations in busy clinical settings (Schalekamp et al., 2022).

Deep-learning frameworks have successfully identified various infectious or inflammatory diseases, such as tuberculosis and bronchiolitis, resulting in increased diagnostic speed and diminished interpretative variability. AI-driven technologies do not stop with diagnosing diseases but also automate the process of evaluation and classification of picture quality, prioritizing anomalous investigations to facilitate emergency procedures (Yan et al., 2025).

AI-assisted skeletal maturity evaluation represents a clinically validated and important application of AI in pediatric musculoskeletal imaging (Offiah, 2022). Automated approaches to assessing bone age from hand radiographs significantly reduce inter-observer variability and reporting time, promoting standardization of growth assessment. Collaboration between humans and AI improves reliability and interpretability as radiologists verify and validate AI-driven decisions (van Leeuwen et al., 2022). AI algorithms can support radiologists in detecting abnormalities or inconsistencies in non-accidental injury, although they are weak compared to the experienced clinical judgment that ensures safety for patients and ethical standards (Offiah, 2022). Reliability of diagnostic findings is indispensable for complicated skeletal trauma - automated fracture detection and growth plate analysis significantly improve final results (Moore et al., 2022).

Moreover, AI radiomics is continuously evolving the approach of oncological imaging regarding the measurement of tumor response and viability. Algorithms developed using multiparametric MRI inputs incorporating diffusion, perfusion, and spectroscopic data in children with sarcomas and lymphomas may differentiate active tumor tissue from posttreatment necrosis and enhance precision in response evaluation (Daldrup-Link, 2019). These various procedures with the help of artificial intelligence allow for the identification of early signs of success following therapy based on objective and reproducible biomarkers that they generate (Davendralingam et al., 2021).

Using the same pipelines to acquire images of the abdomen and kidneys makes it less thorough to find inflammatory and vascular conditions. AI-driven segmentation and 4D-flow analysis in cardiac imaging enable the noninvasive assessment of ventricular function and chemotherapy-induced cardiotoxicity, facilitating the prompt detection of functional impairment and the development of individualized cardiac monitoring (Taylor, 2022).

Artificial intelligence is increasingly being used in interventional radiology to improve the safety and efficacy of interventions. Machine learning algorithms enable pre-procedural planning with automated identification of the best access routes, calculation of needle trajectories, and timing of injections of contrast to avoid challenges (Desai et al., 2022). AI, when used in conjunction with ultra-fast CT scanners, allows real-time dose monitoring and motion correction, thus reducing anesthesia to ensure safety and efficiency of the treatments (Gottumukkala et al., 2019).

These innovative concepts illustrate that AI has surpassed its theoretical status and has become a tangible collaborator in pediatric imaging. The potential of artificial intelligence is to improve the accuracy of radiologists, reduce their burden, and standardize data interpretation. This will create a collaborative environment in which data-driven insights enable compassionate, evidence-based treatment for the most vulnerable and youngest patients.

3.2. AI for Dose Optimization and Image Reconstruction

AI is being applied today not only in image reconstructions but also in the optimization of dose, thus changing pediatric radiology practice in a significant manner. This has directly addressed a significant issue: the reduction of radiation exposure while simultaneously achieving high diagnostic accuracy. Young children are particularly vulnerable to ionizing radiation, and even small reductions in exposure can have long-term consequences. The implementation of more intelligent acquisition tactics, adaptive reconstruction, and post-processing techniques that optimize the equilibrium between safety and image quality is now possible with AI-driven systems (Gallée et al., 2023; van Leeuwen et al., 2022).

The changes are based on deep learning-based image reconstruction. Advanced denoising algorithms and CNNs are used to determine the relationship between high-quality images and raw projection data. DLIR differs from other traditional iterative reconstruction methods in that it does not simply attenuate noise but rather separates noise from actual anatomical information—with preserved contrast, detail, and texture. This is very useful in pediatric CT, where diagnostic confidence needs to be preserved and clarity of minute anatomic features is paramount (Brady et al., 2021; Daldrup-Link, 2019; He et al., 2025; Horst et al., 2025; Hultenmo et al., 2025; Ng, 2022). DLIR allows for substantial dose reductions with preservation or even an increase in diagnostic performance. The literature demonstrates that AI-driven reconstructions can surpass hybrid iterative techniques in various pediatric assessments, including thoracic, cranial, and abdominal CT imaging (Brady et al., 2021; He et al., 2025). CNN-based denoising has achieved better outcomes, thus allowing further dose reduction without compromising detailed information. It was more effective than DLIR in specific contexts, such as ultra-low-dose protocols (Horst et al., 2025). Iterative and AI-assisted adaptive approaches can be employed to dynamically optimize reconstruction parameters in real time. This ensures that the process of acquisition is tailored according to the clinical needs and anatomical prerequisites of the patient. Consequently, the execution of customized low-dose imaging is feasible, substantially reducing radiation exposure while preserving high-quality images and diagnostic reliability across various pediatric cohorts (Brady et al., 2021; Davendralingam et al., 2021; Greffier et al., 2015; Horst et al., 2025; Hultenmo et al., 2025; Nagayama et al., 2018; Ng, 2022).

AI-driven optimization of image quality and workflow in CT, MRI, and US imaging is becoming increasingly important. Deep learning models will become highly prevalent in ultrasonography in order to help the operator scan, select the best imaging planes automatically, and evaluate the quality of images in real time. These technologies allow repetition of tests, uniform diagnostic quality among all institutions, and assistance to less experienced physicians. AI-assisted feedback systems result in more consistent pediatric ultrasound exams, which limits the operator dependency and increases the confidence of diagnosis. AI-driven reconstruction techniques facilitate the acquisition, diminish motion artifacts, and preserve quantitative accuracy in MR imaging studies. Such types of changes have a special importance in pediatrics, where abbreviated scans reduce the need for sedation and improve patient comfort (Davendralingam et al., 2021; Yan et al., 2025). These technologies act in synergy to yield an imaging workflow which is safe, effective, and radiation-free.

3.3. Workflow Optimization and Efficiency

Another very relevant and measurable advantage of the ongoing digitization in pediatric radiology is the use of artificial intelligence in workflow automation (Daldrup-Link, 2019; Ranschaert et al., 2021; van Leeuwen et al., 2022; Yan et al., 2025). Artificial intelligence simplifies the radiologic process by assuming routine tasks such as image acquisition and reporting. Automated triaging systems of images prioritize and emphasize significant or atypical findings for evaluation, categorically according to urgency. This ability is particularly of value in the pediatric emergency and inpatient settings, where the need for rapid identification is paramount to immediate treatment. The pre-filling of preliminary reports and structured data extraction further reduces report writing time while standardizing documentation, thereby reducing cognitive workload and allowing radiologists to focus on more complex interpretive and consultative tasks rather than manual measurements or clerical work (Sammer et al., 2023; Yan et al., 2025).

Implementing AI to PACS (Picture Archiving and Communication Systems) and RIS (Radiology Information Systems) has significantly improved efficiency, resulting in a reduction of reading times while continuing to maintain diagnostic accuracy. Intelligent hanging protocols and automated study routing ensure relevant priors, sequences, or comparative studies are always available, which accelerates interpretation. Seamless connectivity allows radiologists to work uninterruptedly, improving quality, consistency, and reporting speed.

AI-enabled scheduling and protocol optimization is becoming an integral part of workflow management at large pediatric hospitals. Algorithms optimize resource utilization while adhering to the pediatric safety protocols by adapting the scan procedures based on the age, body size, and clinical indication of each child (Calixto & Gee, 2025; Davendralingam et al., 2021). Predictive scheduling algorithms ensure optimal scanner utilization, minimize the number of exam rescheduling, and reduce idle time. This reduces waiting lists and speeds up patient throughput in a measurable manner. The new technologies change work processes through a combination of automation and accuracy that enables radiology departments to deliver care that is more reliable, safer, and quicker without compromising diagnostic accuracy (Ranschaert et al., 2021).

3.4. Diagnostic Accuracy and Error Reduction

Artificial intelligence also plays an important role in improving the accuracy of diagnosis by reducing human error through critical analyses of images and patterns. In this regard, the efficiency of artificial intelligence systems in highlighting subtle or atypical findings not easily recognized by the human eye gives further dimension to the value it has in pediatric radiography (van Leeuwen et al., 2022; Yan et al., 2025). Deep-learning models have demonstrated the capability to accurately detect prevalent and severe pediatric conditions, such as pneumonia on chest X-rays or brain tumors and hemorrhages on neuroimaging, with a similar level of accuracy as a radiologist. These characteristics render them reliable diagnostic tools that enhance human judgment (Huang et al., 2022; Schalekamp et al., 2022).

Automated lesion segmentation and quantitative feature extraction contribute to the reduction of interobserver variability by using unified measurement criteria across institutions. Standardization of the measurement of lesion size, shape, and enhancement patterns ensures consistent outcomes in multicenter studies and long-term follow-ups (Laborie et al., 2023; Lundervold & Lundervold, 2019). AI systems may identify unlooked-for, or incidental, abnormalities that may otherwise have been missed, such as early metastases, minor vascular malformations, or subtle changes in inflammation over time, achieved by rapid and objective analysis of whole image datasets.

AI-enhanced radiomics is gaining in popularity for use in pediatric oncology. AI models study the subtle image-based features related to tumor biology, providing predictive biomarkers related to molecular subtypes, treatment effectiveness, and prognosis. The integration of quantitative imaging, together with clinical data and genomic information, allows for early risk stratification and personalized strategies of treatment.

Coupling AI-driven analysis with radiologists is necessary, as it leads to consistent, evidence-based decision-making and improves diagnostic confidence for equivocal or borderline cases while reducing false negatives (Daldrup-Link, 2019).

3.5. Personalized and Predictive Diagnostics

The integration of radiomics, genomes, and clinical data with artificial intelligence (AI) is propelling pediatric imaging into a new era of predictive, individualized diagnostics (Brady & Neri, 2020; Daldrup-Link, 2019; van Leeuwen et al., 2022). Traditionally, pediatric radiology has relied on population-based interpretation, wherein data are compared to established reference ranges. AI enables moving to individualized patient assessment by examining the imaging data of each child in the context of their own physiological, developmental, and genetic traits. Predictive algorithms are now capable of identifying minor imaging biomarkers that are associated with the development of a disease, treatment response, or recurrence risk. This changes the way in which physicians predict clinical outcomes.

By combining genomic and laboratory data with quantitative imaging features, predictive AI models can predict how a disease will progress, figure out how hazardous it is, and help choose the best treatment strategies (Daldrup-Link, 2019; Yan et al., 2025). These methods are proof that AI is capable of not only diagnosis but also simplifying decision-making through the aggregation of various forms of data to form well-validated predictions that enhance individualized patient care.

Moreover, personalized AI frameworks make further adjustments to the diagnostic thresholds based on patient-specific factors, such as age, organ dimensions, and developmental stage.

Such approach investigates the temporal development of children's anatomy and physiology over time (Daldrup-Link, 2019). This flexibility adds to diagnostic accuracy, whereby algorithms are able to recognize changes in tissue composition, perfusion, and metabolism that come with aging. Diagnostic confidence and therapeutic surveillance are further enhanced with AI-driven personalization. Precision pediatrics has gone a long way in advancing this discipline to factor in the child's unique biology and particular clinical situation into every imaging decision.

Discussion:

4. Challenges, Considerations, and Future Directions

4.1. Radiation Safety and Cumulative Risk

Radiation exposure remains a significant and persisting challenge in pediatric radiology. Due to their extended lifespans, smaller body size, and developing tissues, children are much more vulnerable to being affected by unpredictable impacts of ionizing radiation, which can cause genetic damage and lead to cancerogenesis (Don et al., 2013). Most of the radiation exposure occurs during follow-up imaging and surveillance, rather than during the first diagnosis. This suggests a more thorough justification of serial examinations and the establishment of structured follow-up protocols that balance long-term safety with clinical necessity (Ohana et al., 2018).

Global initiatives, including the Image Gently campaign, have implemented comprehensive mechanisms for dose optimization and education to address these challenges. The campaign promotes imaging methods that are "child-sized," suited for each patient's age, size, and medical needs. It additionally requires periodic inspections of the shielding protocols and a reason for each radiologic exam. This has forced the implementation of the ALARA principle (As Low As Reasonably Achievable) in pediatric imaging workflows.

The beneficial effects of diagnosis consistently surpass the risks related to radiation (Don et al., 2013; Sammer et al., 2023).

Major technological advances have greatly improved the capability of reducing the radiation exposure without compromising diagnostic accuracy. Iterative reconstruction methods offer a significant reduction in dosage while maintaining the clarity of the image, as well as an improvement in contrast resolution and noise suppression (Greffier et al., 2015). A substantial advancement is represented by deep-learning image reconstruction (DLIR) - it preserves precise anatomical information while reducing concentrations more than traditional iterative methods (Brady et al., 2021; Hultenmo et al., 2025; Ng, 2022). AI-driven denoising networks support radiologists' confidence by preserving textures and reducing subjective image fatigue, even during extremely low-dose procedures.

Hardware and software improvements are simultaneously transforming the radiation management. Long axial field-of-view (LAFOV) PET/CT systems improve detector sensitivity, which allows for the rapid imaging of the entire body with minimal tracer dosages. This technique is particularly advantageous for smaller or less cooperative patients because it decreases their radiation exposure and the need for sedation (Dias et al., 2025).

In the future, we will witness a considerable improvement in terms of safety and consistency when adaptive exposure management is combined with AI-driven dosage monitoring. With automated systems capable of real-time dosage auditing and predictive adjustment, institutions will soon be able to monitor and improve exposure continuously. This ensures that every single examination complies with the local and international diagnostic reference levels (Brady et al., 2021). These tools will be essential for data-driven quality assurance, as they will guarantee that all centers consistently adhere to best practices and provide radiology teams with objective feedback.

4.2. Sedation, Anesthesia, and Patient Safety

Sedation and anesthesia are still essential for pediatric MRI, as both techniques enable the acquisition of high-quality diagnostic images by promoting patient cooperation and motion control. The confined and loud setting of an MRI scanner often makes it difficult for young children to remain still during prolonged examinations, requiring pharmacological intervention (Jaimes et al., 2021). Sedation and anesthesia have benefits in clinical settings but are also acknowledged to carry risks of hemodynamic instability, airway obstruction, prolonged recovery post-procedure, and potentially harmful neurodevelopmental outcomes after repeated or prolonged exposures (Ahmad et al., 2018; Chandra et al., 2020; States & Reid, 2020). These risks suggest that interventions aimed at minimizing or eliminating sedation whenever possible will continue to be necessary. Sedation is commonly used, especially in pediatric oncology and neurology, where accurate imaging and extended monitoring are crucial.

Despite the availability of enhanced methods and faster sequencing, this procedure remains accurate. Sedation is still required for numerous follow-up examinations, particularly when imaging must be repeated in a short timeframe, according to research (Hayatghaibi et al., 2023). The current trend suggests a progressive decrease in the use of sedatives, which can be attributed to improved patient preparation, increased parental involvement, and improved environmental adaptation. Centers that implement this methodology demonstrate decreased preparation times, a decreased prevalence of incomplete scans, and elevated patient satisfaction (Hayatghaibi et al., 2023; Regmi et al., 2022).

A growing body of evidence indicates that the presence of a parent can improve the quality of imagery experiences for children. Studies have demonstrated that allowing caregivers to accompany the child during pre-scan preparation results in a safe reduction in anxiety, distress, and examination duration, without impairing image quality (Regmi et al., 2022). In the same way, structured explanations and educational play sessions aid children in understanding the procedure, thereby decreasing their apprehension about the scanner and increasing their willingness to interact with it. These interventions are most effective for children between the ages of four and eight, thereby reinforcing the transition to family-centered imaging models (Iwayama et al., 2025).

This is an essential component of reducing sedation: altering the environment. Child-centric MRI facilities utilizing multimedia distractions, interactive lighting, and virtual scanners have demonstrated efficacy in the reduction of anxiety and restriction of motion during scans (Calixto & Gee, 2025; Harrington et al., 2022; Jaimes et al., 2021). The tailored environment creates a more pleasant and less intimidating experience of the imaging process, promoting, therefore, compliance. In addition, patients with chronic conditions that include epilepsy, cancer, or metabolic disorders and for whom imaging is part of their ongoing treatment can significantly benefit from play therapy, cognitive rehearsal, and child-life specialist support (Calixto & Gee, 2025; Harrington et al., 2022; Regmi et al., 2022).

Technological developments also allow for the performance of MRI without sedation - compressed sensing, parallel imaging, and AI-assisted reconstruction have reduced scan durations by approximately 50%, all while preserving diagnostic quality (Ahmad et al., 2018; Jaimes et al., 2021). Accelerated acquisitions reduce the likelihood of patient movement and the need for repeated sequences. AI-powered motion correction algorithms enhance image detail in real-time and reduce the need for rescanning by compensating for small, unexpected movements. Moreover, workflow efficiency is increased and pharmacologic sedation reduced through dynamic adjustment of imaging parameters, made possible via automatic feedback mechanisms and adaptive scanning protocols.

In addition to imaging hardware and software, reengineering procedures across disciplines has been instrumental in reducing the reliance on sedation. Coordinated communication between the radiology, anesthesia, and nursing teams improves the efficiency of scheduling, reduces waiting periods, and ensures personalized prescan preparation (Ahmad et al., 2018; Hayatghaibi et al., 2023; Jaimes et al., 2021; Mastro et al., 2019). Joint efforts like that ensure the identification of cases where a child does not need sedation for imaging and help avoid overexposure to anesthesia. Radiologists and anesthesiologists must cooperate with the families, making all decisions jointly in an attempt to further enhance the safety and trustworthiness of the process.

Minimally invasive, child-friendly imaging in pediatric treatment is a great stride in radiology. It focuses on the child's mental health and development and, at the same time, the precision of diagnosis. The performance of MRI without sedation will likely be a routine examination in a number of pediatric conditions as imaging techniques advance and AI-assisted techniques improve. This procedure will provide superior diagnostic imaging while simultaneously reducing the risk of harm.

4.3. Validation, Standardization, and Reproducibility of Artificial Intelligence

The field of pediatric imaging is currently in the early stages of research, but artificial intelligence (AI) is advancing at a rapid pace. The primary challenges related to employing AI in clinical environments are validation and standardization. The integration of these technologies into standard pediatric practice is nevertheless challenging due to methodological inconsistencies and a lack of reproducibility, regardless of considerable progress in algorithms and improved workflow integration in recent years (van Leeuwen et al., 2022; Yan et al., 2025). The juvenile population does indeed pose challenges in AI research due to a very low prevalence of certain conditions, rapid physiological changes, and anatomical variability compared to adults - these factors restrict the generalizability and accessibility of data.

The primary obstacle to the development of resilient AI systems is the absence of significant, high-quality, and thoroughly annotated pediatric datasets (Brady & Neri, 2020; Daldrup-Link, 2019). Pediatric datasets are often fragmented, inconsistent, and gathered under diverse acquisition conditions, whereas adult imaging comprises millions of scans in standardized repositories. Consequently, the majority of AI models employed in pediatric radiology are either pre-trained or trained on adult data, which results in inadequate adaptation for use with children. In juvenile patients, systematic bias is introduced by differences in organ size, developmental architecture, and disease presentation, resulting in reduced accuracy and unanticipated failure modes (Daldrup-Link, 2019; Pringle et al., 2022). This miscalibration suggests that it is necessary to establish separate data pathways for children rather than attempting to employ those that are intended for adults.

Recognizing these issues, professional associations have taken significant steps towards the development of reproducible, transparent, and methodologically rigorous AI research. The American College of Radiology (ACR) Pediatric AI Workgroup has designed structured frameworks for the analysis of biases, performance evaluations, and uniform data annotation. These frameworks are aimed at ensuring that algorithms are uniformly trained and evaluated across all universities (Sammer et al., 2023). Finally, to facilitate international collaboration and assure equal opportunities in the availability of training datasets, the European Society of Paediatric Radiology (ESPR) AI Taskforce is working on developing ethical standards for data sharing and establishing multicenter image archives (Brady & Neri, 2020; Laborie et al., 2023). These methods are indispensable for the reduction of research fragmentation and the establishment of universal standards for the development of pediatric AI (Brady & Neri, 2020).

Despite these advancements, the majority of pediatric AI studies are retrospective in nature, limited in size, and administered at a single institution. They frequently lack independent replication or external validation (van Leeuwen et al., 2022). Plenty of individuals rely on limited datasets that inaccurately reflect the true diversity of patient demographics, imaging techniques, or illness patterns. Fewer than 20% of published studies included independent testing cohorts, raising legitimate concerns about clinical reliability, safety, and reproducibility. Without clear evaluation criteria, such as widely accepted definitions of accuracy, sensitivity, or false-positive rates, data comparison across research and assessment of clinical preparedness are impeded.

Global guidelines now call for standardized validation pipelines with publicly available benchmarking datasets, comprehensive model documentation, and multi-center testing. Reporting frameworks like CONSORT-AI and DECIDE-AI are recommended by the ACR for the steps involved in dataset diversity, ground truth validation, estimation of uncertainty, and clinical impact (Sammer et al., 2023). Both frameworks ensure that the models undergo rigorous and reproducible testing before their clinical deployment in practical pediatric workflows.

Federated learning is one of the effective ways to address the concerns related to data scarcity and privacy. In this approach, several hospitals can train AI models simultaneously without raw patient data leaving the hospital, thus guaranteeing the privacy of patients and improving the diversity and statistical power of the dataset (Lundervold & Lundervold, 2019). Preliminary multi-center trials in pediatric radiology successfully validated the feasibility of FL for various tasks like segmenting brain MRI and diagnosing pneumonia. The performance of FL is comparable to that of centrally trained models. These results suggest that federated architectures may provide a framework for forthcoming large-scale validation efforts, as they amalgamate stringent data protection adherence with global cooperation.

4.4. Ethical, Legal, and Educational Barriers

Integration of AI in pediatric radiography presents complex ethical, legal, and education-related challenges, which require rigorous oversight to ensure that the application is responsible, transparent, and equitable (Brady & Neri, 2020; Metin & Özdemir, 2025; Yan et al., 2025). Indeed, the effective application of AI in pediatric contexts requires enhanced vigilance due to increased vulnerability and sensitivity of information in children, even as it holds the ability to revolutionize diagnostic practices and improve operational efficiency. Ethics and regulatory frameworks should keep pace with technological development to maintain confidence, safety, and fairness.

One of the major ethical quandaries emanates from the fact that most AI and deep-learning systems are incomprehensible to humans. Although these models can derive highly accurate predictions or classifications, their decision-making processes often remain untransparent to individuals (Brady & Neri, 2020; Gallée et al., 2023; Lundervold & Lundervold, 2019). The lack of interpretability exacerbates not just explaining AI-assisted conclusions but also negatively impacts doctors' confidence. This is especially important when decisions affect a child's confidence. diagnosis, treatment, or prognosis. In order to find a solution, it has become imperative to prioritize the development of Explainable AI (XAI) frameworks. Attention visualization, saliency mapping, and feature attribution are among the XAI techniques that can provide understandable evidence of algorithmic conclusions. These allow the physician to reconfirm whether the outputs from the model at least align with established medical reasoning (Gallée et al., 2023; Salih et al., 2024). Such transparency indicators are indeed at the center of ethical accountability and clinical validation in pediatric care.

Algorithmic bias—an integral component of health equity—is an emerging issue (Metin & Özdemir, 2025; Yan et al., 2025). Therefore, training a pediatric AI model on small, constrained, or demographically homogeneous data can result in disparities in performance across different age groups, ethnicities, or other socioeconomic categories. This may further exacerbate health disparity by consistently producing worse outcomes in underrepresented population. (Brady & Neri, 2020). Publishing the composition of the dataset and the performance of the model across different demographic subgroups in an open manner is absolutely required for fairness. Bias must also be actively reduced as part of both the training and validation process (Laborie et al., 2023; Meshaka et al., 2022). The RQS and CONSORT-AI/DECIDE-AI recommendations are two structured frameworks that enable the assessment of data origin, reduction of bias, and ensuring repeatability. Complying with these guidelines is imperative to promote transparency and ensure that AI-driven technologies deliver equitable diagnostic results for all pediatric patients.

Education is the next crucial part. The vast majority of pediatric radiologists are enthusiastic about the use of AI, but the majority of them do not possess the formal training to critically assess the validity of the models or interpret algorithmic performance. If clinicians do not understand the capabilities and limitations of AI systems, they can also become overreliant. These elements may have a negative impact on patient safety and efficacy; therefore, the inclusion of AI literacy is critical in radiology curricula (Alkhulaifat et al., 2023; States & Reid, 2020). Training for AI systems should include not only the technical aspects but also the ethical, legal, and clinical aspects as well. Interdisciplinary initiatives that unite radiologists, data scientists, and ethicists enhance collective accountability, encourage critical evaluation of AI outcomes in practical contexts, and promote mutual understanding. Radiologists must engage in continuous professional development and certification programs to assess model performance, track algorithmic drift, and ensure the enduring clarity of results (Gallée et al., 2023).

It is essential to conduct regular revalidation and bias evaluations to ensure diagnostic reliability and patient safety as AI systems improve through the acquisition of new knowledge and data. Individuals should refrain from thinking of ethical AI implementation as a single goal to strive for but as a dynamic process requiring continuous examination across various disciplines and the commitment of the entire organization. Radiologists, engineers, legal professionals, and ethicists must work collectively to ensure that AI-driven tools are transparent, accountable, and aligned with the core principles of pediatric care: safety, equity, and reliability (Alkhulaifat et al., 2023; Gallée et al., 2023; Meshaka et al., 2022).

4.5. Global Inequities and Resource Constraints

Globally, there is still a significant disparity in access to advanced imaging, despite the significant advancements in pediatric radiology technology. Tertiary hospitals in developed countries are increasingly utilizing advanced technologies such as PET/MRI, contrast-enhanced ultrasound (CEUS), MR elastography, and AI-driven reconstruction. However, many children around the world have no access to these and other life-saving diagnostic services, like MRI and computed tomography (CT) scans. This disparity further widens the gap, called the "pediatric imaging gap," between regions with state-of-the-art technology and those where resources are limited, contributing to major differences in early detection, treatment planning, and long-term results (Kibrom et al., 2024).

These unfair situations are made worse by the fact that there are not enough helthcare workers. There are significant disparities around the world in terms of imaging availability and the number of pediatric-trained radiologists and sonographers (Meshaka et al., 2022). Specialist expertise is concentrated in major towns and academic hospitals, and so rural and peripheral areas often have to rely on general radiologists or technicians, many of whom have limited pediatric experience. Lack of specific training may lead to problems with image acquisition, understanding of pediatric-specific conditions, and inability to observe protocols related to safety and the use of anesthetics. International best practice—such as the ALARA principle and guidelines on pediatric dose optimization—is hard to follow without access to modern technology, including digital radiography systems, low-dose CT scanners, and pediatric-optimized MRI coils.

The two possible ways to deal with this issue include the democratization of AI and open-access data sharing. Institutions in resource-constrained environments can augment their contributions to and derive benefits from global research networks by establishing comprehensive, de-identified imaging repositories. Cloud-based AI platforms can assist with diagnostic decisions without requiring any on-site computational resources. Recent evidence indicates that the analysis of digital imaging can be beneficial for facilities equipped solely with fundamental hardware. Federated learning frameworks enable multiple institutions to collaboratively train AI models while safeguarding sensitive data, exemplifying a revolutionary method to enhance global inclusivity (Kibrom et al., 2024; Laborie et al., 2023; Lundervold & Lundervold, 2019). Federated learning enables equitable innovation in pediatric imaging by facilitating knowledge sharing while safeguarding patient confidentiality, reducing geographic and demographic bias, and encouraging data diversity. This knowledge can be subsequently applied within their local communities (Laborie et al., 2023). The programs encourage a global collaborative community in which the transmission of skills is hastened by shared experiences and multidisciplinary mentoring, with increased technical proficiency. Complementing human training, AI-assisted diagnostic tools optimized for portable ultrasound and low-field MRI can bring high-quality imaging closer to the point of care. These portable and low-cost systems, with AI in interpretation, represent a pragmatic pathway to expansion without depending on major investments in infrastructure.

The convergence of AI innovation, open science, and international cooperation is starting to turn pediatric radiology into an inclusive discipline—one where children everywhere, regardless of geography or socioeconomic status, can benefit from timely, safe, high-quality diagnostic imaging. As equity becomes a core principle of digital transformation for the global radiology community, it can begin to close the gap in pediatric imaging and pave the way toward truly universal access to advanced healthcare.

Conclusions:

The convergence of AI innovation, open science, and international cooperation is starting to turn pediatric radiology into an inclusive discipline—one where children everywhere, regardless of geography or socioeconomic status, can benefit from timely, safe, high-quality diagnostic imaging. As equity becomes a core principle of digital transformation for the global radiology community, it can begin to close the gap in pediatric imaging and pave the way toward truly universal access to advanced healthcare. Advanced MRI techniques enable functional, accelerated, and sedation-free imaging. Artificial intelligence has markedly contributed to the digital revolution in radiology by improving workflow efficiency, picture reconstruction, and dose optimization in all modalities. Radiomics and AI-driven analytics open up new avenues for quantitative, predictive, and personalized diagnostics. Its clinical use, however, requires rigorous testing as well as the explanation and adherence to ethical standards. Education and global access are equally important.

Authors' contributions:

Conceptualization: Justyna Kącikowska
Methodology: Piotr Szczepański, Katarzyna Sordyl
Formal analysis: Piotr Szczepański, Magdalena Majkowska
Investigation: Maria Fengier, Oliwia Grzelak
Writing-rough preparation: Krzysztof Rogulski
Writing-review and editing: Oliwia Bolek, Weronika Kuśmierczyk
Supervision: Justyna Kącikowska

All authors have read and agreed with the published version of the manuscript.

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