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REVIEW

International standardization of pediatric magnetic resonance imaging protocols: creation of the World Federation of Pediatric Imaging MR Protocols Committee

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Abstract

The World Federation of Pediatric Imaging (WFPI) MR Protocols Committee was formed in response to the critical need for standardized magnetic resonance imaging (MRI) protocols tailored specifically for pediatric populations. This initiative addresses the inherent challenges and variabilities in pediatric MRI practices due to the unique physiological and anatomical characteristics of children, which often result in extended scan times, increased costs, and greater need for sedation. The committee, comprising a diverse group of international radiologists, pediatric imaging societies, and major MRI vendors, collaboratively developed a comprehensive set of MRI protocols. These protocols are designed to enhance diagnostic accuracy, reduce sedation use, and streamline workflows, thereby minimizing healthcare disparities across global regions. Protocols cover a wide range of applications, including neuroradiology, abdominal imaging, and musculoskeletal conditions, with specific focus on practical implementation in both high-resource and resource-limited settings. After rigorous development and refinement through global feedback, these protocols have been made accessible through the WFPI website and will be directly integrated into MRI systems via vendor collaborations. These protocols provide a flexible, foundational approach that can be adapted to suit the needs of centers worldwide. This ensures that even basic protocols are accessible across different settings, allowing customization based on available resources and specific clinical demands.

Keywords World Federation of Pediatric Imaging (WFPI) · World Federation of Pediatric Imaging MR Protocols Committee · Magnetic resonance imaging (MRI) protocols

Introduction: justification for standardized pediatric MR protocols

The standardization of magnetic resonance imaging (MRI) protocols in pediatric imaging is a crucial initiative due to the distinctive challenges presented by this population. Children require tailored MRI protocols that accommodate their unique physiology and pathologies, which evolve alongside their development. These protocols must be safe and effective, and minimize the need for sedation or anesthesia. The rapid growth of pediatric imaging practices worldwide has led to significant variability in imaging characteristics and diagnostic quality, highlighting the need for consistent, high-standard protocols.

Pediatric MRI requires specific imaging approaches due to the sensitivity of children to sedation, their inability to remain still for long periods, and the complexity of their developing anatomy. This inconsistency in global practices results in longer scan times, higher costs, and unnecessary exposure to sedation. Moreover, the absence of standardized protocols can lead to misdiagnosis or delayed detection of critical conditions, which is particularly harmful to children at vulnerable stages of growth and development.

Recognizing these challenges, the World Federation of Pediatric Imaging (WFPI) established the MR Protocols Committee to create comprehensive MRI protocols that balance diagnostic accuracy with patient safety. By bringing together experts from different regions and leading MRI vendors, the committee sought to develop protocols that could

WFPI MRI Protocols: https://www.wfpiweb.org/Resources/Modalities/MRIProtocols.aspx.

Extended author information available on the last page of the article

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be adapted globally, transcending differences in healthcare resources and equipment capabilities. These protocols aim to reduce imaging time, improve diagnostic yield, and ensure consistency across imaging practices worldwide.

The committee's work is vital in ensuring that every child, regardless of location or economic background, has access to high-quality imaging that will aid in the prompt and accurate diagnosis of various conditions. This standardization will streamline workflows, reduce healthcare costs, decrease sedation times and/or the need for sedation, and foster international collaboration in pediatric radiology. Ultimately, these protocols represent a significant step towards elevating pediatric MRI standards globally and ensuring the best outcomes for all pediatric patients.

The protocols are designed to accommodate a wide variety of hardware and software configurations across regions with varying resources. These are intended to serve as a flexible framework, ensuring that even centers with minimal access to anesthesia or contrast agents (e.g., gadolinium) can perform effective pediatric MRI. The protocols allow customization based on local capabilities, patient needs, and equipment, providing a foundation that can be tailored to specific settings.

Formation of the WFPI MR Protocols Committee

The formation of the MR Protocols Committee followed a rigorous evaluation of global pediatric imaging practices. Initial meetings revealed significant variability in imaging approaches, leading to prolonged scan times, variable diagnostic accuracy, and heightened sedation use. To address these issues, the committee sought to create a diverse representation of pediatric imaging experts and major MRI vendors to ensure comprehensive coverage of pediatric MRI needs.

This committee led discussions that clarified its primary objectives and main protocols that would be standardized with WFPI's endorsement. Table 1 summarizes the primary objectives of this taskforce. The approved structure included experts specializing in different body regions (neuroradiologists and pediatric radiologists) to tailor protocols accordingly. These initial meetings were foundational in setting the committee's trajectory towards comprehensive, universally applicable protocols.

A series of virtual meetings were held between December 2017 and April 2019 to reach consensus on what protocols to standardize, what exam durations to optimize for, and what sequences to include.

Committee representation

The MR Protocols Committee is composed of a diverse mix of professionals representing pediatric imaging societies, major MRI vendors, and international radiologists. This wide-ranging representation ensures that the protocols developed are both comprehensive and practical for global implementation.

The WFPI MRI Protocols Committee includes pediatric radiologists from all five continents, along with experts in MRI technology and physics, as well as representatives from all major MRI vendors. Contributions from regional pediatric imaging societies were crucial in shaping protocols that can be applied universally, even in regions with limited resources. Vendors such as GE, Philips, and Siemens provided technical expertise to ensure that the protocols remain compatible with various equipment, while still incorporating advanced features where available.

The committee's focus was on creating basic protocols that can be implemented across diverse settings, regardless of equipment sophistication or access to resources like anesthesia or contrast agents. Experts from the Americas, Europe, Asia, and Africa worked together to ensure these protocols are adaptable to the specific needs and challenges of different regions, such as variations in equipment availability, disease prevalence, and regulatory requirements.

Vendor representatives offered valuable insights for optimizing MRI protocols to ensure adaptability across various systems and configurations. By tailoring sequence optimization and parameter selection to the latest features of each vendor's machines, the committee was able to develop protocols that are suitable for routine clinical use while also capable of leveraging advanced capabilities, such as parallel imaging, where available. It is important to note that these protocols are not automatically installed but can be requested from vendors. They are designed to be compatible across a wide range of settings, with a focus on providing

Table 1 Principles guiding the workgroups creating the WFPI protocols

1. Comprehensive	Repository of multi-organ protocols covering a broad range of indications
2. Accessible	Available free of charge to members of the global pediatric radiology community
3. Generalizable	Vendor agnostic approach that is robust in settings with varying technical capabilities
4. Adaptive	Modular design to allow for site-specific adjustments and future incremental modifications

a foundational framework that can be used universally, and enhanced with advanced features when resources permit.

The collaboration among pediatric radiologists, societies, and vendors allowed the committee to unify varying imaging philosophies and practices, aligning them under a shared goal: to achieve high-quality, standardized MRI protocols that transcend regional differences. This collective effort ensured that the protocols not only addressed clinical needs but also could be feasibly implemented in regions with limited resources.

In addition, the involvement of regional societies provided a platform for continuous feedback and updates, as these societies remain actively engaged in implementing and refining the protocols. Their ongoing contributions will help ensure the protocols remain relevant and effective, providing a framework for consistent, high-quality pediatric imaging globally.

Discussion and development of the protocols

The development of the pediatric MRI protocols required intensive collaboration among the committee members, with continuous discussions to align regional clinical needs with available MRI technologies. The committee objective was to craft protocols specific to each anatomical region, focusing on balancing diagnostic precision with the practicalities of scanning time, patient compliance, and available equipment.

Neuroradiology protocols

Rapid brain protocol

Developed specifically for children who have limited tolerance for extended scanning, this protocol emphasizes rapid imaging techniques like diffusion-weighted imaging (DWI), echo planar imaging (EPI), and standard sequences T1-weighted images (T1WI) and T2-weighted images (T2WI) (Table 2). The goal was to ensure comprehensive yet quick evaluations that minimize motion artifacts while capturing the essential diagnostic information required for accurate assessments, especially in children that would be unlikely to tolerate more than 10 min on the MR equipment.

Table 2 Rapid brain protocol

Sequence	Plane	Duration
DWI	Axial	1–2 min
EPI (T2*)	Axial	0.5 min
T1WI	Sagittal	2–3 min
T2WI	Axial	2–3 min
FLAIR	Coronal	2–3 min
	Total scan time	~10–11 min

DWI, diffusion-weighted imaging; *EPI*, echo planar imaging; *T1WI*, T1-weighted images; *T2WI*, T2-weighted images

Seizure brain protocol

This protocol was optimized for the precise localization of epileptogenic foci. High-resolution 3D isotropic imaging and parallel imaging techniques were incorporated (if available) to provide clear delineation of structural abnormalities, to maximize the detection of subtle cortical dysplasia, for example (Table 3). When available, 3-T imaging with high channel count phased array coils should be utilized.

Hydrocephalus-ventricle check protocol

This protocol is designed to monitor ventricular size and detect changes in children with hydrocephalus efficiently (Fig. 1, Table 4). It employs rapid T2-weighted imaging sequences such as single-shot fast spin-echo (SSFSE) to visualize the ventricular system and surrounding brain structures with minimal scanning time and with high resistance to motion, virtually eliminating the need for sedation or CT. This protocol aims to provide high-contrast images that highlight ventriculomegaly or shunt complications, ensuring accurate assessment while minimizing patient discomfort and optimizing workflow, within only 3 to 5 min for the patient. It is also appropriate to monitor the size of extra-axial fluid collections.

Tumor/infection brain and spine protocols

These protocols are tailored for the comprehensive assessment of pediatric patients with suspected or confirmed acute processes, such as tumors, infection, or inflammation in the central nervous system (Tables 5 and 6). For brain tumors

Table 3 Seizure brain protocol

Sequence	Plane	Duration
DWI	Axial	1–2 min
T1WI 3D isotropic	Sagittal (with multiplanar reformats)	5–7 min
T2WI	Axial	3–5 min
T2WI	Coronal (hippocampi)	3–4 min
EPI	Axial	2 min
	Total scan time	~14–20 min
Optional: 3D FLAIR[a]	Axial	4–5 min

DWI, diffusion-weighted imaging; *EPI*, echo planar imaging; *T1WI*, T1-weighted images; *T2WI*, T2-weighted images

[a]Recommended for > 2years of age

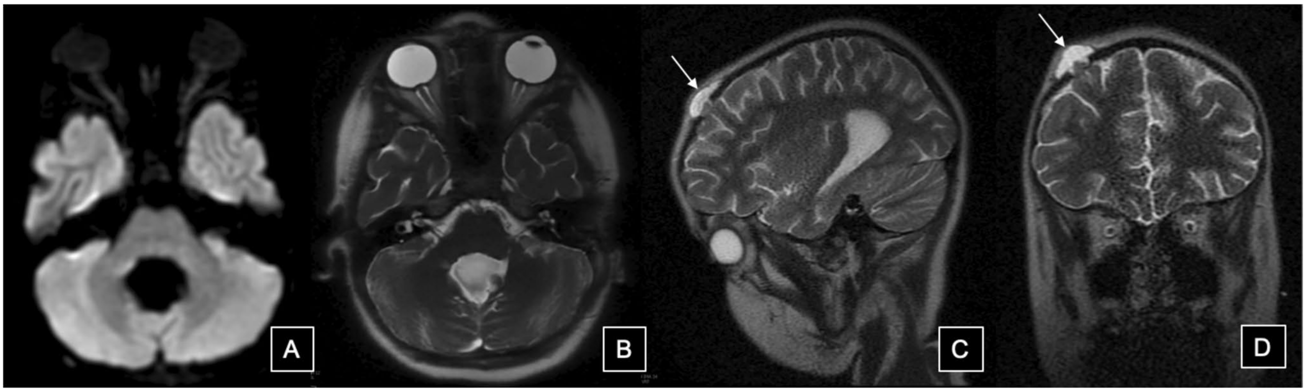

Fig. 1 Example of a Hydrocephalus – Ventricle Check Brain Protocol. Axial DWI (b1000—**A**) and T2WI (**B**) of an 8-year-old female patient showing postoperative changes related to a gross total resection of medulloblastoma with no local recurrence. T2WI (**B**) shows significant optic nerve papillary elevation, indicating papilledema. Sagittal (**C**) and coronal (**D**) T2WI showing a small collection of fluid in the right frontal scalp with minimal protrusion of the right middle frontal gyral cortex through the right frontal burr hole, which is concerning for an encephalocele (*arrow* in **C** and **D**)

Table 4 Hydrocephalus – ventricle check brain protocol

Sequence	Plane	Duration
Single-shot T2WI	Axial	1 min
Single-shot T2WI	Sagittal	1 min
Single-shot T2WI	Coronal	1 min
	Total scan time	~3–5 min
Optional: DWI	Axial	1–2 min

DWI, diffusion-weighted imaging; *T2WI*, T2-weighted images

or infections, it includes 3D isotropic sequences for precise anatomical localization and assessment of lesion margins and also a post-contrast FLAIR to increase sensitivity for leptomeningeal abnormalities. In spinal imaging, it incorporates T1-weighted sequences to evaluate the marrow and fat-suppressed T2-weighted sequences and post-contrast T1-weighted sequences to visualize disease processes and inflammatory changes affecting the bones, joints, and paraspinal soft tissues. By providing comprehensive data on lesion size, location, and enhancement patterns, these protocols facilitate accurate diagnosis and guide surgical or therapeutic planning, while reducing the scan time to 20–30 min for the brain and 20 min for the spine.

Abdominal protocols

The abdominal MRI protocols are differentiated into “short abdomen” and “long abdomen” scans, tailored to the specific needs and capabilities of pediatric patients, particularly regarding their ability to remain still and the need for rapid assessment.

Short abdomen protocol

This protocol is specifically designed for quick detection of abdominal pathology, particularly useful for infants and young children who are unable to hold their breath (Table 7). It utilizes fast imaging sequences with free-breathing

Table 5 Tumor/infection brain protocol

Sequence	Plane	Duration
DWI	Axial	1–2 min
T1WI 3D isotropic	Sagittal (with multiplanar reformats)	5–7 min
T2WI	Axial	3 min
SWI	Axial	3–5 min
Post-contrast T1WI 3D isotropic	Sagittal (with multiplanar reformats)	5–7 min
Post-contrast FLAIR[a]	Coronal	3 min
	Total scan time	~20–30 min

DWI, diffusion-weighted imaging; *SWI*, susceptibility-weighted images; *T1WI*, T1-weighted images; *T2WI*, T2-weighted images

[a]Can perform FLAIR post-contrast for increased sensitivity for leptomeningeal disease or pre-contrast

Table 6 Tumor/infection spine protocol

Sequence	Plane	Duration
T1WI	Sagittal	3 min
T2WI fat saturation (FS)	Sagittal	2:30 min
DWI	Sagittal	1 min
Post-contrast T1WI FS (bone evaluation)	Sagittal	5 min
Post-contrast T2WI	Axial	4 min
Post-contrast T1WI (spinal cord evaluation)	Axial	3:30 min
	Total scan time	~20 min

DWI, diffusion-weighted imaging; *FS*, fat saturation; *T1WI*, T1-weighted images; *T2WI*, T2-weighted images

techniques to minimize motion artifacts, with a total time of 8–10 min.

Long abdomen protocol

Designed for patients who can tolerate longer scan times (15–20 min), this protocol is suited for a thorough evaluation of abdominal pathology with an option to use breath-hold techniques to enhance image clarity and reduce scan time, if the patient is able to cooperate (Fig. 2, Table 8).

Osteomyelitis protocol

This protocol is specifically tailored to evaluate for osteomyelitis in long bones, particularly limiting axial coverage to abnormal regions seen on other imaging planes, which helps to save time while ensuring detailed focus where it is most needed (Fig. 3, Table 9). Using T1WI and T2WI with fat saturation, it aims to be completed in 10–15 min without contrast and 20–25 min when gadolinium is administered.

These protocols were designed to be both robust and adaptable, ensuring their applicability across facilities with varying levels of technology. They accommodate a wide range of hardware and software configurations, making them suitable for regions with differing resources. The protocols are intended to provide a flexible framework, enabling centers with limited access to anesthesia or contrast agents (e.g., gadolinium) to still perform effective pediatric MRI. Customization is possible based on local capabilities, patient needs, and available equipment, allowing for tailored approaches in diverse settings.

The committee's work incorporated iterative feedback from practicing radiologists and clinicians, helping to refine and validate the protocols in real-world clinical environments. This ongoing feedback loop will facilitate continuous improvements, ensuring the protocols remain practical, effective, and reflective of global pediatric MRI standards.

It is important to note that the sequence durations provided are approximate and may vary depending on factors such as scanner strength, motion correction sequences, and the integration of newer AI techniques. This flexibility ensures that the protocols can be adapted to different technological capabilities while maintaining diagnostic accuracy.

Furthermore, slice thickness and slice gap should be customized based on the patient's specific condition and clinical indication. This aspect has been deliberately left flexible to accommodate the varying capabilities of different sites, allowing the protocols to be effective across a broad range of clinical settings.

Publication and accessibility

The strategic publication of all these MRI protocols on the World Federation of Pediatric Imaging (WFPI) website, which went live in October 2019 (WFPI MRI Protocols: https://www.wfpiweb.org/Resources/Modalities/MRIProtocols.aspx), ensures that these foundational protocols are accessible globally. The site is complemented by direct links to major MRI vendors, including GE, Philips, and Siemens, enabling seamless integration into diverse clinical environments. This method of dissemination allows radiologists worldwide to easily access and implement these standardized protocols with

Table 7 Short abdomen protocol

Sequence	Plane	Respiration status	Duration
T2WI single shot	Coronal	Free breathing (FB)	30–45 s
T2WI single shot	Axial	Free breathing (FB)	30–45 s
T2WI SSFSE FS	Axial	Respiratory trigger	3–5 min
DWI	Axial (B=50,400,800)	FB (variable NEX)	3–4 min
T1WI in-opposed	Axial	Respiratory trigger	3–4 min
	Total scan time		~8–10 min

DWI, diffusion-weighted imaging; *FB*, free breathing; *FS*, fat saturation; *SSFSE*, single-shot fast spin-echo; *T1WI*, T1-weighted images; *T2WI*, T2-weighted images

Fig. 2 Example of a long abdomen protocol with free breathing of a 12-year-old male patient, with coronal T2WI single shot (**A** and *zoomed image* in **B**), axial T2WI fat saturation single shot (**C**), axial T1WI (**D**), and axial DWI (b800—**E**). There is a pancreas divisum, with a rudimentary duct of Santorini (*whole arrow* in **B** and **C**) and a dominant duct of Wirsung (*hollow arrow* in **B** and **C**), best seen in T2WI (*arrows* in **A**, **B**, and **C**), without evidence of infectious or inflammatory changes

Table 8 Long abdomen protocol

Sequence	Plane	Respiration status	Duration
T2WI single shot	Coronal	FB	30–45 s
T2WI single shot	Axial	FB	30–45 s
bSSFP	Coronal	RT	2 min
T2WI FSE FS	Axial	RT	3–5 min
T1WI in-opposed	Axial	BH or FB (5 NEX)	2–6 min
DWI (if no contrast)	Axial	FB	3–4 min
T1WI FS (pre or post, if contrast is used)	Axial	BH or FB (5 NEX)	6 min
	Total scan time		~15–20 min

BH, breath hold; *bSSFP*, balanced steady-state free precession; *DWI*, diffusion-weighted imaging; *FB*, free breathing; *FS*, fat saturation; *FSE*, fast spin-echo; *RT*, respiratory trigger; *T1WI*, T1-weighted images; *T2WI*, T2-weighted images

minimal customization, regardless of their technological resources.

Designed for both clinical effectiveness and adaptability, the protocols cater to a wide spectrum of healthcare settings—from state-of-the-art facilities to resource-limited clinics. Their flexibility helps reduce variability in diagnostic practices, enhancing the reliability and consistency of MRI diagnostics across different regions and equipment types.

Moreover, the commitment of the MR Protocols Committee to the continual refinement and update of these protocols is critical in maintaining their clinical relevance. They actively solicit feedback from a global community of radiologists, which is crucial for iterative improvements. This feedback loop is supported by regular review meetings. Such discussions may lead to protocol adjustments or the addition of new protocols to address novel diagnostic challenges.

Training materials and webinars are also provided to facilitate the understanding and implementation of these protocols in different cultural and clinical contexts. By

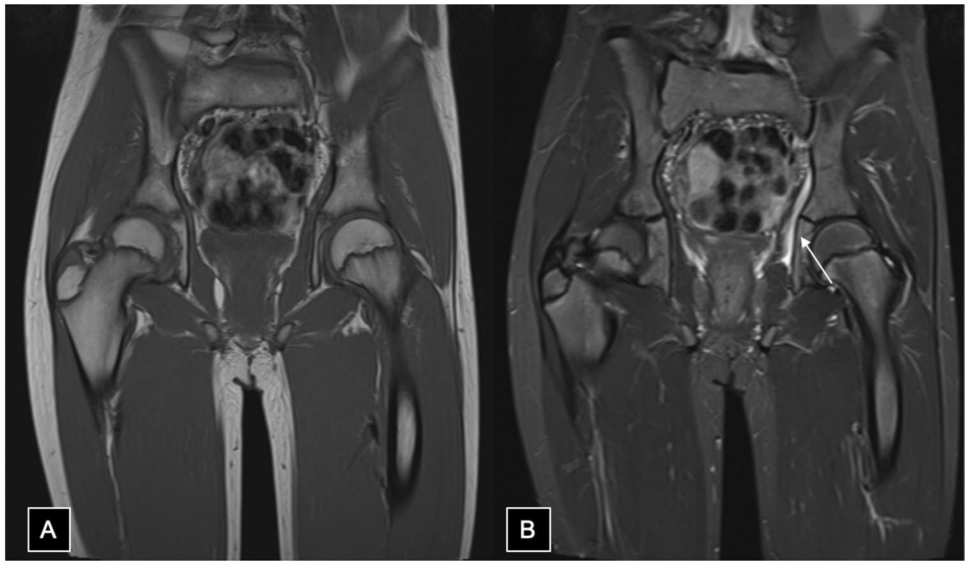

Fig. 3 Example of an osteomyelitis protocol in a 15-year-old female patient. Coronal T1WI single shot (**A**) and coronal STIR (**B**) showing bone edema with hypointense signal in T1WI and hyperintense signal in STIR in the posterior column of the left acetabulum (*arrow* in **B**), associated with a fluid collection and myositis of the left obturator internus, related to left acetabular osteomyelitis

Table 9 Osteomyelitis protocol

Sequence	Plane	Duration
T1WI	Coronal	3 min
STIR	Coronal	3 min
T2WI fat saturation (FS)	Axial	4–6 min
T1WI	Sagittal	3 min
Post-contrast T1WI FS	Sagittal	3 min
Post-contrast T1WI FS	Coronal	3 min
	Total scan time	~ 10–15 min; 20–25 with contrast

FS, fat saturation; *STIR*, short tau inversion recovery; *T1WI*, T1-weighted images; *T2WI*, T2-weighted images

maintaining an open channel of communication with MRI vendors, the committee ensures that any technological advancements that are relevant to be updated can be quickly incorporated into the protocols.

This proactive and inclusive approach not only fosters widespread adoption of standardized practices but also empowers radiologists around the world with the tools and knowledge to deliver high-quality pediatric MRI diagnostics, ultimately improving patient care on a global scale.

Future goals and implementation strategies

The WFPI MR Protocols Committee remains focused on expanding the accessibility and adaptability of its basic, foundational MRI protocols. These protocols offer a flexible framework that can be tailored to clinical settings worldwide, from resource-limited environments to advanced healthcare facilities.

A key next step involves re-engaging with MRI vendors, including Siemens, GE, and Philips, to facilitate the integration of these protocols directly into MRI systems. By embedding the protocols within the machines, the committee seeks to make them readily available and easy to implement across diverse regions and clinical environments. This integration will help ensure that even the most basic versions of the protocols are accessible to healthcare providers globally, promoting uniformity in pediatric imaging practices.

In addition, the committee is working to expand the reach of the protocols by translating them into multiple languages. Currently available only in English, the goal is to make these protocols accessible to radiologists and clinicians worldwide, ensuring that language barriers do not hinder their application. This step is critical to improving global adoption and enhancing pediatric imaging practices across regions with different linguistic needs.

Furthermore, the committee plans to gather feedback from users who implement these protocols in their clinical settings. This feedback will be essential in identifying areas for improvement and ensuring that the protocols remain practical and responsive to the realities of pediatric imaging. Based on the insights received, the committee will make updates and refinements as necessary, ensuring the protocols evolve in alignment with real-world clinical demands. All changes and updates will be clearly highlighted on the WFPI website, allowing users to easily track modifications and adapt their practices accordingly.

Finally, the committee aims to increase the dissemination and knowledge of these protocols by encouraging their reproduction and widespread use across the medical community. Through collaboration with regional societies, radiologists, and vendors, the committee will work to ensure the protocols are adopted and adapted globally, ultimately contributing to standardized pediatric MRI practices and improved patient care across all resource levels.

Conclusion

The WFPI MR Protocols Committee's work represents a pivotal advancement in pediatric imaging. By establishing standardized protocols that reduce variability, improve diagnostic accuracy, and minimize sedation and radiation exposure, the committee ensures better patient care globally. The collaboration among regional societies, vendors, and pediatric radiologists has resulted in protocols that balance practicality with diagnostic precision, making them adaptable to a variety of clinical settings.

It is important to emphasize the significant gains achieved through this international collaboration. The combined expertise of professionals from different regions and institutions has fostered a unified approach to pediatric imaging, ensuring that these protocols can be implemented universally, regardless of available resources. Whether in high-resource environments or regions with limited access to advanced technology, these protocols provide a foundation for quality pediatric MRI.

Continuous updates and refinements, informed by ongoing feedback from global users, will enable these protocols to evolve and remain relevant. This initiative ultimately ensures that children worldwide receive the highest standard of MRI care, promoting equity in healthcare regardless of geographic or economic disparities.

Author contribution All authors contributed to the review of protocols, conception and design of this review. All authors read and approved the final manuscript.

Data availability No datasets were generated or analyzed during the current study

Declarations

Competing interests Competing interests

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