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ISSN 3035-2134 | March 2026 Vol. 4, No. 1

Pediatric Respiratory Journal

Official Journal of the Italian Pediatric Respiratory Society

Official Journal of the Italian Pediatric Respiratory Society (Società Italiana per le Malattie Respiratorie Infantili – SIMRI)

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PEDIATR RESPIR J Vol. 4(1), 2-15, 2026

SYSTEMATIC REVIEW

Impact of digital technologies on pediatric asthma care

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ABSTRACT

Asthma is one of the most common chronic diseases in children, significantly impacting their health, quality of life, and healthcare systems globally. Pediatric asthma accounts for substantial morbidity, including frequent exacerbations, emergency department visits, and missed school days. Despite the availability of effective treatments and clear management guidelines, achieving optimal asthma control remains a challenge. In recent years, digital technologies have emerged as transformative tools in asthma care, offering new ways to monitor, educate, and treat pediatric patients.

A systematic review was conducted to examine the impact of digital technologies on pediatric asthma care, synthesizing evidence on their effectiveness, challenges, and future directions. Covering studies from January 2020 to December 2024, the review analyzed 59 primary studies that involved mobile health (mHealth) applications, electronic medication monitoring systems, wearable devices, artificial intelligence (AI)-powered solutions, and school-based telemedicine programs.

Findings reveal that mHealth applications and serious games promote self-management, improve medication adherence, and support patient education. Telemedicine, including school-based and remote patient monitoring, enhances care accessibility, reduces emergency visits, and promotes continuity of care, particularly in underserved populations. Wearable devices and electronic monitoring tools enhance symptom tracking and evaluation of inhaler technique. AI-driven interventions, such as digital twin systems, show promise in personalizing treatment and predicting exacerbations.

Despite encouraging outcomes, challenges remain, including digital literacy gaps, limited access to devices and the internet, and difficulties integrating digital tools into clinical workflows. Usability and sustainability vary widely depending on design approaches, caregiver engagement, and infrastructure readiness.

IMPACT STATEMENT

Digital technologies show promise in asthma management. Despite encouraging outcomes, challenges remain, including digital literacy gaps, limited access to devices and the internet, and difficulties integrating digital tools into clinical workflows.

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10.56164/PediatrRespirJ.2026.01

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KEY WORDS
Asthma; artificial intelligence-powered solutions; children; mobile health applications; wearable devices.

INTRODUCTION

Asthma is one of the most common chronic diseases in children, significantly impacting their health, quality of life, and healthcare systems globally. Pediatric asthma accounts for substantial morbidity, including frequent exacerbations, emergency department visits, and missed school days. Despite the availability of effective treatments and clear management guidelines, achieving optimal asthma control remains a challenge. In recent years, digital technologies have emerged as transformative tools in asthma care, offering new ways to monitor, educate, and treat pediatric patients. These include mobile health (mHealth) applications, telemedicine platforms, wearable devices, and artificial intelligence (AI)-enabled solutions. Such technologies promise to improve asthma control by facilitating better disease monitoring, enhancing medication adherence, and enabling more proactive and personalized care (1-7).

Mobile health applications have also gained prominence for their potential to enhance asthma control. These apps often include features such as symptom tracking, medication reminders, educational resources, and real-time feedback for children and their caregivers (8-11). However, real-world implementation has revealed practical challenges such as recruitment barriers, communication issues, and low retention in pilot studies, emphasizing the need for adaptable strategies tailored to pediatric populations (12). Additionally, AI-powered solutions, such as digital twin systems (DTS), leverage real-time data to personalize care and predict exacerbation risks, enabling a more tailored approach to asthma management (7, 13).

School-based telehealth programs represent another effective intervention for pediatric asthma. By integrating healthcare services into school settings, these programs address logistical barriers, such as transportation issues and caregiver availability, while engaging school nurses in asthma management. These programs have been shown to improve asthma outcomes by ensuring regular follow-ups, medication adherence, and symptom monitoring during school hours (7, 14, 15).

Furthermore, wearable devices and electronic medication monitoring (EMM) systems have advanced the management of pediatric asthma. These technologies allow real-time tracking of medication use and provide objective data on treatment adherence, a critical factor in achieving asthma control. For instance, Bluetooth-enabled sensors attached to inhalers can monitor usage patterns, offering valuable insights for both caregivers and healthcare providers (16). Similarly, digital wheeze detectors and other wearable devices are enhancing early detection of symptoms, enabling timely interventions and reducing the risk of severe exacerbations (7, 17).

Despite the promising impact of these digital tools, their implementation faces several challenges. Social determinants of health, such as limited internet access, low health literacy, and economic constraints, can hinder the adoption of digital technologies, particularly in underserved populations (18-20).

Moreover, integrating digital technologies into existing healthcare workflows is complex. Healthcare providers often cite concerns about data privacy, the time required to learn new systems, and the lack of interoperability between digital tools and electronic health records (7, 18, 21).

Research on the effectiveness of digital health interventions in pediatric asthma is growing. Evidence suggests that these technologies improve medication adherence, reduce healthcare utilization, and enhance overall asthma control. However, gaps remain in understanding the long-term impact, scalability, and cost-effectiveness of these solutions (2, 7, 14, 15).

This systematic review examines the impact of digital technologies on pediatric asthma care, synthesizing evidence on their effectiveness, challenges, and future directions. By providing insights into the current state of digital asthma care, this review aims to guide clinicians, policymakers, and researchers in leveraging these tools to improve outcomes for children with asthma.

METHODS

The systematic review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, as specified in the reference literature (22).

Outcomes

The primary outcome of this study is the systematic assessment of digital technologies implemented in pediatric asthma care. The analysis focused on evaluating the clinical effectiveness, adherence improvement,

healthcare utilization reduction, feasibility, usability, and equity implications of digital health interventions in children and adolescents with asthma.

The included studies were categorized into four thematic domains: School-Based Telehealth Studies; Serious Game Studies; Asthma Management Technologies; Impact of COVID-19 and Caregivers' Experience.

Inclusion and exclusion criteria

The studies included in the systematic review were published between January 2020 and December 2024, a time frame chosen to ensure that the evidence was relevant and up to date in the context of the study. In order to adequately address the research question, the inclusion criteria are the following: 1) focused on a population with asthma, 2) involved children or adolescents aged 0-18 years, 3) primary study, 4) included an intervention involving a device, and 5) English language text. Our analysis excluded clinical guidelines, case reports, consensus documents, clinical trials and reviews. We also excluded conferences and congress abstracts because of limited data and the potential risk of bias.

Search strategy

A sensitive search strategy was designed to retrieve all articles from the major online databases: PubMed, Web of Science, Embase, and Scopus. Searches were conducted using one or more search terms (**Table 1**). Studies of different methodological types were included, such as cross-sectional studies, non-randomized trials, quasi-experimental studies, before-after controlled studies, Cluster Randomized Trials (CRTs), Randomized Controlled Trials (RCTs), case-control studies, and cohort studies. The identification and removal of duplicate studies was automated using Zotero software. Then three independent reviewers (identified by the initials GP, DLR and PA) performed an initial assessment of the titles and abstracts of the identified studies. The aim of this evaluation was to select articles that met the inclusion criteria. Articles that passed this initial stage were retrieved in full text for a more thorough assessment, to determine whether they met the defined inclusion criteria and to identify the primary studies to be included. Any discrepancies were resolved by discussion and consensus with an additional researcher (RN and SM). The selected studies were then used for data extraction to gather the necessary information to address the objectives of the review.

As illustrated in the PRISMA flowchart (**Figure 1**), the final database search conducted in May 2025 yielded 428 records. Following the removal of 96 duplicate entries, the remaining records underwent a two-step screening process. Initially, titles and abstracts were assessed for relevance, after which full-text reviews were performed. A total of 273 publications were excluded based on predefined exclusion criteria. Ultimately, 59 articles that met all the inclusion criteria were deemed eligible and included in the systematic review.

***Table 1**. Query Research String.*

PubMeD	((((“digital”[All Fields] AND “health”[All Fields]) OR “digital health”[All Fields] AND (“technology”[MeSH Terms] OR “technology”[All Fields] OR “technologies”[All Fields] OR “technology s”[All Fields])) OR (“telemedicine”[MeSH Terms] OR “telemedicine”[All Fields] OR “telemedicine s”[All Fields])) AND (“asthma”[MeSH Terms] OR “asthma”[All Fields] OR “asthmas”[All Fields] OR “asthma s”[All Fields]) AND (“child”[MeSH Terms] OR “child”[All Fields] OR “children”[All Fields] OR “child s”[All Fields] OR “children s”[All Fields] OR “childrens”[All Fields] OR “childs”[All Fields])) AND ((allchild[Filter]) AND (2020:2024[pdat]))
Embase	digital health technology OR telemedicine AND asthma AND children (All Fields) and 2020 or 2021 or 2022 or 2023 or 2024 or 2025 (Publication Years) and English (Languages)
Web Of Science	digital health technology (All Fields) AND telemedicine (All Fields) AND asthma (All Fields) AND children (All Fields) Timespan: 2020-01-01 to 2024-12-31 (Publication Date)
Scopus	TITLE-ABS-KEY (digital AND health AND technology OR telemedicine AND asthma AND children) AND PUBYEAR >2019 AND PUBYEAR <2025

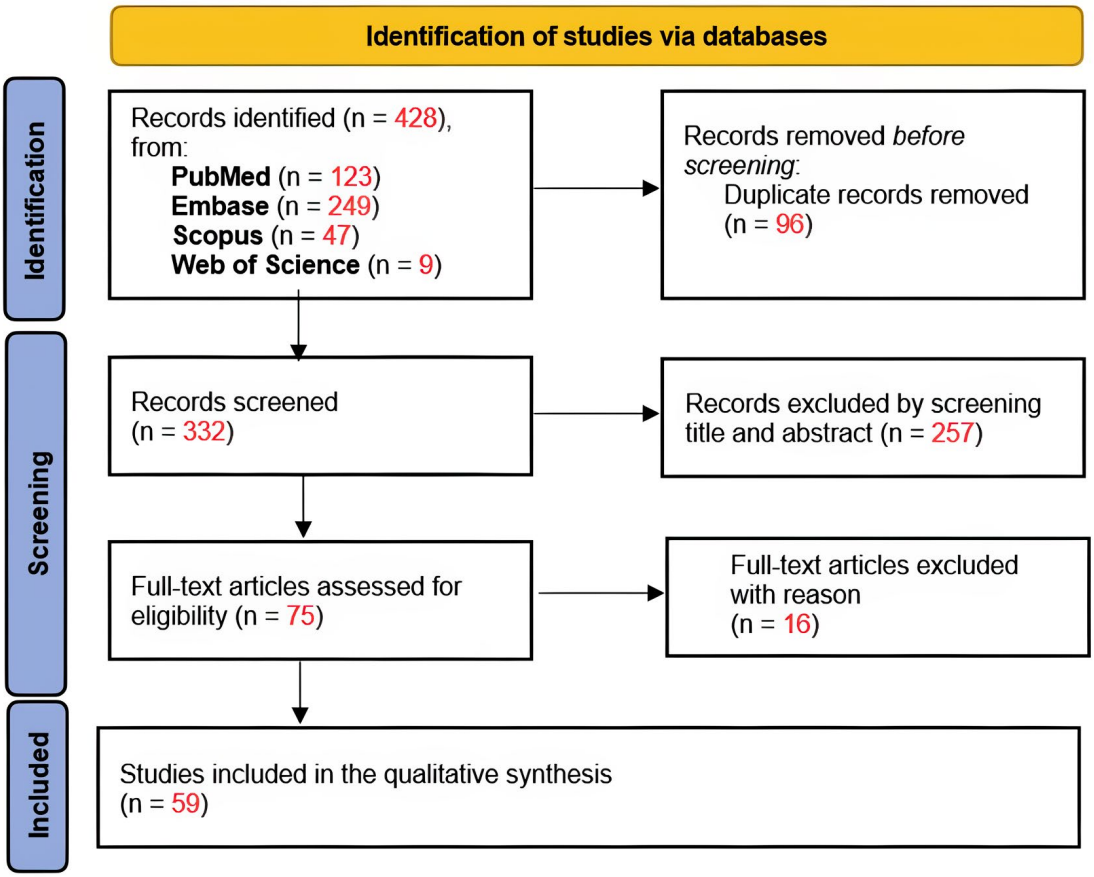

Figure 1. *PRISMA flowchart showing the study selection process.*

Risk of bias assessment

Two reviewers (RN and SM) independently assessed the risk of bias of the included studies, by using a validated checklist, the Johanna Briggs Institute critical appraisal tools (23), according to the design of the study. Selection and information bias, confounders, blinding, data analysis methods were the main domains checked for the risk of bias. An overall risk of bias was reported for each study, then normalized to 100 and expressed as "low", "medium" and "high" (first, second and third tertile, respectively).

RESULTS

Study characteristics

A total of 428 articles were found. After removing 96 duplicates, 332 were reviewed on title and abstract and 257 articles were excluded from this group. 75 full texts were screened, and 16 were excluded based on type of intervention, absence of a control group, small sample sizes, non-relevant context, and interventions not easily implementable in clinical practice. 59 articles were assessed for eligibility. The studies predominantly focus on pediatric populations, encompassing infants (0–12 months), school-aged children (6–12 years), and adolescents (12–18 years). A limited number extend to adult cohorts for comparative analyses. Most investigations center on children aged 5–15 years, a critical developmental window for asthma management and digital health interventions.

Specifically, 6 studies addressed the topic of *School-based Telehealth*, 6 studies where about *Serious games*, 30 studies investigated *Asthma management*, and 17 studies addressed *Impact of COVID-19, caregivers' experience* (**Supplementary Materials Table S1, Table S2** and **Table S3**).

Telemedicine monitoring strategies include remote patient monitoring (8, 24), and school-based telehealth programs

[25-27], and virtual home visits [28], aiming to enhance healthcare accessibility, reduce school absenteeism, and minimize emergency visits. Mobile health (mHealth) applications (2, 19, 29-31), and serious games (29, 32), emphasize asthma self-management, leveraging gamification and family engagement to improve adherence. Electronic medication monitoring devices (EMDs) and digital inhalers (17, 33-35), facilitate the tracking of inhalation techniques, adherence monitoring, and risk pattern identification. Additionally, emerging technologies such as Digital Twin Systems (13) and augmented reality (36), alongside advanced digital monitoring combined with AI solutions (35), offer innovative solutions for asthma education and clinical training. The primary outcomes of these interventions focus on asthma management, healthcare utilization, cost-effectiveness, and user engagement.

Digital tools have been shown to enhance medication adherence by 12–23% (33) and improve symptom control and exacerbation prevention. Telemedicine programs significantly reduce emergency room visits and hospitalizations (21, 24, 37), with some studies reporting a 100-fold increase in telehealth adoption (21). Economic analyses suggest that telehealth interventions mitigate caregiver wage loss and decrease school absenteeism (25, 28). Furthermore, usability studies (30-32, 36), showed feasibility and positive user feedback, especially in preschool and adolescent populations.

Overall, telemedicine has demonstrated substantial improvements in asthma care and accessibility, reducing absenteeism and hospitalization rates while increasing parental satisfaction (26, 27, 38, 39).

mHealth applications effectively promote self-management, with high engagement and better asthma control outcomes (19, 40, 41). Electronic monitoring systems significantly enhance medication adherence (33-35). While augmented reality and artificial intelligence present promising advancements, concerns remain regarding their potential to replace direct clinical interactions, necessitating further validation (36).

DISCUSSION

User-Centered Design for mHealth Applications and Serious Games

The integration of digital tools into pediatric asthma care necessitates a user-centered, strategically planned

***Table 2**. User-centered design methodologies.*

Aspect / Solution	ARCA [1]	REACT [2]	MIRACLE [3]	AIM2ACT [4]
Application Type	mHealth	mHealth	serious game	mHealth
Target Users	Adolescents with asthma and their caregivers	Adolescents with asthma	Children with asthma	Adolescents with asthma and their caregivers
Key Features	Monitoring, action plans, educational materials, medication adherence	Goal intention–formatted messages, motivation assessment, problem-solving modules	Interactive storytelling, educational gameplay	EMA, goal setting, behavioral contracting, skills-training videos
Design Process	Developed with a focus on usability, involved systematic reviews	User-centered design with iterative feedback and algorithm development	User-centered design with focus on engagement	User-centered design with feedback from adolescents and caregivers
Development Approach	Iterative development with usability testing	Iterative development with user feedback	Iterative design with user engagement focus	Iterative design with stakeholder feedback
Implementation Strategy	Multi-platform support, offline functionality	Mobile app with interactive modules	Game-based learning approach	Mobile app with interactive features
Evaluation Methodology	Usability assessed with System Usability Scale	Feasibility, acceptability, and preliminary efficacy evaluated through pilot studies	Engagement and educational impact assessment	Feasibility, acceptability, and preliminary efficacy evaluated through pilot studies

approach that balances technological innovation with clinical utility. Telemedicine, supported by advanced wireless communication, should complement traditional care models (7). Mobile applications, interactive platforms, and serious games for children and adolescents introduce unique challenges in design and implementation. Employing a user-centered design (UCD) framework ensures these tools remain engaging, usable, and responsive to the needs of young patients and caregivers. Continuous end-user involvement throughout development enhances usability, adherence, and clinical outcomes.

Studies indicate that digital interventions can address key adherence barriers, such as forgetfulness, irregular medication use, and insufficient educational resources. Across various models, the literature underscores the necessity of iterative development and systematic incorporation of user feedback.

The ARCA platform (30) exemplifies structured UCD, offering a color-coded dashboard for patient-reported outcomes (PROs) and developed through a seven-phase process, though patient and family involvement was limited to later stages. Usability was evaluated with the System Usability Scale (SUS). REACT (40) focuses on adolescent adherence via a self-regulation tool, integrating feedback from interviews and national crowdsourcing; formal usability testing is still pending. MIRACLE (7), an educational program for Indonesian children, uses storytelling and games based on the NEMD theory and SERES framework, with usability testing planned. AIM2ACT (29) combines ecological momentary assessment, goal setting, behavioral contracts, and skill-building for adolescents and caregivers, and has undergone feasibility and acceptability testing with positive preliminary outcomes. The JASMIN app (12), based on the pediatric self-management model, enhances communication and collaborative care through symptom tracking and shared action plans. Despite methodological differences, these interventions converge on iterative refinement and stakeholder engagement. Of these, only AIM2ACT (29) has progressed to advanced evaluation stages.

Digital technologies and asthma care

Integrating digital technologies into asthma care represents a transformative shift in managing this chronic condition, particularly among pediatric populations. Multiple studies highlight the potential and challenges of digital interventions, including mHealth applications (19), telemedicine, wearable devices [42], augmented reality (AR) (36), and Electronic Medication Monitoring Systems (EMM) (17) (**Table 3**). These innovations aim to address critical barriers in asthma care, such as poor adherence, limited access to specialized healthcare, and inadequate patient education, fostering better outcomes. Likewise, technologies offering real-time provider-patient communication may enhance diagnostic precision for children with asthma who may need ongoing adjustments to treatment (19).

Mobile health applications

Mobile health (mHealth) tools are increasingly integrated into pediatric asthma care, offering functionalities such as symptom tracking, medication reminders, and educational support. A retro-prospective study on the Nemours app found that 56% of providers and 61% of caregivers used the app to enhance communication and caregiver health literacy. Use of its messaging function was positively associated with higher health literacy scores ($\beta = 0.44$, $p = 0.041$) and improved symptom reporting that supported asthma action plan adjustments (19).

In a pilot RCT, the AIM2ACT intervention, combining ecological momentary assessment, tailored feedback, and skills training, significantly improved Asthma Control Test (ACT) scores in adolescents aged 12–15 and their caregivers [29]. Retention was high (97% at follow-up), especially in underserved populations, supporting the feasibility and acceptability of personalized mHealth strategies.

Beyond asthma, mHealth tools like “AllergyMonitor” have addressed allergic rhinoconjunctivitis, a frequent asthma comorbidity. A study of 125 children from Berlin and Ascoli Piceno used the app to collect daily symptom and medication data, analyzed using fuzzy k-medoid clustering of Combined Symptom and Medication Score (CSMS) trajectories (43). This identified symptom severity clusters and linked them to environmental exposures, showing the value of real-time, personalized feedback.

Despite promising outcomes, implementation challenges remain. Wyatt *et al.* (12) reported consistent difficulties across all phases of participant recruitment

in a pediatric asthma mHealth study, highlighting the need for flexible, iterative recruitment strategies. Similarly, “Asmapp” was piloted in preschoolers with recurrent wheeze, allowing daily symptom tracking and clinician access to real-time data (31). Although no clinical improvements were seen, caregiver acceptability exceeded 95%, and app-collected data were more detailed than retrospective questionnaires, underscoring the value of continuous digital monitoring for early childhood asthma management.

Table 3. *Digital technologies and asthma care*

Device/ Instrument Type	Brief Description	Pros	Cons	Impact on Pediatric Asthma Care
Mobile Health Applications (mHealth)	mHealth apps are digital tools designed to support asthma management by providing features like symptom tracking, medication reminders, air quality alerts, and patient education. (Ex:Nemours; AIM2ACT)	• Improves health literacy and self-management. • Provides tailored feedback and real-time insights. • Facilitates communication between patients, caregivers, and providers. • Enables precision medicine approaches. • Effective in fostering caregiver involvement and autonomy in adolescents.	• Dependent on internet access and device availability. • Engagement varies based on socioeconomic factors. • Potential for data overload without proper filtering and presentation. • Some challenges in integrating with clinical workflows.	• **Enhances medication adherence and asthma control**: studies indicate that mHealth apps can improve adherence to treatment plans and overall asthma control in children and adolescents. • **Facilitates parent-child shared management**: apps designed for joint use by parents and children promote collaborative management, leading to better health outcomes. • **Potential to reduce healthcare utilization**: while some studies did not find a significant decrease in emergency visits, mHealth apps have been associated with improved self-management and patient confidence.
Electronic Medication Monitoring (EMM) Systems	EMM systems are devices or sensors attached to inhalers that monitor medication adherence and inhalation technique in real time. (EX Popeller Health sensor; Digihaler)	• Enhances medication adherence monitoring. • Reduces emergency visits through early intervention.Combines data tracking with inspiratory effort measurement (Digihaler). • Promotes provider-patient collaboration. • Improves ICS adherence significantly in pediatric populations.	• Requires integration with existing healthcare workflows. • Interoperability issues with EHR systems. • Limited by technology literacy and administrative burdens. • Occasional discrepancies in data due to incorrect usage of devices.	• **Improves adherence and health outcomes**: EMM systems have been shown to enhance adherence to inhaled corticosteroids and reduce asthma-related exacerbations in children. • **Provides reassurance to caregivers**: parents report increased confidence and a sense of security when using EMM systems, knowing their child’s medication use is being monitored. • **Engages children in self-management**: the interactive nature of EMM devices can motivate children to take an active role in their asthma care.

→

Device/ Instrument Type	Brief Description	Pros	Cons	Impact on Pediatric Asthma Care
Wearable Devices	Wearable devices are technologies designed for continuous monitoring of asthma-related parameters such as lung function, activity levels, and sleep patterns. (Ex: Activity trackers; Handheld spirometers; Smart inhalers)	• Enables continuous real-world monitoring. • Provides insights into trends that episodic evaluations may miss. • Facilitates early detection of poor control and severe exacerbations. • Strong correlation with clinical assessments. • High compliance in pediatric populations when designed for ease of use.	• May not be accessible or affordable for all populations. • Requires adherence to wearing and maintaining the device. • Limited by battery life and potential data syncing issues. • Data accuracy can vary based on compliance and device calibration.	• **Enables personalized asthma management**: continuous monitoring allows for tailored interventions based on individual patterns and triggers. • **Early detection of exacerbations**: wearable devices can identify early signs of asthma attacks, prompting timely interventions. • **Encourages proactive health behaviors**: the use of wearable technology can motivate children to engage in their health management actively.
Augmented Reality (AR) Tools	AR tools are interactive educational technologies that use augmented reality to enhance engagement and understanding of asthma management. (Ex: MIRACLE)	• Highly engaging and user-friendly for children. • Increases retention of educational content. • Improves inhaler techniques and knowledge of asthma triggers. • Encourages proactive self-management behaviors. • Can address educational gaps using immersive, culturally adapted narratives.	• Initial development costs can be high. • Limited usability for older populations. • Requires specific hardware (AR-enabled devices), potentially limiting accessibility. • Challenges in widespread deployment due to technical barriers or resource constraints.	• **Enhances learning and retention**: AR tools make asthma education more engaging, leading to better understanding and recall of management techniques. • **Improves inhaler technique**: interactive simulations help children master proper inhaler use, reducing medication errors. • **Addresses educational disparities**: culturally adapted AR content can bridge knowledge gaps in diverse pediatric populations.
Telemedicine Platforms	Telemedicine platforms are digital systems that enable remote consultations, monitoring, and education through video calls, messaging, or specialized apps. (Ex: MCAV; Remote monitoring systems that integrate wearables)	• Expands access, especially for underserved populations. • Reduces logistical barriers like transportation. • Allows real-time symptom tracking and timely interventions. • Enhances patient-provider communication. • Addresses social determinants of health via resource linkage. • Reduces no-show rates in pediatric programs.	• Internet and device access are prerequisites. • Less effective for populations with low digital literacy. • Requires careful planning to avoid excluding vulnerable groups. • Challenges in integrating with existing clinical practices and workflows. • Limited ability to conduct physical assessments remotely.	• **Increases access to care**: telemedicine overcomes geographical barriers, providing timely medical advice to children in remote areas. • **Facilitates continuous monitoring**: integration with wearable devices allows healthcare providers to monitor patients' conditions in real-time, leading to proactive care adjustments. • **Reduces healthcare costs**: by minimizing emergency visits and hospitalizations through early interventions, telemedicine can lower overall healthcare expenses.

Electronic Medication Monitoring Systems

Electronic Monitoring and Management (EMM) devices, such as the Propeller Health sensor and Digihaler, integrate adherence tracking with real-time feedback. The Digihaler also measures inspiratory effort, providing insight into both inhaler use and drug delivery effectiveness. A non-interventional study comparing the Digihaler with the inhalation profile recorder (IPR) showed accurate, clinically relevant data in pediatric patients, supporting treatment decisions on technique and adherence (34). EMM systems enable personalized asthma care. In the iTRACC trial, automated alerts prompted timely interventions that addressed issues like prescription delays and missed doses (35). A qualitative study based on the Consolidated Framework for Implementation Research (CFIR) explored how ten healthcare providers perceived EMM integration. Interviews highlighted both the benefits and challenges of implementation in pediatric outpatient settings.

By embedding digital monitoring into clinical workflows, EMM tools improved provider-patient communication, identified nonadherence early, and helped prevent exacerbations and emergency visits (17, 29, 34, 43). These systems show promise in optimizing asthma management across diverse care contexts.

Wearable technologies

The WEARCON study adopted a prospective observational design, focusing on children aged 4–14 years (42). The study highlighted their potential by integrating multiple devices to track real-world asthma management. For instance, pre-exercise lung function variation and respiratory rate recovery post-exercise emerged as reliable indicators of asthma control, correlating strongly with clinical assessments. Additionally, wearable devices enable ongoing symptom monitoring, addressing the limitations of episodic outpatient evaluations (42).

Remote Patient Monitoring programs, which integrate wearable and mobile devices, provide real-time monitoring of asthma symptoms and physiological data. A study explored the utility and effectiveness of the New Mexico Pictorial Asthma Action Plan, a telehealth delivery of a pictorial action plan, focused on youth aged 10 to 17 years, significantly improved asthma control scores, particularly in low-literacy, underserved populations. By combining RPM with tailored educational tools, this approach reduced barriers to care and enhanced patient-provider communication (39).

Augmented reality tools

Digital technologies offer innovative tools to improve pediatric asthma management by combining education, engagement, and prediction. Augmented reality (AR) and serious games are increasingly used to enhance asthma education among children. The MIRACLE program (29), for example, integrated culturally adapted interactive storytelling and games to teach Indonesian children about asthma triggers and inhaler use while promoting self-management skills. Another study applied the Theoretical Framework of Acceptability to evaluate AR-based teaching tools co-designed with clinicians, children, and caregivers (36). These tools improved comprehension and retention by using animations and interactive content to support correct inhaler techniques.

Beyond education, digital platforms are being used for early prediction of asthma exacerbations. The DIGIPREDICT study (35) is a prospective observational project that integrates data from wearable sensors, smart inhalers, and mobile apps to detect early physiological, behavioral, and environmental signals associated with asthma attacks. Using machine learning algorithms, the system generates personalized alerts aimed at preventing exacerbations and supporting clinical decision-making. DIGIPREDICT illustrates how AI-driven, patient-centered tools can address limitations in symptom recognition and enable real-time, remote asthma monitoring. These approaches show particular promise for underserved pediatric populations with inconsistent adherence and high variability in exposure patterns.

Telemedicine

The COVID-19 pandemic catalyzed a rapid transition toward digital care in pediatric asthma management. A retrospective cohort study of 3,959 children aged 5–17 showed a sharp decline in in-person visits during the pandemic, offset by a rise in telehealth use. Asthma exacerbations fell from 12.7% to 3.2%, suggesting that remote care-maintained disease control (21).

Peláez *et al.* (44) reported similar findings in Argentina. Their prospective study within a severe asthma program found a 41% reduction in total exacerbations and a 46% decline in severe episodes after transition-

ing to teleconsultations. Remote ACT assessments via WhatsApp and virtual follow-ups helped sustain asthma control, underscoring the feasibility of hybrid care models combining telemedicine and mHealth.

The TEAM-ED program (Telemedicine Enhanced Asthma Management through the Emergency Department) linked ED care with school-based telehealth follow-ups. Though symptom-free days did not improve significantly, the program increased preventive medication use and follow-up visit rates among underserved children (27). These outcomes support integrating structured telehealth into pediatric care, especially in low-resource settings.

Remote patient monitoring (RPM) further extended care beyond acute episodes. At Cincinnati Children's Hospital, a pilot program used inhaler-attached sensors and nurse-led daily monitoring for recently discharged children. The intervention reduced ED visits and improved outpatient follow-up, despite challenges in engagement and retention (37).

Telemedicine has also addressed logistical and social barriers. The Mobile Clinic Asthma Van in Chicago reduced no-show rates through video consultations, improving care access for underserved families (45). At a tertiary academic hospital, a pediatric asthma telemedicine program helped link low-income families to housing and food support during the pandemic (8).

Yet, disparities remain. Pathak *et al.* (10) studied telehealth use in four New York clinics serving low-income, mostly Latino families. They found that Spanish speakers were 48% less likely to activate patient portals than English speakers, and non-Latinos had a 36% lower activation rate. These results emphasize the need for multilingual platforms, virtual rooming, and digital health navigators to close equity gaps.

Hall *et al.* (4) analyzed trends among 6,754 children, finding that telemedicine accounted for 74.3% of asthma visits at the pandemic's peak in April 2020, declining to 13.6% in 2022. Telehealth use was higher among children with persistent asthma, comorbidities, or public insurance. The Social Vulnerability Index did not significantly predict use, but access remained uneven for Black children and non-English speakers.

The BREATHE program in Louisiana employed virtual home visits (VHVs) via the ANDOR platform for Black children in low-income communities. Participants completing all three VHVs showed the greatest improvements in ACT scores, along with increased knowledge of triggers and self-management confidence (28).

Gümüş *et al.* (41) conducted an RCT in Turkey using Zoom-based education and remote monitoring tools. Compared to standard care, their Virtual Care model improved symptom control, increased symptom-free days, and reduced exacerbations and unplanned visits.

Suvarna *et al.* (46) ran an RCT comparing WhatsApp video consultations with standard in-person care in 192 children. Asthma control (ACT/C-ACT) and quality of life (PQLI) scores showed no significant differences, confirming the non-inferiority of telemedicine. High parental satisfaction reinforced its role as a low-cost, scalable option in resource-limited settings.

School-based telemedicine

School-based telemedicine for pediatric asthma management (SBTH) offers an innovative model to improve access, continuity, and outcomes in chronic disease care, particularly for underserved populations. SBTH delivers remote asthma care within schools using video consultations, digital diagnostics, and coordination with healthcare providers. Its appeal lies in reducing emergency visits, increasing treatment adherence, and minimizing disruptions to learning. It is especially relevant for asthma, a major cause of school absenteeism and pediatric emergency department visits (38).

Programs like the School-Based Telemedicine Enhanced Asthma Management (SB-TEAM) integrate monitoring, education, and treatment adjustments into routine school activities. SB-TEAM has shown positive effects on symptom control and quality of life, with fewer emergency visits and hospitalizations (25, 47).

However, operational barriers can impair program sustainability. These include time constraints for school nurses, insufficient telehealth training, and limited caregiver engagement. Facilitators include dedicated telehealth coordinators, strong provider-school partnerships, and active family participation. Engagement of caregivers improves adherence and communication, while support staff can help overcome technological and logistical hurdles (14).

The economic sustainability of SBTH is supported by cost-benefit analyses. For example, the SB-TEAM program reported that operational costs were offset by decreased healthcare utilization, fewer missed school

and workdays, and improved productivity among caregivers (25). The relatively low per-child cost enhances its scalability (26).

CONCLUSIONS

Despite their promise, digital technologies face several barriers to widespread adoption. Limited access to the internet and devices, particularly in rural and underserved communities, continues to restrict the equitable use of these tools. Additionally, caregiver engagement often varies, with socioeconomic factors playing a significant role. Addressing these disparities requires targeted efforts, such as subsidizing technology and designing culturally relevant interventions (19).

Healthcare providers also encounter challenges in integrating digital tools into existing workflows. The lack of interoperability between digital systems and EHRs remains a significant obstacle, increasing administrative burdens and hindering seamless adoption. Training programs and infrastructure investments are essential to address these gaps (36).

The future of digital asthma care lies in harnessing the potential of personalized and precision medicine (17). Moreover, longitudinal studies are needed to evaluate the long-term effectiveness, scalability, and cost-efficiency of digital interventions. While current evidence highlights the potential for improved asthma control, a positive change in QOL, reduced healthcare utilization, and decreased economic burden, understanding the sustainability of these outcomes is crucial (33, 48-51).

Finally, addressing socioeconomic barriers and prioritizing inclusivity can extend the benefits of digital technologies to all children with asthma, regardless of their circumstances (52).

ACKNOWLEDGMENTS

We would like to thank the SIMRI executive committee for approving and supporting the “Impatto delle tecnologie digitali sul controllo dell’asma in età pediatrica” Task Force.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interests

The authors declare that they have no conflicts of interest relevant to the content of this article.

Financial support

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Authors’ contributions

RN, SM, SLG conceived and supervised the study, coordinated the development of the paper and led the drafting of the manuscript. GF, VM, GFP, DPLR, AL contributed to data extraction and organization. PA, AP, LG contributed to data organization, descriptive statistical analysis, prepared tables and figures. SLG assisted in interpreting clinical data and reviewing the manuscript critically for intellectual content. All authors contributed to the study design, led the drafting of the manuscript, revised the manuscript critically, and approved the final version. They all agree to be accountable for the integrity and accuracy of the work.

Data sharing and data accessibility

The data that support the findings of this study are available from the corresponding author upon reasonable request. Data sharing will be considered for academic and research purposes in compliance with applicable data protection regulations.

Publication ethics

The authors declare that this manuscript is original, has not been previously published, and is not under consideration for publication elsewhere. All authors have approved the final version of the manuscript and agree with its submission to this journal.

The authors affirm that the work complies with the highest standards of research integrity. No data have been fabricated, manipulated, or falsified. The manuscript is free from plagiarism, and all sources and contributions have been appropriately acknowledged.

The authors confirm adherence to ethical principles regarding authorship, data transparency, and responsible communication of scientific results.

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PEDIATR RESPIR J Vol. 4(1), 16-21, 2026

REVIEW

Non-invasive respiratory support therapies in the acute setting: how to improve the success rate of weaning

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10.56164/PediatrRespirJ.2026.02

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ABSTRACT

Noninvasive respiratory support modalities such as noninvasive ventilation (NIV), continuous positive airway pressure (CPAP), and high-flow nasal cannula (HFNC) are commonly used in children with various acute respiratory conditions, characterized by oxygen dependence, hypercapnia, or both. The primary goals of noninvasive support in these patients are to reverse moderate respiratory failure while avoiding therapeutic escalation such as intubation and invasive ventilation, or to stabilize the clinical condition of a previously invasively ventilated patient to prevent extubation failure. Despite the strategic role of noninvasive respiratory support to reduce the impact of invasive mechanical ventilation, which requires admission in intensive care unit and exposes patients to higher risk of ventilator-associated complications, currently available evidence is not sufficient to establish solid guidelines or standardized protocols on initiation criteria, operating procedures, weaning strategies, and failure criteria, as well as to define the most appropriate settings in which to deliver noninvasive respiratory support. Further studies are needed to determine where and how to implement noninvasive respiratory support and which weaning strategies might provide the best outcomes in pediatric patients with acute respiratory failure.

IMPACT STATEMENT

Effective weaning from noninvasive respiratory support is essential.

KEY WORDS

Infant; noninvasive ventilation; HFNC, pediatric intensive care unit; weaning.

INTRODUCTION

In recent decades, there has been a progressive increase in the use of non-invasive respiratory support in pediatric patients with viral bronchiolitis, pediatric acute respiratory distress syndrome and other acute pathologies (1-6). However, the evidence currently available does not show that this phenomenon has always been accompanied by an improvement in the most important outcomes, such as the need for and duration of hospitalization in intensive care unit (ICU), the need for intubation and invasive mechanical ventilation, the length of hospital stay, or mortality (7, 8). On the contrary, some authors have found that the widespread use of NIV has significantly increased PICU admissions, without necessarily reducing the incidence of patients treated with intubation and invasive mechanical ventilation (9, 10). In 2024, Pelletier and colleagues conducted a large cross-sectional study on a sample of over

33,000 patients with bronchiolitis admitted to 27 PICUs from 2013 to 2022 (9). During this period, PICU admissions had increased by approximately 350 patients per year, effectively tripling the number compared to 2013. This figure was associated with an annual increase of approximately 368 patients treated with HFNC/NIV, corresponding to a 5-fold increase, while admissions requiring invasive mechanical ventilation remained essentially unchanged (9). In another recent multicenter study conducted in the United States, Slain and colleagues reported a marked increase in costs for infants with bronchiolitis over a 10-year period, with annual hospital charges doubling in 2018-2019 compared to 2009-2010 (10). Interestingly, the increased costs were attributed to a 333% increase in PICU admissions and were primarily related to the increase in the number of infants receiving high-flow nasal cannula (HFNC) or continuous positive airway pressure (CPAP) (10). Other cost-analysis studies have demonstrated that hospital costs for bronchiolitis are primarily related to ICU care (11, 12). Consequently, several centers have sought to reduce PICU admissions or at least admission duration, for example by promoting the implementation of NIV in general pediatric wards (13-15). Indeed, even if noninvasive respiratory assistance is still typically provided in PICUs, NIV treatment is increasingly being provided in general pediatric wards, which are appropriately equipped with both the necessary equipment and adequate medical and nursing resources. One of the main reasons for this is the avoidance of unnecessarily occupied intensive care beds, which can sometimes prove insufficient during epidemic periods, and the marked reduction in healthcare costs associated with PICU stays compared to lower-intensity wards, while maintaining a favorable safety and efficacy profile. However, managing noninvasive respiratory support outside the PICU requires specific medical and nursing skills, as well as the capability to transfer the patient to an intensive care unit in the event of clinical deterioration or poor response to treatment.

GOALS AND MODALITIES OF NONINVASIVE VENTILATION IN THE ACUTE SETTING

The three main objectives of noninvasive ventilation in children with acute respiratory illness are the following:

1) to noninvasively support mild or moderate respiratory failure, characterized by oxygen dependence, hypercapnia, or both.
2) To avoid therapeutic escalation with the need for intubation and invasive ventilation.
3) To promote the stabilization of a patient previously ventilated invasively, avoiding extubation failure.

Noninvasive ventilation can vary in terms of modality, usually from high-flow nasal cannula (HFNC) and continuous positive airway pressure (CPAP), to more complex mechanical ventilation techniques, such as BiPAP, Pressure Support (NIV), Pressure Control (NIV), or Neurally Adjusted Ventilatory Assist (NAVA)-NIV (16-18). The choice of the most appropriate NIV mode must be calibrated to the clinical situation and the characteristics of the individual patient, based on numerous factors that can determine its effectiveness and safety, including the type of available care facilities. Another important aspect of NIV concerns the choice of the interface between the respiratory device and the patient, which should aim to achieve the best possible compromise between effectiveness and the child's comfort.

THE WEANING PROCESS

Once the acute phase of respiratory illness has passed, one of the most delicate aspects of the noninvasive respiratory support is the progressive weaning of the patient from respiratory assistance. The goal is to reduce ventilatory support while ensuring that the patient maintains adequate respiratory function. In recent years, research has focused on optimizing the weaning process from NIV, to prevent excessive prolongation of respiratory support while avoiding too premature attempts, which can jeopardize patient safety. Indeed, the weaning phase often proceeds in parallel with the patient's clinical improvement, allowing for rapid weaning from NIV. However, weaning attempts are sometimes unsuccessful, requiring problematic steps back, sometimes resulting in patient destabilization and the need for a new escalation of ventilatory support. In other cases, healthcare providers hesitate in the decision to suspend NIV support, with the risk of improperly prolonging the hospital stay, either in the PICU or other hospital departments, as well as increasing hospital management costs.

For pediatric patients undergoing invasive mechanical ventilation (IMV), numerous recommendations exist in the literature regarding weaning procedures and ventilator release criteria (19-21). This interest from the scientific community is justified by the risks associated with

mechanical ventilation itself, but also by the potential failure of the extubation procedure, which can pose serious risks to the patient, sometimes with severe destabilization of vital signs, the need for emergency reintubation, subsequent increase in respiratory support, prolonged duration of invasive ventilation, and an increased incidence of related complications.

Conversely, as for the weaning process in children undergoing non-invasive mechanical ventilation, no unanimously agreed-upon guidelines are yet available, either nationally or internationally, so individual institutions, and sometimes individual providers, adopt highly variable methods for implementing it. Actually, this shortcoming is not justified, because weaning from non-invasive ventilation could also be a complicated process, requiring adequate monitoring and an individualized treatment plan, adapted to the patient's clinical characteristics.

The first phase of the weaning process from noninvasive ventilation is similar in many ways to that used in invasively ventilated patients. In both scenarios, it is essential to clinically assess the patients' readiness, that is, their ability to resume sufficiently autonomous breathing to allow them to be freed from mechanical respiratory support. This clinical assessment relies on various physiological parameters to determine whether the patient's condition is stable, respiratory parameters are improving and oxygen requirement is not excessive. Subsequently, a gradual reduction in support can be attempted, for example, by decreasing the peak and end-expiratory pressure values of NIV, or by de-escalate to less powerful respiratory support modes, such as HFNC. In any case, close monitoring should always be maintained to promptly identify any signs of respiratory distress, desaturation, or fatigue in the patient, by relying on a multidisciplinary medical and nursing approach.

It is important to emphasize that there is not yet sufficient scientific evidence to demonstrate the superiority of some weaning strategies over others, enough to allow for precise recommendations on when, how, and how to initiate and complete this fundamental process. Recently, some authors have attempted to provide useful guidance on weaning from NIV through expert consensus, quality improvement projects and clinical investigations (22-26). Mortamet and colleagues used a modified Delphi method to reach expert consensus on the definitions and modalities of weaning from NIV in acute hospital settings (22). Involving 25 international experts from 10 different countries, the authors addressed various aspects of the definition of weaning and weaning failure, the criteria for initiating weaning, and the most effective operating methods to follow. However, out of 35 total statements, the authors were able to reach strong consensus on only 9, weak consensus on 10, and no consensus at all on 16 statements (22). The partial failure of this commendable effort by the panel of experts underscores the difficulty of developing a protocol containing criteria, operating methods, and weaning strategies in the pediatric population that are based on solid scientific evidence. In a recent cross-sectional survey, Suzanne *et al.* described the weaning practices from any type of NIV support in infants with severe bronchiolitis in 29 PICUs from five French-speaking countries (23). The authors reported the weaning procedures adopted in the participating PICUs, according to the mode of ventilator support, namely the BIPAP, CPAP and HFNC. Interestingly, most PICUs used the sudden weaning as the first-line weaning procedure, regardless the type of NIV support, while the choice of intermediate support as a weaning strategy was mainly used as de-escalation from BIPAP. However, given the design of the study, more research is still needed to assess the best weaning strategy in infants with severe bronchiolitis (23).

In 2025, Huang *et al.* reported the results of a quality improvement initiative, which used a detailed protocol guide for initiating and weaning HFNC in 223 children with bronchiolitis, in the absence of other major comorbidities (24). With the application of a standardized protocol for HFNC treatment, the authors found a decrease of about one day in both the length of stay in the ICU and in the hospital, and a decrease of about eight hours in the overall duration of HFNC, without observing an increase in adverse events or hospital readmissions (24). In the same year, Smith *et al.* optimized a weaning strategy in 642 patients with bronchiolitis, treated with HFNC in a PICU and a pediatric intermediate care unit at a children's hospital in USA (25). By iterative modifications to an HFNC weaning pathway that increased the frequency of flow weaning attempts, the authors were able to reduce HFNC duration and hospital LOS without increasing the need for escalation to NIV, ultimately recommending a 1L/Kg/min flow wean attempt every four hours (25).

Finally, in a multicenter prospective observational cohort study conducted in 5 PICUs in France, Mortamet and colleagues described three different NIV weaning strategies (26). Despite the limitations of its observational design, their study suggested that the use of HFNC as a de-escalation may improve comfort in patients with severe bronchiolitis, as well as reduce the length of PICU stay in centers where HFNC is also used in general wards (26).

WEANING FAILURE

In the study by Mortamet *et al*, the overall weaning failure rate was 18.5%, consistent with findings from other studies (9, 26). Therefore, according to the most recent data, weaning failure may occur in approximately one in five patients with bronchiolitis, prompting further research to reduce the incidence of this adverse outcome. It should be noted, however, that the definition of weaning failure can vary markedly between centers. For example, in a multicenter UK study, which demonstrated the non-inferiority of HFNC as a first-line modality of noninvasive respiratory support for acute conditions, compared to CPAP, Ramnarayan *et al.* used the same weaning failure criteria for both HFNC and CPAP, based on worsening respiratory distress and/or an FiO2 >40% (7).
Differently, in another multicenter study conducted in the USA, Pelletier and colleagues considered two distinct definitions of weaning failure, one for HFNC and one for NIV. Specifically, HFNC weaning failure was defined as when the patient, after being weaned to low-flow oxygen therapy or room air, had to resume HFNC or, worse, required escalation to NIV or invasive mechanical ventilation within 48 hours of stopping HFNC. Weaning failure during NIV was defined as when the patient, after being weaned from NIV to HFNC, or low-flow oxygen therapy or room air, had to resume NIV or, worse, required escalation to invasive mechanical ventilation within 48 hours of stopping NIV (9).
Although failure to wean from NIV or HFNC is generally considered less serious than failure to wean in an intubated patient, because healthcare providers can almost always easily return to the previous mode of respiratory support by waiting for the patient's condition to improve before making a subsequent attempt, failure to wean may be associated with a longer PICU or hospital stay, a prolonged need for sedation, and a delay in full feeding tolerance. Therefore, in the pre-weaning phase, it is essential to perform a thorough overall assessment of the patient. Ideally, patients should have stable vital signs, minimal oxygen requirements (*e.g.* FiO_2 <0.4), no signs of increased work of breathing, no recent episodes of apnea or bradycardia, and improving chest radiographs and ultrasound findings, if available. In younger patients, it may also be important to assess feeding tolerance.
The most commonly used strategies for successful weaning from noninvasive respiratory support are shown in **table 1**.

***Table 1**. Common strategies for weaning from noninvasive respiratory support.*

a) Gradual reduction of airway pressure, in the case of NIV or CPAP
b) Gradual reduction of flow/minute, in the case of HFNC
c) De-escalation from NIV to CPAP, or from NIV/CPAP to HFNC, and subsequently low-flow oxygen or room air
d) Gradual temporary suspensions of respiratory support (NIV/CPAP or HFNC) with phases of low-flow oxygen or room air
e) Sudden suspension of respiratory support and transition to low-flow oxygen or room air

Some centers use specific protocols to guide the weaning phase from NIV/HFNC, often based on both objective criteria, such as respiratory rate, oxygen saturation, and blood gas analysis, and more subjective clinical criteria shared by the medical and nursing team, such as respiratory distress, patient comfort, interface efficacy and acceptability, and feeding tolerance.
Some possible causes of weaning failure are described in **table 2**.

***Table 2**. Common cause of weaning failure from noninvasive respiratory support.*

1. Early weaning attempts, which can lead to increased work of breathing, desaturation, and fatigue, leading to respiratory failure
2. Suboptimal ventilator-patient interaction, resulting in asynchrony and patient discomfort
3. Interface-related difficulties, such as poor mask fit or skin lesions, both of which reduce efficacy and tolerability.
4. Lack of standardized protocols, leading to discretionary choices by operators, resulting in inconsistent results and increased risk of failure
5. Inadequate treatment of anxiety, agitation, and pain, which can hinder successful weaning
6. Poor ability to recover the patient's native respiratory function, due to the severity of the underlying disease

CONCLUSIONS

Non-invasive respiratory support has become an essential therapeutic option for infants and children affected by various acute respiratory diseases, bronchiolitis being the most frequent and investigated. However, widespread use of NIV has been associated with a dramatic increase in hospital operating costs, without always being linked to a corresponding improvement in key outcomes, such as the need for and length of hospital and PICU stays, the need for intubation and invasive mechanical ventilation, length of hospital stay, or mortality. Currently available evidence does not allow for the development of widely shared guidelines or standardized protocols on initiation criteria, operating procedures, monitoring methods, weaning strategies, failure criteria, and the most appropriate settings in which to deliver noninvasive respiratory support. Future randomized trials are needed to definitively determine where and how to implement NIV support and which weaning strategies might provide the best outcomes in pediatric patients with acute respiratory failure.

COMPLIANCE WITH ETHICAL STANDARDS

Conflicts of interests

The Authors declare no conflicts of interest.

Fundings

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Ethical approval

Human studies and subjects

N/A.

Data sharing and data accessibility

Data are available upon motivated request to the Corresponding Author.

Publication ethics

Plagiarism

Authors declare no potentially overlapping publications with the content of this manuscript and all original studies are cited as appropriate.

Data falsification and fabrication

All the data correspond to the real.

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PEDIATR RESPIR J

Vol. 4(1), 22-25, 2026

MINI REVIEW

Impact of Early-Life Rhinovirus and Respiratory Syncytial Virus Infections on Recurrent Wheeze and Asthma Development

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10.56164/PediatrRespirJ.2026.03

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ABSTRACT

Early-life viral lower respiratory tract infections (LRTIs), particularly those due to rhinovirus (RV) and respiratory syncytial virus (RSV), play a pivotal role in the developmental origins of pediatric respiratory disease. RV and RSV are among the most prevalent causes of bronchiolitis and early wheezing globally. Longitudinal evidence and mechanistic studies have increasingly shown that these infections do not merely cause acute morbidity but also set the stage for chronic airway inflammation, wheeze, and asthma. Notably, new cohort data (INSPIRE study, and other European birth cohorts) (1) and reviews from 2025 by Hartert and Zar (2, 3) build on this paradigm and reinforce the need to understand early viral exposures as critical modifiers of airway trajectory. This narrative review draws on recent epidemiologic, mechanistic, and interventional evidence, supplemented with recent findings, to detail how RV and RSV exposures in infancy contribute to lasting respiratory morbidity.

KEY WORDS

LRTIs; RVS; bronchiolitis; wheeze; asthma.

EPIDEMIOLOGY: RISK OF RECURRENT WHEEZE AND ASTHMA

A growing evidence base confirms that early-life RV wheezing episodes are strong predictors of later asthma. Initial risk estimates from landmark birth cohorts report odds ratios (ORs) of approximately 3.3 for asthma after RV bronchiolitis, increasing to OR >7 when early allergic sensitization is present (4). A Swedish cohort found that 63% of toddlers hospitalized with RV bronchiolitis were diagnosed with asthma by age 11 (5). On the RSV front, multiple longitudinal studies underscore a similar, albeit slightly less strong, association. A U.S. birth cohort reported that infants who evaded RSV infection in the first year had a 26% lower risk of developing asthma by age five (6), translating to preventable 15% of early asthma cases according to ARDS estimates (3). Reinforcing this, a 2024 meta-analysis found a two- to twelve-fold increase in asthma risk following RSV bronchiolitis (7). A 2025 systematic review focused on early viral LRTIs echoed this, reporting a moderate (OR 3.02) increased asthma risk after RSV infection and a higher but more variable risk after RV infection (2). These and other data (8) firmly establish RSV and RV as significant moderators of long-term respiratory health.

MECHANISTIC PATHWAYS

1) **Antiviral Innate Immunity and Interferon Pathways**
   Proper functioning of type I and III interferon (IFN) pathways is critical for viral clearance. RV and RSV both suppress IFN-β and IFN-λ responses, prolonging viral replication and epithelial injury. Contoli *et al.* reported impaired IFN responses in children with RV wheezing, while RSV-induced suppression is similarly demonstrated in both mechanistic models and human specimens (9, 10). The resultant epithelial damage triggers alarmins (TSLP, IL-25, IL-33) that activate antigen-presenting cells and group 2 innate lymphoid cells, shifting immunity toward a Th2 phenotype—with elevated IL-4, IL-5, and IL-13—hallmarks of allergic airway disease.
2) **Allergen–Virus Synergy**
   Infancy is a time of allergen sensitization and immune imprinting. RV wheezing in infants with eczema or early atopy is particularly predictive of asthma, with ORs exceeding 7 in some studies (11). Cohort data demonstrate that RV and allergen exposures work synergistically, driven by persistent Th2 inflammation, mucus hypersecretion, and airway hyperresponsiveness.
3) **Airway Structural Remodeling**
   Early infection interferes with lung development. Animal studies revealed that neonatal viral infection causes persistent structural abnormalities—including increased airway smooth muscle, subepithelial fibrosis, and reduced alveolarization, changes that echo human asthmatic airway pathology (10). These structural deficits often persist long after viral clearance and are reflected in sustained reductions in lung function and airway hyperreactivity.
4) **Longitudinal Trajectory**
   A recent review by Zar *et al.* discusses the long-term consequences of RSV infection in infancy, documenting persistent lung function deficits into adolescence, including lowered FEV_1/FVC ratios and increased airway hyperresponsiveness (3). Notably, some children develop spirometric profiles akin to early chronic obstructive pulmonary disease, indicating a far broader impact of early airway injury. Many researchers have been extensively discussing the concept of "developmental plasticity" indicating that infancy (when alveolarization, immune education, and epithelial maturation are occurring) represents a vulnerable window during which environmental exposures "program" the airway's structural and immune milieu (2).

GENETIC AND ENVIRONMENTAL MODIFIERS

Genetic Polymorphisms

CDHR3 variants, which serve as receptors for RSV, are linked to increased viral binding, replication, and wheezing severity (12). Similarly, the 17q21 locus (one of the most robust asthma-associated genetic markers), interacts with viral exposures to heighten asthma risk (13).

Environmental Risk Factors

Early-life exposures significantly impact on disease risk. Tobacco smoke, indoor biomass exposure, and air pollutants increase susceptibility to severe viral LRTI, magnifying both acute severity and chronic sequelae. A meta-analysis showed that these exposures also reduce the protective effect of breastfeeding against viral-induced wheeze (14). Conversely, exclusive breastfeeding enhances mucosal immunity and supports microbiome resilience, helping mitigate viral and allergic responses (15).

CLINICAL AND PUBLIC HEALTH IMPLICATIONS

Immunoprophylaxis with Nirsevimab

Nirsevimab, a long-acting monoclonal antibody targeting the RSV F protein, achieves approximately 70% protection against RSV LRTIs during the first RSV season (including both term and preterm infants) (16). Widespread deployment is linked to reductions in RSV hospitalizations; recent CDC data show up to a 71% decline in infants under six months (17). While long-term asthma outcomes remain under investigation, early reductions in severe RSV illness suggest promising asthma prevention potential.

Maternal Vaccination

Maternal RSVpreF vaccines (*e.g.*, Abrysvo) confer passive immunity to neonates, reducing RSV-related hospitalizations by ~80% through six months (18). While long-term benefits for asthma prevention are still being assessed, modeling based on current epidemiologic data supports a preventive effect[2].

Therapeutic Immune Modulation

Inhaled IFN-β has shown efficacy in restoring antiviral immune responses in children with virus-induced

wheeze. Phase II trials confirm safety and decreased wheeze exacerbations, though extended follow-up is needed to determine impacts on asthma incidence (19).

Microbiome and Allergy Modulation

Emerging data suggest that early-life modulation of the airway and gut microbiome—through probiotics, reduced antibiotic use, and breastfeeding—can attenuate Th2 bias and diminish virus-allergy synergies. Though direct evidence on asthma prevention is currently limited, this approach aligns with immune development and epigenetic conditioning models (20).

Future Directions and Research Gaps

- Causal trials assessing whether nirsevimab and maternal RSV vaccination lower childhood asthma rates must include extended follow-up.
- Enhanced cohort studies (like INSPIRE) with serial immune profiling, viral monitoring, and spirometry could define susceptibility windows.
- Strain-specific RSV and RV surveillance, especially RV-C, combined with microbiome profiling, may clarify variation in disease phenotypes (10).
- Detailed gene-environment interaction studies (*e.g.*, CDHR3 and 17q21) and epigenetic analyses are needed to uncover mechanistic drivers.

CONCLUSIONS

Recent evidence strongly supports that early-life RV and RSV infections are central to the development of recurrent wheeze and asthma. Mechanistically, these viruses impair antiviral immunity, promote structural airway remodeling, and synergize with genetic and environmental factors. Advances in immunoprophylaxis (nirsevimab, maternal vaccination), immune modulation, and microbiome interventions offer promising strategies to alter disease trajectories. Achieving lasting reduction in pediatric asthma will depend on integrated research, public health initiatives, and prevention-focused clinical strategies.

COMPLIANCE WITH ETHICAL STANDARDS

Conflicts of interests

The Authors declare no conflicts of interest.

Fundings

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Ethical approval

Human studies and subjects

N/A.

Data sharing and data accessibility

Data are available upon motivated request to the Corresponding Author.

Publication ethics

Plagiarism

Author declare no potentially overlapping publications with the content of this manuscript and all original studies are cited as appropriate.

Data falsification and fabrication

All the data correspond to the real.

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PEDIATR RESPIR J

Vol. 4(1), 26-42, 2026

RESEARCH ARTICLE

Knowledge, Attitudes, and Perceptions of Filipino Pediatricians on Pulmonary Rehabilitation in Children

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ABSTRACT

Background: Pulmonary Rehabilitation (PR) is a multidisciplinary program that improves physical function, symptom control and quality of life (QoL) in patients with chronic lung diseases (CLD). Understanding pediatricians' perspectives on PR is essential to inform strategies that enhance referral practices and expand pediatric PR services.

Objective: the main objective is to assess the knowledge, attitudes and perceptions of Filipino pediatricians on PR among children.

Methods: a cross-sectional analytic study using convenience sampling was conducted through an online survey distributed to social media and Viber accounts of general pediatricians (GPs) and pediatric pulmonologists (PPs) practicing in the Philippines. The survey collected data on demographics, PR knowledge, attitudes, perceived benefits, and barriers to referral. Statistical analyses included t-tests, Mann-Whitney U tests, Chi-square/Fisher's exact tests, and univariate and multivariate logistic regression.

Results: a total of 102 pediatricians participated (51 GPs, 51 PPs). PPs were significantly more likely to refer patients to PR (74.5%) than GPs (23.5%) ($p < 0.001$). Referral was positively associated with subspecialty training, private practice setting, geographic location, longer clinical experience, and strong belief in PR's benefits for anxiety, depression, and disease self-management. Major barriers included limited PR centers, high costs, transportation issues, and lack of awareness — factors reported by both groups.

Conclusion: while Filipino pediatricians acknowledge the value of PR, its utilization remains suboptimal due to systemic and perceptual barriers. Addressing gaps in knowledge, expanding access to PR services, and enhancing referral pathways are essential to optimize care for children with CLD. Strategic efforts involving training, advocacy, insurance coverage and infrastructure development are needed to promote equitable and sustained integration of pediatric PR nationwide.

IMPACT STATEMENT

Significant disparities in referral practices and widespread systemic barriers highlight the urgent need to strengthen pediatric PR awareness, accessibility, and integration into routine pediatric care.

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10.56164/PediatrRespirJ.2026.04

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ABBREVIATIONS

PR: Pulmonary Rehabilitation
QoL: Quality of Life
CLD: chronic lung diseases
GPs: general pediatricians
PPs: pediatric pulmonologists
TRC: Technical Review Committee
IERB: Institutional Ethics Review Board
ETRS-CRD: Education, Training and Research-Clinical Research Division
BPD: Bronchopulmonary Dysplasia
ILD: Interstitial Lung Diseases
CF: Cystic Fibrosis
PCD: Primary Ciliary Dyskinesia

KEY WORDS

Pulmonary rehabilitation; pediatric pulmonology; chronic lung disease; referral practices; physician perceptions.

HIGHLIGHTS BOX

What is already known about this topic? Pulmonary rehabilitation (PR) benefits children with chronic lung disease, but pediatric protocols are limited, access is scarce, and referral rates remain low due to knowledge gaps, inadequate facilities, and financial and logistical barriers. **What does the article add to our knowledge?** This study identifies Filipino pediatricians' positive views of PR, highlights major referral barriers, and shows that subspecialty training, practice setting, and beliefs about psychological benefits strongly influence PR referral practices. **How does this study impact current management guidelines?** Findings support integrating PR into pediatric training, strengthening referral pathways, expanding PR access, and emphasizing its psychological benefits – informing guideline updates to improve utilization and standardize pediatric PR referral practices.

INTRODUCTION

Pulmonary Rehabilitation is a "comprehensive intervention based on a thorough patient assessment, followed by patient-tailored therapies that includes, but is not limited to, exercise training, education, and behavior change, designed to improve the physical and psychological condition of people with chronic respiratory disease and to promote the long-term adherence to health-enhancing behaviors." It is administered by healthcare professionals composing of the general physicians, pulmonologists, cardiologists, physiatrists, psychiatrists, respiratory therapists, nutritionists and others (1, 2).

Pediatric PR largely draws its framework from adult PR guidelines. However, there remains a notable lack of evidence-based protocols and standardized interventions specifically tailored for pediatric patients with pulmonary and cardiovascular diseases. The unique physiological and developmental characteristics of children — particularly their age and developmental milestones — present distinct challenges that can limit the direct application of adult PR models to younger populations. What distinguishes pediatric PR is the complexity of its implementation, especially in younger children, whereas adolescents tend to be more receptive and easier to engage. Younger patients are often motivated by play, sports, and other interactive activities, necessitating a more dynamic and age-appropriate approach to rehabilitation. Despite these challenges, pediatric PR can be a highly rewarding experience not only for the children but also for the healthcare professionals involved in their care (3, 4).

CLDs such as asthma, chronic bronchitis, bronchopulmonary dysplasia (BPD), interstitial lung diseases (ILD), pulmonary hypertension, cystic fibrosis (CF), and primary ciliary dyskinesia (PCD) have a profound negative impact on the lives of affected children and their loved ones. These conditions are commonly associated with dyspnea, reduced exercise tolerance, limited social interaction, and psychological distress, all of which contribute to a diminished overall QoL (5). Although there is limited published data on the efficacy of PR in the pediatric population, there is growing consensus that children with chronic respiratory conditions may derive similar benefits as their adult counterparts. Kim *et al.* (6) reported that a structured and individualized PR program led to significant improvements in exercise capacity, endurance, and psychosocial well-being among children with CLDs, ultimately enhancing their QoL. Similarly, Buschbacher *et al.* (7) highlighted the rehabilitative potential of pediatric PR, noting its role in reducing hospital admissions and emergency room visits, while also fostering family involvement in the care process.

Despite these demonstrated benefits, PR remains underutilized in pediatric clinical practice. Studies by Aldhahir *et al.* (8, 9) identified the unavailability of PR programs in Saudi Arabia—attributed to a shortage of pulmonologists and trained personnel—as a significant barrier to referral and implementation. In the Philippines,

the availability of PR services for children remains markedly limited. Of the 19 identified PR centers nationwide, only one currently offers a structured PR program specifically designed for pediatric patients.

Pediatricians play a critical role in the management and referral of children to PR programs. However, their knowledge, attitudes, beliefs, and perceived barriers may significantly influence referral practices. To the best of our knowledge, this is the first study to examine the perspectives of Filipino pediatricians regarding pediatric PR, specifically exploring their beliefs, attitudes, and the barriers they encounter in clinical practice.

RESEARCH OBJECTIVES

a. General Objective: to assess the knowledge, attitudes and perceptions of pediatricians on PR among children.

b. Specific Objectives:

- to compare the knowledge, attitudes and perception of general pediatricians and pediatric pulmonologists on PR;
- to compare the influence of demographic factors (*e.g.* years of experience, practice setting, geographic location) on general pediatricians and pediatric pulmonologists' attitudes and perceived barriers toward PR;
- to compare the attitudes and beliefs of general pediatricians and pediatric pulmonologists towards referring patients to PR;
- to compare barriers that prevent general pediatricians and pediatric pulmonologists from referring patients to PR programs;
- to determine the impact of general pediatricians and pediatric pulmonologists' perceptions on the utilization of PR services by pediatric patients.

METHODS

a. Study Design: this is cross-sectional analytic study using an online survey through Google form.

b. Setting and Period: the study ran from January to November 2025. Upon the approval of the Technical Review Committee (TRC) and Institutional Ethics Review Board (IERB), data was collected through an online survey that was distributed to social media and Viber accounts and email addresses of GPs and PPs. The study was conducted and completed within a year in compliance with the Education, Training and Research-Clinical Research Division (ETRS-CRD) requirement. Participating in this study was important because it provided valuable insights into the perspectives and practices of pediatricians in managing respiratory conditions in children. By understanding the knowledge, attitudes and perceptions that pediatricians face in implementing PR, it can potentially identify areas for improvement and can develop targeted interventions that would enhance the quality of care for pediatric patients with respiratory issues.

c. Study Population

i. Inclusion Criteria: this included pediatricians who were currently practicing in Philippine hospitals and clinics (public or private), handling patients with CLD (ie. asthma, chronic bronchitis, bronchiectasis, BPD, ILD, pulmonary hypertension, CF, PCD).

ii. Exclusion Criteria: excluded in the study were pediatricians who did not manage patients with CLD.

iii. Sample Size Calculation: using G*Power 3.1.9.7, a minimum of 68 pediatricians (34 GPs, 34 PPs) were required for this study based on an assumed 0.80 effect size between GPs and PPs in terms of their perception towards PR. This computation also accounted for a 5% level of significance and 90% power.

d. Study Maneuver

Convenience sampling was used to recruit study participants. The questionnaire utilized in this study was adapted from a validated survey developed by Aldhahir *et al.* (9) and was posted using a secure survey platform (*e.g.*, Google Forms) and to social media and Viber accounts. A minimum of 68 participants (34 GPs and 34 PPs) were enrolled in this study. It took approximately 15 minutes to answer the online survey. The questionnaire was divided into four sections:

Demographic Information: Age, gender, years of practice, specialty (general pediatrics or pediatric pulmonology), practice setting (public/private), and geographic location.

Perceptions of PR: Questions assessed pediatricians' awareness of PR, knowledge of PR guidelines, and understanding of PR benefits in pediatric patients.

Attitudes and Beliefs about PR: Likert-scale questions explored attitudes toward PR's role in pediatric care, perceived benefits for children with chronic respiratory conditions, and views on the necessity of PR referrals in clinical practice. These Likert-scale responses were treated as continuous variables and scored from 1 (strongly disagree) to 5 (strongly agree). The mean scores represented overall attitudes, where a higher score indicated greater agreement.

Perceived Barriers to PR: Multiple-choice and open-ended questions assessed perceived barriers, including lack of PR facilities, cost issues, lack of knowledge, and time constraints.

e. Identification of Study Variables

i. Independent Variables: Pediatric PR

ii. Dependent Variables:

Attitudes toward PR (measured using Likert scales)

Beliefs about the effectiveness of PR in pediatric care

Perceived barriers to PR referrals

f. Statistical Analyses

Descriptive statistics were used to summarize the demographic characteristics of the pediatricians. Frequency and proportion were used for categorical variables, median and interquartile range for non-normally distributed continuous variables and mean and standard deviation for normally distributed continuous variables. The mean, rank, and frequency differences between PPs and GPs were determined using the Independent Sample T-test, Mann-Whitney U test, and Fisher's exact/Chi-square test. The Shapiro-Wilk test was used to assess the normality of continuous variables. Univariate and multivariate analysis were also used. Missing values were neither replaced nor estimated. Null hypotheses were rejected at the 0.05 α-level of significance. Microsoft Excel and STATA 13.1 were used for data management and analysis.

RESULTS

Table 1 shows the demographic profile of the participating pediatricians. Among the 102 respondents, GPs and PPs were equally represented. There were no significant differences between the groups in terms of age, sex, practice setting, or years of experience. However, a significant difference was observed in geographic distribution ($p = 0.014$) with more PPs based in Metro Manila, while GPs were primarily located in Luzon outside the capital. PPs also managed more complex conditions such as BPD ($p = 0.003$), pulmonary hypertension ($p = 0.005$), and bronchiectasis ($p < 0.001$) reflecting their subspecialty focus. Most notably, referral to PR was significantly higher among PPs (74.51%) than GPs (23.53%) ($p < 0.001$), highlighting a critical disparity in referral practices that may stem from differences in exposure, training, and access.

The perceptions of PPs and GPs regarding the benefits of PR in children with CLD are in **table 2**. Both groups expressed strong agreement across all items, with mean scores generally above 4.0. For the belief that PR improved exercise capacity, the overall mean score was 4.36 ± 1.30, slightly higher among PPs (4.47 ± 1.22) than GPs (4.25 ± 1.38), though not statistically significant ($p = 0.406$). Similar non-significant differences were observed in other domains, including reductions in dyspnea, anxiety, and hospital readmissions, as well as improvements in QoL and disease self-management (all $p > 0.05$). These findings suggest a shared positive outlook on PR's clinical value among both pediatric subspecialties.

Table 3 identifies the key components pediatricians believe should be included in a PR program aside from exercise. The majority of respondents recognized the importance of patient education on CLD, symptom management, psychological support, medication information, nutritional counseling, and smoking cessation. There were no significant differences between PPs and GPs in most components. However, the "Others" category, which included suggestions such as accessible center directories, follow-ups, financial assistance, and preventive measures like vaccination, was significantly more frequently cited by GPs ($p = 0.012$). This may reflect GPs' broader concern for logistical and systemic support needed by patients to access PR services.

The preferred modes of delivering PR among pediatricians are shown in **table 4**. Hospital-based PR was the most preferred mode overall (58.82%), followed by home-based (30.39%) and tele-rehabilitation (10.78%). While PPs leaned more toward hospital-based delivery (64.71%) and GPs slightly favored home-based models (39.22%), these differences were not statistically significant ($p = 0.133$). These preferences suggest a general inclination toward structured, supervised rehabilitation settings, but also recognition of the feasibility and practicality of alternative delivery models, especially in underserved areas.

Table 5 examines patient-related factors that influence pediatricians' decision to refer to PR. Across both groups, factors such as breathlessness affecting mobility, decreased activity levels, low exercise tolerance, patient fatigue, and the need for education in disease management were consistently seen as strong influences to refer the patient to PR. Psychological aspects

like anxiety and depression also played a role but were less strongly emphasized. No significant differences were found between PPs and GPs for any of these factors, indicating a consensus on the clinical indicators that warrant PR referral.

The summary of perceived barriers to PR referral from the pediatricians' perspective is stated in **table 6**. The most commonly reported obstacles were limited availability of PR centers (86.27%), high treatment costs (82.35%), and transportation difficulties (68.63%). Other influential barriers included lack of information about PR, scheduling conflicts, patient refusal, comorbidities, and skepticism from patients or parents about PR's usefulness. None of the barriers showed statistically significant differences between PPs and GPs, highlighting that

Table 1. *Demographic Profile of the Pediatricians.*

	Total (n = 102)	Pediatric Pulmonologists (n = 51)	General Pediatricians (n = 51)	*p*-value
	Frequency (%); Median (IQR)			
Age, years	37 (34 to 46)	39 (35 to 46)	35 (33 to 46)	0.083
Sex				0.813
Male	23 (22.55)	11 (21.57)	12 (23.53)	
Female	79 (77.45)	40 (78.43)	39 (76.47)	
Practice setting				0.113
Private	54 (52.94)	23 (45.1)	31 (60.78)	
Government	48 (47.06)	28 (54.9)	20 (39.22)	
Area of Practice				0.014
Metro Manila	32 (31.68)	21 (41.18)	11 (22)	
Luzon	55 (54.46)	20 (39.22)	35 (70)	
Visayas	12 (11.88)	8 (15.69)	4 (8)	
Mindanao	2 (1.98)	2 (3.92)	0	
Years of Experience in Caring for CLD Patients				0.140
<1 year	9 (8.82)	5 (9.8)	4 (7.84)	
1 to 5 years	49 (48.04)	25 (49.02)	24 (47.06)	
6 to 10 years	20 (19.61)	10 (19.61)	10 (19.61)	
11 to 15 years	5 (4.9)	5 (9.8)	0	
16 to 20 years	10 (9.8)	4 (7.84)	6 (11.76)	
>21 years	9 (8.82)	2 (3.92)	7 (13.73)	
What are the common chronic lung diseases in children you have encountered and managed in your practice?				
Asthma	99 (97.06)	48 (94.12)	51 (100)	0.079
BPD	45 (44.12)	30 (58.82)	15 (29.41)	**0.003**
Pulmonary hypertension	44 (43.14)	29 (56.86)	15 (29.41)	**0.005**
Bronchiectasis	41 (40.20)	34 (66.67)	7 (13.73)	**<0.001**
Cystic fibrosis	6 (5.88)	5 (9.8)	1 (1.96)	0.092
Pulmonary tuberculosis	6 (5.88)	5 (8.8)	1 (1.96)	0.092
Primary ciliary dyskinesia	3 (2.94)	2 (3.92)	1 (1.96)	0.558
Recurrent Pneumonia	1 (0.98)	1 (0.96)	0	0.315
Referral to Pulmonary Rehab				**<0.001**
Yes	50 (49.02)	38 (74.51)	12 (23.53)	
No	34 (33.33)	5 (9.8)	29 (56.86)	
Not sure	18 (17.65)	8 (15.69)	10 (19.61)	

BPD: Bronchopulmonary Dysplasia. Continuous variables were analyzed using the Mann–Whitney U test, while categorical variables were compared using the Chi-square test or Fisher's exact test, as appropriate.

these challenges are widespread and systemic, affecting all pediatricians regardless of specialty.

Table 7 outlines factors associated with PR referral based on univariate analysis. PPs were far more likely to refer than GPs (OR = 18.37, p <0.001). Other significant factors associated with higher referral rates included private practice setting (p = 0.002), Metro Manila location (p = 0.004), experience managing bronchiectasis

Table 2. *Pediatricians' perceptions of referring pediatric patients to PR.*

	Total (n = 102)	Pediatric Pulmonologists (n = 51)	General Pediatricians (n = 51)	*p*-value
	Mean ± SD			
I believe that the pulmonary rehabilitation program will improve patients' exercise capacity	4.36 ± 1.30	4.47 ± 1.22	4.25 ± 1.38	0.406
I believe a pulmonary rehabilitation program would be beneficial in reducing dyspnea and fatigue	4.35 ± 1.30	4.45 ± 1.22	4.25 ± 1.38	0.450
I believe that the pulmonary rehabilitation program will improve patient anxiety and depression	4.23 ± 1.30	4.37 ± 1.22	4.10 ± 1.37	0.288
I believe that a pulmonary rehabilitation program will improve health-related quality of life	4.35 ± 1.30	4.47 ± 1.22	4.23 ± 1.37	0.364
I believe that a pulmonary rehabilitation program would help reduce hospital readmission	4.27 ± 1.30	4.37 ± 1.22	4.18 ± 1.38	0.449
I think that pulmonary rehabilitation will reduce the risk of exacerbations	4.22 ± 1.31	4.22 ± 1.25	4.23 ± 1.38	0.940
I believe that a pulmonary rehabilitation program will improve patient disease self-management	4.24 ± 1.31	4.35 ± 1.23	4.14 ± 1.38	0.408

Differences in mean perception scores were analyzed using the Independent Sample T-test.

Table 3. *Pediatricians' perceptions regarding the important components of PR aside from exercise program.*

	Total (n = 102)	Pediatric Pulmonologists (n = 51)	General Pediatricians (n = 51)	*p*-value
	Frequency (%)			
Information about chronic lung diseases	98 (96.08)	50 (98.04)	48 (94.12)	0.308
Symptoms management	97 (95.1)	48 (94.12)	49 (96.08)	0.647
Psychological support	93 (91.18)	48 (94.12)	45 (88.24)	0.295
Information about medications	92 (90.20)	46 (90.20)	46 (90.20)	1.000
Nutritional counselling	86 (84.31)	43 (84.31)	43 (94.31)	1.000
Smoking cessation	72 (70.59)	35 (68.63)	37 (72.55)	0.664
Others: information about accessible centers, follow ups, demonstration and return demo evaluations, preventive measures such as vaccinations, insurance coverage, financial assistance	6 (5.88)	0	6 (11.76)	0.012

Associations were analyzed using Fisher's exact test.

Table 4. *Pediatricians' preferred mode of delivery of PR.*

	Total (n = 102)	Pediatric Pulmonologists (n = 51)	General Pediatricians (n = 51)	*p*-value
	Frequency (%)			
Hospital-based	60 (58.82)	33 (64.71)	27 (52.94)	
Home-based	31 (30.39)	11 (21.57)	20 (39.22)	0.133
Tele-rehabilitation	11 (10.78)	7 (13.73)	4 (7.84)	

Group comparisons were analyzed using Fisher's exact test.

Table 5. *Patient-related factors that influence the referral decision to PR.*

	Total (n = 102)	Pediatric Pulmonologists (n = 51)	General Pediatricians (n = 51)	*p*-value
	Frequency (%)			
Mobility is affected by breathlessness.				0.571
Strong influence	88 (86.27)	45 (88.24)	43 (84.31)	
Some influence	13 (12.75)	6 (11.76)	7 (13.73)	
No influence	1 (0.98)	0	1 (1.96)	
Decreasing activity levels				0.567
Strong influence	90 (88.24)	46 (90.20)	44 (86.27)	
Some influence	11 (10.78)	5 (9.8)	6 (11.76)	
No influence	1 (0.98)	0	1 (1.96)	
Low exercise tolerance				0.578
Strong influence	80 (78.43)	41 (80.39)	39 (76.47)	
Some influence	21 (20.59)	10 (19.61)	11 (21.57)	
No influence	1 (0.98)	0	1 (1.96)	
Patient anxiety related to the disease				0.350
Strong influence	60 (58.82)	30 (58.82)	30 (58.82)	
Some influence	40 (39.22)	21 (41.18)	19 (37.25)	
No influence	2 (1.96)	0	2 (3.92)	
Patient depression related to the disease				0.528
Strong influence	58 (56.86)	28 (54.9)	30 (38.82)	
Some influence	43 (42.16)	23 (45.1)	20 (39.22)	
No influence	1 (0.98)	0	1 (1.96)	
Patient education and disease management				0.972
Strong influence	77 (75.49)	38 (74.51)	39 (76.47)	
Some influence	23 (22.55)	12 (23.53)	11 (21.57)	
No influence	2 (1.96)	1 (1.96)	1 (1.96)	
Patient fatigue related to the disease				0.508
Strong influence	85 (83.33)	44 (86.27)	41 (80.39)	
Some influence	16 (15.69)	7 (13.73)	9 (17.65)	
No influence	1 (0.98)	0	1 (1.96)	
Dietary advice				0.427
Strong influence	40 (39.22)	18 (35.29)	22 (43.14)	
Some influence	55 (53.92)	28 (54.9)	27 (52.94)	
No influence	7 (6.86)	5 (9.8)	2 (3.92)	

Associations were analyzed using Fisher's exact test.

(p = 0.034), and longer clinical experience (p = 0.005). Belief in the psychological benefits of PR, particularly its effects on anxiety, depression, self-management, and reducing hospital readmissions also significantly increased the likelihood of referral (p <0.01 for each).

Table 8 shows the multivariate analysis of factors independently associated with PR referral. Even after adjusting for other variables, being a PP (aOR = 450.01, p = 0.001), working in a private setting (aOR = 10.64, p = 0.007), and believing that PR improves anxiety and depression

Table 6. *Barriers to referring pediatric patients to PR from pediatrician's perspective.*

	Total (n = 102)	Pediatric Pulmonologists (n = 51)	General Pediatricians (n = 51)	*p*-value
	Frequency (%)			
Don't have enough information about the pulmonary rehabilitation program				0.313
Strong influence	62 (60.78)	30 (58.82)	32 (62.75)	
Some influence	27 (26.47)	12 (23.53)	15 (29.41)	
No influence	13 (12.75)	9 (17.65)	4 (7.84)	
Uncertain that the program is worthwhile				0.581
Strong influence	41 (40.20)	22 (43.14)	19 (37.25)	
Some influence	35 (34.31)	15 (29.41)	20 (39.22)	
No influence	26 (25.49)	14 (27.45)	12 (23.53)	
Patient refuses referral				0.182
Strong influence	58 (56.86)	25 (49.02)	33 (64.71)	
Some influence	41 (40.20)	25 (49.02)	16 (31.37)	
No influence	3 (2.94)	1 (1.96)	2 (3.92)	
Patient comorbidities				0.478
Strong influence	40 (39.22)	20 (39.22)	20 (39.22)	
Some influence	48 (47.06)	26 (50.98)	22 (43.14)	
No influence	14 (13.73)	5 (9.8)	9 (17.65)	
The patient has doubts that rehabilitation is worthwhile				0.500
Strong influence	43 (42.16)	22 (43.14)	21 (41.18)	
Some influence	52 (50.98)	27 (52.94)	25 (49.02)	
No influence	7 (6.86)	2 (3.92)	5 (9.8)	
Transportation problems				0.387
Strong influence	70 (68.63)	38 (74.51)	32 (62.75)	
Some influence	26 (25.49)	10 (19.61)	16 (31.37)	
No influence	6 (5.88)	3 (5.88)	3 (5.88)	
The timing of scheduled pulmonary rehabilitation sessions is not convenient for the patient				0.898
Strong influence	67 (65.69)	34 (66.67)	33 (64.71)	
Some influence	31 (29.41)	15 (29.41)	15 (29.41)	
No influence	5 (4.9)	2 (3.92)	3 (5.88)	
Treatment cost				0.850
Strong influence	84 (82.35)	43 (84.31)	41 (80.39)	
Some influence	13 (12.75)	6 (11.76)	7 (13.73)	
No influence	5 (4.9)	2 (3.92)	3 (5.88)	
Availability of pulmonary rehabilitation centers				0.469
Strong influence	88 (86.27)	46 (90.2)	42 (82.35)	
Some influence	12 (11.76)	4 (7.84)	8 (15.69)	
No influence	2 (1.96)	1 (1.96)	1 (1.96)	

Associations were analyzed using Chi-square test or Fisher's exact test, as appropriate.

(aOR = 8.90, p = 0.001) remained statistically significant predictors of referral. These findings reinforce the importance of specialty training, practice context, and clinician beliefs in shaping referral behavior for pediatric PR.

DISCUSSION

The demographic findings of this study reveal structural differences between PPs and GPs. PPs were more likely to practice in Metro Manila, while GPs were predomi-

Table 7. *Factors Associated with the Referral to Pediatric Pulmonary Rehabilitation (univariate analysis).*

Parameters	Crude odds ratio	95% CI	*p*-value
Group			
General Pediatricians	(reference)	-	**-**
Pediatric Pulmonologists	18.367	5.8169 to 57.992	**<0.001**
Age	0.9484	0.9040 to 0.9949	**0.030**
Practice setting			
Private	(reference)	-	-
Government	4.5322	1.7490 to 11.744	**0.002**
Area/Place of practice			
Metro Manila	(reference)	-	-
Luzon	0.1637	0.0484 to 0.5545	**0.004**
Visayas	0.6316	0.1161 to 3.4368	0.595
Mindanao	-	-	-
Bronchiectasis	2.7778	1.0826 to 7.1269	**0.034**
Years of experience			
≤5 years	(reference)	-	-
6 to 15 years	0.6364	0.2137 to 1.8953	0.417
>15 years	0.1768	0.0524 to 0.5965	**0.005**
I believe that the pulmonary rehabilitation program will improve patient anxiety and depression	3.2065	1.5907 to 6.4637	**0.001**
I believe that a pulmonary rehabilitation program would help reduce hospital readmissions	2.7483	1.4622 to 5.1656	**0.002**
I think that pulmonary rehabilitation will reduce the risk of exacerbations	2.0485	1.3292 to 3.1571	**0.001**
I believe that a pulmonary rehabilitation program will improve patient disease self-management	2.9716	1.5536 to 5.6840	**0.001**

Factors associated with referral to PR based on univariate analysis using simple logistic regression.

Table 8. *Factors Associated with the Referral to Pediatric Pulmonary Rehabilitation (multivariate analysis).*

Parameters	Adjusted odds ratio	95% CI	*p*-value
Group			
General Pediatricians	(reference)	-	**-**
Pediatric Pulmonologists	450.01	11.021 to 18375	**0.001**
Practice setting			
Private	(reference)	-	**-**
Government	10.640	1.9325 to 58.584	**0.007**
I believe that the pulmonary rehabilitation program will improve patient anxiety and depression	8.8967	2.4871 to 31.825	**0.001**

Factors independently associated with referral to pulmonary PR based on multivariate analysis using multiple logistic regression.

nantly based in other areas of Luzon (p = 0.014), and PPs more frequently managed complex respiratory conditions such as BPD (p = 0.003), pulmonary hypertension (p = 0.005), and bronchiectasis (p <0.001). Nationally, there are approximately 6,581 GPs (10) and only 271 PPs (11), with a large concentration in the National Capital Region. This imbalance provides important context for the observed differences in PR referral practices and access to specialized care.

A key finding of this study was the significantly higher referral rate to PR among PPs (74.51%) compared to GPs (23.53%) (p <0.001). This supports prior findings from Aldhahir *et al.* (8, 9), who noted that specialists with advanced training in pulmonology are more likely to refer patients to PR. This may be due to increased familiarity with PR principles, a stronger understanding of its benefits, and greater involvement in structured PR programs. Conversely, studies conducted by Kunoor *et al.* (12) in India and Hao *et al.* (13) in China demonstrated lower referral rates among respiratory physicians in selected regions, largely attributable to the limited availability of PR facilities despite adequate knowledge of and awareness regarding the benefits of PR.

While children in urban regions such as Metro Manila may benefit from better access to PR services, the disparity in specialist distribution underscores the need for policy-level initiatives to ensure equitable access to both general and specialized pulmonary care across the country.

Both GPs and PPs in this study exhibited positive attitudes toward PR, recognizing its potential to enhance exercise tolerance, reduce symptoms such as dyspnea and fatigue, and improve psychosocial well-being. This observation is in concordance with the findings of Aldhahir *et al.* (8, 9) and Sahasrabudhe *et al.* (14), which reported a generally favorable inclination among clinicians to refer patients with CLD—particularly those experiencing reduced exercise capacity, shortness of breath, easy fatigability and compromised airway clearance—to PR programs. These views reflect the broader consensus in the literature about PR's multifaceted benefits in pediatric populations.

Beyond exercise training, pediatricians emphasized the importance of additional PR components such as disease education. Education is one of the key components of PR and health care providers recognize it as essential as exercise training. Disease-specific education plays a critical role in enhancing patients' ability to recognize symptoms and identify disease exacerbations thus allowing them to self-manage their symptoms successfully. Pediatricians further underscored the relevance of nutritional counseling, psychological support and smoking cessation as other integral components of PR. Notably, GPs were more likely to highlight the essential contributions of auxiliary elements such as insurance coverage, follow-up services, and accessibility of PR centers (p = 0.012). Consistent findings across multiple studies (8, 9, 15) demonstrate that healthcare professionals identify education, smoking cessation, nutritional counseling, and symptom management as integral components of PR. In addition, these studies highlight the pivotal role of insurance coverage and the accessibility of PR centers. Taken together, these observations reinforce the need for comprehensive PR programs that systematically integrate educational and psychosocial elements to optimize patient adherence and long-term outcomes, while underscoring the importance of improving the availability and accessibility of rehabilitation services.

Hospital-based PR was the most preferred mode of delivery (58.82%), followed by home-based and telerehabilitation. Similarly, evidence from three studies demonstrates a general preference for hospital-based PR over home-based or telerehabilitation modalities (9, 16, 17). This preference mirrors global trends where hospital-based programs are favored due to structured supervision where patients are monitored closely during exercise, thus enhancing safety and allowing for immediate intervention needed, access to multidisciplinary teams which ensure more holistic care, and immediate clinical support. Nonetheless, evidence also supports the efficacy of home-based and telerehabilitation modalities. A study conducted in the Philippines demonstrated that, in response to the COVID-19 pandemic, PR services transitioned from conventional face-to-face delivery to telerehabilitation, with post-acute COVID-19 adults patients showing improvements in exercise capacity (18). Home-based and telerehabilitation therefore can be modalities, particularly in improving access for families in remote areas and those facing financial or logistical barriers (19-22).

Patient-related clinical indicators such as breathlessness, reduced activity, fatigue, and low exercise tolerance were consistently cited as strong referral drivers by both PPs and GPs. These align with global referral patterns that prioritize functional limitations and symptom burden as key considerations for PR enrollment (8, 9).

Despite generally positive perceptions, our study identified barriers such as lack of adequate information about PR, patient refusal, comorbid conditions, skepticism regarding PR's value, transportation challenges, inconvenient scheduling, financial constraints and limited availability of PR centers. Of all these, transportation and costs were major concerns and the limited number of PR centers was identified as a key barrier.

In the Philippine context, PR utilization is influenced by a combination of cultural, health system, and economic factors that collectively constrain access and uptake. Cultural perceptions of CLD such as underestimating the disease severity due to stoicism, reliance on informal care, traditional and folk medicines and faith-based healing may contribute to delayed health-seeking behavior and reduced prioritization of structured rehabilitation interventions (23). Within the healthcare system, PR remains insufficiently integrated into standard respiratory care pathways, with limited availability of PR services and referral mechanisms, particularly outside urban centers. Importantly, PR is not covered by national health insurance schemes, including the Philippine Health Insurance Corporation (PhilHealth), necessitating full out-of-pocket payment by patients. This represents a substantial barrier in a setting where the average annual income of Filipino families is approximately ₱350,000, or about ₱29,000 per month (24). Consequently, the cost of PR enrollment — estimated at ₱24,000 for a 24-session program — constitutes a considerable financial burden, approaching one month of average household income. These systemic and economic constraints likely contribute to the low utilization of PR services in the Philippines, particularly among low- and middle-income families.

Moreover, the limited number of PR centers in the Philippines with only 19 centers nationwide – most of which cater exclusively to adult patients and only a single center offering PR programs for both adult and pediatric patients – exacerbates existing access disparities. This challenge is compounded by the scarcity of trained personnel and the lack of standardized pediatric PR protocols. Results from studies conducted in upper-middle-income countries including China (13, 25) and Malaysia (26); and low-to-middle-income countries such as India (12, 14) and Kyrgyzstan (27) indicate the same barriers to PR that also largely stem from constrained healthcare resources, limited awareness, and patient-related access and cost burdens. Notably, such limitations are not unique to low-to-middle income resource settings. Even in high-income countries such as Saudi Arabia (8, 9), the United States (28), France (29), Australia (30), and Canada (31), the distribution of PR centers remains inadequate, especially in rural and underserved areas. Collectively, these findings underscore the urgent need to expand PR infrastructure and integrate PR more effectively into national health systems through coordinated efforts among governing bodies and professional organizations.

Additional barriers such as comorbidities, patient or caregiver skepticism, and insufficient physician knowledge about PR were also identified. These factors may delay or prevent referrals, especially among GPs, who may have less exposure to PR in training or practice. Lack of robust pediatric-specific PR data further contributes to these knowledge gaps and reduces confidence in the intervention's efficacy for children.

The multivariate analysis revealed that three key predictors significantly influenced referral behavior: being a PP (aOR: 450.01), practicing in the private sector (aOR: 10.64), and the belief that PR improves anxiety and depression (aOR: 8.90). This last factor is particularly notable, given the rising burden of mental health issues among children with chronic illnesses. PR's holistic approach, which integrates physical rehabilitation with psychosocial support, is well-suited to address this dual burden.

Despite increasing awareness, global PR referral rates remain suboptimal (32), especially in pediatrics. Pediatricians are gatekeepers to PR access, and without their referral, children are unlikely to benefit from these programs. This underscores the need for continuing professional development, including workshops and online training, to enhance pediatricians' understanding of PR.

Furthermore, expanding the use of digital platforms and social media to educate families may foster greater acceptance and adherence to PR.

Lastly, the study's findings highlight structural and systemic challenges that require policy-level interventions. Strengthening referral systems, increasing funding for PR programs, and establishing new centers—particularly in underserved areas—are critical steps toward achieving equitable access.

There are several limitations of the study. The use of convenience sampling and online survey distribution introduces potential selection and response bias. Recruitment through social media platforms, messaging applications, and email networks may have captured pediatricians who are more digitally engaged, affiliated with academic or tertiary centers, or have greater interest or exposure to PR. These sampling methods may have influenced reported attitudes and referral practices. Pediatricians with favorable perceptions of PR or prior experience with PR programs may have been more inclined to participate. In contrast, pediatricians with limited access to PR facilities, lower awareness of PR, or greater practice constraints — particularly those in rural or resource-limited settings — may be underrepresented. Finally, these factors limit the generalizability of the findings. While the study provides important insights into the perspectives of pediatricians accessible through online networks, the results may not fully reflect the views and practices of all Filipino pediatricians nationwide.

Future research should employ probability-based or stratified sampling methods to improve representativeness and reduce selection bias. Targeted recruitment of pediatricians from geographically underserved regions, public sectors, and rural practice settings is particularly important to ensure that perspectives from areas with limited PR access are adequately captured. Expanding sample sizes and including multiple recruitment modalities – such as institutional registries, professional society databases, and on-site data collection – may further enhance external validity and generalizability. Further, prospective studies evaluating changes in knowledge, attitudes, and referral practices following targeted educational interventions are needed to establish causal relationships and inform effective implementation strategies.

CONCLUSION

This study highlights the generally positive perceptions of Filipino pediatricians regarding PR for children with CLD but also underscores a significant gap between recognition of PR's benefits and actual referral practices—particularly among GPs. PPs demonstrated higher referral rates, likely due to their specialized training and greater clinical exposure to complex respiratory conditions.

Key factors associated with the increased likelihood of referral included subspecialty training, private practice setting, geographic location, and strong beliefs in PR's psychological and physical benefits. Conversely, major barriers to referral were limited availability of PR centers, high out-of-pocket costs, transportation difficulties, and insufficient awareness or understanding of PR programs—challenges that disproportionately affect patients in underserved and rural areas.

By addressing these gaps, healthcare providers can optimize the delivery of multidisciplinary care and improve long-term outcomes for pediatric patients with CLD. First, the integration of PR principles into pediatric residency and subspecialty training curricula is essential to strengthen early exposure, improve knowledge, and normalize PR referral as a standard component of chronic respiratory care. Second, the expansion of telerehabilitation and hybrid PR pilot programs should be prioritized to address geographic inequities, transportation barriers, and workforce limitations, particularly in underserved and rural areas. Third, the development of clear, standardized national referral pathways — linking GPs, PPs, and rehabilitation teams — may streamline referrals and reduce variability in practice. Lastly, sustained policy engagement is critical; government stakeholders must formally include PR within national health priorities by strengthening insurance reimbursement mechanisms and expanding health coverage to encompass PR services. Collectively, these measures may enhance access, improve referral practices, and support the long-term integration of pediatric PR into the Philippine healthcare system.

ACKNOWLEDGEMENT

The researchers thank Mr. Rhalp Jaylord Villanueva for his assistance in statistical analysis.

COMPLIANCE WITH ETHICAL STANDARDS

Conflicts of interests

Dr. Bernice Ong-Dela Cruz received honoraria for lectures conducted for Astra Zeneca, Phil United American Philippines (UAP), Orient Euro Pharma (OEP) and Glaxo-Smith-Kline (GSK). Her other renumerations included clinical trials conducted for GSK Healthcare Phil, Astra Zeneca.

Dr. Martijn A. Spruit obtained research grants from Boehringer Ingelheim, TEVA, Chiesi, GSK, TEVA, Sanofi, Stichting Astma Bestrijding and Netherlands Lung Foundation, all outside the scope of the current study; and he is founder/owner of Care2Know B.V.

There are no other identified conflicts of interest between the other investigators, the participants, or the Philippine Heart Center.

Fundings

The authors declare that no financial support or funding sources were granted in the making of the study design, data collection and interpretation and the decision to submit the manuscript for publication.

Author contributions

Conceptualization: DR, PP, CD, MS, BD, SP, KB, MS. Data Curation: DR, CD, MS. Formal Analysis: DR, PP, CD, MS, BD, SP, KB, MS: Investigation: DR, PP, CD, MS, BD, SP, KB, MS. Methodology: DR, PP, CD, MS, BD, SP, KB, MS. Project Administration: DR, PP, CD. Resources: DR, CD, MS: Software: DR, KB. Supervision: DR, PP. Validation: DR, PP, CD, MS, BD, SP, KB, MS. Visualization. DR. Writing – original draft: DR, PP, CD, MS, BD, SP, KB, MS. Writing – review and editing: DR, PP, CD, MS, BD, SP, KB, MS.

Ethical approval

Human studies and subjects

This study was conducted in accordance with the Declaration of Helsinki and the National Ethical Guidelines for Health and Health-Related Research (NEGHHR 2017). The study protocol, informed consent, and subsequent amendments were reviewed and approved by the Philippine Heart Center IERB (PHC.IERB.01.25.09; EP.OR.005.24) and adhered to the Data Privacy Act of 2012 of the Philippines.

Informed consent was obtained electronically through an online link containing the consent form and survey. Participants indicated consent by selecting “Yes, I will join the study” and were directed to the online survey. Those who selected “No” exited without completing the questionnaire.

Data sharing and data accessibility

Data are available upon motivated request to the Corresponding Author.

Publication ethics

Plagiarism

Authors declare no potentially overlapping publications with the content of this manuscript and all original studies are cited as appropriate.

Data falsification and fabrication

All the authors of the manuscript hereby declare that the submitted manuscript represents original and unpublished material. Furthermore, the authors also declare that there are no potentially overlapping publications on submission. No parts of the manuscript has been written and produced with the aid of artificial intelligence.

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APPENDICES

GOOGLE FORM

QUESTIONNAIRE

I. Demographic Information

Participant code number: _____

Are you a practicing: ◊ General Pediatrician who handles chronic respiratory diseases

◊ Pediatric Pulmonologist

Age: _____

Gender: _____

Practice Setting: Private ____ Government ____

Area of Practice: _____

What are the common chronic lung diseases in children that you have encountered and managed in your practice?

◊ Asthma

◊ Bronchiectasis

◊ Bronchopulmonary dysplasia

◊ Pulmonary hypertension

◊ Cystic fibrosis

◊ Primary ciliary dyskinesia

◊ Others: _____

How many years of experience do you have in caring for pediatric patients with chronic lung diseases?

◊ <1 year

◊ 1-5 years

◊ 6-10 years

◊ 11-15 years

◊ 16-20 years

◊ >21 years

Will you refer a pediatric patient with chronic respiratory disease to pulmonary rehabilitation?

◊ Yes

◊ No

◊ Not sure

II. Perceptions of Pulmonary Rehabilitation Program

1. For each statement, please select the answer that best suits your opinion.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I believe that pulmonary rehabilitation program will improve patient's exercise capacity.					
I believe that pulmonary rehabilitation program would be beneficial in reducing dyspnea and fatigue.					
I believe that pulmonary rehabilitation program will improve patient anxiety and depression.					
I believe that pulmonary rehabilitation program will improve health-related quality of life.					

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I believe that pulmonary rehabilitation program would help in reducing hospital readmission.					
I think that pulmonary rehabilitation will reduce the risk of exacerbations.					
I believe that pulmonary rehabilitation program will improve patient nutritional status.					
I believe that pulmonary rehabilitation program will improve patient disease self-management.					

III. Referral to Rehabilitation Program

1. In your opinion, what factors might influence decision to refer pediatric patients with chronic lung diseases to a pulmonary rehabilitation program?

	No influence	Some influence	Strong influence
Mobility, affected by breathlessness			
Decreased activity levels			
Low exercise tolerance			
Patient anxiety related to disease			
Depression related to disease			
Patient education and disease management			
Fatigue related to disease			
Dietary advice			
Others please give details			

2. In your opinion, what factors might influence decision on NOT to refer to pediatrics patients to a pulmonary rehabilitation program?

	No influence	Some influence	Strong influence
I don't have enough information about pulmonary rehabilitation program			
I'm uncertain that the program is worthwhile			
I am uncertain to refer to pulmonary rehabilitation program because of my patient's co-morbidities			
My patient has doubts that pulmonary rehabilitation is worthwhile			
My patient has transportation problems			
Timing of scheduled pulmonary rehabilitation sessions not convenient for my patient			
Treatment cost			
Availability of pulmonary rehabilitation centers			
Others please give details			

CASE REPORT

Pneumonia with a twist: Intravascular Foreign Body – Case Report

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ABSTRACT

Intravascular foreign bodies (IFBs) are a rare but potentially serious condition in pediatrics, often iatrogenic due to central venous catheterization. We present the case of a girl with history of congenital cytomegalovirus (CMV) infection, who underwent central venous access placement in early infancy. Following the years, during investigations for a respiratory infection, an incidental finding of a hyperdense formation about 15 mm in size was noted at the bifurcation of the right interlobar artery, interpreted as an intraluminal foreign body, likely endothelialized. In the absence of clinical or laboratory signs of infectious or thromboembolic complications, surgical or percutaneous intervention was ruled out, and a clinical-radiological surveillance strategy was adopted. A review of the literature highlights the need for a personalized therapeutic approach, with preference for percutaneous removal in symptomatic patients or when complications are presumable. However, in the presence of stable, endothelialized, and clinically silent foreign bodies, a conservative approach is feasible. This case emphasizes the importance of follow-up in patients with a history of central venous access and contributes to defining criteria for individualized management.

CASE REPORT

G, female, was born at term from an uneventful pregnancy via spontaneous vaginal delivery. Congenital cytomegalovirus (CMV) infection was diagnosed, and she was hospitalized for about two weeks in the neonatal care unit, where blood and imaging investigations were performed. She underwent antiviral therapy with valganciclovir but stopped at around three months of age due to the absence of major symptoms and viral DNA clearance in urine. *During the hospitalization an umbilical venous catheter (UVC) was placed and maintained in situ for 3 days, no complications observed.*

Around one year old, the patient was hospitalized again due to edema of the hands and feet, along with ecchymoses on the lower limbs, without fever, and tested positive for SARS-CoV-2. Due to swelling, warmth and an antalgic posture of the right lower limb, deep vein thrombosis (DVT) was suspected. Doppler ultrasound revealed thickening and increased echogenicity of the subcutaneous soft

KEY WORDS
Case report; intravascular foreign body; Central venous catheter; conservative management.

tissues of the right thigh and leg, with partial collapse and compression of venous branches. A CT angiography was requested but not performed due to difficulties in obtaining peripheral venous access. *Given metabolic acidosis, she underwent surgical and vascular evaluation and had a central venous catheter placed in the operating room to continue diagnostic procedures and left in situ for about a week without any complications.*

At 5 years old, she was evaluated by her pediatrician for cough and diagnosed with pneumonia. She was started on amoxicillin/clavulanate (Augmentin), later switched to azithromycin (Zitromax) due to persistent symptoms. A chest X-ray was performed to rule out complications due to poor clinical response and revealed bilateral bronchial thickening and a filamentous, radiopaque image of about 10 mm at the basal regions of the right lower lobe, not better characterized (**figure 1**).

For further evaluation, a chest CT was performed and revealed a hyperdense formation of about 15 mm at the bifurcation of a vascular branch, likely arterial, with uncertain diagnostic interpretation.

She was subsequently admitted to the Pediatric Unit for Allergy and Pneumology at the "G. Di Cristina" Hospital – A.R.N.A.S. Civico. Upon admission, she was in good general condition, afebrile, with no signs of respiratory distress, and exhibited diffuse coarse breath sounds on lung auscultation. Clarithromycin therapy was initiated, blood tests were performed, including D-dimer and fibrinogen (within normal limits) along with cardiology consultation (which recommended further studies including angio-CT and pulmonology assessment).

Eventually the interventional radiologist specialist evaluation ruled out interventional procedures. Serology for *Mycoplasma pneumoniae* showed positive IgM and IgG, consistent with a recent or ongoing infection.

Chest angio-CT excluded filling defects in the main, segmental, and subsegmental pulmonary arteries and confirmed the previously noted hyperdense image at the bifurcation of a right interlobar arterial branch, supplying the posterior and lateral segments of the lower lobe. There were no indirect signs of distal thromboembolism. Subsequent vascular surgery consultation suggested the hyperdense image corresponded to a likely endothelialized endoluminal lesion at the bifurcation of the right interlobar artery, with no indication for vascular surgery. Pediatric surgery also ruled out the need for lung parenchyma resection, considering the absence of local complications, the deep location, and the non-infective, endothelialized nature of the material. The child was discharged in good general condition with a plan for close clinical and radiological follow-up (**figure 2**).

At 1-year outpatient follow-up, no complications were observed and no indication for surgical intervention was found.

MINI REVIEW

Introduction

Intravascular foreign bodies (IFBs) are rare in children but may be associated with severe complications. Among these, foreign bodies located in the pulmonary circulation are the most common subtype, usually due to iatrogenic causes (1). Catheter fracture with embolization

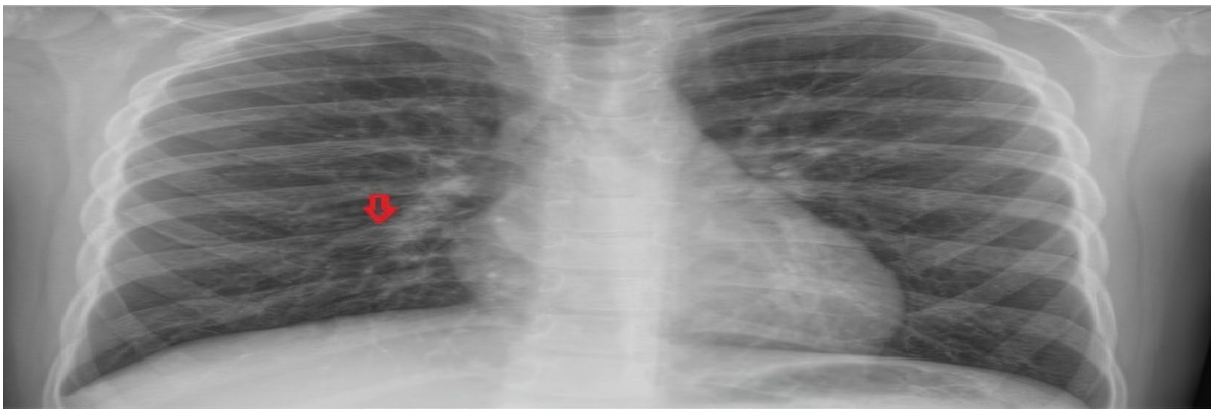

***Figure 1**. Chest X-Ray: the red arrow marks the filamentous, radiopaque image.*

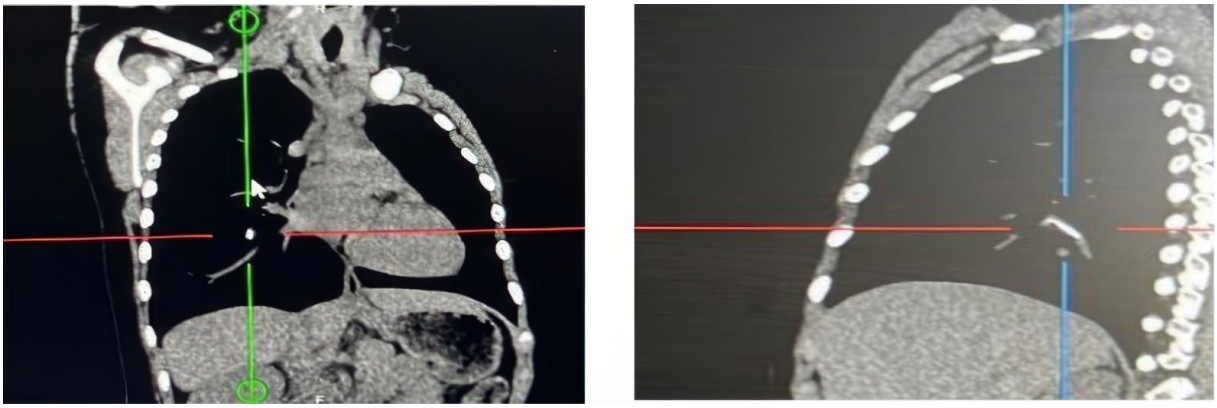

***Figure 2**. Multiplanar reconstrnction (MPR) of TC images.*

is a rare but serious complication, with an incidence in adults ranging from 0.2% to 4.2% (2). This review summarizes the existing literature on pediatric intrapulmonary IFBs, focusing on their etiology, clinical presentation, diagnostic workup, and therapeutic strategies.

Epidemiology and Etiology

In children, the vast majority of IFBs result from complications of central catheterization (e.g. central venous catheters, port-a-caths, umbilical venous catheters, PICCs). The most common migration sites are the right heart chambers and pulmonary arteries (3).

Clinical Manifestations

In the cohort analyzed by Pazinato et al., 77% of patients were asymptomatic at diagnosis, which was often incidental, as in our case. A minority of cases reported symptoms such as fever, systemic infection signs, pulmonary embolism, respiratory distress, or thrombotic complications. No pediatric mortality was directly attributed to the presence of an IFB.

Imaging Diagnostics

The diagnosis of IFBs primarily relies on radiological methods, including (4):

- **chest X-ray**, useful as an initial tool when a radiopaque foreign body is suspected or incidentally discovered;
- **chest angio-CT**, considered the gold standard for characterizing the location, morphology, and relationship of the foreign body with vascular structures;
- **echocardiography**, in cases with suspected cardiac involvement or paradoxicalembolism.

Therapeutic Management

Treatment options for IFBs include percutaneous extraction, surgical removal, anticoagulant therapy, and in selected cases, a conservative approach (“watchful waiting”). The choice should be tailored based on clinical status and risk of complications (1). Most children with catheter migration have complex underlying conditions (e.g. oncology, hematology, cardiology) that make them suboptimal candidates for surgery (8).

Over the years, non-surgical percutaneous techniques have evolved significantly since the first reported case in 1964, becoming the first-line treatment. Devices such as loop-snares, helical baskets, biopsy forceps and hooked guidewires have significantly improved the efficacy and safety of these procedures (5).

A systematic review in adults covering 215 cases reported a 93.5% success rate for percutaneous extraction. Similarly, a pediatric series including 19 IFBs in 18 children showed an 89.5% success rate, supporting the effectiveness of this approach in the pediatric population (6, 7). Another pediatric review of 14 cases reported a 92.8% success rate (1). None of the previous reviews, however, described an endothelialized foreign body.

Various cases of conservative management have been described, either as a primary choice or after failed procedures, with follow-ups of varying duration. Based on literature and known outcomes, Chan *et al*. (**figure 3**) proposed a management algorithm (9). If a device is small and immobile without foreseeable complications, removal may not be necessary (10). In the presence of complications, percutaneous retrieval should always

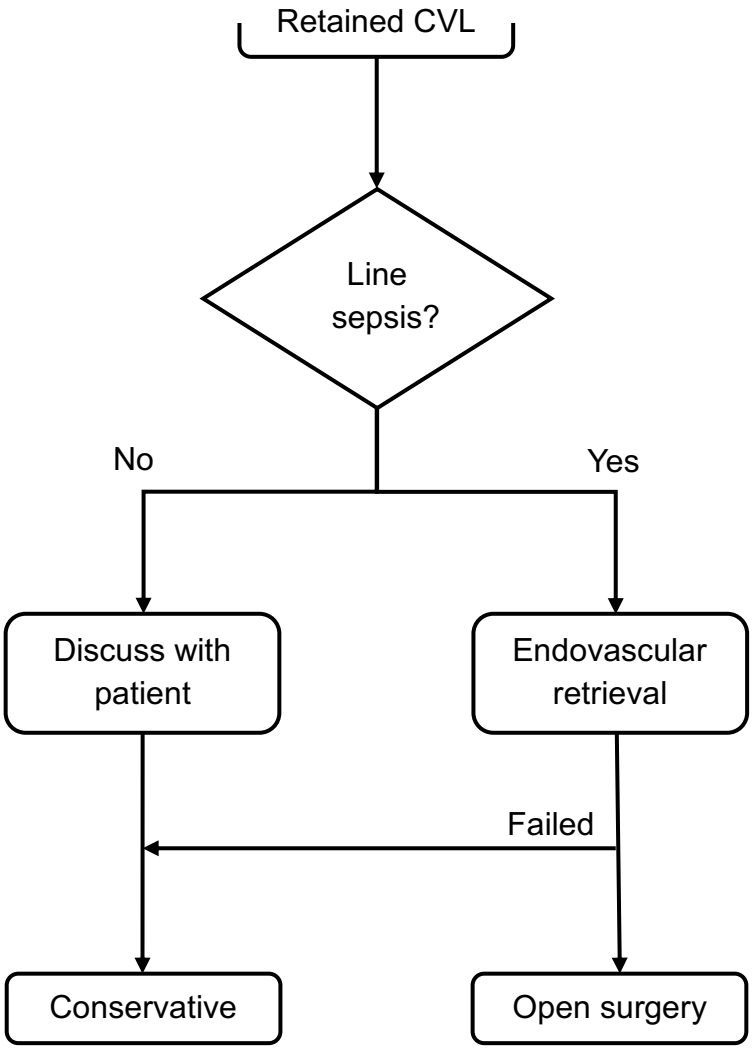

***Figure 3**. Proposed treatment algorithm according to Chen et al.*

be the first option, with surgical intervention as second-line (11).

Conclusions

Endovascular foreign bodies constitute a rare but clinically significant finding that demands careful evaluation and management. In this report, we describe an endothelialized endovascular foreign body — a condition that, to the best of our knowledge, has not much been previously documented in the literature. This observation highlights a potentially emerging nosological entity, particularly relevant as endovascular procedures become increasingly common in the pediatric population. Awareness of this phenomenon is essential, as clinicians are likely to encounter similar cases more frequently in the upcoming years. A multidisciplinary approach and continued research into the mechanisms of endothelialization and retrieval strategies are crucial to improve patient outcomes and broadening our understanding of this evolving clinical scenario.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interests

The Authors have declared no conflict of interests.

Financial support

There was no institutional or private funding for this article.

Author contributions

All the Authors confirmed the contribution to the manuscript's conception and approved its final version.

Ethical approval

Human studies and subjects

This case report was determined not to require Ethics Committee review.

Data sharing and data accessibility

Data are available upon motivated request to the Corresponding Author.

Publication ethics

Plagiarism

Authors declare no potentially overlapping publications with the content of this manuscript and all original studies are cited as appropriate.

Data falsification and fabrication

All the data corresponds to the real.

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