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RESEARCH ARTICLE

Digital Health Adoption in Pediatric Respiratory Care in Italy: A National Survey and Machine Learning-Based Clustering Analysis

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ABSTRACT

The integration of digital health technologies into pediatric respiratory care is growing, yet patterns of adoption and clinician readiness remain poorly understood. This study explores the integration of digital technologies in pediatric respiratory care through the first nationwide survey officially supported by the Italian Pediatric Respiratory Society (IPRS/SIMRI). Conducted in January 2025, the survey collected responses from 132 clinicians and aimed to identify distinct profiles based on digital technology use, competencies, and perceived barriers. Using Random Forest analysis and t-distributed Stochastic Neighbor Embedding, two main clusters emerged: “Users” (76.5%), primarily younger professionals working in tertiary settings and managing complex respiratory conditions, and “Non-Users” (23.5%), mainly older clinicians in primary or secondary care with no adoption of digital tools. The most commonly used technologies included electronic health records, telemedicine, and portable spirometry. Barriers reported by Users included lack of resources, high costs, and system complexity, despite a generally high level of digital skills. These findings provide a unique perspective on the current state of digital readiness and clinical integration in pediatric respiratory medicine. This nationwide survey is among the first to explore digital health adoption in pediatric respiratory care using machine learning techniques for pattern identification. Despite the limitations inherent to its cross-sectional design and possible self-selection bias, the study establishes a valuable foundation for developing targeted educational strategies, guiding health policy, and informing future longitudinal research.

IMPACT STATEMENT

This is the first study to provide a national overview of how pediatric respiratory clinicians in Italy engage with digital health technologies. By identifying distinct user profiles and mapping perceived barriers and benefits, the study highlights existing gaps in digital readiness and informs the development of targeted educational programs and infrastructure policies. These findings support a more equitable and effective integration of digital tools in pediatric respiratory care, aligning clinical innovation with real-world practice.

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KEY WORDS
Pediatric respiratory care; digital health; technology adoption; telemedicine; machine learning.

HIGHLIGHTS BOX

What is already known about this topic? Digital health tools, such as telemedicine and electronic health records, are increasingly used in pediatric medicine, but data on their adoption, perceived value, and barriers in pediatric respiratory care are limited. **What does this article add to our knowledge?** This study provides the first national overview of digital technology use in pediatric respiratory care, identifying two distinct clinician profiles, Users and Non-Users, and highlighting differences in age, care setting, clinical complexity, digital competencies, and perceived barriers. **How does this study impact current management guidelines?** By uncovering digital readiness gaps and the real-world use of technology, the findings support the need for targeted training and institutional investment. They inform future strategies aimed at integrating digital tools into routine pediatric respiratory care and aligning practice with innovation.

INTRODUCTION

The digital transformation of healthcare is rapidly reshaping the clinical landscape, offering new opportunities to improve diagnosis, monitoring, and treatment, particularly in chronic and complex conditions (1). In pediatric respiratory medicine, digital tools such as telemedicine, portable spirometry, electronic health records (EHRs), and remote monitoring systems have demonstrated growing potential to enhance continuity of care, reduce the burden of in-person visits, and support patient-centered approaches (2, 3).

In the field of pediatric respiratory medicine, where long-term follow-up, multidisciplinary collaboration, and real-time data are often essential, digital technologies could offer significant clinical and organizational benefits. However, while innovation continues to advance, the integration of such tools into daily practice remains uneven. Evidence on how clinicians actually use digital health solutions, which tools are most commonly adopted, and what barriers hinder their implementation is still limited, especially in the pediatric respiratory domain.

In Italy, the strategic push toward healthcare digitization has been strongly emphasized in recent years through the Piano Nazionale di Ripresa e Resilienza (PNRR), which promotes investments in telemedicine, health data infrastructure, and digital training for healthcare professionals (4, 5). At the international level, both the World Health Organization (WHO) and the European Respiratory Society (ERS) have highlighted the importance of digital innovation in respiratory care and the need to address disparities in access and digital literacy (6-8). Yet, despite this growing attention, there is a lack of national-level data on how digital tools are actually being adopted in pediatric respiratory practice.

To address this gap, the present study reports the results of the first nationwide survey specifically designed to investigate these aspects, conducted by the Pediatric Digital Technologies for Respiratory Care (PeDiTCare) Study Group and officially endorsed by the Italian Pediatric Respiratory Society (IPRS/SIMRI). By offering a comprehensive, data-driven overview of clinicians' experiences, practices, and perspectives, this study aims to support the advancement of equitable, evidence-based digital transformation in pediatric respiratory care.

MATERIALS AND METHODS

Study Design and Objectives

This was a cross-sectional, observational study conducted through an anonymous online survey aimed at exploring the knowledge, use, and perceived value of digital health technologies among pediatric respiratory clinicians in Italy. The primary objective was to identify distinct clinician profiles based on patterns of digital technology adoption. Secondary objectives included assessing the clinical settings in which such technologies are used, the perceived benefits and barriers to their implementation, and the level of digital literacy among respondents.

Survey Development and Distribution

The survey was developed by the PeDiTCare Study Group and officially endorsed by IPRS/SIMRI. The questionnaire consisted of 23 items, organized into two sections: Section 1 collected demographic and professional data (age, gender, specialization, region of work, years of experience, and type of clinical setting); Section 2 explored awareness, access, and use of digital tools, perceived benefits, digital competencies, and barriers to implementation. The full English translation of the survey is available as Supplementary File 1. The survey was distributed in January 2025 via the IPRS/SIMRI national newsletter and hosted on the Google Forms platform. At the time of distribution, the society counted 986 active members (708 full members and 278 residents), resulting in a response rate of approximately 13.4%. Participation was voluntary, and completion time was approximately 10 minutes. Data collection was anonymous, and no identifiable personal information was requested. All responses were stored securely for statistical analysis.

Sample and Inclusion Criteria

All members of IPRS/SIMRI were eligible to participate. The society includes primarily pediatricians working in primary care, hospitals, and academic settings. Inclusion criteria required being a practicing clinician involved in pediatric respiratory care and completing the entire questionnaire. No incentives were offered.

Data Analysis and Statistical Methods

Descriptive statistics were used to summarize demographic and clinical characteristics, reporting frequencies and percentages for categorical variables, and mean ± standard deviation (SD) for continuous variables.

To identify patterns in digital technology use, we applied a Random Forest (RF) classification model (9), a non-parametric ensemble learning method that constructs multiple decision trees to enhance predictive accuracy and reduce overfitting. Model performance was evaluated using out-of-bag (OOB) error estimation (9) and standard classification metrics (accuracy, precision, recall, F1-score) (10).

To visualize the latent structure of the dataset and support cluster identification, we employed t-distributed Stochastic Neighbor Embedding (t-SNE), a dimensionality reduction technique designed to preserve local similarities and reveal high-dimensional patterns in a low-dimensional space (11). The algorithm's hyperparameters, perplexity, learning rate, and number of iterations, were optimized using a greedy search strategy based on Kullback–Leibler divergence minimization (11).

The mathematical formulation of the RF and t-SNE models, including relevant equations and hyperparameter selection procedures, is provided in Supporting Information.

Ethical Considerations

Given the anonymous, voluntary nature of the survey and the absence of clinical or sensitive personal data, formal ethics committee approval was not required under current Italian regulations. All participants were informed about the aims of the study and provided implicit consent by completing the survey.

RESULTS

Study Population

The survey was completed by 132 clinicians actively engaged in pediatric respiratory care. The majority of respondents were under 40 years of age (59.1%) and female (68.1%). Most of respondents were pediatricians (54.5%), followed by residents in Pediatrics (33.3%), allergologists (6.1%), and pulmonologists (3.0%). Regarding professional experience, 56.1% had been practicing for 5–9 years, 33.3% for over 10 years, and 10.6% for fewer than 5 years. Respondents were geographically distributed across Italy, with 41.7% working in the South, 30.3% in the North, and 28.0% in Central regions. Clinical settings varied, with 37.1% employed in tertiary referral hospitals, 35.6% in primary care outpatient clinics, and 27.3% in secondary care centers. Hospital or university institutions were the most common workplaces (47.7%), followed by local hospitals (28.8%) and research institutes (17.4%). Detailed demographic and professional characteristics are reported in **Table 1**.

Patterns of Digital Technology Use

Analysis of digital technology use revealed uneven adoption across the study population. The most frequently used tool was the electronic health record (EHR), reported by 18.9% of respondents. Telemedicine was used by 14.5%, followed by portable spirometry (11.8%). Home-based technologies such as home sleep studies and home ventilation monitoring were each used by

***Table 1**. Demographic and Professional Characteristics of the Study Sample: summary of age, gender, specialization, years of clinical experience, type of outpatient clinic, geographic distribution, and institutional setting for the 132 respondents included in the analysis.*

	Total (N = 132)
Years of Professional Experience	
<5 years	14 (10.6%)
5 - 9 years	74 (56.1%)
>10 years	44 (33.3%)
Specialization	
Pediatricians	72 (54.5%)
Allergology	8 (6.1%)
Pulmonology	4 (3.0%)
Residents	44 (33.3%)
Unknown/Declined to answer	4 (3.0%)
Region of work	
North of Italy	40 (30.3%)
Center of Italy	37 (28.0%)
South of Italy	55 (41.7%)
Type of outpatient clinic	
Primary care	47 (35.6%)
Secondary care	36 (27.3%)
Tertiary Referral Hospitals	49 (37.1%)
Patients Seen per Month	
<10	19 (14.4%)
Between 10 and 20	17 (12.9%)
Between 20 and 50	48 (36.4%)
>50	47 (35.6%)
Unknown/Declined to answer	1 (0.8%)
Work Setting	
Hospital/University Institution	63 (47.7%)
Research Center/IRCCS	23 (17.4%)
Local Hospital	38 (28.8%)
Unknown/Declined to answer	8 (6.1%)

IRCCS: Scientific Institute for Research, Hospitalization and Healthcare.

9.17% of respondents. In contrast, emerging technologies, including augmented reality, robotic rehabilitation, and digital twin platforms (defined as virtual models that integrate patient-specific data and computational simulations to predict disease trajectories and treatment responses) (12, 13), showed minimal uptake (0.3%). These frequencies are illustrated in **Figure 1**. Overall, respondents reported a preference for well-established technologies aimed at clinical documentation and patient monitoring, whereas advanced or experimental tools were rarely used, likely due to limited availability, high costs, or lack of training.

Clustering of Respondents Based on Digital Engagement

Using t-distributed Stochastic Neighbor Embedding (t-SNE), two distinct clusters of respondents were identified based on digital tool usage and associated variables. Cluster 1 (Non-Users) comprised 23.5% of respondents (n = 31), while Cluster 2 (Users) included the remaining 76.5% (n = 101). The average probability of cluster assignment was higher among Users (0.694) than Non-Users (0.305), suggesting greater internal homogeneity in the digital adopter group. The two-cluster distribution and the visualization of respondent profiles are shown in **Figure 2**.

Cluster Characteristics

Non-Users were predominantly female (80.6%) and older, with 38.7% aged over 50. They were more commonly employed in primary (54.8%) or secondary (35.5%) care settings. In contrast, Users were younger (38.6% aged 30–39) and more frequently worked in tertiary hospitals (45.5%).

Non-Users primarily managed common conditions such as asthma (83.9%) and upper airway diseases (61.3%), with no reported use of digital tools in their clinical activities. Conversely, Users reported regular or occasional use of telemedicine (48.5%), EHRs (63.3%), portable spirometry (39.6%), and remote monitoring (27.7%). They were more likely to manage complex respiratory diseases, including bronchopulmonary dysplasia (36.6%), primary ciliary dyskinesia (39.6%), cystic fibrosis (22.7%), and chronic respiratory failure (33.6%).

Digital literacy was higher among Users, with 78.2% reporting proficiency in secure software use, 55.4% in digital communication, and 49.5% in telemedicine. Among Non-Users, such competencies were markedly lower or absent. The most frequently reported barriers among Users included lack of resources (52.4%), high system costs (40.5%), complexity of platforms (31.7%), and interpretability issues (33.7%). Connectivity challenges were also noted (21.8%).

Users identified several advantages associated with digital tools, including improved disease monitoring and adherence (70.3%), reduction in healthcare costs

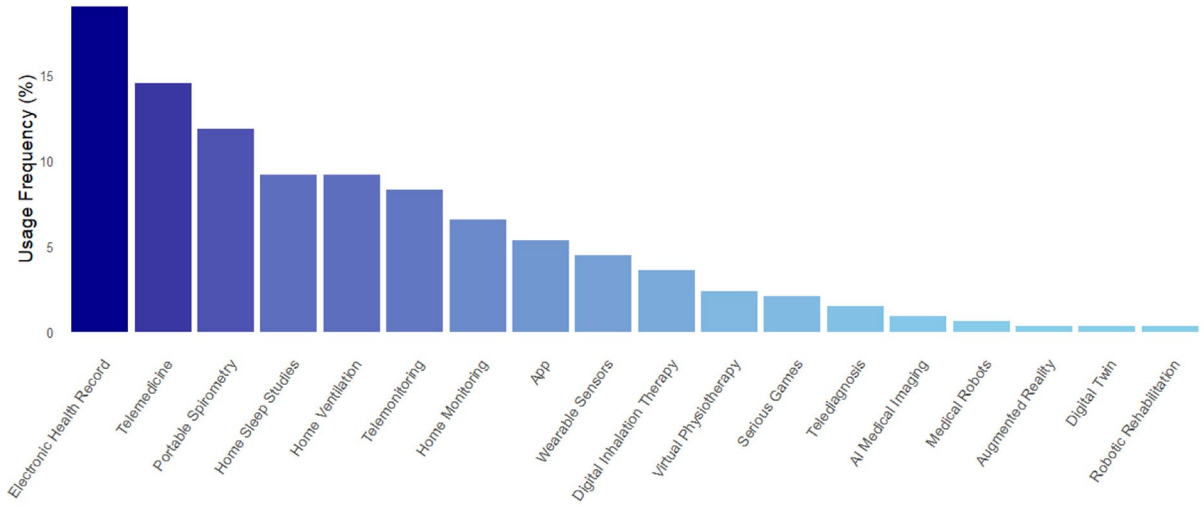

Figure 1. *Frequency of Use of Digital Technologies in Pediatric Respiratory Care.*

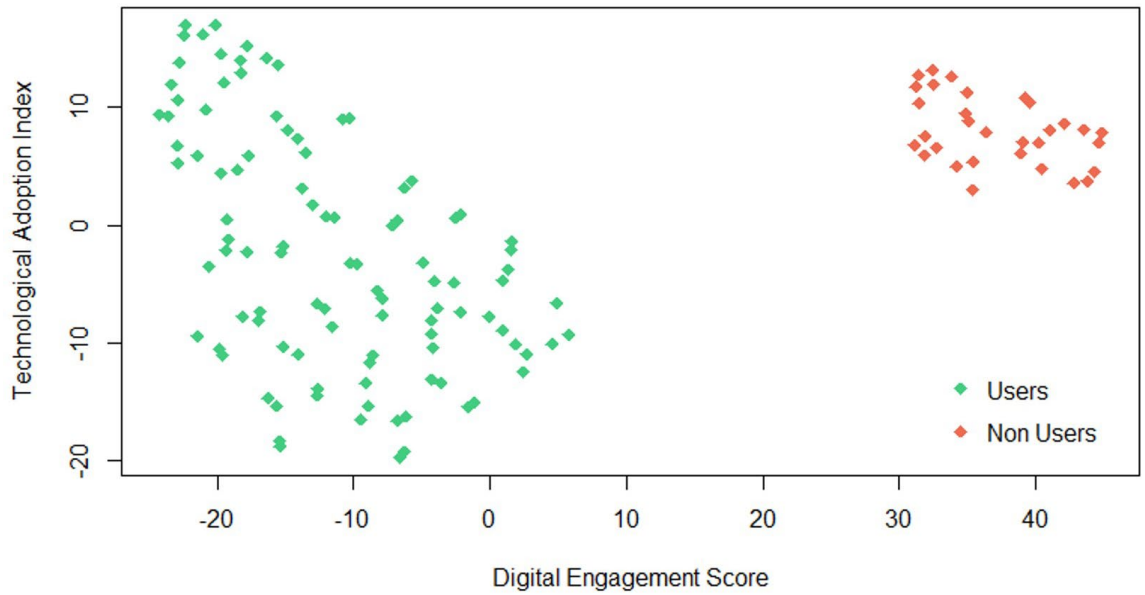

Figure 2. *Clustering of Respondents Based on Digital Engagement and Technological Adoption. Two-dimensional representation of unsupervised clustering results visualized using t-distributed Stochastic Neighbor Embedding (t-SNE). Each point represents a clinician and is color-coded by cluster membership: Cluster 1 (Users, 76.5%) and Cluster 2 (Non-Users, 23.5%). Axes correspond to derived components capturing variation in digital engagement score and technological adoption index. The clear separation between clusters reflects distinct patterns of digital tool usage and associated clinical-demographic characteristics.*

(49.5%), and the ability to deliver personalized care plans (34.7%). These benefits were not reported by Non-Users, likely due to their lack of direct experience with such technologies.

DISCUSSION

The results of the PeDiTCare national survey reveal a considerable heterogeneity in the integration of digital technologies among pediatric respiratory clinicians across Italy. While a significant proportion of respondents (76.5%) reported using digital tools to varying degrees in their clinical workflows, a notable minority (23.5%), referred to as the "Non-Users" cluster, declared that they neither have access to nor employ such tools in their daily practice. This discrepancy underscores a persistent digital divide within the Italian pediatric respiratory community, where innovation and traditional practice models coexist. Such divergence may stem from multiple interrelated factors, including disparities in institutional infrastructure, resource allocation, and organizational culture, as well as individual clinician readiness to embrace innovation. This aligns with international data suggesting that despite the growing availability of digital health tools, their implementation is not uniform and tends to lag in community and non-academic settings (6).

The analysis of demographic and professional variables within the survey sample provides compelling evidence that clinician characteristics and practice setting are key determinants of digital adoption. The "Non-Users" cluster was predominantly composed of older clinicians (with 38.7% aged over 50) and professionals working in primary or secondary care facilities (90.3% combined). In contrast, "Users" were significantly younger, with 38.6% aged 30–39, and more likely to work in tertiary referral hospitals (45.5%). These findings reinforce the idea that digital maturity is more pronounced in high-complexity clinical environments, where institutional investments in innovation, multidisciplinary collaboration, and access to technological infrastructure are more common. Moreover, generational factors likely play a role, with younger clinicians demonstrating greater digital literacy, flexibility, and comfort in using emerging technologies, an effect previously documented in digital adoption literature within the healthcare sector (14).

Another prominent pattern emerging from the survey is the co-occurrence of younger age, work in tertiary hospitals, and frequent management of complex respiratory diseases among clinicians in the 'Users' cluster. These variables are interrelated, as residents and early-career professionals are typically based in referral centers where technological infrastructures are more developed and where complex cases are more frequently seen. The "Users" cluster reported frequent management of severe and chronic respiratory conditions such as bronchopulmonary dysplasia (36.6%), primary ciliary dyskinesia (39.6%), cystic fibrosis (22.7%), and chronic respiratory failure (33.6%). These diseases often require close longitudinal follow-up, multidisciplinary coordination, and the collection of detailed physiological data, all of which are facilitated by the use of telemonitoring, portable spirometry, and electronic health records.

However, it is important to acknowledge that this association may reflect a confounding effect: younger clinicians, more digitally literate and receptive to innovation, are often based in tertiary hospitals, where both access to digital tools and exposure to complex cases are higher. Rather than implying a direct causal relationship between disease complexity and technology use, our findings suggest that digital engagement is primarily shaped by demographic and institutional characteristics of participants. Importantly, digital health solutions are not exclusive to high-complexity settings and could provide substantial benefits in managing common conditions such as asthma, particularly in primary care, where they may improve continuity, adherence, and self-management. Implementation strategies should therefore promote the use of digital tools across all care levels, not only in referral centers (15).

Beyond demographic and institutional factors, individual digital competencies also emerged as key elements influencing clinicians' likelihood to adopt and effectively utilize digital health tools. In the "Users" group, respondents demonstrated high familiarity with secure software use (78.2%), digital communication platforms (55.4%), and key concepts related to data privacy (42.5%) and telemedicine (49.5%). These skills appear to form a foundational layer enabling the confident and effective use of digital solutions.

However, even among the digitally proficient, significant barriers to broader integration persist. The most fre-

quently reported obstacles included insufficient resources (52.4%), high system costs (40.5%), complexity of interfaces (31.7%), and issues related to data interpretability (33.7%). Connectivity problems were also cited (21.8%), especially in regions with limited digital infrastructure. It is worth noting that some reported barriers, such as "insufficient resources" and "high system costs," may partially overlap and reflect the broader issue of structural underinvestment in digital infrastructure and support. These challenges are consistent with those described in other European studies, where lack of institutional support and fragmented digital ecosystems have been shown to hinder widespread adoption (16). The presence of such barriers, even among adopters, emphasizes the need not only for improved clinician training but also for structural reforms and investments at the healthcare system level. Personalized digital health can easily offer remote monitoring, especially when healthcare systems are overwhelmed and frequent follow-up visits are impractical. However, the healthcare sector is often slow to embrace change, and many technologies still need to be developed to a level of reliability suitable for clinical integration. For this reason, a collaborative approach is essential to fully harness the potential of digital health in pediatric respiratory care. Healthcare professionals, researchers, technology developers must work together to overcome challenges and ensure equitable access (15). This involves considering individual needs, providing continuous support, and addressing issues related to legal responsibility, workload, and training for healthcare providers. A cost-effective strategy could be to start with stand-alone digital interventions and then shift to integrated solutions with additional support if patients do not show improvement (17). The stratification of digital engagement observed in the study population has clear implications for both medical education and health policy. First, the evident gap in digital proficiency between clusters highlights the urgent need for structured digital health training across all levels of pediatric respiratory education, including continuing medical education programs. Targeted efforts should be directed toward clinicians in primary care and those with more years of professional experience, who may not have been exposed to formal digital training during their initial education. Second, policy-makers and institutional leaders must prioritize the development of supportive infrastructures, both technological and organizational, to facilitate digital transformation. This includes ensuring equitable access to digital tools, interoperability of systems, and clear regulatory frameworks addressing privacy and ethical concerns. Without such systemic support, even the most motivated clinicians may face insurmountable obstacles to effective technology adoption.

A key strength of this study lies in its originality and institutional support. To our knowledge, this is the first national survey specifically designed to investigate the knowledge, use, and perceived impact of digital technologies in pediatric respiratory care. Its development and dissemination were officially supported by the IPRS/SIMRI through the PeDiTCare Study Group, underscoring the scientific relevance and timeliness of the topic. The survey addresses a significant gap in the literature and provides a foundational dataset that can inform future policy, clinical practice, and research initiatives in this evolving field. In addition, the use of advanced analytical approaches, including Random Forest models and unsupervised clustering through t-distributed Stochastic Neighbor Embedding (t-SNE), represents a novel methodological asset. These tools allowed us to explore latent profiles of technology adoption and to visualize complex multidimensional relationships in a clinician population, offering insights that go beyond conventional descriptive analysis.

Despite these strengths, certain limitations must be acknowledged. First, the cross-sectional design of the survey limits the ability to establish causal relationships between clinician characteristics and digital adoption behaviors. Second, as participation was voluntary and distributed through a scientific society newsletter (with a response rate of 13.4%), there is a risk of self-selection bias, whereby clinicians more interested or involved in digital health may have been more likely to respond. This should be considered when interpreting the generalisability of the findings. Third, the modest sample size, though representative of different geographic areas and care levels, may not capture the full diversity of clinical settings across the country.

Finally, although machine learning techniques offer advantages in exploratory data analysis, their interpretability and sensitivity to parameter tuning must be considered. Specifically, t-SNE is known to be influenced by

perplexity and learning rate choices and may obscure intermediate or hybrid user profiles. Future research with larger, longitudinally tracked cohorts and mixed-methods designs (including qualitative interviews or focus groups) could complement these findings and provide a more nuanced understanding of how digital health is transforming pediatric respiratory practice.

CONCLUSIONS

The integration of digital technologies into pediatric respiratory care represents a growing priority yet remains inconsistent across clinical settings and professional profiles. This study offers a timely contribution by mapping the current landscape of digital health use through a national survey supported by IPRS/SIMRI, shedding light on how clinicians engage with technological innovation in real-world practice. Rather than presenting a uniform picture, the findings reveal a stratified scenario, shaped by differences in experience, infrastructure, and clinical context. These insights call for a rethinking of implementation strategies, shifting from general promotion of digital tools to more targeted, needs-based approaches that consider existing disparities.

As healthcare systems increasingly invest in digital transformation, aligning these investments with the realities of pediatric respiratory care will be essential. Moving forward, the integration of technological solutions should not be viewed merely as a matter of access, but as an evolving process that requires institutional support, continuous education, and a clear vision of digital health as an enabler of equity and quality in pediatric care.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest

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

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Authors' contributions

AL, GF and SLG conceived and supervised the study, coordinated the development of the survey, and led the drafting of the manuscript. AP contributed to survey dissemination, data organization, and descriptive statistical analysis. AP performed the machine learning analysis and prepared the figures and supplementary material. VM, SM and RN assisted in interpreting clinical data and reviewing the manuscript critically for intellectual content. All authors contributed to the study design, revised the manuscript critically, and approved the final version. They all agree to be accountable for the integrity and accuracy of the work..

Ethical approval

Human studies and subjects

This study involved the voluntary and anonymous participation of clinicians through an online survey and did not include any collection of sensitive personal data or clinical information. In accordance with current Italian regulations, ethics committee approval was not required.

Animal studies

N/A.

Data sharing and data accessibility

The data that support the findings of this study are available from the corresponding author upon reasonable request. Due to the nature of the survey and the anonymized dataset, no individual identifiable information is included. 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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