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REVIEW

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Telemonitoring of pediatric asthma in outpatient settings: A systematic review

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Abstract

Telemonitoring technologies are rapidly evolving, offering a promising solution for remote monitoring and timely management of asthma acute episodes. We aimed to describe current pediatric asthma telemonitoring technologies. A systematic review was conducted until September 2023 on Medline, Scopus, and Web of Science. We included studies of children (0–18 years) with asthma or recurrent wheezing whose respiratory condition was telemonitored outside the healthcare setting. A narrative synthesis was performed. We identified 40 telemonitoring technologies described in 40 studies. The more frequently used technologies for telemonitoring were mobile applications ($n = 21$) and web-based systems ($n = 14$). Telemonitoring duration varied between 2 weeks and 32 months. Data collection included asthma symptoms ($n = 30$), patient-reported outcome measures (PROMs) ($n = 11$), spirometry/peak flow readings ($n = 20$), medication adherence ($n = 17$), inhaler technique ($n = 3$), air quality ($n = 2$), and respiratory sounds ($n = 2$). Both parents and children were the technology target users in most studies ($n = 23$). Technology training was reported in 23 studies of which 3 provided ongoing support. Automatic feedback was found in 30 studies, mostly related with asthma control. HCP were involved in data management in 27 studies. Technologies were tested in samples from 4 to 327 children, with most studies including school-aged children and/or adolescents ($n = 38$) and eight including preschool children. This review provides an overview of existing technologies for the outpatient telemonitoring of pediatric asthma. Specific technologies for preschool children represent a gap in the literature that needs to be specifically addressed in future research.

KEYWORDS

adolescent, ambulatory, asthma, child, monitoring

1 | INTRODUCTION

Asthma is one of the most prevalent pediatric chronic diseases, affecting around 10% of children worldwide.[1] Up to one-third of preschool children have recurrent wheezing, known to be an important asthma manifestation.[2] These conditions are assessed routinely in outpatient clinics but their episodic nature poses a challenge in promptly addressing exacerbations and adjusting baseline medication.[3,4] Parents often resort to unscheduled/emergency room visits, placing a high burden on themselves and healthcare systems.[5–7]

This healthcare scenario may benefit from digital health approaches. Digital health is the field of knowledge and practice associated with the development of digital technologies to enhance health.[8] As stated in an article from the Organization for Economic Co-operation and Development (OECD), digital tools are transforming how health services are delivered and how chronic conditions are managed and prevented.[9] Concomitantly, telemonitoring allows patients to monitor symptoms, share data with healthcare professionals (HCPs) and receive tailored treatment plans based on the information shared from outside of the hospital setting.[10–12] It has shown to be useful for the management of long-term conditions in adults, namely chronic pulmonary obstructive disease, heart failure, and asthma.[13–16] In the pediatric population, telemonitoring of diabetes has shown to improve patient–clinician communication, facilitate disease monitoring, and improve adherence to treatment guidelines.[17,18]

Regarding pediatric asthma, technological advancements have produced affordable tools such as mobile applications and wearable home-monitoring devices, that facilitate monitoring outside of clinical settings.[13,19] Although these technologies are often not tailored to children and their use in real-world practice is still difficult, electronic monitoring of medication adherence in children and adolescents with asthma has been well described. Several studies have focused on this subject, but not on other forms of measuring respiratory status and disease control.[20–23]

A recent review provided an overview of e-health for pediatric asthma monitoring and treatment.[24] It included a wide range of heterogenous studies in mixed settings, some of which only described the theoretical framework of the technology.[24] There is a need for a systematic review dedicated to telemonitoring technologies tested outside of the healthcare setting, for example in the community or at home. Additionally, there also seems to be a lack of in-depth description of pediatric asthma telemonitoring systems in current reviews.[24,25] This description is essential to optimize the design of future technologies and accelerate digital health transformation.

The aim of our systematic review is to provide a comprehensive description of the technologies used for pediatric asthma and recurrent wheezing telemonitoring, in the community or at home. Furthermore, we aim to identify the main challenges for future pediatric asthma telemonitoring research.

2 | METHODS

2.1 | Study design

This systematic review was registered in PROSPERO, ref. CRD42023364636, in February 2023 and follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyzes (PRISMA) guidelines.[26]

2.2 | Information sources and search strategy

A literature search was performed until February 2023, and updated in September 2023, in the medical databases Medline (1964–2023) and Scopus (1971–2023) and in the wide-ranging scientific database Web of Sciences (1991–2023). Search terms were based on a combination of keywords regarding telemonitoring, asthma, recurrent wheezing, and pediatric age. The search strategy is described in File S1. Additional searches for relevant studies were performed within the reference list of the selected articles.

2.3 | Eligibility criteria

Eligible studies included children (0–18 years old) with asthma or recurrent wheezing whose respiratory condition was telemonitored outside of the healthcare setting. We used the following inclusion criteria: (i) children with a clinical diagnosis of asthma or recurrent wheezing; (ii) children/parents had to periodically record the child's clinical data (e.g., physiological signs or symptoms) in an outpatient setting (home or community). Studies were excluded if they: (i) involved downloading data during healthcare visits or at the end of the study, without continuous data telemonitoring; (ii) were limited to a technical description of the technology; (iii) provided telemonitoring within a healthcare setting; (iv) focused exclusively on asthma medication monitoring; asthma education or asthma environmental triggers, without respiratory status monitoring. Studies including both pediatric and adult asthma subjects or subjects with asthma and other respiratory diseases were included if data from children with asthma could be extracted individually. If the data presented was pooled and could not be obtained after contacting the authors, the studies were excluded. We included quantitative (randomized controlled trials-RCTs, quasi-experimental, observational), mixed-methods, and qualitative studies Review articles and abstracts of communications were not considered suitable and were excluded from this review. In cases where multiple publications were identified as referring to the same study and technology, we prioritized the most recent publication, to capture the most up-to-date information on the telemonitoring technology.

2.4 | Study selection

Screening was performed by two independent reviewers (I. P. C. and A. L. A.). Disagreements were resolved by a third reviewer (C. J.). Initial screening of articles was based on the type of publication and relevance based on their title, abstract and keywords. Afterwards, full-text screening was performed to decide which ones fulfilled the inclusion criteria.

2.5 | Data extraction

Data extraction from the included articles was performed by two reviewers (I. P. C. and J. M.), who checked each other's extracted data. Data regarding technologies was extracted in a table-format according to the following topics: first author's surname and year of publication, technology description, telemonitoring duration, frequency of data collection, data collected, educational material, target users, technology/data collection training, user and HCP output, feedback availability. To better describe the study, we also collected: country, study design, participants who used the technology (number, age, and sex). In case of quantitative studies, study objective, intervention(s), primary clinical outcomes (as defined by original authors of the original studies), and respective results were also extracted. Study objectives were classified as early feasibility, traditional feasibility, pivotal, and postmarket based on FDA guidance on medical device clinical studies.[27,28]

2.6 | Quality assessment

Quality of studies was assessed using the Mixed Methods Appraisal Tool (MMAT).[29] This tool, designed for the appraisal stage of systematic mixed studies reviews, which is our case, allows appraisal across a range of study designs including RCTs, nonrandomized studies, quantitative descriptive studies, qualitative research, and mixed methods studies. This method consists of five items for each type of study and establishes validity and reliability of overall quality, using a 3-point scale: "yes," "no" or "cannot tell" for each item. Quality appraisal was independently assessed by two reviewers (I. P. C. and J. M.) and inter-rater agreement was calculated using the Cohen's κ coefficient. The κ values can be interpreted as: slight agreement (≤0.20), fair agreement (0.21–0.40), moderate agreement (0.41–0.60), substantial agreement (0.61–0.80), and almost perfect agreement (≥0.81).[30]

2.7 | Data analysis

To synthesize technology and study characteristics, we employed a narrative synthesis. Results of the quantitative studies outcomes were also summarized, as a meta-analysis was not possible to conduct.

3 | RESULTS

3.1 | Study selection

Our search identified 8591 articles. After duplicate removal, 4464 records were screened for relevant content and 68 articles were included for full-text appraisal. After full-text assessment, 33 were excluded. Reasons for exclusions were: adult population (*n* = 12); no telemonitoring (*n* = 12); solely technology description (*n* = 4); focused exclusively on medication monitoring (*n* = 3) and telemonitoring within healthcare settings (*n* = 2). Search for relevant papers within the reference list of the selected articles retrieved three records and updated search from databases found two articles. In total, 40 articles with 40 technologies were included (Figure 1).

3.2 | Telemonitoring technologies

3.2.1 | Description

Telemonitoring technologies were different across studies - (Table 1). The main devices used were mHealth applications (app) for smartphones/tablets (*n* = 21)[31–51] and web-based systems (*n* = 14).[40,47,52–63] Two studies used interactive short messaging systems,[52,64] one of them as an alternative to the web-based system.[52] Some of these technologies were used together with additional peripheral devices, namely home peak flow meter/spirometer (*n* = 15)[32,34,36,38,41,43,47,49,52–56,58,63]; smart inhaler device (*n* = 4)[35,42,43,58]; air quality monitor (*n* = 2)[32,34]; activity and sleep monitor (*n* = 1)[34]; and intelligent sound pick-up device (*n* = 1).[48]

Six technologies consisted exclusively in home devices[65–70]—5 peak flow meters/spirometers[65,66,68–70] and one fractional exhaled nitric oxide (FENO) monitor (*n* = 1).[67] All studies from 2015 onwards included either an app or a web-based system (*n* = 26).[32-51,58-63]

3.2.2 | Duration and frequency

The length of telemonitoring varied from 2 weeks to 32 months (Table 1): 18 lasted less than 6 months[12,32,34,36,38,41,42,45,47,49,52,53,55,57,62,64–66,69] 11 lasted 6 months to 1 year[31,33,35,39,43,46,48,51,58,60,67] and 10 lasted 1 year or longer.[37,40,50,54,56,59,61,63,68,70] One article did not specify telemonitoring duration.[44]

Regarding frequency of data collection (Table 1), most studies (*n* = 20) demanded daily telemonitoring[32,33,35,42,47,52–57,62–70]; 4 twice daily[34,36,41,45]; 3 weekly,[39,40,43]; 2 twice a week[48,49] and 3 monthly.[59–61] Eight studies did not report the frequency of data collection.[31,37,38,44,46,50,51,58]

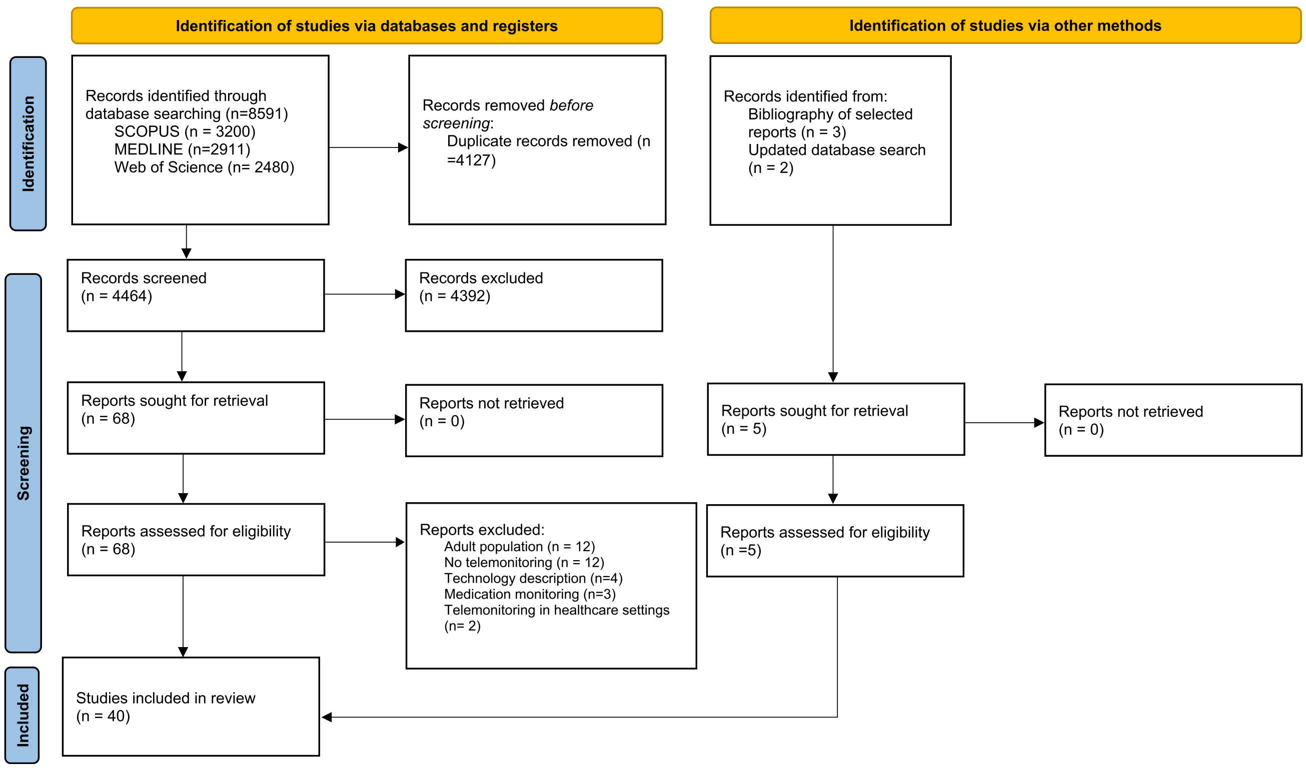

FIGURE 1 Flow diagram for study selection according to the preferred reporting items for systematic reviews and meta-analyzes (PRISMA) guidelines.[26]

3.3 | Collected data

Thirty technologies inquired about asthma symptoms (Table 2).[31–35,37,38,40–42,44,45,47,49–51,53–60,62,65–68,70] Eleven studies collected patient reported outcome measures (PROMs): c-ACT (*n* = 3)[43,59,61]; Asthma Control Test (ACT) (*n* = 3)[34,40,59]; Asthma Control Questionnaire (ACQ) (*n* = 2)[52,63]; Control of Allergic Rhinitis and Asthma Test (CARAT) (*n* = 1)[39]; modified Asthma Therapy Assessment Questionnaire (ATAQ) (*n* = 1)[64]; Japanese Pediatric Asthma Control test (JPAC) (*n* = 1)[46]; EuroQol five-dimension (EQ-5D) (*n* = 1)[44] and Visual Assessment Scale (VAS) for dyspnea (*n* = 1).[43] Spirometry or peak flow reading inputs were collected in 20 studies[32,34,36,38,41,43,47,49,52–56,58,63,65,66,68–70] and medication adherence in 17.[33–35,37,39,40,43,45,46,53,55,57,58,60,62,65,68] Participant's inhaler technique (*n* = 3)[42,43,54]; air quality (*n* = 2)[32,34] and respiratory sounds (*n* = 2)[43,48] were also collected. Fourteen technologies included disease information and educational materials.[31,37,39,45,46,51,53,54,58,60,63–65,68]

3.4 | Target users and training

In 23 studies,[32–35,37,38,40,42–47,49,51,53,54,57–59,61,65,70] target users were both parents and their child/adolescent (Table 1). Adolescents/children were the target users in 13 studies[31,36,39,41,52,55,56,63,64,66–69] and parents in 4.[48,50,60,62] Training to use the technology or collect data was provided in 23 studies.[32–37,40,41,43,45,47,50,52–56,58,62,63,65,68,69] Three studies referred continuous support[32,47,69] and two studies specified training for parent/children and HCP.[58,68]

3.5 | Children/parent's output

Thirty-one technologies[31–48,50–53,56–58,60,61,63,65,66,68] provided automatic feedback: asthma control levels display (*n* = 25)[31–47,51–53,56–58,60,63] and treatment advice based on asthma symptoms/PROMs (*n* = 9),[37,40,50,51,53,60,61,63,65] asthma symptoms/medication use (*n* = 2),[33,68] or spirometry/peak flow values (*n* = 4).[38,41,53,56] Other automatic feedbacks included air quality index notifications[51] and low oxygen levels alerts (*n* = 1).[32] Nine studies included automatic medication reminders.[33,37,39,45,46,48,51,57,66]

3.6 | HCP/researcher output and feedback

HCP/researchers were involved in data management in 27 studies.[31,37,39,40,42–44,47–49,51,54,56–58,60,61,64–66,68–70 53,59,63,67] Different HCP groups were included: physicians

TABLE 1 Technology description and characteristics ($n = 40$).

References	Technology description	Telemonitoring duration and frequency	Data collected	Educational material	Target users	User training	Children/parent output	HCP/researcher output	Feedback
Guendelman et al.[65]	Main technology: Interactive communication device (Health Buddy®), displaying screen questions, connected to a telephone Peripheral device: Home PFM Data: Automatically sent from telephone to a processing center at night	90 days Daily	Asthma symptoms PEF Medication adherence	Asthma facts Trivial questions	Child Parent	PFM teaching session Tracking method instructions, at baseline	Automatic text message with treatment indications based on asthma symptoms	Website with participant's data	Daily queries sent by a nurse via web browser
Cai et al.[66]	Main tecnhology: Home unit (Carecompanion®) connected to a telephone Peripheral device: Home PFM (PiKo-1®) Data: Automatically sent via telephone to a laptop	3 months Daily	Asthma symptoms PEF	-	Adolescent	-	Medication reminders	Laptop with participant's data	Daily monitoring by a study nurse who intervened in case of emergencies
van der Meer et al.[52]	Main technology: Web app/text message Peripheral device: Hand-held electronic spirometer (PiKol®) Data: NA	1 month Daily	FEV_1 PEF ACQ	-	Adolescent	Spirometer training	Asthma control levels (instant message with % FEV_1 and PEF of expected/ personal best value)	-	-
Jan et al.[53]	Main technology: Internet-based monitoring system (Blue Angel for Asthma Kids®) Peripheral device: Electronic PFM (microlife PF 100 Electronic Asthma Monitor®) Data: Uploaded to a central server	12 weeks Daily	Asthma symptoms PEF Medication adherence	Basic information regarding the care of the child with asthma	Child Parent	PFM technique instructions Website log in and data upload demonstration	Asthma control level (color-coded data) Automatic treatment feedback based on symptoms and PEF	Retrieval analysis system to review accumulated data	Telephone/e-mail treatment instructions sent by physician

TABLE 1 (Continued)

References	Technology description	Telemonitoring duration and frequency	Data collected	Educational material	Target users	User training	Children/parent output	HCP/researcher output	Feedback
Chan et al.[54]	Main technology: Website for data upload Peripheral device: PFM; computer-mounted video camera Data: NA	12 months Daily	Asthma symptoms PEF Inhaler technique videos	Interactive asthma education that followed the same curriculum as the office-based asthma education	Child Parent	On-site, in-home instructions on equipment and website use including video recording and submission	-	Data downloaded by the case manager	Communication via website. Weekly e-mail to review treatment plan and symptoms. Telephone/e-mail contact if closer observation was needed.
de Jongste et al.[67]	Main technology: Electronic diary (PalmOne Tungsten W PDA® equipped with TrialMax® software) Peripheral device: Airway inflammation monitor (NIOX MINO®) Data: Transmitted to the coordinating center	30 weeks Daily	Asthma symptoms FENO	-	Child	-	-	-	Phoned every 3 weeks for medication adjustment
Weisel et al.[55]	Main technology: Web-based questionnaire Peripheral device: handheld PFM Data: NA	2–4 months Daily	Asthma symptoms PEF Medication adherence	-	Child	PFM and website use demonstration	-	Administrative monitoring system with participant's data. Alert if any change in medication use was made or conflicting medication was used.	-
Jacobson et al.[68]	Main technology: Hand-sized electronic device with four keys and cords that plug into an electrical outlet and a telephone jack Peripheral device: PFM Data: Automatically sent to a password-protected website every night	32 months Daily	Asthma symptoms Medication adherence	Trivial questions	Child	PFM use and determination of personal best value Home device instructions Case managers training and website setup	Automatic treatment feedback based on symptoms and medication use	Website with participant's data	Case manager adjusts medication/recommends appointment. Telephone contact when needed.

(Continues)

TABLE 1 (Continued)

References	Technology description	Telemonitoring duration and frequency	Data collected	Educational material	Target users	User training	Children/parent output	HCP/researcher output	Feedback
Arnold et al.[56]	Main technology: Web-based symptom tracking program (ALERTS—Automated Live E-Health Response Tracking System) Peripheral device: PFM Data: NA	2–15 months Daily	Asthma symptoms PEF	-	Child	PFM demonstration and coaching technique Computer program training, at baseline	Asthma control level Automatic treatment feedback based on PEF values	System reports sent to nurse and physicians	-
Deschildre et al.[69]	Main technology/peripheral device: Pocket-sized electronic Asthma Monitor spirometer (AM1; Jaeger®) supplied with an automated modem Data: transmitted to an expert center	2 months Daily	FEV1(1 measurement in the morning and evening, after medication)	-	Child	Spirometer use and expiratory maneuvers instructions Every 4 months, the equipment was tested at the child's home	-	Data analyzed daily by a physician	Contact in case of exacerbation
Yun et al.[64]	Main technology: Text message Data: Transmitted to a web service	3–4 months Daily	Modified ATAQ	Fifteen true/false questions about general asthma knowledge	Child	-	-	Website with participant's data. Automatic e-mail sent to physicians if the child answered "yes" to questions in the "Red zone."	Physician emailed nurse in case of concern Nurse could contact parents
Haze and Lynaugh[31]	Main technology: mHealth app Data: NA	3–6 months	Asthma symptoms	A slide/video on a selected asthma topic	Adolescent	-	Asthma control level	Website with participant's data	Communication via text-message
Rhee et al.[57]	Main technology: Text-messaging system connected to a web page interface (Mobile phone-based asthma self-management aid for adolescents—mASMAA) Data: NA	2 weeks Daily	Asthma symptoms Medication adherence	-	Adolescent Parent	-	Asthma control level Automatic answers to user-initiated text messages about asthma symptoms Medication reminders	Website with participant's data. Automatic alert when the system was not able to answer adolescent's text messages.	Asthma educator intervened, when necessary, via text message

TABLE 1 (Continued)

References	Technology description	Telemonitoring duration and frequency	Data collected	Educational material	Target users	User training	Children/parent output	HCP/researcher output	Feedback
van Vliet et al.[70]	Main technology/ peripheral device: Home monitoring device—handheld spirometer (AM2+® (Asthma Monitor; Jaeger) Data: Transferred to a secured web-based portal two times/week	12 months Daily	Asthma symptoms FEV_1	-	Child Parent	-	-	Website with participant's data	-
Wiecha et al.[58]	Main technology: Website (BostonBreathes®) Peripheral device: Digital PFM; inhaler doser Data: NA	6 months	Asthma symptoms FEV_1 Medication adherence	Asthma web educational activities (puzzles, word searches, quizzes) Asthma educational flash animations	Child Parent	In-home patient website training (login procedures, data entry) PFM instructions Physician website training	Asthma control level (graphical data display)	Website with participant's data. Website alerts and staff's pagers activation in case of red zone values.	Communication via website
Voorend-van Bergen et al.[59]	Main technology: Web-based questionary Data: NA	12 months Monthly	Asthma symptoms c-ACT ACT	-	Child Parent	-	-	-	Treatment advice via e-mail within 3 working days from questionnaire submission
Fiks et al.[60]	Main technology: Electronic health related-linked shared decision-making portal (MyAsthma®) Data: NA	6 months Monthly	Asthma symptoms Medication adherence/side effects	Asthma educational content including videos	Parent	-	Asthma control level (data timeline display) Automatic treatment feedback based on asthma symptoms	Website with participant's data	Contact if asthma was not well-controlled/ medication side-effects
van den Wijngaart et al.[61]	Main technology: Monitoring website (Virtual asthma clinic) Data: NA	16 months Monthly	c-ACT	-	Child Parent	-	Automatic treatment feedback based on c-ACT	Feedback sent to the physician with the request to contact participants when c-ACT score below threshold	Contact by physician within 2 working days of exacerbation

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TABLE 1 (Continued)

References	Technology description	Telemonitoring duration and frequency	Data collected	Educational material	Target users	User training	Children/parent output	HCP/researcher output	Feedback
Thomson et al.[32]	Main technology: Home monitoring system with a mHealth app (Aspira®) Peripheral device: Digital spirometer (Microlife PF100 Asthma Analyzer®) and air quality monitor (Dylos DC1100®) Data: sent to a cloud server	2 weeks Daily	Asthma symptoms PEF Air quality	-	Child Parent	In-home system set-up and instruction use, at baseline. Bi-weekly phone calls to determine technology functioning.	Asthma control level (color-coded data) Alerts when low O_2 levels	Web app to monitor participant's engagement	-
Stukus et al.[33]	Main technology: mHealth app (AsthmaCare®) Data: Downloadable data stored in device and not transmistted to a server. No internet access required.	6 months Daily	Asthma symptoms Medication adherence	-	Child Parent	App download and setup in the emergency department, at baseline	Asthma control level (color-coded data) Automatic treatment feedback based on asthma symptoms and medication use Medication and trigger reminders	-	-
Venkataramanan et al.[34]	Main technology: Asthma kit (kHealth®) connected to a mHealth app Peripheral devices: Activity and sleep monitor (Fitbit®); air quality monitor (Footbot®), and electronic PFM (Microlife®) and a dashboard Data: Synched with cloud server on real-time	1–3 months Twice daily	Asthma symptoms adapted ACT PEF, FEV_1 Medication adherence Air quality	-	Child Parent	Education on kHealth kit use, upon recruitment	Asthma control level	Website with participant's data	-

TABLE 1 (Continued)

References	Technology description	Telemonitoring duration and frequency	Data collected	Educational material	Target users	User training	Children/parent output	HCP/researcher output	Feedback
Teufel Ii et al.[35]	Main technology: mHealth app Peripheral device: Bluetooth inhaler caps (CareTRX®) Data: Transferred to web-based porta on an encrypted server	6 months Daily	Asthma symptoms Medication adherence	-	Child Parent	Inhaler caps setup and app testing, at enrollment	Asthma control level	Web-based portal with participant's data. Automatic reports on child's symptoms and medication adherence.	-
Mikalsen et al.[36]	Main technology: mHealth app (Blowfish®) Peripheral device: Vortex whistle Data: Sent to a cloud server	4 weeks Twice daily	PEF	-	Child	App setup and whistle technique instructions.	Asthma control level	-	-
Lv et al.[37]	Main technology: mHealth app Data: Transmitted to healthcare center computers	12 months -	Asthma symptoms Medication adherence	Videos and articles describing methods to reduce risk of asthma exacerbation	Child Parent	Software setup in children/parent's smartphone and healthcare computers	Asthma control level Medication reminders Automatic treatment feedback based on asthma symptoms	Desktop app with participant's data. Alert of acute exacerbations.	Communication via app
Ljungberg et al.[38]	Main technology: mHealth app (AsthmaTuner®) Peripheral device: Bluetooth spirometer (MIR SmartOne®) and a healthcare interface Data: stored in a cloud-server	8 weeks -	Asthma symptoms FEV1	-	Child Parent		Asthma control level (longitudinal data display) Automatic treatment feedback based on FEV1	Computer healthcare interface with participant's data	-
Hashi et al.[62]	Main technology: Web-based symptom diaries Data: NA	1 month Daily	Asthma symptoms Medication adherence	-	Parent	Explanation about interventions, upon recruitment	-	-	Weekly feedback summarized by researchers without instructive data

(Continues)

TABLE 1 (Continued)

References	Technology description	Telemonitoring duration and frequency	Data collected	Educational material	Target users	User training	Children/parent output	HCP/researcher output	Feedback
Kosse et al.[39]	Main technology: mHealth app (Adolescent Adherence Patient Tool ADAPT®) Data: NA	6 months Weekly	CARAT Medication adherence	Short educational and motivational movies on asthma related to- pics	Adolescent	-	Asthma control level (graphical data display) Medication reminders	Desktop app with participant's data. E-mail alerts when a CARAT score is below the threshold.	HCP communication via app
Nkoy et al.[40]	Main technology: web and mHealth app (electronic-AsthmaTracker: e-AT®) Data: NA	12 months Weekly	Asthma symptoms Modified ACT Medication adherence	-	Child Parent	Clinical staff training Families' education on e-AT using standardized teaching flipcharts	Asthma control level (color coded and graphical data display) Automatic treatment feedback based on PROM	Website with participant's data. E-mail/dashboard alert for early signs of asthma deterioration.	Contacted by HCP in case of asthma deterioration
Schneider et al.[41]	Main technology: mHealth app Peripheral device: PFM Data: NA	3 months Twice daily	Asthma symptoms Peak flow values	-	Adolescent	PFM training	Asthma control level (color coded and graphical data display) Automatic treatment feedback based on peak flow values	-	-
Nichols et al.[42]	Main technology: mHealth app Peripheral device: Inhaler Bluetooth cap. Data: Encrypted data sent to a server	2 months Daily	Asthma symptoms Inhaler technique	-	Child Parent	-	Asthma control level	Analysis of inhaler technique videos	HCP send on-screen prompts regarding inhaler use technique
Beerthuizen et al.[63]	Main technology: Website for data upload Peripheral device: Hand-held spirometer (PiKo-1®) Data: NA	12 months Daily	ACQ FEV1	Asthma information, news, and frequently asked questions	Adolescent	Website and spirometer use training (highest value of 3 measurements in the morning, before medication), at baseline	Asthma control level Automatic treatment feedback based on PROM	-	HCP communication via website/phone in case of acute worsening

TABLE 1 (Continued)

References	Technology description	Telemonitoring duration and frequency	Data collected	Educational material	Target users	User training	Children/parent output	HCP/researcher output	Feedback
van der Kamp et al.[43]	Main technology: mHealth app (Puffer app®) Peripheral device: Hand-held spirometer (Spirobank® advanced II) and smart inhaler (Amiko® Respiro smart inhaler) Data: NA	6 months Weekly	VAS for dyspnea c-ACT FEV1, FVC; FEF_{25-75}; PEF Medication adherence Inhaler technique Respiratory sounds Video/photo of symptoms	-	Child Parent	Technology instruction, at baseline	Asthma control level	Web-based app with participant's data	HCP communication via app
Mayoral et al.[44]	Main technology: mHealth app Data: NA	-	EQ-5D Asthma symptoms Medication adherence	-	Child Parent	-	Asthma control level	Website with participant's data	-
Fedele et al.[45]	Main technology: mHealth app (AIM2ACT®) Data: NA	4 months Twice daily for 1 week, every 2 months	Asthma symptoms Medication adherence	Animated skills-training videos	Adolescent Parent	Mobile app setup, at baseline	Asthma control level (graphical data display) Medication reminders Definition of asthma management goals and a behavioral contract for adolescents and their parents	-	-
Iio et al.[46]	Main technology: mHealth app Data: NA	6 months -	JPAC Medication adherence	Manga and quiz, preparing for asthma exacerbation, including asthma action plan and preparing for disaster	Child Parent	-	Asthma control level Medication reminders	-	-

(Continues)

TABLE 1 (Continued)

References	Technology description	Telemonitoring duration and frequency	Data collected	Educational material	Target users	User training	Children/parent output	HCP/researcher output	Feedback
Wen et al.[47]	Main technology: Web-based system (eAsthma Care®) with mHealth app interface (tablet, computer, laptop, smartphone, desktop) and HCP interface Peripheral device: PFM Data: transmitted to a web server	3 months Daily	Asthma symptoms PEF	-	Child Parent	Account setup and website training, at baseline. Research contact during study for operation problems.	Asthma control level (color coded and graphical data display)	Website with participant's data	Weekly phone consultation Contact by HCP when abnormal readings reported
Zhang et al.[48]	Main technology: mHealth app Peripheral device: Intelligent sound pick-up device (Omron Corporation®) Data: transmitted to a cloud server	6 months Twice a week and exacerbations	Respiratory sounds	-	Parent	-	Medication reminders	Cloud platform with participant's data	Timely treatment feedback based on consensus of audio interpretation by two out of three specialists
Fossati et al.[49]	Main technology: mHealth app (Pneumotel uploader®) Peripheral device: Electronic spirometer (Spirobank Smart®) Data: Automatically transmitted to a secure internet platform	3 months Twice a week and exacerbations	Asthma symptoms FEV_1	-	Child Parent	-	-	Internet platform with participant's data E-mail/text message received in case of asthma worsening	Phone call/e-mail within 24 h in case of exacerbation
Beydon et al.[50]	Main technology: mHealth app Data: NA	12 months -	Asthma symptoms	-	Parent	Exacerbation data entering training, during telephone interview, on week 1	Automatic treatment feedback based on symptoms	-	Instant treatment feedback

TABLE 1 (Continued)

References	Technology description	Telemonitoring duration and frequency	Data collected	Educational material	Target users	User training	Children/parent output	HCP/researcher output	Feedback
Lewis et al.[51]	Main technology: mHealth app Data: NA	6 months -	Asthma symptoms	Educational resources, articles, and a terminology word bank inform about asthma. Videos to demonstrate proper use of asthma medication.	Child Parent	-	Asthma control level Medication reminder Automatic treatment feedback based on symptoms Air quality index notifications	Dashboard to access patient's data	Communication via app Telehealth visits

Abbreviations: ACQ, Asthma Control Questionnaire; ACT, Asthma Control Test; App, application; ATAQ, Asthma Therapy Assessment Questionnaire; c-ACT, children Asthma Control Test; CARAT, Control of Allergic Rhinitis and Asthma Test; EQ-5D, EuroQol-5 dimension; FEF25-75, forced expiratory flow at 25% and 75%; FENO, fractional exhaled nitric oxide; FEV1, forced expiratory volume in 1 second; FVC, forced vital capacity; HCP, health care professional; JPAC, Japanese Pediatric Asthma Control Test; PEF, peak expiratory flow; PFM, peak flow meter; PROM, patient reported outcome measures; VAS, Visual Assessment Score.

($n = 15$)[37,40,43,44,48,49,51,53,56,58,59,61,64,69,70]; nurses ($n = 11$)[31,37,43,47,54,56,58,63,65–67]; pharmacists ($n = 2$)[39,54] and respiratory therapists ($n = 1$).[42] Three studies did not report the HCP group involved.[57,60,68] A specific HCP/researcher platform with patient data was part of 24 technologies.[31,32,34,35,37–40,43,44,47–49,51,53,55,57,58,60,64–66,68,70] In seven studies, HCP/researchers received automatic alerts for asthma deterioration.[37,39,40,49,58,61,64] In nine studies, participants received HCP/researcher feedback via e-mail/telephone.[47,49,53,54,59,61,67–69] In seven studies, participants could contact the HCP at any time via website/smartphone app[37,39,43,51,54,58,63] and in one study via text message.[31]

3.7 | Study characteristics

Included articles ranged from 2002[65] to 2023[50,51] and were from America, Europe, and Asia (File S2). The United States of America ($n = 19$)[31-34,36,40-42,45,51,54-58,60,64,65,68] and the Netherlands ($n = 8$)[39,43,52,59,61,63,67,70] were the countries with more studies conducted (File S3).

3.8 | Design and quality appraisal

Most articles were RCT ($n = 19$),[33,37,45,47,48,50,53,54,58–61,64,65,67–69,38,39] followed by quantitative nonrandomized s tudies ($n = 12$),[34–36,40,43,44,51,55,56,62,63,70] qualitative studies ($n = 5$)[31,41,42,57,66] and mixed-method studies ($n = 4$).[32,46,49,52] Regarding quality appraisal (File S2): five studies met all seven criteria (two qualitative studies[41,42], two mixed-methods studies[46,52] and one quantitative nonrandomized study).[40] Regarding RCTs, 10 did not report participant's adherence to intervention.[33,37–39,47,48,50,53,58,61] Cohen's κ coefficient revealed almost perfect inter-rater agreement ($κ = .95$, $p < .001$, 95% confidence interval [CI] 0.91–0.99).

3.9 | Participants

Population sample size varied from 4[32] to 327.[40] Four articles specifically included children with moderate-to-severe asthma[43,49,68,69]; two included high-risk asthma[35,42] and one poorly controlled asthma.[45] Two articles included children with mild to moderate asthma.[31,67] The remaining articles ($n = 32$) did not specify asthma severity. Regarding participant's age, 16 articles included school-aged children and adolescents.[34,35,38,42,44,49,54,55,58,61,64,65,67–70] Eight articles focused only on adolescents[31,39,41,45,52,57,63,66], eight on school-aged children[32,36,47,50,51,53,56,60], two on preschool and school-aged children[37,46] and other two on infants and preschool children.[48,62] Four articles included more than two age groups.[33,40,43,59]

TABLE 2 Type of pediatric telemonitoring data.

References	Asthma symptoms	PROMs	Spirometry/ peak flow readings	Medication adherence	Inhaler technique	Respiratory sounds	Air quality	Other data
Guendelman et al.[65]	•		•	•				
Cai et al.[66]	•		•					
van der Meer et al.[52]		• (ACQ)	•					
Jan et al.[53]	•		•	•				
Chan et al.[54]	•		•		•			
de Jongste et al.[67]	•							• (FENO)
Weisel et al.[55]	•		•	•				
Jacobson et al.[68]	•		•	•				
Arnold et al.[56]	•		•					
Deschildre et al.[69]			•					
Yun et al.[64]		• (modified ATAQ)						
Haze and Lynaugh[31]	•							
Rhee et al.[57]	•			•				
van Vliet et al.[70]	•		•					
Wiecha et al.[58]	•		•	•				
Voorend-van Bergen et al.[59]	•	• (c-ACT and ACT)						
Fiks et al.[60]	•			•				• (medication side effects)
van den Wijngaart et al.[61]		• (c-ACT)						
Thomson et al.[32]	•		•				•	
Stukus et al.[33]	•			•				
Venkataramanan et al.[34]	•	• adapted ACT	•	•			•	
Teufel Ii et al.[35]	•			•				
Mikalsen et al.[36]			•					
Lv et al.[37]	•			•				
Ljungberg et al.[38]	•		•					
Hashi et al.[62]	•			•				
Kosse et al.[39]		• (CARAT)		•				
Nkoy et al.[40]	•	• (modified ACT)		•				
Schneider et al.[41]	•		•					
Nichols et al.[42]	•				•			
Beerthuizen et al.[63]		• (ACQ)	•					
van der Kamp et al.[43]		• (VAS for dyspnea and c-ACT)	•	•	•	•		• (photos/videos of symptoms)

TABLE 2 (Continued)

References	Asthma symptoms	PROMs	Spirometry/ peak flow readings	Medication adherence	Inhaler technique	Respiratory sounds	Air quality	Other data
Mayoral et al.[44]	•	• (EQ-5D)						
Fedele et al.[45]	•			•				
Iio et al.[46]		• JPAC		•				
Wen et al.[47]	•		•					
Zhang et al.[48]						•		
Fossati et al.[49]	•		•					
Beydon et al.[50]	•							
Lewis et al.[51]	•							

Abbreviations: ACQ, Asthma control Questionnaire; ACT, Asthma Control Test; ATAQ, Asthma Therapy Assessment Questionnaire; c-ACT, children Asthma Control Test; CARAT, Control of Allergic Rhinitis and Asthma Test; EQ-5D, EuroQol- 5 dimension; JPAC, Japanese Pediatric Asthma Control test VAS, Visual Assessment Score.

3.10 | Objectives and primary outcome results

Concerning the objective of the 31 quantitative studies, we identified 7 early feasibility studies[35,36,45,56,64,68,69], 22 traditional feasibility studies [33,34,37–39,43,44,47,48,50,51,53–55,58–60,62,63,65,67,70] and 2 pivotal studies.[40,61] Five of these did not present any clinical outcomes.[34–36,44,55] File S4 describes the primary clinical outcomes used and results of the remaining 26 quantitative studies. The most frequently used primary outcome was the number of unscheduled medical visits ($n = 6$),[33,48,50,54,58,68] followed by the Pediatric Asthma Quality of Life Questionnaire (PAQLQ) ($n = 5$).[53,54,63–65] The majority of the quantitative studies ($n = 16$, 62%) demonstrated that the use of telemonitoring technologies was related with better clinical results.[37–40,43,48,51,53,56,60–65,70]

4 | DISCUSSION

This systematic review offers a detailed overview of telemonitoring technologies in pediatric asthma, outside healthcare facilities. It includes articles published since 2002, most of which emerged after 2015, signaling a growing interest in integrating telemonitoring into the pediatric asthma healthcare pathways.

4.1 | Advancements in telemonitoring technologies

Studies employed various telemonitoring technologies, including mobile apps, web-based systems, home devices, and interactive messaging systems. Earlier technologies relied on exclusive home or peripheral devices.[65,66] However, with technological progress, a shift occurred around 2015 and all technologies since then have incorporated websites and/or smartphone apps. In parallel, the first telemonitoring technologies relied mostly on peripheral devices—around two-thirds before 2015, compared to less than half since then. Recent studies adopt a more practical approach, placing a greater emphasis on smartphone sensors and computational capacity. Smartphone-based solutions are cost-effective and easy to integrate into patients' lives, whereas peripheral devices are more difficult to deploy and costly in real-world practice.[71] Modern user-friendly apps positively influence participant's adherence to telemonitoring protocols and are thus more appealing to different stakeholders, highlighting the importance of user experience and co-creation approaches.[72,73] Design of future telemonitoring solutions should meaningfully involve children and parents.[74]

4.2 | Technology training and support

Telemonitoring success depends on patient's understanding of the technology system.[16] Although most studies mentioned participant training in data collection or technology use, a non-negligible proportion of studies ($n = 17$) did not specify the type of training. Few studies specified the timing and setting (home, hospital, other location) of the training and only three claimed to provide ongoing support throughout the study period. Technology training and assistance have an important impact on patient and HCP technology adherence. Furthermore, adequate technical instructions and support are likely to improve physician's acceptance of telemonitoring.[75] In fact, technical literacy and lack of technical support have been described as barriers, emphasizing the importance of providing appropriate assistance.[76,77] To ensure patient's adherence, information on technology training should be better described in future studies and ongoing support strategies should be carefully considered.

4.3 | Data management and HCP involvement

Most technologies provided users with automatic displays of asthma control levels, as well as automatic treatment feedback, which promote patient engagement and disease understanding. This type of feedback has been reported to empower both children and parents in asthma management, while reducing HCP burden and helping to optimize healthcare resources.[78–81]

HCPs also played an active role in data management in several telemonitoring systems. Literature has shown that patients feel more supported and adhere better to technologies when tailored feedback is provided by HCPs.[81,82] As technology advances, telemonitoring is moving beyond mere automated feedback and becoming seamlessly integrated into clinical care.[83] The use of dashboards is well established in many clinical settings as it allows real-time data monitoring, promoting timely interventions.[84] Several studies included HCP dashboards to manage patient data and tailor treatment plans. In some studies, dashboards also allowed for direct communication between children/caregivers and their HCPs. This availability improves patient–physician engagement and helps determine when patients can be managed remotely or if face-to-face visits are required.[85,86]

Although only a minority of studies allowed for HCP communication at any time, patients seem to value direct HCP communication and accessibility.[87] Nevertheless, HCP may perceive telemonitoring participation as an additional burden to their daily workload.[82,88] Included studies reported data management performed not only by physicians, but also by nurses, pharmacists, and respiratory therapists. This multidisciplinary approach to asthma management allows for task sharing and resource management, effectively reducing the overall workload.

Although our emphasis was on technologies for children and their parents, future reviews focusing on HCP dashboards and their development processes, are of great value to complement our results.

4.4 | Electronic PROMs

Most studies focused on collecting asthma symptoms, often through PROMs. Their use engages patients in disease management, allows HCP to monitor progression and tailor treatment.[89] Electronic PROMs have been gaining popularity and also seem to be useful in research involving long-term conditions,[90,91] making them good candidates for telemonitoring technologies. We found the c-ACT score to be a frequently applied PROM. This is one of the most popular scores used to assess asthma control under 12 years old[92,93] and its electronic application has already been validated.[94] The online version of the ACQ score, also employed in the included studies, has been validated for pediatric patients as well.[95] Another interesting PROM used was the CARAT score. This tool for children aged 12 years and over had its measurement properties evaluated in a first-of-its-kind meta-analysis, confirming good internal consistency, reliability, construct validity, and responsiveness.[96] Additionally, it has been validated for mobile app use, making it particularly attractive for telemonitoring.[96,97] Furthermore, CARATkids (adapted to children aged 6–12 years) has also shown adequate psychometric properties for clinical use.[98] Although most PROMs included were for digital use, the included articles did not specify this information in their methodological sections. Detailing and guaranteeing validation of electronic PROMs for children is crucial to ensure reliable results.

Even though we found different PROM instruments, none were specifically designed for preschool children. There is recent literature focusing on scores related to preschool asthma and recurrent wheezing[99–101] but, as of our knowledge, there are still no digital validated scores. This gap makes it challenging to effectively evaluate the perception of disease control in the context of telemonitoring. Limited research in this age cohort underscores the urgent need for studies tailored to the unique challenges and requirements of preschool children.

4.5 | Target users and age-specific considerations

The majority of studies targeted both parents and their children/adolescents, emphasizing the importance of family involvement in the management of pediatric asthma. However, there was no distinction between the technology design used for parents and children. To establish effective engagement, it is essential to adapt interface design to children, taking into account their developing abilities, shorter attention spam, language, and reading particularities.[83,102] As mentioned above, the co-creation of these interfaces is a way to ensure tailored technologies and consequently improve patient engagement. In fact, a recent exploratory study found that including children in the creation of telehealth systems resulted in practical ideas which took the entire family into consideration.[103] Future telemonitoring tools should include specific designs intended for parents and children. We believe that tools without user-centric interfaces will tend to fall behind as technology advances.

Notably, there was a paucity of studies on preschool children, despite this being a critical period with more severe asthma exacerbations, emergency visits, and hospital admissions compared to school-aged children.[104,105] One of the challenges in this age group is patient cooperation. Although spirometry and peak flow measurements were among the most commonly collected data, few children under the age of five can perform a reliable exam.[106] Therefore, objective measures that do not rely on patient collaboration are of most interest in younger children. These could include remote auscultation, detection of respiratory patterns and measurement of vital signs, as well as child and proxy-reported PROMs adapted for this age group, as mentioned before.

We identified two studies that included respiratory sound recordings: one relied on a sound collecting device[48] and the other on uploading sound recordings to a platform[43]. Recent literature has shown the possibility of reproducing lung auscultation in children/adolescents using the smartphone microphone without the need for a peripheral device.[107,108] Although these results are encouraging and could simplify remote auscultation, further testing in the outpatient setting is still necessary. Simultaneously, pediatric cough sound devices also seem to be promising. Lindenhofer and colleagues tested a device to capture nocturnal wheezing and cough which was found to be user-friendly and to identify relevant symptoms often not described by children or their parents.[109] Smartphone monitoring of oxygen saturation levels has also shown positive outcomes in healthy children,[110] making it a potential tool for respiratory monitoring. Moreover, video assessment of breathing patterns in adults has shown encouraging results.[111] These developments offer potential avenues for incorporating novel monitoring techniques in pediatric asthma, especially in younger children.

4.6 | Study objectives and primary outcomes

Most quantitative studies were in the early phases of technology assessment (early/traditional feasibility) and only two in the pivotal phase.[40,61] These preliminary research stages explains why some studies did not include clinical outcomes. Nevertheless, although focusing solely on primary clinical outcomes, we were able to show that most studies showed a significant positive impact of telemonitoring technologies on healthcare use and quality of life. These findings can support future sample size estimations and highlight the promising role of telemonitoring on asthma care. We found a wide variety of clinical outcomes across the included studies, which hampered meta-analysis. There is a need to standardize clinical outcomes and define common endpoints for future evaluation and comparison of telemonitoring effectiveness in pediatric asthma.

4.7 | Limitations

This review has certain limitations. We established broad inclusion criteria, including studies with different asthma definitions, disease severities, and different age groups, which led to heterogeneous telemonitoring technologies and data. Future reviews with meta-analysis that compare feasibility/effectiveness of technologies on specific age groups could be of great interest. To ensure a comprehensive review of the topic, we did not restrict the publication date; however, given the rapid pace of technological evolution, we acknowledge that older studies may lack current applicability. Nevertheless, their inclusion provides insights into the evolution of telemonitoring technologies. Although we recognize their contribution to asthma telemonitoring, we decided to exclude studies focusing exclusively on medication adherence as there is already substantial literature on this topic.[20–23] Lastly, quality assessment revealed that most studies did not specify their desired level of adherence to intervention, which hinders study replication. Addressing these limitations and ensuring rigorous study designs in future research will enhance real-world applicability of telemonitoring technologies.

TABLE 3 Summary of challenges for future pediatric asthma telemonitoring technologies development and research.

- The shift away from peripheral device-dependent technologies emphasizes the need for simplified, single-device solutions based on smart device sensors and their computational capacity
- Addressing the gap on providing technology training and ongoing support may improve participant's adherence
- Although patients value direct HCP communication and accessibility, the development of HCP dashboards for customized asthma data management needs to balance communication and availability with the burden on HCPs
- PROMs are good candidates to be integrated in telemonitoring technologies, but their electronic validation should be assured
- The absence of technologies with distinct designs for children and parents highlights the importance of co-creating interactive interfaces engaging target users
- The low proportion of technologies and absence of PROMs targeting preschool children draws the need for the development of specific technologies and PROMs for this age-range

Abbreviation: PROMs, patient-reported outcome measures.

Our results highlight important aspects that should be considered when developing future pediatric asthma telemonitoring technologies for the outpatient setting, which are summarized in Table 3.

5 | CONCLUSION

Our findings underscore the importance of continued research and collaboration between HCPs, researchers, and technology developers to advance telemonitoring strategies for pediatric asthma. Specific technologies for preschool children represent a gap in literature that needs to be specifically addressed. Managing the identified challenges will pave the way for more effective, user-friendly, and clinically robust telemonitoring solutions.

AUTHOR CONTRIBUTIONS

Inês Pais-Cunha: Conceptualization; formal analysis; investigation; methodology; writing—original draft; writing—review & editing. **José Fontoura Matias**: Investigation; writing—review & editing. **Ana Laura Almeida**: Investigation; writing—review & editing. **Manuel Magalhães**: Writing—review & editing. **João A. Fonseca**: Conceptualization; writing—review & editing. **Inês Azevedo**: Conceptualization; supervision; writing—review & editing. **Cristina Jácome**: Conceptualization; methodology; supervision; writing—review & editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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REFERENCES

1. Asher MI, Montefort S, Björkstén B, et al. Worldwide time trends in the prevalence of symptoms of asthma, allergic rhinoconjunctivitis, and eczema in childhood: Isaac phases one and three repeat multicountry cross-sectional surveys. *Lancet*. 2006;368(9537): 733-743.
2. Mallol J, Garcia-Marcos L, Sole D, Brand P. International prevalence of recurrent wheezing during the first year of life: variability, treatment patterns and use of health resources. *Thorax*. 2010;65(11):1004-1009.
3. Vervloet M, van Dijk L, Weesie YM, Kocks JWH, Dima AL, Korevaar JC. Understanding relationships between asthma medication use and outcomes in a sabina primary care database study. *NPJ Prim Care Respir Med*. 2022;32(1):43.
4. Amin S, Soliman M, McIvor A, Cave A, Cabrera C. Understanding patient perspectives on medication adherence in asthma: a targeted review of qualitative studies. *Patient Prefer Adherence*. 2020;14:541-551.
5. Gibson GJ, Loddenkemper R, Lundbäck B, Sibille Y. *Childhood Asthma in the European Lung White Book. European Respiratory Society*; 2013.
6. Borges J, Rosa MV, Fernandes RM, Nogueira PJ, Bandeira T. Hospital admissions in children with acute respiratory disease in Portugal. *Pulmonology*. 2019;25(2):122-125.
7. Ferreira de Magalhães M, Amaral R, Pereira AM, et al. Cost of asthma in children: a nationwide, population-based, cost-of-illness study. *Pediatr Allergy Immunol*. 2017;28(7):683-691.
8. Innovation WT-DHa. *Global Strategy on Digital Health 2020-2025*. Innovation WT-DHa; 2020.
9. OECD. *Health at a Glance 2023*. OECD; 2023.
10. Carlqvist C, Hagerman H, Fellesson M, Ekstedt M, Hellström A. Health care professionals' experiences of how an ehealth application can function as a value-creating resource—a qualitative interview study. *BMC Health Serv Res*. 2021;21(1):1203.
11. Meystre S. The current state of telemonitoring: a comment on the literature. *Telemed E Health*. 2005;11(1):63-69.
12. Metting E, Dassen L, Aardoom J, Versluis A, Chavannes N. Effectiveness of telemonitoring for respiratory and systemic symptoms of asthma and copd: a narrative review. *Life*. 2021; 11(11):1215.
13. Hanlon P, Daines L, Campbell C, McKinstry B, Weller D, Pinnock H. Telehealth interventions to support self-management of long-term conditions: a systematic metareview of diabetes, heart failure, asthma, chronic obstructive pulmonary disease, and cancer. *J Med Internet Res*. 2017;19(5):e172.
14. Hui CY, Walton R, McKinstry B, Jackson T, Parker R, Pinnock H. The use of mobile applications to support self-management for people with asthma: a systematic review of controlled studies to identify features associated with clinical effectiveness and adherence. *J Am Med Inform Assoc*. 2017;24(3):619-632.
15. Rebolledo Del Toro M, Herrera Leaño NM, Barahona-Correa JE, Muñoz Velandia OM, Fernández Ávila DG, García Peña ÁA. Effectiveness of mobile telemonitoring applications in heart failure patients: systematic review of literature and meta-analysis. *Heart Fail Rev*. 2023;28(2):431-452.
16. Cruz J, Brooks D, Marques A. Home telemonitoring in copd: a systematic review of methodologies and patients' adherence. *Int J Med Inform*. 2014;83(4):249-263.
17. De Guzman KR, Snoswell CL, Taylor ML, et al. A systematic review of pediatric telediabetes service models. *Diabetes Technol Ther*. 2020;22(8):623-638.
18. Fogel JL, Raymond JK. Implementing telehealth in pediatric type 1 diabetes mellitus. *Pediatr Clin North Am*. 2020;67(4):661-664.
19. Dunn J, Runge R, Snyder M. Wearables and the medical revolution. *Pers Med*. 2018;15(5):429-448.
20. Dhruve H, Jackson DJ. Assessing adherence to inhaled therapies in asthma and the emergence of electronic monitoring devices. *Eur Respir Rev*. 2022;31(164):210271.
21. Pearce CJ, Fleming L. Adherence to medication in children and adolescents with asthma: methods for monitoring and intervention. *Expert Rev Clin Immunol*. 2018;14(12):1055-1063.
22. Boutopoulou B, Koumpagioti D, Matziou V, Priftis KN, Douros K. Interventions on adherence to treatment in children with severe asthma: a systematic review. *Front Pediatr*. 2018;6(NA):232.
23. Licari A, Ferrante G, Marseglia GL, Corsello G, La Grutta S. What is the impact of innovative electronic health interventions in improving treatment adherence in asthma? The pediatric perspective. *J Allergy Clin Immunol Pract*. 2019;7(8):2574-2579.
24. van der Kamp MR, Hengeveld VS, Brusse-Keizer MGJ, Thio BJ, Tabak M. Ehealth technologies for monitoring pediatric asthma at home: scoping review. *J Med Internet Res*. 2023;25:e45896.
25. Milne-Ives M, Lam C, Meinert E. Digital technologies for monitoring and improving treatment adherence in children and adolescents with asthma: scoping review of randomized controlled trials. *JMIR Pediatr Parent*. 2021;4(3):e27999.
26. Page MJ, McKenzie JE, Bossuyt PM, et al. The prisma 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71.
27. ISO. *Clinical Investigation of Medical Devices for Human Subjects*. ISO; 2020.
28. US Food and Drug Administration CfBEaR. *Investigational Device Exemptions (IDEs) for Early Feasibility Medical Device Clinical Studies, Including Certain First in Human (FIH) Studies: Guidance for Industry and Food and Drug Administration Staff*. US Food and Drug Administration CfBEaR; 2013.
29. Hong QNPP, Fàbregues S, Bartlett G, et al. *Mixed Methods Appraisal Tool (MMAT), Version 2018, Registration of Copyright (#1148552)*. Canadian Intellectual Property Office, Industry Canada; 2018.
30. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33(1):159-174.
31. Haze KA, Lynaugh J. Building patient relationships: a smartphone application supporting communication between teenagers with asthma and the rn care coordinator. *Comput Inform Nurs*. 2013;31(6):266-271.
32. Thomson J, Hass C, Horn I, et al. Aspira: employing a serious game in an mhealth app to improve asthma outcomes. Paper presented at: 2017 IEEE 5th International Conference on Serious Games and Applications for Health (SeGAH), Perth Australia. 2017.
33. Stukus DR, Farooqui N, Strothman K, et al. Real-world evaluation of a mobile health application in children with asthma. *Ann Allergy Asthma Immunol*. 2018;120(4):395-400.
34. Venkataramanan R, Thirunarayan K, Jaimini U, et al. Determination of personalized asthma triggers from multimodal sensing and a mobile app: observational study. *JMIR Pediatr Parent*. 2019;2(1):e14300.

35. Teufel Ii RJ, Patel SK, Shuler AB, et al. Smartphones for real-time assessment of adherence behavior and symptom exacerbation for high-risk youth with asthma: pilot study. *JMIR Pediatr Parent*. 2018;1(2):e8.
36. Mikalsen IB, Nassehi D, Øymar K. Vortex whistle and smart phone application for peak flow recordings in asthmatic children: a feasibility study. *Telemed E Health*. 2019;25(11):1077-1082.
37. Lv S, Ye X, Wang Z, et al. A randomized controlled trial of a mobile application-assisted nurse-led model used to improve treatment outcomes in children with asthma. *J Adv Nurs*. 2019;75(11): 3058-3067.
38. Ljungberg H, Carleborg A, Gerber H, et al. Clinical effect on uncontrolled asthma using a novel digital automated self-management solution: a physician-blinded randomised controlled crossover trial. *Eur Respir J*. 2019;54(5):1900983.
39. Kosse RC, Bouvy ML, de Vries TW, Koster ES. Effect of a mhealth intervention on adherence in adolescents with asthma: a randomized controlled trial. *Respir Med*. 2019;149:45-51.
40. Nkoy FL, Fassl BA, Wilkins VL, et al. Ambulatory management of childhood asthma using a novel self-management application. *Pediatrics*. 2019;143(6):e20181711.
41. Schneider T, Baum L, Amy A, Marisa C. I have most of my asthma under control and i know how my asthma acts: users' perceptions of asthma self-management mobile app tailored for adolescents. *Health Informatics J*. 2020;26(1):342-353.
42. Nichols M, Miller S, Treiber F, Ruggiero K, Dawley E, Teufel Ii R. Patient and parent perspectives on improving pediatric asthma self-management through a mobile health intervention: pilot study. *JMIR Form Res*. 2020;4(7):e15295.
43. van der Kamp M, Reimering Hartgerink P, Driessen J, Thio B, Hermens H, Tabak M. Feasibility, efficacy, and efficiency of ehealth-supported pediatric asthma care: six-month quasi-experimental single-arm pretest-posttest study. *JMIR Form Res*. 2021;5(7):e24634.
44. Mayoral K, Garin O, Caballero-Rabasco MA, et al. Smartphone app for monitoring asthma in children and adolescents. *Qual Life Res*. 2021;30(11):3127-3144.
45. Fedele DA, Thomas JG, McConville A, et al. Using mobile health to improve asthma self-management in early adolescence: a pilot randomized controlled trial. *J Adolesc Health*. 2021;69(6): 1032-1040.
46. Iio M, Sato M, Narita M, et al. Development and feasibility of a mobile asthma app for children and their caregivers: mixed methods study. *JMIR Form Res*. 2022;6(5):e34509.
47. Wen TN, Lin HC, Yeh KW, Huang JL, Chiang LC. Effectiveness of easthmacare on symptoms, childhood asthma control test, and lung function among asthmatic children. *J Med Syst*. 2022;46(11):71.
48. Zhang P, Gong Z, Li J, et al. Intelligent evaluation of the efficacy of smart stethoscope in monitoring childhood acute asthma exacerbation. *Chin J Appl Clin Pediatr*. 2022;24:1093-1098.
49. Fossati A, Challier C, Dalhoumi AA, et al. Telehome monitoring of symptoms and lung function in children with asthma. *Healthcare*. 2022;10:1131.
50. Beydon N, Taillé C, Corvol H, et al. Digital action plan (web app) for managing asthma exacerbations: randomized controlled trial. *J Med Internet Res*. 2023;25:e41490.
51. Lewis K, Zettler-Greeley CM, Blake KV, Milkes A. A digital health application for managing pediatric asthma: use and benefits. *Inform Health Soc Care*. 2023;48(4):370-386.
52. van der Meer V, van Stel HF, Detmar SB, Otten W, Sterk PJ, Sont JK. Internet-based self-management offers an opportunity to achieve better asthma control in adolescents. *Chest*. 2007;132(1): 112-119.
53. Jan RL, Wang JY, Huang MC, Tseng SM, Su HJ, Liu LF. An internet-based interactive telemonitoring system for improving childhood asthma outcomes in Taiwan. *Telemed E Health*. 2007;13(3):257-268.
54. Chan DS, Callahan CW, Hatch-Pigott VB, et al. Internet-based home monitoring and education of children with asthma is comparable to ideal office-based care: results of a 1-year asthma in-home monitoring trial. *Pediatrics*. 2007;119(3):569-578.
55. Weisel CP, Weiss SH, Tasslimi A, Alimokhtari S, Belby K. Development of a web-based questionnaire to collect exposure and symptom data in children and adolescents with asthma. *Ann Allergy Asthma Immunol*. 2008;100(2):112-119.
56. Arnold RJ, Stingone JA, Claudio L. Computer-assisted school-based asthma management: a pilot study. *JMIR Res Protoc*. 2012;1(2):e15.
57. Rhee H, Allen J, Mammen J, Swift M. Mobile phone-based asthma self-management aid for adolescents (masmaa): a feasibility study. *Patient Prefer Adherence*. 2014;8:63-72.
58. Wiecha JM, Adams WG, Rybin D, Rizzodepaoli M, Keller J, Clay JM. Evaluation of a web-based asthma self-management system: a randomised controlled pilot trial. *BMC Pulm Med*. 2015;15:1-10.
59. Voorend-Van bergen S, Vaessen-Verberne AA, Brackel HJ, et al. Monitoring strategies in children with asthma: a randomised controlled trial. *Thorax*. 2015;70(6):543-550.
60. Fiks AG, Mayne SL, Karavite DJ, et al. Parent-reported outcomes of a shared decision-making portal in asthma: a practice-based rct. *Pediatrics*. 2015;135(4):e965-e973.
61. van den Wijngaart LS, Roukema J, Boehmer ALM, et al. A virtual asthma clinic for children: fewer routine outpatient visits, same asthma control. *Eur Respir J*. 2017;50(4):1700471.
62. Hashi S, Tsukasaki K, Nakamura T, Kyota K, Itatani T. Effects of maintaining web-based diaries by caregivers on adherence to care regimens in preschoolers with asthma. *J Spec Pediatr Nurs*. 2019;24(4):e12263.
63. Beerthuizen T, Rikkers-Mutsaerts ERVM, Snoeck-Stroband JB, Sont JK. The role of education, monitoring, and symptom perception in internet-based self-management among adolescents with asthma: secondary analysis of a randomized controlled trial. *JMIR Pediatr Parent*. 2021;4(4):e17959.
64. Yun T-J, Jeong H, Hill T, et al. Using sms to provide continuous assessment and improve health outcomes for children with asthma IHI'12: Proceedings of the 2nd ACM SIGHIT International Health Informatics Symposium. Association for Computing Machinery; 2012.
65. Guendelman S, Meade K, Benson M, Chen YQ, Samuels S. Improving asthma outcomes and self-management behaviors of inner-city children: a randomized trial of the health buddy interactive device and an asthma diary. *Arch Pediatr Adolesc Med*. 2002;156(2):114-120.
66. Cai P, Hebert M, Cowie R, Meadows L. Experience with home telehealth to support disease management in teenagers with asthma. *J Telemed Telecare*. 2006;12(suppl 3):23-25.
67. de Jongste JC, Carraro S, Hop WC, Baraldi E. Daily telemonitoring of exhaled nitric oxide and symptoms in the treatment of childhood asthma. *Am J Respir Crit Care Med*. 2009;179(2):93-97.
68. Jacobson JS, Lieblein A, Fierman AH, et al. Randomized trial of an electronic asthma monitoring system among New York city children. *Am J Manag Care*. 2009;15(11):809-814.
69. Deschildre A, Beghin L, Salleron J, et al. Home telemonitoring (forced expiratory volume in 1 s) in children with severe asthma does not reduce exacerbations. *Eur Respir J*. 2012;39(2):290-296.
70. van Vliet D, van Horck M, van de Kant K, et al. Electronic monitoring of symptoms and lung function to assess asthma control in children. *Ann Allergy Asthma Immunol*. 2014;113(3): 257-262.e1.
71. Howard S, Lang A, Sharples S, Shaw D. What are the pros and cons of electronically monitoring inhaler use in asthma? A multi-stakeholder perspective. *BMJ Open Respir Res*. 2016;3(1):e000159.

72. Bosworth T, Williams A, Wilson G, Flowers L. Development and design needs of mobile health (mhealth) apps for adolescents. *Ann Fam Med*. 2023;21(suppl 1):4225.
73. Jakob R, Harperink S, Rudolf AM, et al. Factors influencing adherence to mhealth apps for prevention or management of noncommunicable diseases: systematic review. *J Med Internet Res*. 2022;24(5):e35371.
74. Baines R, Bradwell H, Edwards K, et al. Meaningful patient and public involvement in digital health innovation, implementation and evaluation: a systematic review. *Health Expect*. 2022;25(4): 1232-1245.
75. Asua J, Orruño E, Reviriego E, Gagnon MP. Healthcare professional acceptance of telemonitoring for chronic care patients in primary care. *BMC Med Inform Decis Mak*. 2012;12:139.
76. Liljeroos M, Arkkukangas M. Implementation of telemonitoring in health care: facilitators and barriers for using ehealth for older adults with chronic conditions. *Risk Manag Healthc Policy*. 2023;16:43-53.
77. Kruse C, Fohn J, Wilson N, Nunez Patlan E, Zipp S, Mileski M. Utilization barriers and medical outcomes commensurate with the use of telehealth among older adults: systematic review. *JMIR Med Inform*. 2020;8(8):e20359.
78. Haleem A, Javaid M, Singh RP, Suman R. Telemedicine for healthcare: capabilities, features, barriers, and applications. *Sens Int*. 2021;2:100117.
79. Chatterjee A, Prinz A, Riegler MA, Das J. A systematic review and knowledge mapping on ict-based remote and automatic covid-19 patient monitoring and care. *BMC Health Serv Res*. 2023;23(1):1047.
80. Chatterjee A, Prinz A, Gerdes M, Martinez S. Digital interventions on healthy lifestyle management: systematic review. *J Med Internet Res*. 2021;23(11):e26931.
81. Creber A, Leo DG, Buckley BJR, et al. Use of telemonitoring in patient self-management of chronic disease: a qualitative meta-synthesis. *BMC Cardiovasc Disord*. 2023;23(1):469.
82. Floch J, Vilarinho T, Zettl A, et al. Users' experiences of a mobile health self-management approach for the treatment of cystic fibrosis: mixed methods study. *JMIR Mhealth Uhealth*. 2020;8(7):e15896.
83. Foster C, Schinasi D, Kan K, Macy M, Wheeler D, Curfman A. Remote monitoring of patient- and family-generated health data in pediatrics. *Pediatrics*. 2022;149(2):42-54.
84. Khairat SS, Dukkipati A, Lauria HA, Bice T, Travers D, Carson SS. The impact of visualization dashboards on quality of care and clinician satisfaction: integrative literature review. *JMIR Hum Factors*. 2018;5(2):e22.
85. Krey M. Mhealth apps: potentials for the patient-physician relationship. *J Adv Inf Technol*. 2018;9(4):102-109.
86. Qudah B, Luetsch K. The influence of mobile health applications on patient—healthcare provider relationships: a systematic, narrative review. *Patient Educ Couns*. 2019;102(6):1080-1089.
87. Moulaei K, Sheikhtaheri A, Fatehi F, Shanbehzadeh M, Bahaadinbeigy K. Patients' perspectives and preferences toward telemedicine versus in-person visits: a mixed-methods study on 1226 patients. *BMC Med Inform Decis Mak*. 2023;23(1):261.
88. Hanley J, Pinnock H, Paterson M, McKinstry B. Implementing telemonitoring in primary care: learning from a large qualitative dataset gathered during a series of studies. *BMC Fam Pract*. 2018;19(1):118.
89. Snyder CF, Aaronson NK, Choucair AK, et al. Implementing patient-reported outcomes assessment in clinical practice: a review of the options and considerations. *Qual Life Res*. 2012;21(8):1305-1314.
90. Sivan M, Rocha Lawrence R, O'Brien P. Digital patient reported outcome measures platform for post-covid-19 condition and other long-term conditions: user-centered development and technical description. *JMIR Hum Factors*. 2023;10:e48632.
91. Benze G, Nauck F, Alt-Epping B, et al. Proutine: a feasibility study assessing surveillance of electronic patient reported outcomes and adherence via smartphone app in advanced cancer. *Ann Palliat Med*. 2019;8(2):104-111.
92. Chu F, Kappel N, Akel M, Press VG, Alexander JT, Volerman A. Validity of the childhood asthma control test in diverse populations: a systematic review. *Pediatr Pulmonol*. 2023;58(5):1322-1336.
93. Liu AH, Zeiger R, Sorkness C, et al. Development and cross-sectional validation of the childhood asthma control test. *J Allergy Clin Immunol*. 2007;119(4):817-825.
94. Koolen BB, Pijnenburg MWH, Brackel HJL, et al. Validation of a web-based version of the asthma control test and childhood asthma control test. *Pediatr Pulmonol*. 2011;46(10):941-948.
95. Jovicic N, Petrovic M, Radovic I, Lazovic B, Soldatovic I. Validation of online version of asthma control questionnaire in pediatric patients. *J Asthma*. 2023;60(8):1553-1557.
96. Vieira RJ, Sousa-Pinto B, Cardoso-Fernandes A, et al. Control of allergic rhinitis and asthma test: a systematic review of measurement properties and cosmin analysis. *Clin Transl Allergy*. 2022;12(9):e12194.
97. Jácome C, Pereira A, Almeida R, et al. Validation of app and phone versions of the control of allergic rhinitis and asthma test (carat). *J Investig Allergol Clin Immunol*. 2021;31(3):270-273.
98. Linhares DVBR, da Fonseca JAL, Borrego LM, et al. Validation of control of allergic rhinitis and asthma test for children (caratkids)—a prospective multicenter study. *Pediatr Allergy Immunol*. 2014;25(2): 173-179.
99. Heidi M, Emily K, Benjamin H, et al. Patient reported outcomes for preschool children with recurrent wheeze. *NPJ Prim Care Respir Med*. 2019;29(1):7.
100. Ducharme FM, Jensen ME, Mendelson MJ, et al. Asthma flare-up diary for young children to monitor the severity of exacerbations. *J Allergy Clin Immunol*. 2016;137(3):744-749.e6.
101. Jensen ME, Mendelson MJ, Desplats E, Zhang X, Platt R, Ducharme FM. Caregiver's functional status during a young child's asthma exacerbation: a validated instrument. *J Allergy Clin Immunol*. 2016;137(3):782-788.
102. Markopoulos P, Read J, Giannakos M. *Design of Digital Technologies for Children*; 2021:18.
103. Beneteau E, Paradiso A, Pratt W. Children's designs for the future of telehealth. *AMIA Annu Symp Proc*. 2021;2021:207-216.
104. Akinbami LJ, Moorman JE, Garbe PL, Sondik EJ. Status of childhood asthma in the United States, 1980-2007. *Pediatrics*. 2009; 123(suppl 3):S131-S145.
105. Donath H, Kluge S, Sideri G, et al. Hospitalization, asthma phenotypes, and readmission rates in pre-school asthma. *Front Pediatr*. 2020;8:562843.
106. Onisor MO, Turner S. 2023. Routine fev(1) measurement is essential in diagnosis and monitoring of childhood asthma: myth or maxim? *Breathe*. 19(2):230048.
107. Ferreira-Cardoso H, Jácome C, Silva S, et al. Lung auscultation using the smartphone-feasibility study in real-world clinical practice. *Sensors*. 2021;21(14):4931.
108. Silva C, Ferreira-Cardoso H, Silva S, et al. Smartphone lung auscultation in pediatrics: feasibility and acceptance by end-users. *JMIR Pediatr Parent*, 7:e52540.
109. Lindenhofer M, Roth L, Mädel C, et al. Wheeze and cough measurements at night in children with respiratory symptoms. *BMC Pediatr*. 2020;20(1):556.
110. Tomlinson S, Behrmann S, Cranford J, Louie M, Hashikawa A. Accuracy of smartphone-based pulse oximetry compared with hospital-grade pulse oximetry in healthy children. *Telemed E Health*. 2018;24(7):527-535.

111. Valenzuela A, Sibuet N, Hornero G, Casas O. Non-contact video-based assessment of the respiratory function using a rgb-d camera. *Sensors*. 2021;21(16):5605.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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