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UNSOLICITED REVIEW

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Paediatric and adolescent asthma: A narrative review of telemedicine and emerging technologies for the post-COVID-19 era

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Abstract
Children and young people with asthma need regular monitoring to maintain good asthma control, prevent asthma attacks and manage comorbidities. The COVID-19 pandemic has resulted in healthcare professionals making fundamental changes to the way healthcare is delivered and for patients and families adapting to these changes. Comprehensive remotely delivered, technology-based healthcare, closer to the patients home (reducing hospital footfall and possibly reducing carbon footprint) is likely to be one of the important collateral effects of the pandemic. Telemedicine is anticipated to impact everyone involved in healthcare - providers and patients alike. It is going to bring changes to organization, work areas and work culture in healthcare. Healthcare providers, policymakers and those accessing healthcare services will experience the impact of technology-based healthcare delivery. Telemedicine can play an exciting role in the management of childhood asthma by delivering high-quality care closer to the child's home. However, unlike adults, children still need to be accompanied by their carers for virtual care. Policymakers will need to take into account potential additional costs as well as the legal, ethical and cultural implications of large scale use of telemedicine. In this narrative review, we review evidence regarding the role of telemedicine and related emerging technologies in paediatric and adolescent asthma. Although there are gaps in the current knowledge, there is evidence demonstrating the important role of telemedicine in management of childhood and adolescent asthma. However, there is an urgent need for healthcare researchers and policymakers to focus on improving the technologies and address the disparities in accessing novel technology-based management strategies to improve asthma care.

KEYWORDS
asthma, paediatrics, remote monitoring, technology

Prasad Nagakumar and Atul Gupta equal contribution.

1 | INTRODUCTION

The COVID-19 pandemic presents a significant challenge in striving to ensure ongoing medical care for patients while simultaneously attempting to minimize risk of exposure of staff, children and families to infection in hospital or outpatient clinics. This has led to a rapid shift in outpatient working with implementation of telemedicine to reduce or replace face-to-face visits.[1,2] Telemedicine overcomes the barrier of distance and is valuable in providing multidisciplinary care. Although the rapid adoption of telemedicine has been necessary to provide business continuity in the face of an acute reduction in traditional face-to-face clinical consultations, it is also timely to consider the variety of digital technologies available to paediatric asthma services in the "pandemic recovery phase" or post-COVID-19 era. Even before the current pandemic, there was recognition of the maturity of technology solutions for delivering telemedicine and debate about an increasing role for such consultations alongside, or even instead of, traditional in-person medical reviews.[3] Telemedicine has been increasingly of interest over the last decade as a means of improving asthma outcomes with a particular emphasis upon problematic and "difficult-to-manage" asthma. There are, however, concerns among health care professionals, young people and their families about issues such as access, confidentiality and the implications for safeguarding.

2 | DEFINITION OF TELEMEDICINE

There are many subtle variations in the definition of telemedicine in the literature. The literal meaning of telemedicine is also the most functional: tele- is a prefix denoting "at or over a distance" while medicine refers to the practice of the prevention, alleviation and cure of disease as well as the maintenance of health.

Our definition of telemedicine is adapted from Miller[4] and the Cochrane review of telemedicine interventions for asthma.[5] Telemedicine consists of three domains,

1. . Information obtained from the patient
2. . Electronic transfer of this information to a health care professional over a distance
3. . Delivery of personalized feedback tailored to the patient

Telemedicine refers to clinical healthcare applications, while the broader term "telehealth" is used more widely to describe both clinical and non-clinical applications, for example health education, administration and research. "Emerging technologies" are the devices or interfaces which aim to improve virtual care such as smartphone applications, web-based services for adherence and virtual presence devices.

Telemedicine can comprise many different technologies applicable to delivering paediatric and adolescent asthma services including telephone consultations, video consultations, e-mail correspondence and remote patient monitoring. Such technologies are usually described as asynchronous or synchronous[6] and the key differences are illustrated in Figure 1. Asynchronous telemedicine is where the communication between patient and healthcare provider occurs despite them not being connected simultaneously, for example interpretation of diagnostic tests or e-mail correspondence of patient questionnaires including C-ACT or PAQLQ. This type of telemedicine encounter has the advantage of requiring less coordination of the availability of patient and healthcare provider. Synchronous telemedicine refers to an encounter where both patient and healthcare provider are connected concurrently. Although this necessitates coordination of personnel, the response to clinical questions can take place in real time.

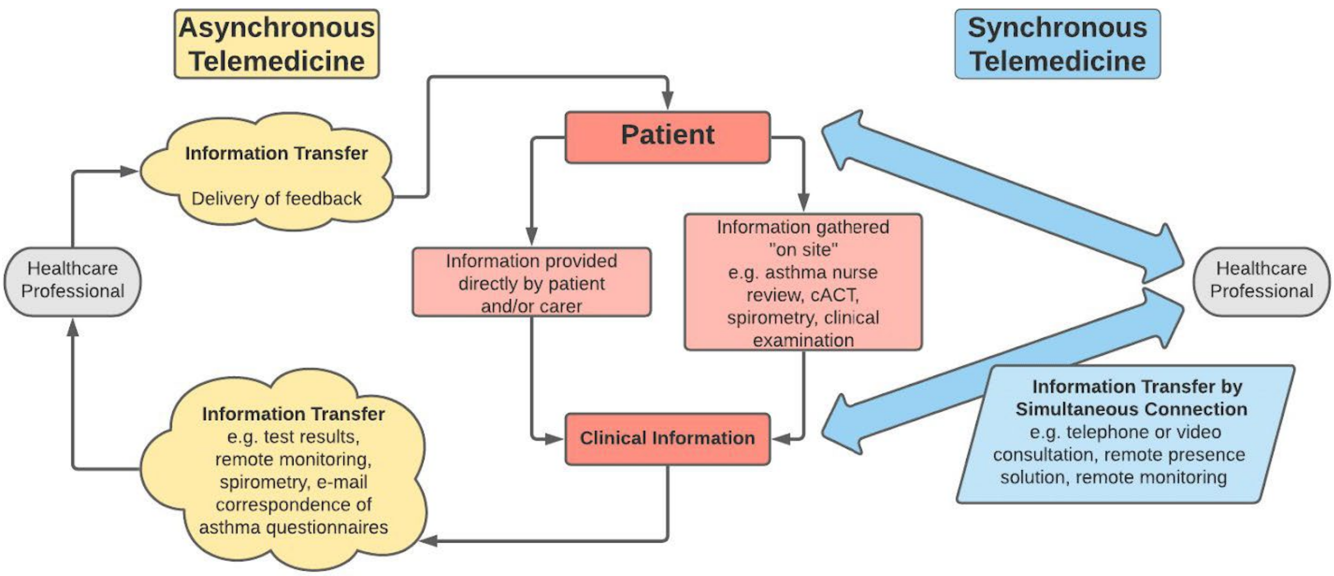

FIGURE 1 Schematic illustrating the key differences in asynchronous and synchronous telemedicine in paediatric asthma. In practice, these are complementary rather than exclusive strategies

Recent systematic review[7] identified five studies (three randomized and two cohort) that utilized synchronous (real-time) telemedically delivered education for schoolchildren with asthma. These studies demonstrated that the effect upon asthma symptom management, symptom burden and Quality of Life were either positive or non-significant.

3 | AIM

This narrative review examines the outcomes in children with asthma for both synchronous and asynchronous telemedicine interventions in both school and clinic-based settings. We describe the role of telemedicine and emerging technologies in the management of children with asthma and highlight cost-implications and pitfalls in the wider adoption of these in the post-COVID era. We have widened the scope of review to include both synchronous and asynchronous telemedicine as well as to incorporate the use of "emerging technologies" such as smartphone applications, web-based services for adherence and virtual presence devices. We also include the use of these technologies outside school-based settings.

4 | SEARCH STRATEGY

We searched Cochrane, PubMed, CINAHL, ERIC and Embase using MeSH terms and keywords related to asthma and telemedicine. Searches were completed in June 2020, limiting studies to those conducted in the previous 20 years such that internet connectivity and communications technology would be most similar to that available today. One hundred and forty studies were available using the search criteria of "(telemedicine / telehealth / e-health / virtual visit / remote consult / e-consult / remote monitoring), asthma, (school / school-based)". One author screened each abstract, conducted full text review, assessed study quality and extracted information. Two authors independently reviewed this appraisal and all authors conducted synthesis and analysis for narrative review.

5 | CLINICAL OUTCOMES OF SCHOOL-BASED INTERVENTIONS FOR PAEDIATRIC ASTHMA

There is a relatively limited number of randomized controlled trials specifically addressing clinical outcomes with telemedicine. However, there is a larger body of evidence examining the impact of school-based self-management interventions which suggests that community and school-based partnerships are promising solutions in effective management of paediatric asthma. Since a number of the studies describing the impact of telemedicine intervention on children with asthma also involve school-based interventions, the clinical outcomes of school-based interventions themselves require consideration.

A 2019 Cochrane Review identified 55 studies examining which components of school-based interventions were successful and the effect upon asthma control, school attendance and presentation to hospital or General Practitioner.[8] Self-management describes a process of education and enabling children to achieve adequate control over their own asthma symptoms including a focus upon proper inhaler technique and ability to recognize / respond to asthma symptoms. Meta-analysis suggested school-based self-management interventions reduced mean hospitalization by 0.16 admissions per child over 12 months. There was a decrease in the proportion of Emergency Department visits (from 7.5% to 5.4%) over 12 months and a reduction in unplanned hospital or primary care visits (from 26% to 21%) at 6–9 months.

6 | CLINICAL OUTCOMES OF SYNCHRONOUS TELEMEDICINE FOR PAEDIATRIC ASTHMA

A combination of school-based supervision with telemedicine was assessed by the SB-TEAM randomized controlled trial which enrolled 400 children aged 3 to 10 years in New York, USA.[9] The intervention was a combination of school-supervised asthma therapy and between 1–3 telemedicine visits over the course of one school year. History and examination data were gathered by telemedicine assistants. Assessment and patient feedback was completed by a clinician by either telephone or videoconference. Symptom-free days, emergency department visits and asthma hospitalization (OR 0.52) were better in the intervention group compared to children who did not receive either directly observed therapy or telemedicine visits. However, although the comparison group received guideline-based feedback and advice based upon reported symptoms at a similar interval to telemedicine interventions, this group also did not undertake directly observed therapy. It is therefore difficult to separate the contribution of the telemedicine element of the intervention from the effect of school-supervised asthma therapy itself.[10]

Synchronous telemedicine in regular video asthma education sessions was combined with asynchronous telemonitoring of spirometry data in a randomized controlled trial enrolling 393 children aged 7–14 from rural schools in Arkansas, USA.[11] Children were randomized to their usual care from a Primary Care Provider or to the telemedicine programme. The programme involved a number of asthma education sessions provided for children, their caregivers and school nurse. Five interactive video education sessions were conducted with the child over a 5–9 week period. These were delivered alongside two video education sessions for the caregivers and one for the school nurse. Video sessions comprised asthma education, symptom recognition, use of reliever / controller medications, use of a personalized asthma medication plan and proper use of asthma medication devices and spacers. This assessment was completed by asynchronous information gathering using asthma questionnaires and spirometry at baseline and after 3 months. The "usual care" arm of the study received medical care from their primary care provider and completed follow-up surveys at the same interval as the "telemedicine" arm of the study. There was no statistically significant difference in the primary outcome measure of symptom-free days, nor in other outcome measures including quality of life questionnaires or spirometry.

We identified two other studies that examined the clinical outcomes of synchronous telemedicine in school-aged children with asthma. Seventeen patients aged 5–18 years with persistent asthma symptoms in a rural school setting in the USA[12] had an initial specialist face-to-face assessment to perform spirometry, confirm asthma diagnosis and provide an asthma action plan. Patients were reassessed at 4, 12 and 24 weeks by remote nurse consultation together with spirometry. There was an improvement in symptom-free days and quality of life (measured by the asthma caregiver's quality of life questionnaire). However, in the absence of a comparison group, these results are subject to bias from temporal or asthma seasonal effects. Ninety six children aged 5–12 years with mild to moderate asthma were recruited to a prospective cohort study from three inner-city schools in the USA.[13] Children and an on-site school nurse participated in video consultations with an asthma specialist clinician at baseline and then at 8, 16 and 32 weeks. There were no significant changes in spirometry, hospital admissions nor Emergency Department / Primary Care visits.

A group of 169 children with asthma were offered an alternative implementation of synchronous telemedicine, a “Remote Presence Solution”.[14] Instead of simple telephone or videoconference based consultation, this involves the real-time use of a high-resolution camera for examination in combination with digital stethoscope, otoscope and spirometry. Children and their families self-allocated to either three telemedicine or usual in-person visits over a 6-month period. There was no inferiority demonstrated in C-ACT and family satisfaction scores between the two groups.

BOX 1 Synchronous Telemedicine - Ready for the Clinic?

Synchronous telemedicine encompasses a range of technological complexity from telephone calls to “Remote Presence Solutions”. Many clinicians will have developed experience of remote consultations through the necessity of service continuity during the COVID-19 pandemic. Data on clinical outcomes in paediatric asthma are limited and some studies assessing synchronous telemedicine interventions also incorporated school-based interventions of known benefit. Studies either did not report statistical differences in their primary end-points or demonstrated non-inferiority. Although it is likely that data on telemedicine during COVID-19 will become increasingly available, we argue that adequately powered, prospective studies designed to minimize biases resulting from the current enforced use of synchronous telemedicine are required.

7 | CLINICAL OUTCOMES OF ASYNCHRONOUS TELEMEDICINE FOR PAEDIATRIC ASTHMA

We identified two studies reporting the outcome of asynchronous telemedicine on clinical outcomes in children with asthma. Twenty four children aged 6–12 years with asthma were enrolled in a web-based tracking system which recorded peak flow metre readings and symptom questionnaire scores.[15] This web-based symptom tracker (ALERTS) provided real-time feedback to the children regarding their symptoms and provided recommendations based upon their prescribed asthma action plan. Assessments were undertaken and recommendations were provided to the children at a frequency of between one to five times per week (depending upon asthma severity). Reports were also sent to their primary care provider and clinical review was escalated by the identification of severe symptoms. Although the number of children in the study was relatively small, the follow-up period was up to 15 months. There was a significant decrease in wheeze episodes (1.86 to 0.43; $p = .02$) and a decrease in visits to a doctor (1.23 to 0.38; $p = .04$), although the study lacked any control.

A similar study involving an interactive record of symptoms, peak flow and patient-reported medication use for 41 children with asthma was supplemented over a 6-month period by monthly asthma education sessions delivered by an asthma nurse at school.[16] A 67% decrease in missed school days was reported although follow-up rates beyond 6 months precluded further analysis.

8 | OVERALL CLINICAL AND COST-EFFECTIVENESS OF TELEMEDICINE FOR PAEDIATRIC ASTHMA

The evidence to support clinical efficacy of virtual asthma care, whether delivered by synchronous or asynchronous telemedicine is limited. Much of the existing research into telemedicine is focused upon acceptability and technical feasibility rather than clinical outcomes. Only three studies employing a randomized controlled trial design were identified in the literature. An overview of the study population and description of the telemedicine intervention in the cited studies is provided in Table 1. Table 2 summarizes the

BOX 2 Asynchronous Telemedicine - Ready for the Clinic?

Data upon clinical outcomes of asynchronous telemedicine interventions are limited but promising. We would suggest that research focused upon clinical outcomes and designed to avoid temporal / seasonal bias would be beneficial alongside cost-effectiveness analyses.

TABLE 1 Overview of study population and telemedicine intervention description

Reference (first author, year)	Telemedicin e Type	Age Range (years)	Study Design	Location	Urban versus Rural	Socioeconomic Deprivation (Author Report)	Description of Telemedicine
Halterman, 2018[9]	Both	3–10	Randomized	New York, USA	Urban	"High rates of poverty and adversity"	Synchronous video of patient and on-site assistant. Asynchronous data assessing asthma control / severity. Daily observed therapy.
Perry, 2018[11]	Both	7–14	Randomized (cluster)	Arkansas, USA	Rural	"Impoverished" 47% with household income <$15000	Synchronous video to provide asthma education. Asynchronous monitoring of spirometry data and asthma symptom questionnaires.
Romano, 2001[12]	Synchronous	5–18	Pre/Post Cohort	Texas, USA	Rural	"Medically underserved area"	Baseline face-to-face evaluation by clinician with spirometry. Follow-up by synchronous video assessment including history, spirometry and review of symptom diary.
Bergman, 2008[13]	Synchronous	5–12	Pre/Post Cohort	California, USA	Urban	92% of families were Medicaid eligible	Synchronous video assessment and follow-up by specialist clinician.
Portnoy, 2016[14]	Synchronous	0–16	Cohort	Missouri and Kansas, USA	Both	Not reported	Video communication by "Remote Presence Solution" - including clinician controlled camera, digital stethoscope, digital otoscope. On-site spirometry.
Arnold, 2012[15]	Asynchronous	6–12	Pre/Post Cohort	New York, USA	Urban	>95% students qualified for free lunch programme	Asynchronous monitoring of patient reports based upon daily peak flow and weekly asthma symptom questionnaire data.
Tinkelman, 2004[16]	Asynchronous	5–15	Pre/Post Cohort	Colorado and Texas, USA	Urban	Not reported	Asynchronous monitoring of asthma diary incorporating daily peak flow data.
van den Wijngaart, 2017[17]	Asynchronous	6–16	Randomized	Netherlands	Both	Not reported	Frequency of face-to-face outpatient reviews decreased from four to eight-monthly. Monthly assessment of (Childhood) Asthma Control Test data with combination of automated feedback and asthma team contact with the patient.

TABLE 2 Test statistics, significance and confidence intervals

Reference (first author, year)	Test Statistic; (95% Confidence Intervals); p-value
Halterman, 2018[9]	*Symptom-free days (/14 days): 11.6 versus 10.97; difference 0.69; 95% CI (0.15, 1.22); p = .01* *≥1 ED visit or hospitalization per year: 7% versus 15%, Odds Ratio 0.52; 95% CI (0.32, 0.84) FeNO: mean difference −5.54; 95% CI (−9.8, −1.3)*
Perry, 2018[11]	*Symptom-free days (/14 days): 8.4 versus 8.0; difference 0.4; p = .55*
Romano, 2001[12]	*Symptom-free days (/7 days): 2.35 versus 4.31; difference 1.96; p < .05* *Mean symptom scores: 2.32 versus 1.31; difference 1.01; p < .001* *Pediatric Asthma Quality of Life Questionnaire: data not reported but stated "significant improvement"; p < .01*
Bergman, 2008[13]	*Asthma attacks (/14 days): 0.33 versus 0.15; difference 0.18; p = .07 CHSA - physical activity index: 84.2 versus 87.4; p = .009*
Portnoy, 2016[14]	*Adjusted Asthma Score after 30 days: 15.9 versus 16.1; difference 0.2; p = .35* *Adjusted Asthma Score after 6 months: 19.6 versus 18.5; difference 1.1; p = .33*
Arnold, 2012[15]	*Number of wheezing episodes (/14 days): 1.86 versus 0.43; p = .02* *Number of visits to doctor / clinic (/14 days): 1.23 versus 0.38; p = .04* *Physical health score (child): 65.6 versus 76.3; p = .045*
Tinkelman, 2004[16]	*PACQLQ (perceived activity) at 6 months: 6.76 versus 6.11; p = .04 (same measure was not significant at 12 months) Missed school days: 67.1% reduction; p < .01* *Day-time symptom frequency: 62% reduction; p < .007* *Night-time symptom frequency: 34% reduction; p < .03*
van den Wijngaart, 2017[17]	*Symptom-free days (/4 weeks): 27.3 versus 28.5; difference 1.23; 95% CI (0.42, 2.04); p = .003 Childhood Asthma Control Test: 22.3 versus 23.7; difference 1.17; 95% CI (0.09, 2.25); p = .03*

test statistics, significance and confidence intervals. Further high-quality research focused upon clinical outcomes and designed to avoid temporal / seasonal bias would be beneficial alongside cost-effectiveness analyses.

High-financial cost is a concern frequently raised about the development of telemedicine practice. A randomized controlled trial across eight asthma centres in the Netherlands examined 210 school-aged children with asthma over a 16-month follow-up period.[17] Children were randomized to either their usual care (comprising 4-monthly outpatient visits) or to 8-monthly outpatient visits combined with monthly web-based monitoring. Children receiving the latter "virtual asthma clinic" review demonstrated better symptom-free days and improved Childhood Asthma Control Test score. This suggests that monthly virtual asthma care is at least as effective as routine in-person visits.

A priori cost-effectiveness analysis was performed in parallel to the above multi-centre Netherlands study.[18] Direct and indirect patient costs were lower for children attending virtual asthma clinics compared to usual care (median virtual asthma clinic €889.77; median usual care €1081.47; $p = .014$) while there were no other differences identified in other healthcare and societal costs. This suggests that monthly virtual asthma care is at least cost-neutral, if not a more cost-effective option compared to routine in-person visits.

9 | REMOTE MONITORING: SPIROMETRY

In general, spirometry is performed in the hospital setting for children with asthma as part of long-term monitoring and assessment of acute asthma attacks. Spirometry is a valuable part of respiratory patient assessment that requires special consideration of how this data can be acquired when reviewing patients by telemedicine instead of in hospital. A concern about remote monitoring is the potential for discrepancy between lung function measurements at home and those that would be obtained by trained staff as part of an "in-person" clinical assessment.

A number of devices are available for the measurement of forced expiratory spirometry manoeuvres in children which are capable of reproducible measurements that are comparable to those obtained with a hospital spirometer.[19,20] 81 children with asthma in the RASTER cohort study performed FEV_1 measurements on a home spirometer in the home setting on the same day as FEV_1 was measured on a hospital spirometer during a clinical visit.[21] Home measurements are statistically significantly lower when measured in the home setting, although it is questionable whether the difference would be clinically significant (0.12 L; 95%CI 0.05–0.19 L; $p < .001$). The mean age of spirometry participants was 9.6 years (with standard deviation of 3.0) and no subgroup analysis was undertaken for age of participants.

10 | EMERGING TECHNOLOGIES, ASTHMA EDUCATION AND eHEALTH REMINDERS

Telemedicine can be delivered by a number of technology solutions including telephone, video links and e-mail. Technological progress is fast-paced however with a number of more recent studies employing sophisticated emerging technologies such as remote presence solutions and remote monitoring of spirometry. Some emerging technologies advance synchronous or asynchronous delivery of telemedicine while others (such as the ALERTS web-based symptom tracker that advises the child on the appropriate step of their prescribed asthma action plan) blur this artificial distinction completely.

Although the principal focus of this review has been telemedicine in the form of a virtual consultation, there is tremendous potential benefit to be derived from the delivery of asthma education remotely. Systematic review of five school-based studies including a mechanism for training and asthma education showed either positive or non-significant improvement in quality of life scores, ability to manage symptoms and reduction in symptom burden.[7]

Emerging technology permits use of smartphone applications, text messaging or web-based services to promote adherence to inhaled corticosteroids. A systematic review of twelve trials (including both adults and children with asthma) that undertook qualitative analysis of such interventions demonstrated a small but significant improvement in inhaled corticosteroid adherence - especially when the intervention included mobile devices.[22]

11 | PITFALLS OF TELEMEDICINE

Although current wider adoption of telemedicine is necessary as part of service continuity in a time of global pandemic, there are a number of potential benefits to the integration of telemedicine into routine paediatric asthma care even after the infection control necessities of COVID-19 have subsided. Telemedicine has the potential to increase access to healthcare by providing the opportunity for clinical review in a more convenient manner. It can be cost-neutral, if not potentially more cost-effective. Equally, there are a number of real and potential pitfalls that must be mitigated.

Patients and parents may be concerned about privacy and how personal information will be safeguarded during a telemedicine intervention. The means of remote information exchange needs to be a secure technology approved for use for the transfer of patient information. It may be necessary to educate patients and families about this and that confidentiality is a professional obligation taken as seriously for telemedicine as for face-to-face interactions. The General Medical Council updated guidance on remote consultations makes it explicit that the principles of "Good Medical Practice" apply to remote consultations too.[23] Patient confidentiality, information sharing and professionalism on part of both the parties is crucial. The patient satisfaction with telemedicine for adult patients from an allergy/immunology clinic in Rochester during the COVID-19 pandemic was high.[24] However, such data in children with chronic conditions including asthma are lacking. The implementation of remote consultations and monitoring when children are back at school poses further challenges which need to be addressed.

BOX 3 Remote Monitoring - Ready for the Clinic?

Remote assessment of FEV_1 now is now technically feasible with the potential for useful clinical information and is being increasingly adopted for children with asthma during the COVID-19 pandemic.

BOX 4 Challenges Affecting the Remote Consultation in Young People[25]

1). Access
Poverty and other health inequalities can impact on ability to access care digitally. Not all families have equality of access to technology (internet, broadband, WiFi, data or devices). Some may have additional issues (learning disability, auditory or visual needs). Some may not have English as their first language.

2). Confidentiality
Digital remote consulting can make it harder to hear the young person's story and fully understand their perspective if the parent or carer is always present. It is more difficult to ensure that a consultation is confidential on both sides of the screen, and the ability to do so is also affected by inequalities such as access to private space.

3). Quality of consultation
Although we assume young people prefer to engage digitally, they have told us that is not always the case.[25] An effective consultation needs a protected space and the full attention of both the clinician and the young person. This can be harder to achieve when people are using the flexibility offered by mobile technology rather than meeting face-to-face.

4). Safeguarding
It can be more difficult in a remote consultation to observe and react to nonverbal cues, for example the body language between a young person and the accompanying adult that would alert the clinician to a possible safeguarding issue. Use of digital consultation should be combined with a consistently low threshold for face-to-face consultation if there is any suggestion of a safeguarding concern or need for physical examination.

The Young People's Health Special Interest Group together with the Royal College of Paediatrics and Child Health, Royal College of General Practitioners and the Association for Young People's Health in the UK have recently issued a joint statement regarding the remote consultation.[25] They have highlighted the importance of service designers to seek young people's views before implementing virtual consultations. The joint statement highlights the key four issues (Box 4). Health inequality and socioeconomic disparity are recognized as drivers for poor asthma control.[26] Social deprivation can result in barriers to accessing telemedicine (e.g., poor internet access, living in temporary accommodation, language barriers and poor access to interpreters). The potential of increasing adoption of telemedicine to widen health inequality in children with asthma is therefore a serious concern.

Conversely, telemedicine has the potential to address barriers in access to care, for example by delivering specialist healthcare in regions without local access to specialists and in reducing the travel burden for families.[27] In Table 1, we have summarized the geographical location, urban/rural setting and author assessment of study population socioeconomic deprivation for the cited studies. It is notable that all studies where socioeconomic status was qualified were undertaken in subjects with a high proportion of surrogate markers of socioeconomic deprivation. Further research is required to assess optimal telemedicine strategies to address disparities in access to care related to ethnicity, socioeconomic status and rural community living.[28] It is imperative that future studies of telemedicine interventions clearly state study interventions undertaken to aid subject access of telemedicine - for example payment for mobile network "minutes" or provision of information technology devices. Targeted healthcare spending or government funding to provide information technology access to socioeconomically deprived populations might be an effective public health instrument in the future but this requires to be robustly evaluated.

12 | SUMMARY AND FUTURE DIRECTIONS

The COVID-19 pandemic has accelerated the adoption of telemedicine in health care. Rather than a "one size fits all" approach, the role of telemedicine in children needs to be evaluated by well-designed research studies. In particular, its role in reducing asthma attacks, improving asthma control, use by ethnic minority groups and comparing cost-effectiveness with traditional face-to-face delivery of healthcare needs to be explored in both primary and secondary health care systems. Children, young people, parents and health care provider views should be evaluated rigorously.

Telemedicine and emerging technologies have the potential to revolutionize future healthcare delivery to children and young people with asthma. Young people and carers should be involved in designing the technology and delivery of telemedicine. It is likely that the health care sector will have access to multiple telemedicine platforms. Future telemedicine platforms should be rigorously evaluated by adequately powered clinical trials. The interface between various platforms is crucial for improving communication between patients and health care providers. Collaborative and collective working between professionals and teams can also be enabled in place of "silo working".

Future technologies should focus on platforms to improve adherence to asthma medications, arrange repeat prescriptions and provide regular asthma education in the family's native language. Developments in Artificial Intelligence and algorithm-based monitoring could transform asthma education, self-management and provide early warning of acute asthma attacks. Healthcare policy and clinical governance will have to adapt to such innovations and to forge acceptable links with "big data" technology companies. The greatest advantage of telemedicine is in overcoming the barriers of distance and time and the focus should be to make the technology available to all to improve asthma care in children.

CONFLICTS OF INTEREST

BD, PK and PN have no conflicts of interest to declare. AG has no conflicts of interest directly related to this paper but reports fees for lecturing / advisory board work from: GlaxoSmithKline, Novartis Pharmaceuticals, Boehringer Ingelheim and Astra Zeneca. AG has been CI/PI of clinical trials with GlaxoSmithKline, Novartis Pharmaceuticals, Boehringer Ingelheim and Airsonett for which his institution has been paid. AG is also a director of the non-profit organization Paediatric Respiratory Academy which organizes educational meetings.

DATA AVAILABILITY STATEMENT

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

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