Early View

Original research article

Feasibility and value of a domiciliary spirometry programme in the assessment of severe asthma: a real-world evaluation

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This manuscript has recently been accepted for publication in the ERJ Open Research. It is published here in its accepted form prior to copyediting and typesetting by our production team. After these production processes are complete and the authors have approved the resulting proofs, the article will move to the latest issue of the ERJOR online.

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Feasibility and value of a domiciliary spirometry programme in the assessment of severe asthma: a real-world evaluation

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Word count: 3468

Take home message:

A physiologist-led domiciliary spirometry programme can capture new obstructed lung function and favourably impact the management of individuals with treatment refractory asthma. Further work is needed to address patient-centric issues that lead to poor uptake and adherence.

Keywords: asthma, spirometry, monitoring, management, domiciliary
ABSTRACT

Background: Domiciliary spirometry (DS) is a novel tool that is widely employed in the assessment of respiratory disease. We assessed real-world feasibility, effectiveness and value of a physiologist-led home spirometry programme, in patients with treatment-refractory severe asthma.

Methods: Patients were referred and provided with a hand-held DS device. Patients completed baseline measurements in a physiologist led virtual-clinic and were instructed to provide further values during symptomatic periods +/- during an exacerbation. Outcome measures included prevalence of new obstructed events, DS adherence and uptake of this approach.

Results: 112 patients were enrolled from November 2020 to January 2023. 102 individuals, mean (SD) age 44 (13) years (86% female), FEV1% predicted 88% (77 – 97%), successfully recorded baseline spirometry values. During follow-up (24-months), 11 (11%) were identified with new obstructive spirometry and subsequently commenced biologic therapy. Patient engagement was poor with median (IQR) of 4 (2 – 6) attempts of contact made before baseline values were recorded, and 2 (1 – 3) attempts required to record technically acceptable values. Continued DS use was sub-optimal; 34% failed to use their device after baseline and only 10% continued at the end of the study period. The cost of DS measurements was greater than a single hospital-based visit, but enables multiple event capture.

Conclusion: Overall, DS measurement uptake was poor, with a minority of patients continuing to use the device at the end of the study period. However, for those that engage, DS provides an alternative approach to traditional hospital-based spirometry measurements that can alter clinical management.
INTRODUCTION

Asthma is a heterogenous disease that often presents with non-specific respiratory symptoms. (1) Accordingly, guidelines emphasise the importance of obtaining objective evidence to ensure a diagnosis is secure. (2) These tests include the characterisation of pulmonary physiology, to detect variable airflow obstruction. (2) Utilising robust objective tests in assessment and diagnosis is particularly important when evaluating individuals with 'difficult-to-treat' or 'treatment-refractory' disease. In this context, several differential diagnoses (e.g. inducible laryngeal obstruction [ILO]) may act to mimic the diagnosis of asthma, leading to inappropriate use and escalation of asthma medications. (3) Reports indicating that asthma remains frequently misdiagnosed underpin why most prescribing guidelines mandate the presence of airflow obstruction, prior to commencement of a novel therapies, such as biologic treatments. (4)

The ability to undertake objective physiological testing, to reliably capture evidence of airflow obstruction in people with asthma symptoms, can be challenging. Typically, physiological measurement is undertaken in a clinic or hospital-based setting. The variable nature of asthma, however, means that pulmonary function may be normal during periods of stable disease and abnormalities may only become apparent during a symptomatic period. Thus, undertaking physiological assessment in individuals when they are symptomatic is desirable, but may be limited by the ability to schedule pulmonary function testing in a formal setting and more recently by constraints arising from SARS-CoV-2 pandemic restrictions.

Technological advances have facilitated access to home or domiciliary, self-administered, measurement of pulmonary function. (5) Domiciliary spirometry (DS) is
now frequently deployed for monitoring chronic pulmonary conditions such as cystic fibrosis and interstitial lung disease.\(^{(5)}\) In this setting, DS has been used to detect and characterise pulmonary impact at a time commensurate to exacerbations, evaluate subsequent disease progression and assess response to treatment.\(^{(5,6)}\) Modern devices for DS are light-weight, portable, simple to use, and interface with mobile phone technology to allow rapid transmission of data.

In the assessment of asthma, DS was first reported in the 1990s\(^{(7)}\), with more recent work evaluating the feasibility and safety of remote spirometry in monitoring asthma control and exacerbations.\(^{(8,9)}\) The cost and accessibility of DS devices has improved over the past five years but to date there is no real-world evidence describing the practical application of a DS approach outside a dedicated research setting. Moreover, many devices now permit recording and subsequent visualization of the full flow volume loop, including measurement of forced-expiratory volume in one second (FEV\(_1\)), which presents a distinct advantage over simple peak expiratory flow measurement. This functionality can provide insight regarding the reproducibility of measurements and permits an evaluation of the appearance of the flow volume loop, to detect expiratory flow limitation and attenuation of inspiratory flow, e.g. as may be seen in the differential diagnosis of ILO +/- breathing pattern disorder (BPD).

Over the course of the SARS-CoV-2 pandemic we accelerated the use of DS in a home spirometry programme (HSP), with the aim to enable capture of variable expiratory flow limitation and evidence of obstructive pattern spirometry in otherwise treatment refractory, severe asthma patients. We herein report the effectiveness of this asthma-service HSP, focussing on describing uptake, patient experience, safety, data quality and estimated cost impact (i.e. both from a financial and environmental /
carbon cost perspective). We also report the outcome of monitoring, in prompting access to novel asthma therapies.
METHODOLOGY

STUDY DESIGN AND SUBJECTS

This was a pragmatic, real-world, retrospective report of adult patients evaluated in the asthma service at the Royal Brompton Hospital, UK. Patients were enrolled onto a physiologist-led HSP between November 2020 and January 2023. Patients were referred by a respiratory clinician, for HSP clinic review, primarily to undertake DS when symptomatic. This retrospective analysis of HSP outcomes was approved by the Royal Brompton Hospital (Quality and Safety team Project ID: 004611).

HOME SPIROMETRY PROTOCOL

The HSP involved three stages; stage (I) to obtain consent and ensure the use of DS was appropriate; stage (II), to undertake training and validation of measurement; stage (III), to obtain and review results acquired when symptomatic.

STAGE I

Following referral, a respiratory physiologist contacted the patient, via telephone, to re-assess eligibility criteria including contraindications to spirometry as per guidelines(10) and patient suitability. The patient completed consent and provided demographic details.(11) A hand-held spirometer (MIR Spirobank, Italy) was then posted to eligible patients. The DS device connects to a smartphone via Bluetooth, with the mobile application running on either iOS or Android operating systems.

STAGE II

Once a patient received a DS device, a virtual physiologist-led clinic appointment time was scheduled (via a secure video call service), to help with instruction on device use and to obtain reproducible (as defined by ERS/ATS pulmonary function guidelines(12))
baseline spirometry values. During the virtual clinic, the aims of the spirometry were explained to the patient, contraindications to spirometry were assessed again and patients were then asked to perform a minimum of three technically acceptable forced manoeuvres, in a seated position. Spirometry technique was described to the patients prior to commencement of readings and patients subsequently attempted measurements with real-time physiologist instructions. Upon completion, results were transferred directly via email using the MIR phone application to the physiologist, who reviewed and determined if numerical results met spirometry reproducibility criteria. Flow volume loops (FVL) were also interrogated to ensure high-quality technique and to determine if they were free from artifact. If deemed technically acceptable and reproducible, results were uploaded to the patient’s electronic healthcare record.

**STAGE III**

After baseline, patients were asked to complete measurements during periods of increased symptom burden, e.g. during an exacerbation. In this context, the patient was asked to contact the asthma clinical nurse specialist, via telephone or email, prior to performing DS. This was to re-assess safety of performing spirometry, but also to alert the clinical team to a deterioration in clinical status. Spirometry measures were then performed and transferred to the physiologist for review. If deemed technically acceptable, the FVL and numerical report were uploaded to the patient’s record and the clinician alerted. Respiratory clinicians would then retrospectively review spirometry results and where relevant, those who presented with obstructive spirometry pattern, were later discussed in multi-disciplinary team (MDT) meeting, to determine onward management.
OUTCOME MEASUREMENTS

Key outcome measurements evaluated include patient group characteristics, the number of physiologist contact attempts required to schedule an initial virtual clinic appointment (stage I), the number of attempts required to obtain baseline spirometry results of adequate quality, and the frequency of DS device use (stage II). Stage III outcomes include identification of obstructive spirometry pattern, classified according to the ERS/ATS guidelines by an FEV₁/FVC ratio less than the lower limit of normal (LLN [z-score<-1.645](12)) and subsequent initiation of biologic therapy in the appropriate patient. We also report qualitative physiologist and patient feedback, as well as the impact of HSP on healthcare cost and carbon emission offset associated with DS (for additional detail see methodology in this article’s online repository).

STATISTICAL ANALYSIS

Data is presented using descriptive statistics including means and standard deviations (SD), median (IQR) for continuous variables, and counts (percentages) for categorical variables. Group differences and relationships between obstructive and non-obstructive individuals were analysed using Mann-Whitney U-test and Chi-squared analysis, where appropriate. Statistical calculations were made using GraphPad Prism (GraphPad software, La Jolla, CA, USA). Statistical significance was accepted as p<0.05.
RESULTS

PATIENT DEMOGRAPHICS

From the 112 patients who enrolled to the HSP, 102 successfully completed stage I and recorded baseline DS measurements (Table 1). Reasons for not recording a baseline DS value are detailed below. Figure 1 illustrates the flow of patients through the HSP.

The demographic of the cohort was in keeping with national severe asthma registry data, with a female preponderance (84% female) and 74% classified as being overweight (BMI>25kg/m²). At the time of referral, the majority of individuals (97%) were using regular high dose (in accordance with British Thoracic Society guideline on management of asthma) inhaled corticosteroid (ICS) and the majority (72%) had been prescribed two or more courses of oral steroid in the prior 12-month period or were taking maintenance oral corticosteroid (Table 1). Patients resided a median of 20 (11 – 46) miles from the hospital.

FEASIBILITY AND DELIVERY OF HSP

STAGE I

The median (IQR) contact attempts made before successful stage I was 4 (2 – 6) (figure 2a). Only 15% of the cohort could be contacted successfully after an initial attempt. There was no difference observed in the number of contact attempts made between individuals with and without the presence of obstructive spirometry identified (p=0.73, median (IQR) 2 (1 – 8) vs 4 (2 – 6) respectively). Ten patients failed to record baseline DS, most (60%) due to a failure to respond to emails. Two individuals were unable to perform technically acceptable spirometry technique, one was hospitalised during the recruitment period, and one had no access to email.
**STAGE II**

A median (IQR) of 2 (1 – 3) virtual clinic sessions were required to achieve technically acceptable and reproducible baseline spirometry, irrespective of obstructive spirometry pattern (p=0.36) (figure 2b). Just under a third (29%) of the cohort successfully recorded baseline spirometry after one virtual clinic (figure 3). Virtual clinic appointments were on average 30 minutes in duration, although not formally recorded.

**STAGE III**

A second spirometry measurement was performed by approximately 50% of the cohort within the first six months of their baseline measurement, but only 6% continued to perform DS in the 12-months following baseline and 10% continued to use their device at the end of the study period. Thus, approximately one third (34%) of the cohort performed DS at baseline only. A median (IQR) of 31 (0 – 130) days passed before patients performed a secondary DS measurement, with no difference observed in duration for those with or without the presence of obstructive DS (p=0.71, median (IQR): 31 (0 – 116) vs 31 (0 – 152) respectively). There was no association found between frequency of DS device use during the study period and individuals who presented with obstructive spirometry (table 2). Obstructive spirometry was identified in six individuals at baseline and was a new finding in a further 11 (11%) individuals over the study period, median (IQR) FEV1/FVC ratio: 69% (65 – 69). All of these individuals were subsequently commenced on biologic asthma therapy after discussion of their case at our local severe asthma MDT. There were no findings of inspiratory loop attenuation or reduced peak inspiratory flow.
OUTCOMES

PHYSIOLOGIST AND PATIENT FEEDBACK

Key difficulties reported by the physiologist included poor overall uptake and adherence to DS measurements and communication difficulties, e.g. ignoring repeated contact attempts and/or patient failure to alert clinical nurse specialists during symptomatic periods. The physiologists also reported difficulties with poor spirometry technique and at stage III sending in physiologically improbable results. Although patient feedback is limited, one patient reported performing DS successfully “changed their life as they were able to commence biologic therapy”. Another patient, “found home spirometry incredibly interesting and informative”.

HEALTHCARE RELATED COST

From initial referral by the clinician to completion of stage II the HSP incurs a cost of approximately £195 per patient which includes the initial cost of the DS device (£167), the postage from the hospital to the patient’s residence (£2.99) and the physiologist’s time spent performing the virtual training clinic and performing administrative duties such as contacting the patient (£25). The cumulative cost to conduct 102 DS device setup and baseline assessments equates to approximately £19,900. Comparatively, the cost of 102 hospital-based spirometry measurements is 38% lower at approximately £7600. The cost of a single hospital-based spirometry assessment is calculated by the cost of performing a hospital-based spirometry test (£102), the manufacturer equipment and servicing contract cost (£9), the physiologist time conducting the test (£6) and the bacterial filter (£1.50).

CARBON EMISSION COSTS

Carbon emission cost analysis reported in supplementary material.
DISCUSSION

In a real-world pragmatic scenario, a home monitoring programme using DS, appears to provide reliable, objective physiological data, that enables capture of airflow obstruction and thus augments an investigative strategy in the assessment of patients with asthma symptoms. In the evaluation of a diagnostic test modality, it is important to determine if the test provides valid results, is safe to conduct and alters clinical management. We report evidence that a physiologist-led HSP satisfies all of these criteria and negates the need for laboratory attendance. Of the total cohort, one in ten subsequently enrolled had airflow obstruction captured and this altered their management, specifically their work-up process for biologic-based asthma treatment. These individuals had non-obstructed spirometry at baseline. Furthermore, this approach was associated with potential beneficial financial and environmental implications, when compared to the traditional clinic or hospital-based approach to measurement.

Nevertheless, it was apparent that successful delivery of a HSP, in this context, is not without considerable patient-focussed challenges and in our experience, overall evidence of poor uptake and device utility. The strikingly low engagement and uptake after baseline DS measurements may have impacted the prevalence of obstructive spirometry pattern identified within our cohort. There were no obvious patient characteristics detected in the analysis that identified individuals with better adherence or clinical features that alluded to better uptake. Thus, whilst DS is a useful tool, it remains an expensive, time consuming approach to clinical asthma management that requires future work to refine inclusion criteria and evaluate potential predictors that may improve uptake. Future studies should explore patient characteristics and these features with the aim of improving DS delivery.
It is conceivable that patients could have attended for bronchoprovocation testing (e.g. a Methacholine or Histamine provocation testing), but this requires laboratory attendance and mandates a specific period of medication withdrawal to permit interpretation of a valid test. This runs a risk of exacerbating symptoms, and its positive predictive value is dependent on the presence or absence of symptoms at the time of testing.(15) A recent evaluation of DS in the context of symptomatic, athletic individuals found value in the presence of negative bronchoprovocation tests.(16) Further studies are needed to compare the use of DS in patients symptomatic with asthma against bronchoprovocation testing. Similarly, the utility of DS may extend to the assessment and detection of asthma mimics, such as ILO and/or laryngeal dysfunction. Although not formally evaluated, we report no findings of inspiratory loop attenuation or reduced peak inspiratory flow. The application and value of DS to identify these conditions needs to be validated.

Our findings do not eliminate the need to detect and identify other important ‘biomarkers of asthma’, such as those indicating heightened airway inflammation and/or type II asthma biology (e.g. serum eosinophil counts or elevated fractional exhaled nitric oxide [FeNO]). Recently, Wang and colleagues(9) reported poor overall measurement adherence as a significant challenge in their assessment of domiciliary FeNO and DS. They note that 40% failed to record a single FeNO measurement and only one third of the cohort performed twice daily measurements as requested. Sub-optimal DS measurement adherence was also reported as low as 33% and 65% to twice and once daily measurements respectively, with 15% failing to record a single DS measurement. In contrast, higher adherence rates of ~85% have been observed in asthma cohorts who conducted once daily DS measurements(8,17), and those who performed infrequent readings during a short study period.(18) Some research studies
show a higher uptake, but DS performed in the context of a research protocol is likely to be associated with closer scrutiny and support.

In our study, overall measurement adherence was not assessed as patients were requested to perform measurements during symptomatic periods and thus we didn’t pre-specify the number of measurements required. This may explain the poor device usage findings within this cohort. In a research setting, the optimal required DS measurement frequency and timing of measurements has yet to be determined, which can make the real-world implementation of a HSP challenging. Future research should continue to explore the optimal monitoring frequency over extended periods of time in different disease cohorts.

Some studies have identified concerns regarding data quality and the difference in DS readings with and without direct supervision of a healthcare professional. Although the majority report high quality DS performance and a strong agreement between DS and hospital-based measurements.(5) In contrast, some case series report significant measurement variability, physiologically impossible results and lower DS readings than those from supervised spirometry.(19,20) We identified similar challenges in respect of irreproducible FVL and spirometric values that required repeat DS attempts. The increased variability and technique breakdown could be attributed to potential BPD that necessitates specialist respiratory physiotherapy intervention. To circumvent these challenges, a highly skilled physiologist trained, reviewed and identified poor patient technique/ results, providing additional support where required. In addition, appropriate patient selection of individuals capable of performing high quality, unsupervised spirometry safely at home are key factors when implementing HSP. Improvements in adherence, data quality and mass data interpretation may improve
with emergence of novel digital tools such as artificial intelligence (AI) and machine learning.\(^{(12)}\) The use of AI may enable rapid DS data acquisition that provides quality assurance, determines measurement acceptability and usability. Furthermore, there may be scope to utilise AI to facilitate interpretation of physiological data, FVL and optimise classification of obstructive vs non-obstructive spirometry patterns.

An outcome of the study was to evaluate DS in relation to hospital-based spirometry to determine the impact on cost. The total costs for a one-time hospital-based spirometry assessment were approximately 40% lower than the cost to perform DS. However, after the initial cost of DS setup, the patient is able to perform multiple DS measurements without incurring additional charges. In contrast, repeat spirometry measurements will incur additional cost per measurement.

The reported carbon footprint benefit of DS is primarily through travel associated reductions. These findings are in line with Purohit and colleagues\(^{(21)}\) systematic review who provided evidence that implementation of telemedicine services leads to a reduction in carbon footprint, particularly as a result of reduction of travel. In this context, there is scope to reduce patient hospital attendance frequency, thus increasing availability of hospital lung function appointments for other clinical circumstances. Environmental and carbon emission impact is multi-factorial and the analysis conducted was limited in scope and detail. Further analysis is required within a HSP setting to fully determine the impact, particularly in relation to emissions produced by device manufacturing, delivery and cost of conducting virtual clinics.

**PRACTICAL CHALLENGES AND LIMITATION**

We note several limitations to our findings. During the stage I consent process, height and weight were self-reported without formal verification which may have implications
when interpreting predicted values. A further limitation is we cannot precisely report the proportion of individuals who present with mixed obstructive and restrictive spirometry patterns. We recognise a limitation of portable DS devices is the tendency to under read overall lung volumes (i.e. FVC measures) in comparison to lab-based results.(22) In our cohort, despite physiologist input, it is likely that FVC measurements may be lower than results performed in a laboratory setting, as we cannot truly verify that full patient effort occurred during the manoeuvre retrospectively. Furthermore, to accurately characterise restrictive patterns, formal measurement of lung volumes including total lung capacity must be performed, using either body plethysmography, helium dilution or nitrogen washout. These measures were not performed in this study, but are important when assessing this area, given the context of an elevated BMI, i.e. as seen in this cohort.(23)

The MIR Spirobank operating system requires patients to manually transfer results upon completion. Manual data input and transfer is prone to errors as well as missed data due to internet failure, equipment failure or patient error. An automation of this service and alerts notifying patients when to perform measurements may potentially improve adherence.

Our approach to the analysis of health related and carbon emission costs was limited in detail and subject to estimates. To better evaluate this issue, a more robust model is required that uses prospective study design and data collection, that assesses the implications of treatment impact on overall HSP cost and accurately captures the total number of tests performed.

Furthermore, the introduction of DS into clinical services has the potential to widen healthcare and socio-economic inequalities, primarily for those who are less digitally
proficient, have limited internet access and affordability for smart devices. This is an important area to address when considering barriers to DS adherence and successful delivery of a HSP. Fortunately, no patients in our cohort who were put forward for enrolment into the HSP had to be excluded due to limited/ no access or poor digital proficiency.

In conclusion, real-world application of DS within a specialist asthma service, facilitates the capture of obstructive spirometry, leading to a meaningful impact in the clinical care of some patients. However, there are significant challenges with implementation of a HSP, including primarily the poor uptake and usage rates following baseline virtual clinics and difficulties obtaining reliable measures despite multiple contact attempts. Future research should focus on addressing patient-focused barriers, challenges to help increase accessibility and usability of this valuable tool and identify individuals that will benefit most from use of this diagnostic approach.
**LIST OF TABLES**

**Table 1: Patient Characteristics**

<table>
<thead>
<tr>
<th></th>
<th>Total (n=102)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>44 ± 13</td>
</tr>
<tr>
<td>Sex (female)</td>
<td>86 (84)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>85 ± 26</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>33 ± 13</td>
</tr>
<tr>
<td>Ethnicity,</td>
<td></td>
</tr>
<tr>
<td>Caucasian</td>
<td>79 (77)</td>
</tr>
<tr>
<td>Black</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Northeast Asian</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Polynesian</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Other</td>
<td>21 (21)</td>
</tr>
<tr>
<td><strong>Domiciliary spirometry</strong></td>
<td></td>
</tr>
<tr>
<td>Baseline FEV₁ (L)</td>
<td>2.66 (2.13 – 3.09)</td>
</tr>
<tr>
<td>FEV₁ % pred</td>
<td>88 (77 – 97)</td>
</tr>
<tr>
<td>Baseline FVC (L)</td>
<td>3.31 (2.58 – 3.70)</td>
</tr>
<tr>
<td>FVC % pred</td>
<td>89 (79 – 100)</td>
</tr>
<tr>
<td>FEV₁/FVC Ratio (%)</td>
<td>81 (76 – 85)</td>
</tr>
<tr>
<td>Patients obstructed at baseline based on FEV₁/FVC &lt; LLN</td>
<td>6 (6)</td>
</tr>
<tr>
<td>On a high dose inhaled corticosteroid (ICS),</td>
<td>99 (97)</td>
</tr>
<tr>
<td>On daily maintenance dose of Prednisolone</td>
<td>12 (12)</td>
</tr>
<tr>
<td>No of patients who had 2 or more courses of prednisolone in last 12 months</td>
<td>73 (72)</td>
</tr>
<tr>
<td>Number of courses of prednisolone in last 12 months</td>
<td>4 (1 – 5)</td>
</tr>
<tr>
<td>Daily Prednisolone (mg)</td>
<td>10 (6 – 13)</td>
</tr>
</tbody>
</table>

Data presented as n (%), mean ± SD or median (IQR). BMI: body mass index, FEV₁: forced expiratory volume in one second, FVC: forced vital capacity, ICS: inhaled corticosteroid, IQR: interquartile range, kg: kilogram, kg/m²: kilogram per square metre, LLN: lower limit of normal, mg: milligram.

**Table 2: Domiciliary spirometry device usage**

<table>
<thead>
<tr>
<th></th>
<th>Total (n = 102)</th>
<th>Obstructive Spirometry identified (n = 17)</th>
<th>No Obstructive Spirometry identified (n = 85)</th>
<th>p-value obstructive spirometry versus non-obstructive spirometry pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of physiologist contact attempts</td>
<td>4 (2 – 6)</td>
<td>2 (1 – 8)</td>
<td>4 (2 – 6)</td>
<td>p=0.73</td>
</tr>
<tr>
<td>Attempts to achieve baseline</td>
<td>2 (1 – 3)</td>
<td>2 (1 – 3)</td>
<td>2 (1 – 3)</td>
<td>p=0.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td>----------------------------------------------------------------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>Number of days until second domiciliary spirometry measurement</td>
<td>31 (0</td>
<td>31 (0</td>
<td>31 (0</td>
<td>p=0.71</td>
</tr>
<tr>
<td>performed</td>
<td>130)</td>
<td>116)</td>
<td>152)</td>
<td></td>
</tr>
<tr>
<td>Domiciliary spirometry performed at baseline only</td>
<td>35 (34)</td>
<td>6 (35)</td>
<td>29 (34)</td>
<td>p&gt;0.99</td>
</tr>
<tr>
<td>Domiciliary spirometry performed within 6-months of baseline</td>
<td>51 (50)</td>
<td>9 (53)</td>
<td>42 (49)</td>
<td>p=0.79</td>
</tr>
<tr>
<td>Domiciliary spirometry performed within 12-months of baseline</td>
<td>6 (6)</td>
<td>0 (0)</td>
<td>6 (7)</td>
<td>p=0.59</td>
</tr>
<tr>
<td>Continued domiciliary spirometry use</td>
<td>10 (10)</td>
<td>2 (12)</td>
<td>8 (9)</td>
<td>p=0.67</td>
</tr>
</tbody>
</table>

Data expressed as n (%) or median (IQR) unless stated otherwise. IQR: interquartile range. Please note: number of physiologist contact attempts and attempts to achieve baseline data available in 92 patients, obstructive spirometry group n=15; non-obstructive spirometry group n=77.
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FUNDING INFORMATION
This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

CONFLICT OF INTEREST
Authors ZW, JHH, YG, JM, CR and SR have no conflict of interests to declare. P.H. Patel reports attending advisory boards for AstraZeneca, Celltrion Healthcare and GlaxoSmithKline; he has received speaker fees from AstraZeneca, GlaxoSmithKline, Novartis, and Sanofi/Regeneron; he has attended international conferences sponsored by AstraZeneca.

AUTHOR CONTRIBUTION
P.H. Patel and J.H. Hull conceived the study idea. J. Ming, C. Roberts and S. Rhamie led the virtual physiologist-led clinics and collected the data. Y. Ge, J. Ming and Z. Williams conducted study analysis. Z. Williams and JH Hull contributed to the preparation of the final manuscript. P.H. Patel and J.H. Hull act as guarantors of the paper, taking responsibility for the integrity of the work from inception to published article. All authors approve of final manuscript.
Figure 1

Initial Referral (n=112)
Consent obtained by clinician

Telephone Screening (n=112)
Study consent
Telephonic eligibility screening
Contraindications to spirometry

Patients excluded (n=10)
6, who failed to respond to communication
2, who were unable to perform technical acceptable spirometry
1, due to hospitalisation
1, no email access

Virtual physiologist led clinic appointment (n=102)
Contraindications reassessed
Baseline spirometry recorded

Stage I

Stage II

Stage III

Monitoring and review (n=102)
Spirometry performed during periods of exacerbation
Figure 2
Domiciliary Spirometry Advantages

- Enhanced ability to capture obstructive spirometry.
- Positive patient experience including financial savings.
- More frequent patient monitoring.
- Reduced carbon emission associated travel.

Domiciliary Spirometry Disadvantages

- Poor uptake and adherence.
- Cost of physiologist time.
- Poor spirometry technique and irreproducible result.
- Patient digital literacy challenges.
- DS device IT limitations.

Figure 4
Feasibility and value of a home spirometry programme in the assessment of severe asthma: a real-world evaluation: Supplementary material

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Addition Methodology

- Healthcare Associated Costs
- Patient Carbon Emission Calculator

Additional Results

- Carbon Emission Costs
ADDITIONAL METHODOLOGY

OUTCOMES

HEALTHCARE ASSOCIATED COST

The associated costs for the HSP include the one-time purchase of £167 per unit (including UK tax) for the MIR Spirobank smart spirometer, the cost of £2.99 delivery for the device to be posted to the patient’s residents, and the cost of the respiratory physiologist’s time to conduct virtual clinics, perform administrative duties and review results. See online repository for additional breakdown of HSP associated costs and costs associated with hospital-based spirometry.

The physiologist was employed as an National Health Service (NHS) band 7, which in accordance with 2022/23 NHS agenda for change pay-scales (higher cost area inclusive) equates to approximately £25 per hour. To determine the cost of physiologist time the HSP incurred, bank time sheets were reviewed. The hospital incurs a charge of £102 per test to perform a hospital-based spirometry assessment according to the 2023-2024 NHS national tariff health resource group (HRG) code DZ59Z. The additional costs of £1.50 is required for the bacterial filter and nose peg used per patients, the equipment rental and servicing contract the lung function department has with the manufacturing company currently costs approximately £9 per patient. The cost is calculated by sum of the two contracts relative to the total number of patients the department tested from the start to the end of the 2022 financial year. Furthermore, each spirometry test requires a band 6 NHS respiratory physiologist to perform, review and produce a report of the spirometry findings which based on the 2022/23 NHS agenda for changes (higher cost area inclusive) pay scales equates to approximately £21 per hour.
PATIENT CARBON EMISSION CALCULATOR

Initial analysis was performed to determine the carbon emissions generated by the patient travelling from their residence to the hospital by car or train. Google Maps routing tool was used to determine distance patients travelled to the hospital from their residency, expressed in miles. Carbon emissions associated with each journey were estimated using the London North-Eastern Railway calculator. The calculations are based on an average car emitting 0.359 kilograms of carbon dioxide equivalent (kgCO₂e) per mile and national rail train journeys 0.0715kgCO₂e. Conversion factors are all scopes taken from GOV.UK ‘Greenhouse gas reporting: conversion factors 2021’.(1)

ADDITIONAL RESULTS

CARBON EMISSION COSTS

Per hospital-based spirometry examination, the approximate carbon emission produced by patient travel via an average petrol car or train equates to 4.79kgCO₂e or 1.43kgCO₂e respectively. We did not calculate the carbon cost of producing the equipment, device delivery to the hospital and patient’s residence. Advantages and disadvantages of DS are presented in figure 4.

REFERENCES