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Home monitoring to detect progression of interstitial lung disease: A prospective cohort study

To the Editors:

Patients with interstitial lung disease (ILD) may experience acute exacerbations or disease progression with unpredictable inter-patient variability.[1] Traditional measures of disease severity, such as pulmonary function tests (PFT), might not fully capture the complexities of the disease.[2] ILD patients often endure symptoms including cough, dyspnoea and fatigue, impacting their quality-of-life (QoL).[3] Evidence for home-monitoring in managing ILD has increased in recent years, with home-spirometry gaining attention.[4,5] Despite technical issues,[5] studies have demonstrated that home-spirometry can predict outcomes by monitoring the rate of decline in FVC, and its measures correlate with hospital-spirometry.[2,4,6]

A significant gap remains in the current literature; specifically, there is scant evidence supporting the benefit of continuous monitoring of both physiological parameters and symptoms in detecting progression or response to treatment.[2,3,6] The potential of this approach to augment or replace in-hospital spirometry offers an interesting possibility. This study evaluated a real-time multimodal program using commercially available technology to detect outcomes in ILD through continuous monitoring of physiological parameters and symptoms.

In this prospective observational cohort study, 20 IPF and non-IPF patients, as diagnosed by a multidisciplinary team were recruited from the University College London Hospital (UCLH) between August 2021 and January 2022 using 2018 ATS criteria. Patients who met the criteria for ILD other than IPF, including those with sarcoidosis, and hypersensitivity pneumonitis, were grouped together as non-IPF. They were monitored over 26 weeks using the RADAR-Base mHealth platform. Data collection tools included: questionnaires, a Garmin wearable device, finger pulse oximeter and a NuvoAir smart-spirometer.[7] In addition, participants underwent lung function testing in a hospital setting as part of their usual hospital visits. Patients were divided into two groups: progressed and stable. Progression was defined as a ≥5% decline in forced vital capacity (FVC) at[6] months by hospital-based spirometry and/or death. The protocol is available online.[7]

Data are represented as frequencies, percentages and mean ± SD or as median and interquartile range (IQR). Paired *t*-tests for normally distributed data, and the Wilcoxon signed-rank tests were applied for non-normal distributed data. Excluding initial week data for training effect, we compared the mean of 7 days of daily home-spirometry to hospital measures.

Only ATS-acceptable measurements were analysed to ensure accuracy. A box and whisker plot were used to visualize the rate of change in hospital-spirometry in relation to other physiological parameters and symptoms. A linear regression model calculated changes in physiological parameters and symptoms over the follow-up time. Rate of change was defined as the percentage change relative to baseline values, calculated without imputing missing data. All statistical analyses were run using Python libraries (version 3.11.1).

Baseline questionnaire scores differed between progressed and non-progressed groups (Table 1).

The statistical comparison of home spirometry measurments between progressed and stable groups was signifcant, with *p*-values of 0.015 over three months and 0.003 over six months (Figure 1A,B). A significant $FVC_{HOSPITAL}$ decline rate of 5% or more was noted for three patients, and an additional three patients died during the study. There was a strong correlation between home and hospital FVC measurements (Figure 1C). Home measurements from patients mirrored these findings, with clear differences in FVC_{HOME} between progressed and stable groups. At baseline, the stable group had a mean FVC_{HOME} of 2.76 L (±1.23 L) and 2.86 L (±1.35 L) at six months, with a mean difference (MD of 0.10 L (Figure 1D). Conversely, the progressed group had a mean FVC_{HOME} of 2.16 L (±0.42 L) at baseline, which declined to 1.91 L (±0.49 L) at six months, a mean difference (MD) of −0.25 L (Figure 1E). A comparative analysis of the stable and progressed patient groups revealed significant differences in the FVC_{HOME} rate of change (RoC) at three and six months. In the stable group ($n = 11$), the FVC_{HOME} RoC over six months showed a mean of 3.46%, while the mean was 0.18% over the three-month period (Figure 1D). In contrast, the progressed group ($n = 6$) demonstrated a mean FVC_{HOME} RoC of −12.90% decrease at six months and −9.09% at three months (Figure 1E).

The mean difference in finger pulse oximeter heart rate values (HR_{FINGER}) between the progressed and stable groups

TABLE 1 Baseline characteristics.

Description	Label	Progressed		Stable		Total		p-value
		N	%	*N*	%	*N*	%	
Gender	Male	5	25%	4	20%	9	45%	0.049
	Female	1	5%	10	50%	11	55%	
Age (years)			63 ± 9*		58 ± 15*		59 ± 13*	0.45
BMI (kg/m^2)			28.24 ± 4.05*		31.47 ± 7.15*		29.38 ± 6.45*	0.22
Ethnicity	White	2	10%	6	30%	8	40%	0.03
	Black			6	30%	6	30%	
	Asian	4	20%	2	10%	6	30%	
Diagnosis	IPF	4	20%	1	5%	5	25%	0.013
	Non-IPF	2	10%	13	65%	15	75%	

Baseline characteristics	Median or mean	IQR or SD	Median or mean	IQR or SD	Median or mean	IQR or SD	p-value
FVC_{HOME} (L)	2.16	0.42	2.76	1.23	2.52	1	0.29
HR (bpm)$_{FINGER}$	76.83	12.98	80.55	11.59	80.2	17.53	0.23
HR (bpm) $_{GARMIN}$	72.14	12.94	78.53	8.36	77.85	11.63	0.039
FSS score	4.5	1.22	5.36	1.5	5.1	1.45	0.23
VAS	39	35.38	35	33.56	33.56	36.5	0.78

Note: Data are presented as frequency and percentages unless indicated * (mean ± SD). The table includes the *p*-value for each variable. If the continuous data is normally distributed, we used a *t*-test; otherwise, we used the Mann–Whitney test. For categorical data, we used the chi-square test. Baseline characteristics: data are presented as (mean ± SD), unless indicated * median (IQR).
Abbreviations: FSS, Fatigue Severity Scale; HR, heart rate; VAS, Visual Analogue Scale.

was statistically significant, with a *p*-value of 0.03 (Figure 1F). For the progressed group, the mean heart rate from Garmin wearable devices (HR_{GARMIN}) at baseline was 72 ± 13 bpm, which increased to 81 ± 16 bpm after six months. The stable group demonstrated a decrease in HR_{GARMIN} from a baseline mean of 79 ± 8 bpm to 76 ± 7 bpm after six months. The mean difference between the two groups was statistically significant, with a value of −11 bpm and a *p*-value of 0.02 (Figure 1G). When considering $SpO_{2FINGER}$, the difference between the groups was not statistically significant (*p*-value = 0.24) (Figure 1H).

The mean score of the cough severity Visual Analogue Scale (VAS) for the progressed group was 36.4 ± 34.0 mm at baseline, and increased to 49.7 ± 40.1 mm. In contrast, the stable group's baseline VAS mean score was 30.9 ± 29.9 mm, which decreased to 21.7 ± 24.6 mm at six months. The VAS score change between the two groups was statistically significant, with a mean difference of −22.5 mm and a *p*-value of 0.002 (Figure 1I). The mean Fatigue Severity Scale (FSS) increased from 4.67 ± 1.0 to 5.4 ± 0.8 in the progressed group. In contrast, the mean FSS decreased from 4.5 ± 2.0 to 4.3 ± 1.9 in the stable group. The FSS score over time trended towards, but was not statistically significant, with a *p*-value of 0.06 (Figure 1J).

Our study is one of the first to employ a comprehensive multidimensional remote monitoring system to investigate the potential of home-monitoring to detect progression in ILD. Our findings present early evidence demonstrating that home-spirometry, heart rate, VAS for cough and fatigue are indicators of disease progression. There was a strong correlation between hospital and home FVC measurements ($r = 0.82$; $p < 0.0001$), with home-spirometry data mirroring hospital-spirometry trends. This implies that home-monitoring of FVC complements hospital measurements and highlights the potential value of regular home measurements for early detection of disease progression. This echoes existing literature on the importance of regular home-spirometry measurements in ILD patients to capture rapid disease progression that is usually not identified during less frequent hospital visits.[2,6]

As suggested, poorer lung function may lead to increased cardiovascular burden, our study found most patients in the progressed group showed an increase in both Garmin and finger oximeter HR over six months, while the stable group demonstrated a decrease, providing evidence of the potential of HR as an additional physiological indicator of disease progression in ILD. These findings agree with previously published studies, which indicated that cardiovascular parameters, including HR, can reflect changes in physiological conditions.[4] A future area of interest will be to explore the relationship of physiological, imaging and serum biomarkers with home spirometry to ensure early and accurate stratification of patients and prediction of outcomes. When assessing fatigue, the progressed group showed an increased mean FSS. Although this trend was not statistically significant, with a *p*-value of 0.06, it suggests a potential link between fatigue and disease progression, reinforcing the importance of fatigue assessment.[8,9] Our findings of a statistically significant difference in VAS cough severity between the groups support the findings of previous studies, which suggest that changes in VAS is a reliable indicator of disease progression.[10]

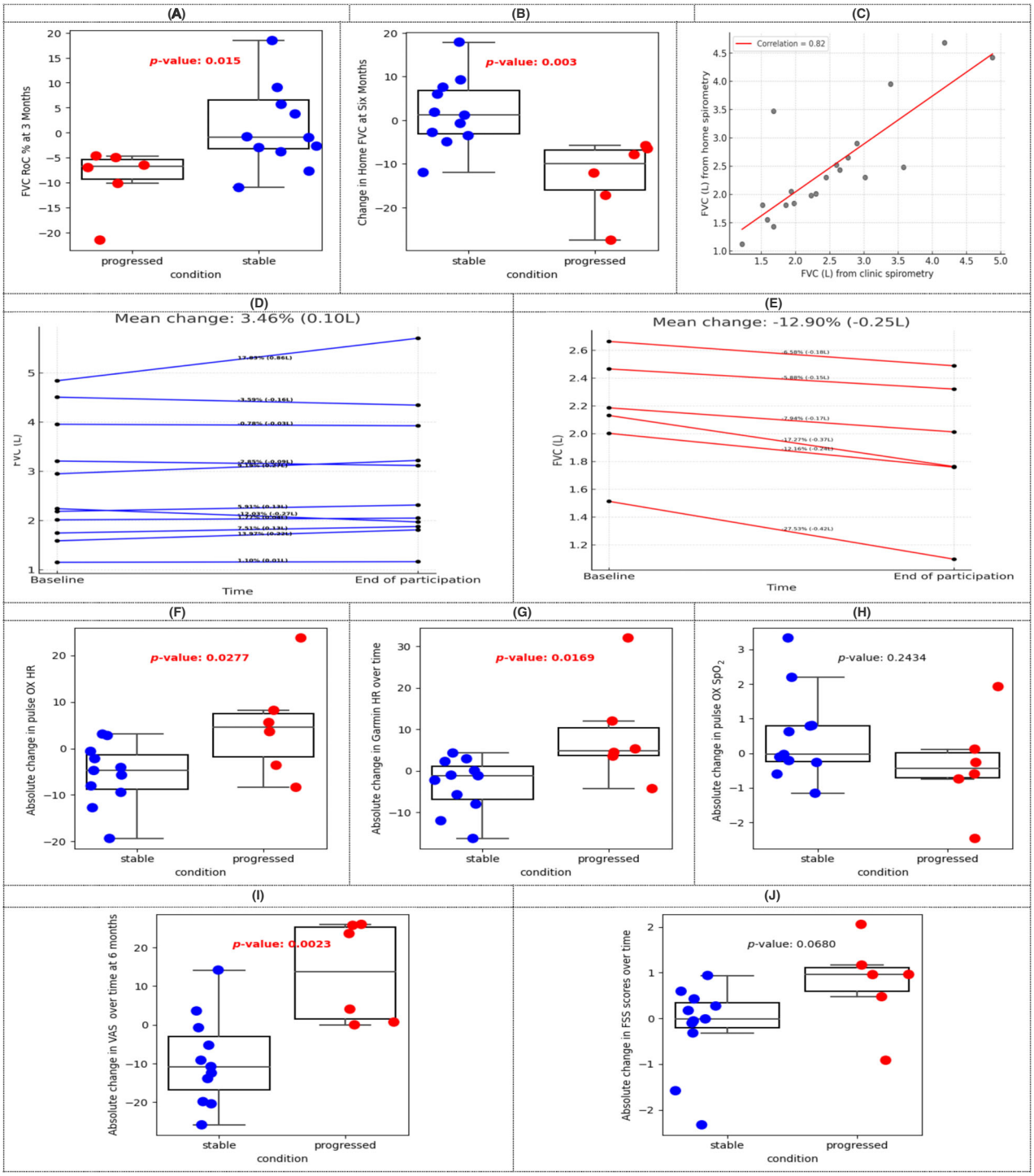

FIGURE 1 (A) and (B) show the different trends in FVCHOME changes over the study period. The progressed group is in red, while the stable group is shown in blue. Each point on the figures represents the rate of change (RoC) from baseline FVCHOME. (C) Correlation of clinic versus home handheld spirometry. (D) and (E) Daily forced vital capacity FVC (L) values were plotted for each participant. The rate of change in FVC over 180 days was calculated by regression line. The difference between the last day of participation and the first day of participation in the fitted line was calculated and then divided by the first-day value in the fitted line and multiplied by 100. (F)–(H) box and whiskers plots show the different trends in heart rate (HRFINGER), (HRGARMIN) and (SpO_2FINGER). (I) and (J) show the box and whiskers plot for the Visual Analogue Scale (VAS), and for the Fatigue Severity Scale (FSS), respectively.

Limitations include potential bias from self-reported questionnaires, limited hospital measurements, small sample size and follow-up period.

This study demonstrated that remotely measured disease progression in ILD is associated with worsening cough, fatigue and an increased heart rate. These findings highlight

the potential of home measurements to understand the progression of ILD and lay the groundwork for larger studies, including the development of progression detection models and real-time interventions.

AUTHOR CONTRIBUTIONS

Malik A. Althobiani: Conceptualization (lead); data curation (lead); formal analysis (lead); funding acquisition (lead); investigation (lead); methodology (lead); project administration (lead); resources (lead); software (lead); supervision (lead); validation (lead); visualization (lead); writing – original draft (lead); writing – review and editing (lead). **Yatharth Ranjan:** Conceptualization (lead); data curation (lead); formal analysis (lead); funding acquisition (lead); investigation (lead); methodology (lead); project administration (lead); resources (lead); software (lead); supervision (lead); validation (lead); visualization (lead); writing – original draft (lead); writing – review and editing (lead). **Anne-Marie Russell:** Supervision (lead); visualization (lead); writing – original draft (lead); writing – review and editing (lead). **Joseph Jacob:** Conceptualization (lead); investigation (equal); methodology (lead); project administration (lead); supervision (equal); visualization (equal); writing – original draft (equal); writing – review and editing (lead). **Michele Orini:** Conceptualization (lead); methodology (lead); project administration (equal); supervision (equal); visualization (equal); writing – original draft (equal); writing – review and editing (equal). **Heet Sankesara:** Validation (equal); visualization (equal); writing – review and editing (supporting). **Pauline Conde:** Validation (equal); visualization (equal); writing – review and editing (supporting). **Zulqarnain Rashid:** Validation (equal); visualization (equal); writing – review and editing (supporting). **Richard J. B. Dobson:** Conceptualization (lead); data curation (lead); formal analysis (lead); funding acquisition (lead); investigation (lead); methodology (lead); project administration (lead); resources (lead); software (lead); supervision (lead); validation (lead); visualization (lead); writing – original draft (lead); writing – review and editing (lead). **John R. Hurst:** Conceptualization (lead); data curation (lead); formal analysis (lead); funding acquisition (lead); investigation (lead); methodology (lead); project administration (lead); resources (lead); software (lead); supervision (lead); validation (lead); visualization (lead); writing – original draft (lead); writing – review and editing (lead). **Joanna Porter:** Conceptualization (lead); data curation (lead); formal analysis (lead); funding acquisition (lead); investigation (lead); methodology (lead); project administration (lead); resources (lead); software (lead); supervision (lead); validation (lead); visualization (lead); writing – original draft (lead); writing – review and editing (lead). **Amos Folarin:** Conceptualization (lead); data curation (lead); formal analysis (lead); funding acquisition (lead); investigation (lead); methodology (lead); project administration (lead); resources (lead); software (lead); supervision (lead); validation (lead); visualization (lead); writing – original draft (lead); writing – review and editing (lead).

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CONFLICT OF INTEREST STATEMENT

None declared.

DATA AVAILABILITY STATEMENT

Data are available on request from the corresponding author.

HUMAN ETHICS APPROVAL DECLARATION

This study was performed in accordance with the Declaration of Helsinki. This human study was approved by West Midlands-Black Country Research Ethics Committee (approval: 21/WM/0087). Participant registration took place from August 2021 to January 2022. All adult participants provided written informed consent to participate in this study.

Clinical trial registration: ISRCTN16275601 at www.isrctn.com/.

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