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# Home monitoring of lung function, symptoms and quality of life after admission with COVID-19 infection: The HOMECOMIN' study

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## Abstract

**Background and objective:** To develop targeted and efficient follow-up programmes for patients hospitalized with coronavirus disease 2019 (COVID-19), structured and detailed insights in recovery trajectory are required. We aimed to gain detailed insights in long-term recovery after COVID-19 infection, using an online home monitoring programme including home spirometry. Moreover, we evaluated patient experiences with the home monitoring programme.

**Methods:** In this prospective multicentre study, we included adults hospitalized due to COVID-19 with radiological abnormalities. For 6 months after discharge, patients collected weekly home spirometry and pulse oximetry measurements, and reported visual analogue scales on cough, dyspnoea and fatigue. Patients completed the fatigue assessment scale (FAS), global rating of change (GRC), EuroQol-5D-5L (EQ-5D-5L) and online tool for the assessment of burden of COVID-19 (ABCoV tool). Mixed models were used to analyse the results.

**Results:** A total of 133 patients were included in this study (70.1% male, mean age 60 years [SD 10.54]). Patients had a mean baseline forced vital capacity of 3.25 L (95% CI: 2.99–3.44 L), which increased linearly in 6 months with 19.1% (Δ0.62 L, $p < 0.005$). Patients reported substantial fatigue with no improvement over time. Nevertheless, health status improved significantly. After 6 months, patients scored their general well-being almost similar as before COVID-19. Overall, patients considered home spirometry useful and not burdensome.

**Conclusion:** Six months after hospital admission for COVID-19, patients' lung function and quality of life were still improving, although fatigue persisted. Home monitoring enables detailed follow-up for patients with COVID-19 at low burden for patients and for the healthcare system.

KEYWORDS
chronic lung disease, coronavirus disease, COVID-19, eHealth, health-related quality of life, home spirometry, patient-reported outcome measures, telemedicine

This study was previously presented at the 2021 Annual Congress of the European Respiratory Society (ERS).

## INTRODUCTION

With more than 424 million cases and almost 6.4 million deaths worldwide in February 2022, the coronavirus disease 2019 (COVID-19) pandemic has enormous impact on worldwide healthcare systems.[1] Hospitalization rates are estimated to be around 5% in patients with COVID-19.[2,3] Not only hospital admissions have impacted our healthcare systems, but also the aftercare and follow-up of COVID-19 patients after discharge.

The long-term effects of COVID-19 have been described in different studies. Months after COVID-19 infection, many patients still have lung function impairment and experience fatigue, muscle weakness, joint pain and psychological problems, with significant impact on quality of life.[4–6] Although the total number of patients with post COVID-19 sequelae is large and continues to expand, there is no consensus on follow-up schedules after hospitalization. Different follow-up strategies have been proposed[7–9]; however, the optimal frequency of hospital visits and best time points for lung function testing and imaging still need to be determined. To develop targeted and efficient follow-up programmes, more structured and detailed insights in recovery trajectory of patients are required.

Together with patients, we developed an online home monitoring programme for interstitial lung diseases (ILD), including home spirometry and patient-reported outcome measures (PROMs). This online home monitoring programme has shown to be feasible, reliable and much appreciated by patients.[10–13] It facilitates detailed insights in disease course at low burden for patients and healthcare providers, and continuity of care during the COVID-19 pandemic.[14] We modified this existing online home monitoring programme into a version for patients with COVID-19 that could be used for home-based follow-up after hospital discharge.

In this study, we aimed to gain more detailed insights in long-term recovery after COVID-19, using an online home monitoring programme. Moreover, we evaluated patient experiences with the home monitoring programme.

### SUMMARY AT A GLANCE

We aimed to gain insights in the long-term recovery after coronavirus disease 2019 (COVID-19) infection using an online home monitoring programme including home spirometry. Six months after hospital admission, quality of life and lung function were still improving; however, fatigue persisted. Home monitoring enables detailed follow-up at low burden for patients and hospital systems.

## METHODS

### Study design and participants

This is an ongoing observational, multicentre study conducted at three hospitals in the Netherlands. Adults (≥18 years) were eligible for participation if they had PCR-proven COVID-19 and parenchymal abnormalities on imaging during hospital admission. Patients without internet access were excluded. Patients were either included at discharge, or during their first regular outpatient clinic visit 6 weeks after discharge. Patients were followed up for at least 6 months after discharge.

### Study procedures

Data were collected via the Conformité Européenne (CE)-certified HOMECOMIN' application (Curavista©, The Netherlands). We have adapted the HOMECOMIN' application from a previous version of the application for ILD.[13] Patients have real-time access to their own data. Data are directly sent to the healthcare team through the application. The application includes home spirometry, using a validated Bluetooth-enabled home spirometer (Spirobank Smart, MIR©, Italy). Patients were asked to perform daily home spirometry (forced vital capacity, FVC) during the first 2 weeks after hospital admission and weekly home spirometry (three consecutive measurements a day at approximately the same time) thereafter. The highest of these three values was used for further analysis. In addition, patients reported weekly pulse oximetry results and completed visual analogue scales (VAS) on cough, fatigue and dyspnoea via the application. Different health-related quality of life and other PROMs were collected at discharge, 6 weeks, 3 months and after 6 months. Included questionnaires were the EuroQol five dimensions 5-level questionnaire (EQ-5D-5L),[15] the fatigue assessment scale (FAS)[16] the global rating of change (GRoC)[17] and the online tool for the assessment of the burden of COVID-19 (ABCoV tool).[18] All results are visualized in graphs and directly available for patients and healthcare team (Figure 1 and Figure S2 in the Supporting Information).

VAS scores ranged from 0 to 10, with a higher score indicating more severe symptoms. The EQ-5D-5L consists of five questions on a 5-point Likert scale and a VAS on general health status with scores from 0 to 100. Higher scores indicate better health status. The FAS is a 10-item self-administered questionnaire about fatigue. The score ranges from 5 to 50 points, with a score of ≥22 points as cut-off for fatigue. The GRoC scale is a 1-item questionnaire in which patients describe their current well-being compared to a previous moment on a Likert scale from −7 (a very great deal worse) to 7 (a very great deal better). The ABCoV tool is created to monitor COVID-19 patients over time. The tool has been adapted from the assessment of burden of chronic obstructive pulmonary disease (ABC) tool, which is used for patients with chronic obstructive pulmonary disease (COPD).[19] The questionnaire consists of several domains, such as functional status, mental status, emotions and fatigue, BMI, smoking status and different symptoms. A 7-point Likert scale was used for all domains other than the risk factors. Higher score on the Likert scale

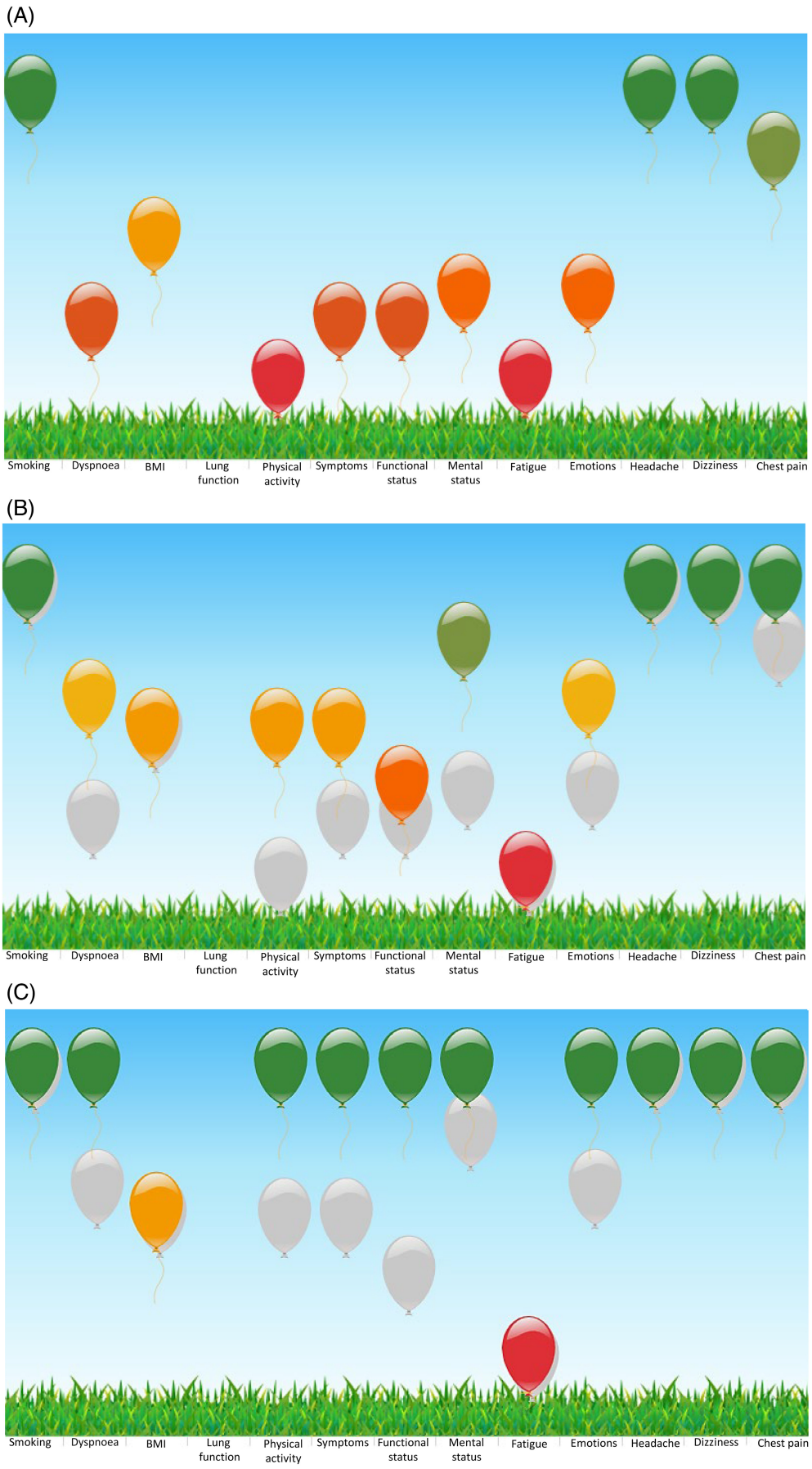


**FIGURE 1** Visualization of the online tool for the assessment of the burden of COVID-19 (ABCoV tool) over time. Green balloons indicate a satisfactory score, orange balloons an intermediate score and red balloons a low score. Grey balloons represent the location of the previous balloons. (A) ABCoV tool assessed at baseline. (B) ABCoV tool assessed at 3 months. (C) ABCoV tool assessed at 6 months

indicates more burden. The Clinical COPD Questionnaire (CCQ) is part of the ABCoV tool, providing information on health status. A higher score indicates a lower overall health status. Symptoms in the ABCoV tool are scored on a VAS ranging from 0 to 10, with a higher score indicating more complaints. Outcomes are visualized using coloured balloons. Green balloons indicate a satisfactory score, orange balloons an intermediate score and red balloons a low score. Grey balloons represent the location of the previous balloons (Figure 1). Experiences and satisfaction on the use of the home monitoring programme were assessed using a 9-item questionnaire with scores ranging from 0 to 10. A higher score indicates a better score, except for 'burdensome', where scores are reversed.

Schedules for outpatient clinic follow-up differed per hospital, but all patients were seen at 3 months after discharge. At this visit, we collected hospital-based lung function measurements, consisting of FVC and diffusing capacity of the lung for carbon monoxide adjusted for haemoglobin (DLCO). The Global Lung Function Initiative Network (GLI) reference values were used; a $Z$-score of $-1.64$ was defined as the lower limit of normal (LLN).[20,21] In addition, HRCT data were obtained. HRCT images were scored for the presence of air trapping, consolidations, fine reticulations, ground-glass opacification and traction bronchiectasis and/or bronchiolectasis.

## Statistical analysis

Baseline characteristics, patient experiences and ABCoV tool domains were analysed using descriptive statistics. Normally distributed data were reported with mean and SD. Non-parametrically distributed data were reported with median and interquartile range (IQR). Home-based FVC, oxygen saturation and PROMs were analysed using linear mixed models accounting for within-patient correlations. Time in days was added as fixed effect, and we included random intercepts and random slopes. We assumed that the missing data in the outcomes were missing completely at random or missing at random. We used Pearson correlation coefficient to determine the correlation between in-hospital lung function and home spirometry results.

Due to the high number of zeros and non-normal distribution of data, weekly VAS were analysed using hurdle mixed models. Hurdle models are two-part models, used in data with excess zeroes, where the zero part is modelled separately from the non-zero part.[22,23] For our models, we assumed the non-zero part as log-normal data. For the non-zero part of the model, we included time in days as a fixed effect and random intercepts and random slopes. For the zero part, we included time in days as a fixed effect. Marginal coefficients were calculated to summarize coefficients of the two parts of the model to obtain one overall estimate.

For all models, we investigated the residuals to evaluate the assumptions of the models.

All data were analysed using SPSS version 25.0.0.1. (IBM) and R (version 4.1.0). We used package nlme for the mixed models, GLMMadaptive for the hurdle models and DHARMA package for the residuals of the hurdle models.

# RESULTS

A total of 133 patients were included between May 2020 and February 2021. Sixteen patients withdrew before the start of the study, and their data were excluded from analysis. 70.1% of the patients were male, and the mean age was 60 years (SD 10.5). Median time between diagnosis and admission was 0 days (IQR: 0–5). Forty-nine patients had been admitted to the intensive care unit (ICU) for mechanical ventilation; median duration of mechanical ventilation was 18 days (IQR: 9–30). Median duration of hospital admission in the overall cohort was 13 days (IQR: 5–31), and in the cohort admitted to the ICU 36 days (IQR: 20–53). Baseline characteristics are described in Table 1.

## Spirometry, pulse oximetry and imaging

One hundred and one patients (86%) performed home spirometry. Patients had a mean baseline FVC of 3.25 L (95% CI: 2.99–3.44 L). During 6 months after hospitalization, FVC increased significantly with 19.1% ($\Delta +$ 0.62 L, $p < 0.005$). At 6 months, lung function was still linearly increasing (Figure 2). An example of home spirometry values over time in an individual patient is presented in Figure S2 in the Supporting Information. Adherence to weekly spirometry decreased over time, with 86.1% of patients performing weekly home spirometry after 3 months, and 74.2% after 6 months. Ninety patients (77%) performed in-hospital lung function measurements 3 months after discharge. Mean FVC was 3.86 L (SD 1.12) or 91.16% of predicted (SD 16.37). Mean forced expiratory volume in 1 s (FEV1) was 2.97 L (SD 0.92) or 89.01% of predicted (SD 16.98). Mean FEV1/FVC ratio was 0.78 (SD 0.15). Mean DLCO was 78.20% (SD 18.11). Of all patients, 74.4% had an FVC above the LLN. 78.9% of the patients had an FEV1 above the LLN and 82.2% of the patients had an FEV1/FVC ratio above the LLN. 58.6% ($n = 87$) had a DLCO above the LLN. Correlation between home spirometry and in-hospital measurements at 3 months was very strong ($r = 0.93$, $p < 0.001$). One hundred and five patients collected pulse oximetry data; mean baseline value was 96.1% (95% CI: 95.72–96.49). There was a small significant but clinically irrelevant increase of 0.4% over a period of 6 months ($p < 0.005$). At 3 months, 67.4% of patients had an abnormal computed tomography scan, mostly showing traction bronchiectasis and/or bronchiectasis (38.2%), ground-glass opacifications (38.2%), fine reticulations (22.5%), consolidation (13.5%) and air trapping (6.7%).

**TABLE 1** Patient characteristics

| Demographics | ($n = 117$) | |
|---|---|---|
| Male | 82 | 70.1% |
| Age, years (mean, SD) | 60 | 10.42 |
| Smoking status | | |
| Former | 46 | 39.3% |
| No | 63 | 53.8% |
| Yes | 8 | 6.8% |
| BMI (mean, SD) ($n = 97$) | 29.02 | 5.41 |
| Immunosuppressive medication for other diseases | 15 | 12.8% |
| Comorbidities | | |
| Cardiovascular disease | 50 | 42.7% |
| Cerebrovascular disease | 2 | 1.7% |
| Deep venous thrombosis | 1 | 0.9% |
| Pulmonary embolism | 2 | 1.7% |
| Diabetes mellitus | 23 | 19.7% |
| Autoimmune disorder | 8 | 6.8% |
| Lung cancer | 3 | 2.6% |
| Asthma | 13 | 11.1% |
| COPD | 8 | 6.8% |
| Bronchiectasis | 1 | 0.9% |
| Obstructive sleep apnoea | 7 | 6.0% |
| Depression/depressive disorder | 1 | 0.9% |
| Hypercholesterolaemia | 6 | 5.1% |
| Obesity | 6 | 5.1% |
| Kidney transplant | 3 | 2.6% |
| Hospital admission | | |
| Time from diagnosis till admission, days (median, IQR) | 0.0 | 0.0–5.0 |
| Admission duration, days (median, IQR) | 13.0 | 5.0–30.8 |
| Admission duration for ICU patients (median, IQR) | 36.0 | 20.0–52.5 |
| Admission duration for non-ICU patients (median, IQR) | 6.0 | 4.0–10.0 |
| Mechanical ventilation | 49 | 41.9% |
| Duration of mechanical ventilation, days (mean, SD) | 21.29 | 14.68 |
| Other oxygen suppletion | | |
| Nasal cannula | 46 | 34.6% |
| Non-rebreather mask | 8 | 6.0% |
| Partial rebreather mask | 1 | 0.8% |
| Air entrainment mask (Venturi) | 2 | 1.5% |
| Nasal high-flow oxygen therapy | 6 | 4.5% |
| Unknown | 2 | 1.5% |
| Immunosuppressive medication for COVID-19 | | |
| Prednisolone | 4 | 3.4% |
| Dexamethasone | 48 | 41.0% |
| Methylprednisolone | 3 | 2.6% |
| Hydroxychloroquine | 1 | 0.9% |
| Tocilizumab | 1 | 0.9% |
| Delirium | 35 | 29.9% |
| Thromboembolic events | 28 | 23.9% |

Abbreviations: COPD, chronic obstructive pulmonary disease; COVID-19, coronavirus disease 2019; ICU, intensive care unit; IQR, interquartile range.

## Patient-reported outcome measures

Estimated cough score, as modelled by the hurdle model, directly after hospital admission was 1.03 (95% CI: 0.88–1.21), with no significant difference over time ($\Delta + 0.13$, $p = 0.56$). Baseline dyspnoea score was 3.61 (95% CI: 2.69–4.84) and did not change over time ($\Delta - 0.80$, $p = 0.32$). Patients had a baseline VAS fatigue score of 5.29 (95% CI: 4.34–6.45), with no improvement in 6 months ($\Delta - 0.87$, $p = 0.31$). Similar to the results of the VAS fatigue, the FAS showed a high baseline score of 23.23 (95% CI: 20.93–25.33), with stable fatigue over time ($\Delta + 2.21$, $p = 0.36$). The mean baseline EQ-5D-5L utility score was 0.71 (95% CI: 0.65–0.74) and improved significantly during the study ($\Delta + 0.12$, $p < 0.001$). Baseline GRoC score was −3.52 (95% CI: −4.48 to −2.86). Scores improved significantly to a mean of 0.23 ($\Delta + 3.39$, $p < 0.001$) after 6 months, indicating that patients scored their general well-being almost the same as before COVID-19. Results are visualized in Figure 3. The mean baseline score of the CCQ was 1.89 (95% CI: 1.72–2.15) and showed a significant improvement over time ($\Delta - 1.00$, $p < 0.001$). An overview of other domains of the ABCoV tool over time is shown in Figure S1 in the Supporting Information.

## Patient experiences

Fifty-nine patients (50%) completed the questionnaire on experiences and satisfaction with the home monitoring programme. More than three-quarters (76.3%) would recommend the home monitoring programme to others, and 59.3% would like to continue using the app. The remaining patients stated that home monitoring was no longer needed as they felt fully recovered. 76.3% of patients answered that home spirometry provided more insights in their recovery trajectory. In general, patients considered home spirometry useful, pleasant and not burdensome (Figure 4).

# DISCUSSION

In this study, we found that pulmonary function linearly increased during the first 6 months after hospital admission for COVID-19. Six months after discharge, FVC was still improving and had not reached a plateau, indicating that lung function is expected to further improve over time. However, symptoms such as fatigue and mild dyspnoea

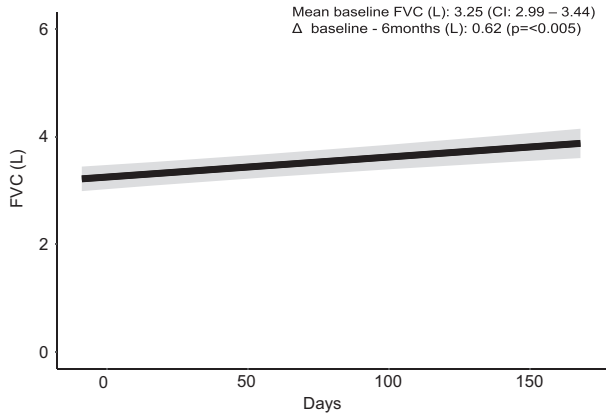


**FIGURE 2** Forced vital capacity over time measured with home spirometry ($n = 101$). The black line indicates the modelled trajectory based on the mixed model results, including the 95% CI in grey

persisted. Health status improved significantly over time, with general well-being after 6 months being valued almost the same as before the COVID-19 infection. Home monitoring provided patients better insights in their recovery trajectory, and was considered useful and not burdensome.

Previous studies in patients hospitalized for COVID-19 have shown that lung function improved over time in most patients.[6,24,25] Wu et al.[24] found that 77% of patients had a normal FVC at 3 months. Even though many included patients in our study had been admitted to the ICU (42%), 79% of patients had a normal FVC after 3 months, and DLCO normalized in 59% of the patients. The higher percentage of patients with impaired DLCO could also be partly due to pulmonary vascular abnormalities and should be monitored for a longer period of time. Compared with previous studies, we were able to describe a more granular overview of lung function recovery over time, because of the frequent home spirometry measurements.

Early in the pandemic, one of the most feared complications of COVID-19 was development of pulmonary fibrosis with progressive lung function impairment. Reasons for this were similarities in the pathophysiology of acute respiratory distress syndrome and pulmonary fibrosis, and development of pulmonary fibrosis in a subset of patients after severe acute respiratory distress syndrome coronavirus in 2003 and the Middle East respiratory syndrome coronavirus infection.[26,27] Therefore, studies on the use of anti-fibrotic medication in patients with post COVID-fibrosis are currently ongoing (NCT04856111, NCT04282902, NCT04541680, NCT04607928 and NCT04619680). Mean increase in FVC in our population was 19.1%. Therefore, although there may be a mechanistic rationale for the use of anti-fibrotic medication post-COVID, our data suggest that the target population for the use of anti-fibrotic medication post-COVID-19 will be limited.[28,29]

Our study confirmed that a majority of patients have remaining symptoms after COVID-19 infection, with fatigue being the most reported symptom.[30,31] Although lung function generally improved, mild complaints of dyspnoea persisted in many patients, which could possibly be due to deconditioning. Nevertheless, general well-being measured with the GroC scale indicated that patients returned to prior health, and health status measured with the EQ-5D-5L after 6 months was comparable to the Dutch norm population > 60 years.[32]

Several home monitoring programmes have been developed for patients with COVID-19, which aimed at early detection of disease deterioration for non-hospitalized patients, or facilitating earlier discharge by monitoring oxygen saturation at home.[33–35] In this study, we evaluated the use of an online home monitoring programme for patients recovering from severe COVID-19. We found a strong correlation between in-hospital measurements and home monitoring measurements, which is in line with previous studies.[10,12,36,37] Our home monitoring programme focuses on long-term monitoring and empowerment of patients after hospitalization. This can be especially useful for personalized follow-up and treatment of patients with long COVID. The patients can see a visual overview of their results, helping them gain detailed insights in disease course and become more confident with regard to their recovery process. Home monitoring could not only replace hospital visits, but also make hospital visits more structured and efficient. Replacement of hospital visits by home monitoring will probably also lead to reduction in healthcare costs and help lowering the burden on our healthcare system. We found that most patients were positive towards home monitoring, comparable with previous experiences in patients with ILD.[10–12,36] Moreover, this study confirmed that online home monitoring is feasible in elderly patients Nevertheless, adherence to home spirometry decreased over time. Patients stated that home monitoring was useful as it provided better insights in their recovery process, but had no added value after they felt fully recovered. Thus, in patients with a fast recovery trajectory, the additive value of home monitoring is likely limited.

We believe that home monitoring can be used to gain better insights in the recovery trajectory of the individual patient, and provide personalized care after hospital admission. In-hospital follow-up could be discontinued earlier, guided by home monitoring results. In addition, home monitoring has the potential to identify the small group of patients with abnormal recovery trajectories or who may develop progressive pulmonary fibrosis. For patients with persisting symptoms, the home monitoring tool can also facilitate home-based interventions, such as pulmonary rehabilitation.[38] The current study shows the feasibility of home monitoring in this patient group, but future studies should further confirm the hypotheses regarding potential benefits.

The strengths of this study are its prospective multicentre design, and the inclusion of patients during both first and second COVID-19 waves. This study also had some limitations. Many patients were not able to participate at the time of discharge from the hospital as they were still too weak. Patients were often transferred from the hospital to a rehabilitation centre before they could return to their homes. We therefore also included patients 6 weeks after

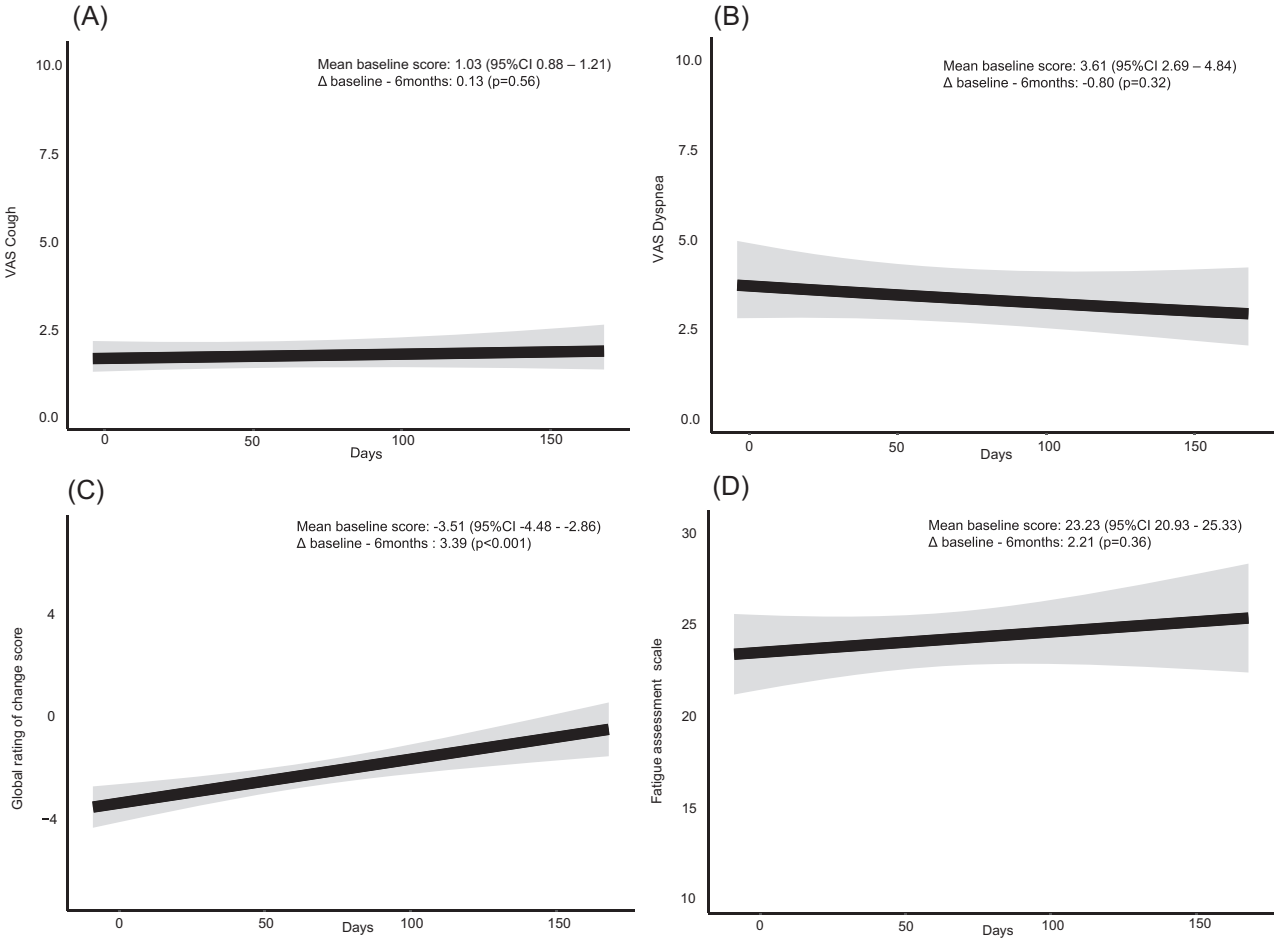


**FIGURE 3** Patient-reported outcome measures over time. The black line indicates the modelled trajectory based on the mixed model results, including the 95% CI in grey. (A) Visual analogue scale (VAS) on cough ($n = 106$). (B) VAS on dyspnoea ($n = 106$). (C) Global rating of change ($n = 109$). (D) Fatigue assessment scale ($n = 111$)

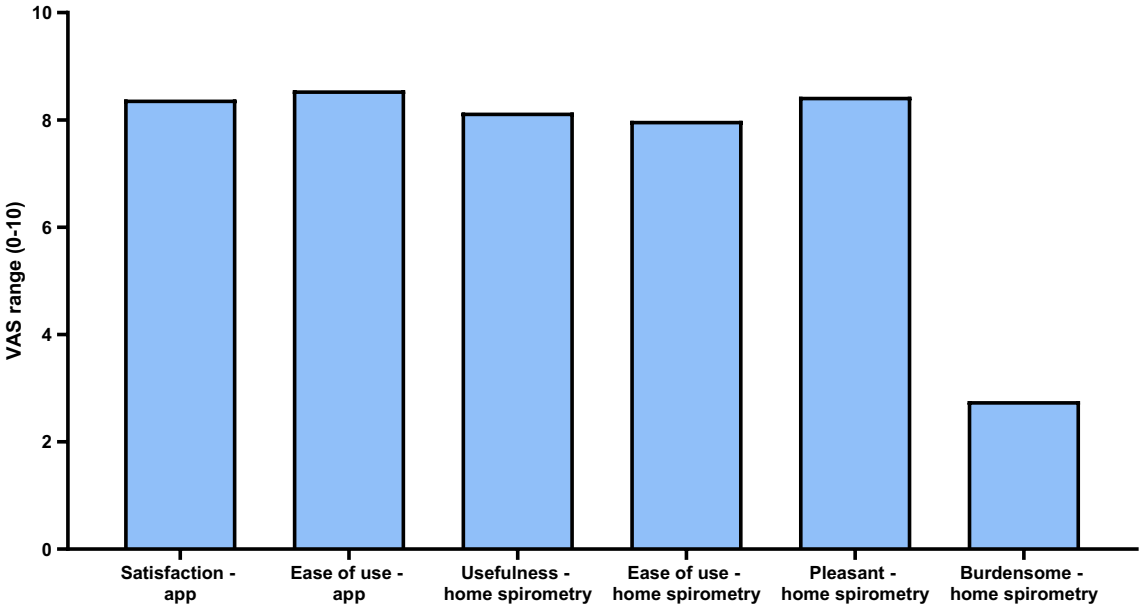


**FIGURE 4** Patient experiences with the home monitoring app and home spirometry, scored on visual analogue scales from 0 to 10. High scores indicate better experiences with the home monitoring app, except for 'burdensome' where scores are reversed

discharge, during regular outpatient clinic visits. Second, due to different follow-up schedules at the participating hospitals, we did not have access to serial in-hospital lung function measurements.

In conclusion, this study has provided detailed insights in recovery trajectory of patients hospitalized due to COVID-19. Six months after hospital admission, patients' lung function and quality of life were still improving, although fatigue persisted. Home monitoring programmes enable long-term detailed monitoring of patients and can facilitate personalized follow-up strategies in the future for patients with COVID-19 at low burden for patients and for the healthcare system.

## ACKNOWLEDGEMENT

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## CONFLICT OF INTEREST

None declared.

## AUTHOR CONTRIBUTION

**Gizal Nakshbandi:** Data curation (lead); formal analysis (lead); investigation (lead); methodology (lead); project administration (lead); resources (lead); software (lead); visualization (lead); writing – original draft (lead). **Catharina C. Moor:** Conceptualization (lead); data curation (supporting); formal analysis (supporting); funding acquisition (lead); investigation (supporting); methodology (lead); resources (lead); software (lead); supervision (equal); visualization (supporting); writing – original draft (lead). **Esther J. Nossent:** Conceptualization (supporting); data curation (supporting); funding acquisition (supporting); investigation (supporting); writing – review and editing (equal). **J. J. Miranda Geelhoed:** Conceptualization (supporting); data curation (supporting); funding acquisition (supporting); investigation (supporting); writing – review and editing (equal). **Sara J. Baart:** Formal analysis (equal); methodology (equal); visualization (supporting); writing – review and editing (equal). **Bart G. Boerrigter:** Conceptualization (supporting); data curation (supporting); investigation (supporting); writing – review and editing (equal). **Joachim G. J. V. Aerts:** Supervision (supporting); writing – review and editing (equal). **Suzan F. M. Nijman:** Data curation (supporting); investigation (supporting); writing – review and editing (equal). **Helger Y. Santema:** Data curation (supporting); investigation (supporting); writing – review and editing (equal). **Merel E. Hellemons:** Data curation (supporting); investigation (supporting); writing – review and editing (equal). **Marlies S. Wijsenbeek:** Conceptualization (lead); data curation (supporting); formal analysis (supporting); funding acquisition (lead); investigation (supporting); methodology (lead); resources (lead); software (lead); supervision (lead); visualization (supporting); writing – original draft (lead).

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

## HUMAN ETHICS APPROVAL DECLARATION

The study was performed in accordance with the Declaration of Helsinki, and approved by the Medical Ethics Committee of the Erasmus Medical Center (MEC-2020-0318) and participating sites. All participants provided written informed consent.

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## SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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