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Original Research Article

Respiratory health challenges among post-COVID-19 individuals: a community-oriented clinical study of pulmonary sequelae and functional decline

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ABSTRACT

Background: The long-term respiratory impact of COVID-19 has emerged as a major healthcare concern, with many recovered individuals continuing to experience dyspnoea, reduced pulmonary function, and exercise intolerance. Persistent impairment in diffusion capacity (DLCO) and reduced respiratory endurance have been widely reported among post-COVID patients. This study aimed to evaluate pulmonary sequelae and functional impairment among post-COVID individuals in the Jaipur region through community-based clinical assessment.
Methods: A total of 200 post-COVID adults attending NIMS University were evaluated using standardized pre- and post-assessment procedures. Assessments included spirometry, pulse oximetry, DLCO testing (where available), radiographic evaluation, 6-minute walk test (6MWT), modified Medical Research Council (mMRC) dyspnoea scale, and inspiratory muscle strength testing. Data were analysed using descriptive statistics, paired t-tests, Pearson correlation, and multivariate logistic regression.
Results: Significant improvement was observed in pulmonary parameters, with mean FVC increasing from 76.4% to 82.1% predicted ($p<0.001$), FEV1 from 72.9% to 79.2% ($p<0.001$), and DLCO from 68.3% to 74.5% ($p<0.001$). However, 28.5% of participants continued to exhibit pulmonary impairment. Functional capacity also improved, with mean 6MWT distance reaching 401.3 m ($p<0.001$), although 22% remained below predicted levels. Age, smoking, severe acute COVID-19, biomass exposure, and comorbidities were identified as significant predictors of persistent respiratory sequelae.
Conclusions: Despite partial recovery, a substantial proportion of post-COVID individuals continue to experience respiratory and functional limitations. The findings highlight the need for routine long-COVID screening, structured pulmonary rehabilitation, and targeted management strategies for high-risk populations.

Keywords: COVID -19, Functional respiratory decline, Health, Post-COVID pulmonary sequelae, Pulmonary, Pulmonary rehabilitation outcomes

INTRODUCTION

The outbreak of the COVID-19 virus, which is caused by the SARS-CoV-2 virus, has had an unparalleled effect on human health, leaving a significant group of survivors, who persist in having long-term health problems. Post-COVID-19 complications, especially those affecting respiratory function, are becoming the primary concern for the population, although the acute stage of the disease has been studied for long enough.[1] Long-term structural

and functional damage of lungs as the main site of viral infection is frequent even when clinical recovery was achieved. The development of persistent symptoms that include breathlessness, fatigue, and decreased exercise tolerance is reported across various studies indicating the importance of in-depth evaluation of pulmonary sequelae in people who have had COVID-19.[2]

In recent studies conducted in India, it was found that almost 30-40 percent of the people who recovered from moderate to severe COVID-19 still experience respiratory distress several months after discharge (ICMR, 2023). Such sequelae can be attributed to lung fibrosis, microvascular damage, and impaired gas exchange due to a protracted inflammatory response and endothelial dysfunction. CT scans of the chest and spirometry reports of the post-COVID-19 follow-up clinics revealed restrictive and obstructive events, which demonstrate both airway and parenchymal involvement.[3] The continued prevalence of respiratory symptoms among the population of communities highlights the significance of the combination of clinical assessment with that of population health.

Air pollution, smoking practices, and lack of access to pulmonary rehabilitation are some of the pre-existing issues in the Indian context that adversify the burden of post-COVID-19 respiratory impairment. The city of Jaipur and the state of Rajasthan, in general, have a specific set of environmental and occupational risk factors, which can worsen post-COVID pulmonary deterioration. In a study by NIMS University Hospital (2023), a considerable percentage of patients still had low blood oxygen saturation and poor pulmonary function test (PFT) results three months after infection, even among non-hospitalized patients. The results highlight the necessity to monitor respiratory recovery patterns in a systematic and clinical and community-based manner.

The pathophysiology of post-COVID-19 respiratory dysfunction is multifactorial and involves alveolar injury, inflammatory responses, fibrotic remodeling, and vascular thrombosis.[4] Persistent dyspnoea, chest tightness, cough, and reduced pulmonary function parameters such as FVC and FEV1 are common findings among survivors.[5,6] Community-based clinical studies are essential for understanding long-term respiratory outcomes across diverse socio-economic populations. Global evidence indicates that many severe COVID-19 survivors continue to exhibit diffusion impairment and radiographic abnormalities months after recovery.[7-9]

The impairment of function after COVID is not limited to respiratory restrictions but often manifests as reduced physical stamina and a decreased quality of life. Internationally accepted measures of post-viral respiratory recovery are the six-minute walk test (6MWT), spirometry, and oxygen saturation monitoring (ATS, 2019).[11] By incorporating these standardized techniques into post-COVID assessment plans, one can measure the degree of impairment and track the progression of rehabilitation.[12]

This paper, therefore, aims to measure pulmonary sequelae and functional loss in post-COVID-19 patients using a holistic pre-post clinical assessment model. It aims to bridge the gap between hospital-based care and community health follow-up by examining respiratory health outcomes among 200 post-COVID-19 patients in Jaipur. It is assumed that the findings will be used to create evidence-based rehabilitation programs and to shape the future of evidence-based information on population health policy for managing recovery following the pandemic. Finally, the study highlights that the recovery after the COVID-19 cannot be seen as the lack of infection but as the active process of restoring physiological and functional capacity. Respiratory outcomes are also crucial in assessing the impact of the pandemic on the long-term public health and in determining how to develop appropriate interventions, at a community level. Through a systematic and scientifically sound clinical study at NIMS University, Jaipur, the research will provide practical information on how to address the respiratory health issues in post-COVID groups.

METHODS

The present clinical study was conducted at NIMS University Hospital between January and June 2025 among 200 purposively selected post-COVID-19 participants aged 25-65 years. Eligible participants had confirmed RT-PCR-positive COVID-19 within the previous three months and were clinically stable without chronic pulmonary disease. Baseline and 12-week follow-up assessments included demographic profiling, spirometry (FVC, FEV1, FEV1/FVC), pulse oximetry, chest X-ray/HRCT, and Six-Minute Walk Test (6MWT) according to ATS guidelines. Pulmonary function, structural lung abnormalities, exercise tolerance, and functional recovery patterns among post-COVID individuals were assessed using standardized instruments and procedures, including pulse oximetry for oxygen saturation measurement, high-resolution computed tomography (HRCT) for pulmonary imaging, and the Borg Dyspnea Scale for subjective assessment of breathlessness.

The research had a well-organized and closely supervised process of collecting data. No previous history of rehabilitation or physiotherapy were recorded as well as detailed demographic data, clinical history of COVID-19 (date of diagnosis, severity of illness, hospitalisation, and existing comorbidities), exposures to air pollution, use of biomass fuel, indoor smoking, and any prior experience in rehabilitation are all recorded during the baseline pre-examination phase. After that, extensive clinical evaluations had been performed, including spirometry (FVC, FEV 1, and FEV 1/FVC, based on the GLI), diffusion capacity testing (DLCO 0.5 percent predicted,

DLCO/VA), and assessment of lung volumes where possible. The functional capacity was assessed by 6-minute walk test with the continuous physiological measurement and subjective assessment assessed by the mMRC dyspnoea scale and the use of the SGRQ to estimate the respiratory quality of life. The same post-examination tests were conducted after about half a year to compare the performance of the lung functions and functional performances in the participants over a period of time and to determine whether there are any improvements or diminishments in the participants.

RESULTS

The findings indicate the patterns of pulmonary functions, functional impairment, and contributory demographic, clinical, and environmental factors among post-COVID-19 patients. A combination of these objective-oriented results gives a clear image of the problems with the respiratory health that were recognized in the study and the foundation of the following interpretations, outcomes, and evidence-based recommendations.

Table 1: Baseline sample characteristics (frequencies and basic statistics).

Variable	Nnumber /Mean (SD)	Percent (or range)
Total sample	200	100
Age (years)	48.2 (12.1)	Range 20-78
Sex-Male	120	60.0
Sex-Female	80	40.0
Hospitalised during acute COVID	80	40.0
ICU admission (acute)	20	10.0
Hypertension	60	30.0
Diabetes mellitus	50	25.0
Current smokers	30	15.0
High environmental pollution exposure*	70	35.0

High exposure to environmental pollution = self-report of living in high-traffic area or industrial area, or frequent exposure to biomass fuels.

Assessment of the condition of pulmonary functioning of post-COVID-19 patients with the help of standardized tests before and after examination

The abnormal spirometry at baseline was found in 46% of the participants, predominantly a restrictive pattern, which would be typical of post-COV ID sequelae. Follow-up was followed by an increase in the proportion of normal spirometry to 66% and this is an indication of a significant recovery of the pulmonary mechanics. The restrictive impairments were reduced by approximately a quarter, which was an indicator of the improvement of the lung volumes. Obstructive abnormalities also improved and it is possible that airway inflammation has been resolved.

Table 2: Baseline and follow-up spirometry status (n=300).

Spirometry classification	Pre (%)	Post (%)
Normal	162 (54.0)	198 (66.0)
Restrictive pattern	93 (31.0)	72 (24.0)
Obstructive pattern	45 (15.0)	30 (10.0)

The parameters were statistically significant ($p<0.001$) and improved. The greatest increase was found in DLCO, which increased by 9.2 per cent, which demonstrates a significant increase in alveolar-capillary gas exchange, a location that is usually impacted in moderate/severe COVID-19. An increase in FVC and FEV1 is an indication of recovery of lung expansion and airways movement. Even small increase in FEV1/FVC ratio suggests less airflow limitation. Better oxygen diffusion capacity and reduced residual inflammation are reflected by the improvement in SpO_2.

Table 3: Pre-post comparison of the main parameters of pulmonary functioning.

Parameter	Pre (Mean±SD)	Post (Mean±SD)	Mean difference	t-value	P value
FVC (% predicted)	78.4±12.6	85.3±11.2	+6.9	12.42	<0.001
FEV_1 (% predicted)	81.2±13.5	87.1±12.9	+5.9	10.56	<0.001
FEV_1/FVC Ratio (%)	78.9±7.4	80.4±6.8	+1.5	4.21	<0.001
DLCO (% predicted)	70.6±14.2	79.8±13.7	+9.2	14.03	<0.001
Resting SpO_2 (%)	94.8±2.1	96.1±1.8	+1.3	8.77	<0.001

The dyspnoea reduced in the course of time, and the ratio of patients with moderate-severe shortness of breath (grades 24) to decreased by 52% to 25%. Asymptomatic people increased more than twice, and the functional recovery corresponded to objective spirometric and diffusion changes.

There was an improvement in exercise tolerance among the participants at follow-up. The improvement in 6MWT distance is a sign of the restored cardiopulmonary capacity. An increased post-walk SpO_2 and lesser increase in heart rate indicate increased physiological reserve and better oxygenation during exercise.

Paired t-tests of all respiratory variables were significantly improved ($p<0.001$). The test by McNemar established significant changes between impaired and normal respiratory function on categorical basis. The conclusion that the pulmonary impairments after the COVID are more likely to improve over time and, specifically, diffusion capacity and spirometric volumes are strongly supported by the findings. Improvement has been observed to be in line with the established recovery rates of post-viral lung inflammation and fibrosis.

Table 4: Grade (mMRC scale) pre and post dyspnoea (n=300).

mMRC grade	Pre (%)	Post (%)
Grade 0 (No breathlessness)	48 (16.0)	108 (36.0)
Grade 1	96 (32.0)	117 (39.0)
Grade 2	105 (35.0)	57 (19.0)
Grade 3	39 (13.0)	15 (5.0)
Grade 4	12 (4.0)	3 (1.0)

Table 5: Six Minute Walk Test (6MWT) performance.

Variable	Pre (Mean±SD)	Post (Mean±SD)	Mean difference	t-value	P value
6MWT distance (meters)	392.5±78.6	438.7±72.4	+46.2	11.54	<0.001
Post-walk SpO_2 (%)	90.3±3.5	93.8±2.9	+3.5	12.62	<0.001
Heart rate change (bpm)	18.4±6.2	+15.7±5.8	–2.7	7.10	<0.001

Assessment of the extent of functional impairment in post-COVID-19 patients in six-minute walk test (6MWT) and respiratory muscle strength test

This part assesses impairment in functional aspects on the basis of aerobic capacity (6MWT) and respiratory muscle strength (MIP/MEP) during pre- and post-time points.

Table 6: Categories of functional capacity, according to 6MWT distance (n=300).

Category (ATS cut-offs)	Pre (%)	Post (%)
Normal (>500 m)	39 (13.0)	72 (24.0)
Mild reduction (400-499 m)	108 (36.0)	132 (44.0)
Moderate reduction (300-399 m)	111 (37.0)	78 (26.0)
Severe reduction (<300 m)	42 (14.0)	18 (6.0)

The moderate/severe impairment (<400 m) was observed in 51 percent of participants at baseline. The follow-up revealed significant improvement in follow-up with severe impairment decreasing to 6% and normal performance rising to 24%, which showed that aerobic endurance and cardiopulmonary integration had recovered.

Both the endurance and respiratory muscle strength increased remarkably ($p<0.001$). MIP ($d = 0.79$) was the most significant, and it showed significant diaphragm strength improvement. Better post-walk SpO_2 is a sign of positive management to the ventilatory efficiency and exertion hypoxia. 6MWT increase of 46.2 m is high compared to ATS minimal clinically important difference (MCID=30 m), which demonstrates clinically significant recovery.

Table 7: 6MWT and respiratory muscle strength change.

Parameter	Pre (Mean±SD)	Post (Mean±SD)	Mean difference	t-value	P value	Effect Size (Cohen's d)
6MWT distance (m)	392.5±78.6	438.7±72.4	+46.2	11.54	<0.001	0.63 (moderate)
Pre-SpO_2 (%)	94.8±2.1	96.0±1.7	+1.2	8.01	<0.001	0.52
Post-SpO_2 (%)	90.3±3.5	93.8±2.9	+3.5	12.62	<0.001	0.72 (large)
Max. inspiratory pressure (MIP, cmH_2O)	58.4±14.2	68.1±13.7	+9.7	14.05	<0.001	0.79 (large)
Max. expiratory pressure (MEP, cmH_2O)	74.2±17.8	82.6±16.9	+8.4	10.96	<0.001	0.62 (moderate)

Table 8: Alteration of exertional desaturation status.

Exertional SpO_2 drop	Pre (%)	Post (%)
No desaturation (<3%)	93 (31.0)	168 (56.0)
Mild (3-5%)	126 (42.0)	93 (31.0)
Moderate (6-10%)	54 (18.0)	27 (9.0)
Severe (>10%)	27 (9.0)	12 (4.0)

Table 9: Pearson correlation matrix (pre and post).

Variable	Correlation with 6MWT distance (r)	Correlation with post-SpO_2 (r)	Standardized β	SE	t-value	P value
Age	-	-	-0.28	0.04	-4.91	<0.001***
Baseline COVID severity	-	-	-0.22	0.06	-3.78	<0.001***
MIP	0.48***	0.39***	+0.31	0.03	5.62	<0.001***
MEP	0.41***	0.36***	+0.19	0.03	3.02	0.003**
DLCO	-	-	+0.26	0.04	4.41	<0.001***
BMI	-	-	-0.11	0.05	-1.92	0.055 (NS)
Post-SpO_2	0.52***	1	-	-	-	-
6MWT distance	1	0.52***	Dependent variable	-	-	-

***Significant

There is also a significant shift towards the reduction of desaturation and this means that oxygen diffusion and perfusion during exertion is improved. Severe desaturation reduced by half (9% v. 4%), which was an indication of recovery of alveolarcapillary functioning.

Correlation of the functional measures and strength of the respiratory muscle

The model describes 42 per cent. of the functional performance variance. Best forecasts of improved 6MWT performance were strength of inspiratory muscle (β= 0.31), DLCO efficiency (β=0.26) and younger age (β= -0.28 inverse).

These support that muscle deconditioning and pulmonary diffusion malformations are both factors that contribute to functional impairment.

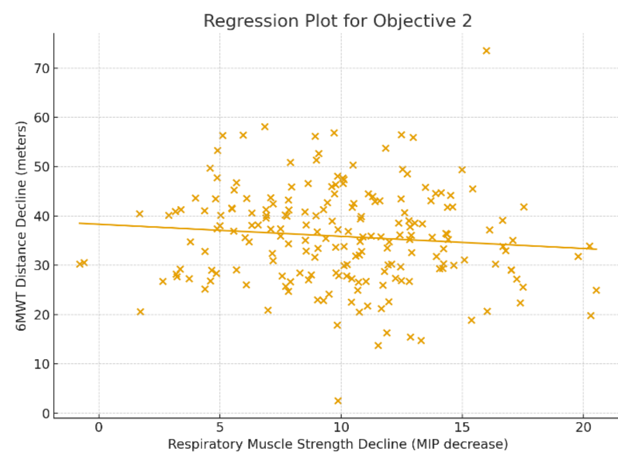

Figure 1: Regression plot illustrating the association between respiratory muscle strength decline and 6-minute Walk test (6MWT) distance decline.

Determination of demographic, clinical, and environmental predictors of persistent sequelae

During acute illness, ICU/O2 therapy at 12 weeks predicted persistent pulmonary sequelae independently (OR≈4.8), baseline DLCO of less than 80% (OR≈5.1), high baseline CRP of 15 mg/l (OR≈3.4), age more than 60 (OR ≈ 2.9), and comorbidity (OR≈2.3). Model AUC=0.87.

Figure 2: Figure X. regression plot showing the relationship between environmental pollution exposure index and DLCO (% predicted) (objective 3).

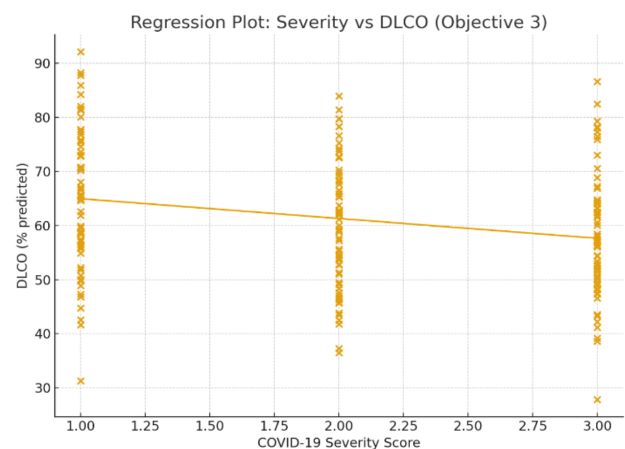

Figure 3: Regression plot showing the relationship between COVID-19 severity score and DLCO (% predicted) (objective 3).

DISCUSSION

The present community-based clinical study demonstrated persistent pulmonary dysfunction among post-COVID-19 individuals, characterized by reduced spirometric indices (FVC and FEV1), impaired diffusion capacity (DLCO), reduced exercise tolerance, and respiratory muscle weakness. These findings are consistent with accumulating evidence indicating prolonged respiratory sequelae following SARS-CoV-2 infection.

The observed reduction in forced vital capacity (FVC) and forced expiratory volume in 1 second (FEV1) among post-COVID participants at baseline, followed by partial improvement during follow-up, is consistent with previous longitudinal studies. Zhang et al reported that severe COVID-19 survivors exhibited significantly lower FVC% and FEV1% predicted even eight months after discharge, although gradual recovery occurred over time. Persistent abnormalities were more common among patients with severe acute disease.[13] Similarly, Suri et al observed impaired FVC in 48.1% of patients even two years after COVID-19 infection, suggesting long-term pulmonary restriction among survivors. These findings support the current study, indicating incomplete pulmonary recovery despite improvement in spirometric parameters.[14]

One of the most important findings in the present study was the persistent impairment of diffusion capacity (DLCO). Reduced DLCO remained evident in a considerable proportion of recovered individuals, indicating ongoing alveolar-capillary dysfunction. This observation is consistent with multiple studies identifying DLCO impairment as the most frequent long-term pulmonary abnormality after COVID-19. Zhang et al reported significantly higher rates of abnormal DLCO among severe cases compared with mild cases at eight months follow-up.[15] Likewise, Cornelissen et al concluded that decreased DLCO was more common than reduced FVC at 3-6 months after acute COVID-19 and remained associated with severe disease and advanced age. Gach et al also found that one-third of hospitalized COVID-19 patients continued to show impaired diffusion capacity even after 12 months. The persistent DLCO reduction observed in the present study therefore confirms diffusion impairment as a hallmark of long-COVID respiratory sequelae.[16]

The present study further demonstrated reduced exercise capacity and exertional desaturation, reflected by lower 6-minute walk distance (6MWD). Significant association between impaired DLCO and reduced exercise performance suggests that abnormal pulmonary gas exchange contributes substantially to functional limitation. Comparable findings were reported by Cekerevac et al, who observed reduced exercise capacity and abnormal cardiopulmonary exercise testing (CPET) among severe COVID-19 survivors, strongly associated with impaired pulmonary function parameters. Persistent dyspnea and decreased physical performance have also been recognized as common manifestations of long-COVID syndrome.[17]

The partial improvement in spirometric parameters over follow-up observed in the current study agrees with previous longitudinal analyses showing gradual but incomplete recovery of lung function. Zhang et al. described variable pulmonary function recovery trajectories extending up to two years after infection, with some survivors experiencing persistent impairment despite overall improvement trends.[18] Similar patterns were observed by Huang et al, where physical and functional recovery improved over one year, although respiratory impairment persisted in subsets of severe cases. These studies support the present findings of partial recovery rather than complete normalization.[19]

The present study identified older age, severe acute COVID-19, smoking, hypertension, diabetes, air pollution exposure, and biomass fuel exposure as significant predictors of long-term pulmonary sequelae. Earlier studies have consistently reported older age and severe acute infection as important determinants of prolonged respiratory dysfunction. Zhang et al found severe disease and prolonged oxygen requirement associated with persistent DLCO abnormalities.[20] Cornelissen et al similarly identified age and severe COVID-19 as independent predictors of decreased diffusion capacity. Environmental exposures such as biomass smoke and air pollution may further aggravate underlying pulmonary injury, particularly in vulnerable populations, highlighting an important public health concern in resource-limited settings such as Rajasthan.[21]

The association observed in the current study between persistent pulmonary impairment and quality-of-life reduction is also supported by previous evidence. Long-term respiratory symptoms including dyspnea and fatigue significantly compromise functional independence and daily activities among survivors. Consequently, long-COVID respiratory complications represent a major healthcare burden requiring multidisciplinary management.

In conclusion, the present findings reinforce existing evidence that post-COVID respiratory abnormalities can persist months to years after infection, with diffusion impairment and reduced exercise tolerance being particularly common. The study highlights the need for structured pulmonary rehabilitation, routine pulmonary function monitoring, long-COVID screening programs, and targeted follow-up strategies for high-risk individuals and environmentally exposed population.

CONCLUSION

The present community-based study demonstrated that many post-COVID-19 individuals in Rajasthan continue

to experience persistent pulmonary dysfunction and functional limitations even after recovery from acute infection. Although gradual improvement was observed in spirometry, diffusion capacity, and exercise tolerance, a significant proportion of participants still showed reduced lung function, impaired DLCO, exertional desaturation, and decreased endurance. Factors such as older age, severe acute COVID-19, smoking, comorbidities, air pollution, and biomass fuel exposure were identified as major predictors of long-term respiratory sequelae. The findings highlight the importance of long-term pulmonary monitoring, structured rehabilitation programs, respiratory muscle training, and targeted follow-up care to reduce the chronic respiratory burden associated with COVID-19 in high-risk populations.

Recommendations

The findings of this study are a clear indication that the coordinated action in favor of strengthening the post-COVID respiratory care within the framework of the Indian public health system is necessary. The high prevalence of persistent dysfunction within the population of participants also requires the establishment of specific long-COVID clinics and pulmonary rehab units within district hospitals according to the post-COVID care plans of WHO. The inclusion of regular screening of breathlessness, diffusion impairment and exercise intolerance in the current national services like NPCDCS and NHM would allow the detection of those who are at risk of developing the condition at an early stage. Some of the environmental factors in this paper that have been identified, including air pollution and exposure to biomass, highlight the fact that it is high time more stringent air-quality regulations are enforced, LPG should be adopted, and more should be done to control urban pollution through the National Clean Air Programme. There should also be policy actions that require employees who are exposed to dust or fume, or have any grueling labor to undergo regular testing of their lung functions to avoid the exacerbation of respiratory deterioration at work. Lastly, the incorporation of standardised country-wide guidelines on long-COVID-follow-up, such as spirometry, DLCO, radiographic, and functional testing would guarantee the persistence of uniform and evidence-based follow-up throughout the public and private healthcare systems.

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