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Role of hybrid virtual pulmonary rehabilitation in improving performance status of patients eligible for lung transplantation

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Abstract

Pulmonary rehabilitation (PR) in chronic respiratory diseases improves symptoms, quality of life, and exercise capacity and has an integral role in lung transplantation (LT). Virtual PR has recently emerged to cater to patients who otherwise may not have regular access to PR. However, little is known about the effect of virtual PR strategies on candidates for LT. The primary objective was to study the effect of a protocolized hybrid PR program on performance status using the Karnofsky Performance Status (KPS) score. Secondary objectives were Eastern Cooperative Oncology Group (ECOG) status, quality of life, symptom severity, sarcopenia, spirometry (pulmonary function test and diffusing capacity of the lung for carbon monoxide), 6-minute walk distance, and eligibility for LT waitlisting. This is a prospective, single-arm, interventional study on patients with end-stage lung disease, meeting referral criteria for LT. A protocolized 12-week hybrid hospital and home-based virtual PR intervention was conducted, and all outcomes were assessed at baseline and at completion of the intervention. A total of 75 patients were enrolled, and the intervention was completed by 51 patients (68%). A total of 35 patients met LT listing criteria, 27 being "unfit" for LT at baseline, 18 of whom completed the intervention. Significant improvement was seen in KPS, ECOG, St. George's Respiratory Questionnaire score, visual analog scale score for cough and dyspnea, and sarcopenia for all 51 patients. Of the 18 patients unfit for waitlisting, 12 became fit, and 7 were waitlisted for LT. Patients eligible for LT who do not have access to regular PR may benefit from a hybrid (virtual and hospital-based) PR program, with improvement in KPS, quality of life, sarcopenia, and eligibility for LT waitlisting.

Key words: pulmonary rehabilitation, lung transplantation, performance status, quality of life, chronic respiratory diseases.

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Introduction

Lung transplantation (LT) is an important therapeutic modality for end-stage chronic respiratory diseases (CRDs) progressing despite maximal medical therapy. It improves health-related quality of life (QoL) [1], exercise capacity, lung function [2,3], and survival [4-6]. However, poor pre-operative performance status (PS) and a low exercise capacity have worse perioperative outcomes [7]. Therefore, the International Society of Heart and Lung Transplant (ISHLT) 2021 consensus criteria for LT lists "limited functional status with low potential for post-transplant rehabilitation" as a relative contraindication for LT [8]. This state can be corrected with pulmonary rehabilitation (PR), allowing many patients with poor PS to enter a transplant waitlist.

PR is a comprehensive strategy involving exercises, disease education, and health-promoting behaviors [9]. Despite its beneficial effects on symptoms, QoL, lung function, and survival, it is woefully underutilized [10,11]. Most PR programs are hospital/center-based, with a paucity of data on tele-rehabilitation programs. Regular visits to a PR center are challenging for most patients due to logistical, financial, and social reasons. After the COVID-19 pandemic, tele-rehabilitation using smartphones has emerged to provide virtual home-based rehabilitation. To date, studies evaluating the benefit of PR before LT have focused on center-based PR, with a lack of data on home-based tele-rehabilitation. Our study was thus designed to explore the effect of a hybrid hospital and home-based tele-rehabilitation program in patients with CRDs who are LT candidates, and their subsequent eligibility of getting fit for inclusion in our transplant waitlist.

Materials and Methods

The study was a prospective, single-arm, pre- and post-interventional study, done in the Department of Pulmonary Medicine at a tertiary care hospital. Patients with end-stage CRDs [chronic obstructive pulmonary disease (COPD), diffuse parenchymal lung disease (DPLD), and bronchiectasis] who met ISHLT 2021 LT referral criteria were recruited from the outpatient clinics and wards between January 2022 and December 2023 [8]. The primary objective was to study the effect of a protocolized "hybrid" hospital (center-based) and home-based PR program on PS using the Karnofsky Performance Status scale (KPS). Secondary objectives included the effect of this hybrid PR program on QoL, sarcopenia using anthropometric indices, Short Physical Performance Battery (SPPB) score, Body Composition Analysis (BCA), lung function using spirometry, diffusion capacity of lung carbon monoxide (DLCO), and 6-minute walk test (6MWT), and estimation of proportion of patients deemed eligible for listing for LT (*via* improvement in PS). Patients who were unable to or unwilling to come to the hospital for PR were excluded. Institutional ethics committee approval was obtained prior to commencement of the study.

Parameters recorded

At enrolment, baseline demographic profile and clinical parameters were recorded, including severity of cough and dyspnea using the Visual Analog Scale (VAS) and modified Medical Research Council (mMRC) scale for dyspnea, proportion of patients with oxygen requirement at rest, *etc*. Socio-economic status was assessed using the modified Kuppuswamy scale [12]. The primary outcome of PS was assessed using the KPS [13]. In addition, the Eastern Cooperative Oncology Group (ECOG) score for PS was also recorded [14]. QoL was assessed using St. George's Respiratory Questionnaire (SGRQ) after permission from the developers, using both the English and translated Hindi versions [15]. Sarcopenia was assessed as per the Asian Working Group for Sarcopenia consensus criteria of 2019 [16]. Sarcopenia was defined as low appendicular skeletal muscle mass index (ASMI) along with either low muscle strength (using a hand grip dynamometer) or low physical performance (using SPPB). Low physical performance was diagnosed clinically if the total SPPB score was 9 out of 12 [16]. The SPPB score is a composite of balance score, 3 or 4-metre gait speed, and the 5 times chair stand test, each parameter scored from 0 to 4. BCA was done *via* bio-impedance analysis (ACCUNIQ BC720 analyzer, SELVAS Healthcare, South Korea). ASMI, which is the skeletal muscle mass of all 4 limbs divided by the height in meters squared, was used to define low muscle mass (<7.0 kg/m^2 in males and <5.7 kg/m^2 in females). If BCA was not available, but the patient had low muscle strength or low physical performance, a diagnosis of "possible" sarcopenia was made. Baseline assessment of lung function and exercise capacity was done using spirometry (COSMED, Rome, Italy), DLCO, and 6MWT. All patients were assessed for the presence of ISHLT 2021 listing criteria for LT and the presence of any contraindications. Poor PS and low rehabilitation potential as a contraindication to LT were noted at baseline. Since no objective criteria exist as per ISHLT to label a patient "unfit" for LT, this assessment was done by the treating physician based on a combination of PS (KPS and ECOG), presence of sarcopenia, and exercise capacity at initiation of PR. Previously, Rathi *et al.* have used the same criteria while studying the clinical profile of LT candidates at our center [17].

Intervention

Patients were started on a protocolized "hybrid" hospital and home-based pulmonary tele-rehabilitation program. Each patient underwent 1 supervised hospital visit and 2 supervised (video call using a smartphone) home exercise sessions per week, with a total of 12 supervised hospital visits and 24 supervised home exercise sessions over 3 months, with a relaxation of 1 additional month to complete the 36 sessions. A patient was labelled as "adherent" to the intervention if they completed 2/3rd of both types of sessions (*i.e.*, 8 hospital and 16 home sessions) by the end of 4 months. Attendance was recorded for each patient for every session. The post-intervention follow-up visit and recording of all parameters were done within 1 month of the last exercise session. Patients who had an exacerbation during the intervention had to restart the exercises after improvement in their PS (baseline KPS+/-10).

Statistical analysis

Descriptive analysis was done for demographic and clinical data [mean, standard deviation, median, interquartile range (IQR)]. Tests for statistical significance (paired/unpaired t-test, Wilcoxon rank sum test, chi-square/Fisher exact test, symmetry test) were used to look for significant differences in primary and secondary outcome parameters for continuous and categorical variables, assessed at baseline and end of the rehabilitation program. Subgroup analysis was done by adherence to the program as well as by diagnosis. Change (pre- and post-rehabilitation) in individual outcomes [median (IQR)] between adherent and non- adherent was further compared using tests for statistical significance.

Results

Over the study duration, 136 patients were screened, and 75 were enrolled in the rehabilitation program. Their baseline data is depicted in Table 1. The most common reason for exclusion was the inability to visit the hospital for physical rehabilitation. The intervention was completed by 51 patients (68%), and post-rehabilitation parameters were recorded. Of the 24 patients who did not complete the intervention, 10 died during the rehabilitation period, 10 were lost to follow-up, 2 had recurrent exacerbations, and 2 stopped early as they underwent a transplant. Among those completing the intervention, 25 (49.0%) met the strict pre-defined criteria for adherence (both hospital and home sessions). Additionally, 46 (90.2%) were adherent to the home-based tele-rehabilitation. A total of 8 patients had an exacerbation during the intervention and had to restart the sessions once the exacerbation had resolved.

The mean age of our population was ~48 years, with nearly equal males (n=38) and females (n=37). The most common diagno-sis was DPLD, seen in 51 (68.0%) cases. Amongst the 51 cases of DPLD, fibrotic hypersensitivity pneumonitis was the most common etiology (41.1%), followed by connective tissue disease-associated interstitial lung disease (31.4%), idiopathic fibrotic non-specific interstitial pneumonitis (17.6%), and idiopathic pulmonary fibrosis (3.9%). The diagnosis was established after a multidisciplinary discussion with the radiologist, and a histopathological diagnosis was present in 10 (19.6%) cases. Comorbidities were present in 31 (41.3%) patients, with diabetes mellitus being the most common (20.0%).

Following the completion of rehabilitation sessions, significant improvement was observed in the primary outcome (Table 2) of

KPS score category (p<0.001) and the ECOG score for PS (p=0.001). Among secondary outcomes, the mean SGRQ score showed significant improvement (61.8 to 45.2 points, p<0.001). The decrease in minimal clinically important difference by 4 points for SGRQ was seen in 40 patients (78.4%). Significant improvement was noted in symptom severity scores of cough (VAS 5.0 to 3.7), shortness of breath (VAS 7.0 to 5.4), mMRC grade category, patients on oxygen at rest (49% to 35%), SPPB mean score (9.3 to 9.9 points), and categorically (p=0.008). The proportion of patients with sarcopenia decreased significantly (53% to 41%, p=0.014). Paired BCA, spirometry, DLCO maneuvers and 6-minute walk distance (6MWD) did not show a significant difference. At baseline, 35 patients also met the ISHLT "listing criteria" for LT. Of these, 27 had poor functional status and were labelled "unfit" for LT, 18 of whom completed the intervention. Out of these 18 patients, 12 (~66%) later became fit for LT after rehabilitation, and 7 (~39%) were subsequently waitlisted.

Subgroup analysis was done (Table 3) for adherent (n=25) and non-adherent (Table 4) patients (n=26), with significant improvement seen in both groups in the KPS Score (primary outcome), SGRQ score (QoL), symptom severity scores (VAS) for cough and shortness of breath, the mMRC grade of shortness of breath, proportion of patients with supplemental oxygen requirement at rest and proportion of patients with sarcopenia. A statistically significant improvement in the adherent subgroup alone was seen in ECOG score, forced vital capacity (FVC)%, and forced expiratory volume in 1 second (FEV1)%.

Additionally, the difference (proportions and median change) in pre-rehabilitation and post-rehabilitation values (post-rehabilitation value subtracted from pre-rehabilitation) was comparedin adherent and non-adherent groups (*Supplementary Table 1*). The proportion of patients whose KPS category improved was compared, with no significant difference.

Table 1. Baseline demographic parameters.

Clinical variable [mean±SD) or n (%)]		All patients (n=75)	Intervention completed (n=51)
Mean age (y)		47.8±13.6	47.0±13.8
Males		38 (50.6)	26 (51.0)
Diagnosis	DPLD	51 (68.0)	37 (72.5)
	COPD	9 (12.0)	6 (11.8)
	Bronchiectasis	15 (20.0)	8 (15.7)
Karnofsky Performance Status score	Complete assistance	5 (6.7)	2 (3.9)
	Partial assistance	61 (81.3)	43 (84.3)
	No assistance	9 (12.0)	6 (11.8)
ECOG score	1	11 (14.7)	8 (15.7)
	2	39 (52.0)	32 (62.7)
	3	25 (33.3)	11 (21.6)
SGRQ score (quality of life)		64.2±18.9	61.8±18.5
Patients on oxygen at rest		42 (56.0)	25 (49.0)
Patients with sarcopenia		44 (58.6)	27 (53.0)
Cough severity (VAS)		5.3±2.1	5.0±2.2
SOB severity	VAS	7.2±1.6	7.0±1.7
	mMRC grade 0-2	22 (29.3)	15 (29.4)
	mMRC grade 3-4	53 (70.7)	36 (70.6)
BMI (kg/m^2)		22.4±6.1	22.7±6.3
Hand grip strength [kgf], median (IQR)		22 (8-30)*	22 (8-30)##
Short Physical Performance Battery (SPPB)	Mean score	8.9±2.6	9.3±2.6
	<9	28 (37.3)	14 (27.5)
	≥9	47 (62.7)	37 (72.5)
Patients with sarcopenia, n (%)		44 (59.4)	27 (53.0)
Body composition analysis	ASMI [kg/m^2]	5.5±1.1*	5.7±1.2$
	Body fat%	32.5±12.7	33.2±12.1
FVC [L]		1.43±0.73*	1.48±0.74
FVC %predicted		41.6±16.4*	43.0%±15.5%
FEV1 [L]		1.07±0.60*	1.13±0.62
FEV1 %predicted		38.3±18.4*	40.3%±18.8%
DLCO [mL/min/mmHg]		7.72±4.98##	8.06±4.76#
DLCO %predicted		30.4±18.7##	31.4%±17.4%#
6-minute walk distance		287±109	307.9±98.8

SD, standard deviation; DPLD, diffuse parenchymal lung disease; COPD, chronic obstructive pulmonary disease; ECOG, Eastern Cooperative Oncology Group; SGRQ, St. George's Respiratory Questionnaire, VAS, visual analog scale; mMRC, modified Medical Research Council; BMI, body mass index; IQR, interquartile range; ASMI, appendicular skeletal muscle mass index; FVC, forced vital capacity; FEV1, forced expiratory volume in 1 second; DLCO, diffusion capacity of lung carbon monoxide. *n=69, #n=33, ##n=48, $n=35.

Table 2. Primary and secondary outcomes [intervention completed (n=51)]

Clinical variable [mean±SD) or n (%)]		Pre-rehabilitation	Post-rehabilitation	p
Karnofsky Performance Status score	Complete assistance Partial assistance No assistance	2 (3.9) 43 (84.3) 6 (11.8)	0 28 (54.9) 23 (45.1)	<0.001
ECOG score	1 2 3	8 (15.7) 32 (62.7) 11 (21.6)	19 (37.3) 25 (49.0) 7 (13.7)	0.001
SGRQ score (quality of life)		61.8±18.5	45.2±23.6	<0.001
Cough severity (VAS)		5.0±2.2	3.7±1.6	<0.001
SOB severity	VAS mMRC grade 0-2 mMRC grade 3-4	7.0±1.7 15 36	5.4±1.7 35 16	<0.001 <0.001
Patients on oxygen at rest		25 (49)	18 (35%)	0.019
BMI (kg/m^2)		22.7±6.3	22.7±6.1	0.986
Hand grip strength (kgf), median (IQR) (n=48)		22 (8-30)	26 (16-34)	0.128
SPPB score (0-12)	Mean score <9 ≥9	9.3±2.6 14 37	9.9±2.5 7 44	0.007 0.008
Body composition analysis (n=35)	ASMI [kg/m^2] Body fat%	5.7±1.2 33.2±12.1	5.5±1.1 35.3±11.5	0.019 0.041
Patients with sarcopenia		27 (53)	21 (41)	0.014
FVC %predicted		43.0%±15.5%	45.5%±21.5%	0.095
FEV1 %predicted		40.3%±18.8%	42.5%±24.9%	0.305
DLCO %predicted (n=33)		31.4%±17.4%	36.3%±19.5%	0.088
Six-minute walk distance [m]		307.9±98.8	306.7±92.5	0.499

SD, standard deviation; ECOG, Eastern Cooperative Oncology Group; SGRQ, St. George's Respiratory Questionnaire; VAS, visual analog scale; mMRC, modified Medical Research Council; BMI, body mass index; IQR, interquartile range; SPPB, Short Physical Performance Battery; ASMI, appendicular skeletal muscle mass index; FVC, forced vital capacity; FEV1, forced expiratory volume in 1 second; DLCO, diffusion capacity of lung carbon monoxide.

Table 3. Primary and secondary outcomes [adherent to the intervention (n=25)].

Clinical variable [mean ± SD or n (%)]		Pre-rehabilitation	Post-rehabilitation	p
Karnofsky Performance Status score	Complete assistance Partial assistance No assistance	0 21 (84) 4 (16)	0 12 (48) 13 (52)	0.002
ECOG score	1 2 3	6 (24) 15 (60) 4 (16)	12 (48) 12 (48) 1 (4)	0.011
SGRQ score (quality of life)		60.9±17.6	41.6±23.8	<0.001
Cough VAS		4.5±2.3	3.2±1.5	<0.001
SOB	VAS mMRC grade 0-2 mMRC grade 3-4	7.0±1.5 8 17	5.2±1.5 18 7	<0.001 0.001
Patients with oxygen requirement at rest		12 (48)	8 (32)	0.045
Hand grip strength [kgf] (IQR)		24 (13-40)	28 (17-40)	0.016
SPPB score (0-12)	Mean score <9 ≥9	9.8±1.7 5 20	10.6±1.4 1 24	0.004 0.045
Patients with sarcopenia		11 (44)	9 (36)	0.157
ASMI [kg/m^2]		5.8±1.2	5.7±1.2	0.141
FVC %predicted		45.6±17.1	50.7±24.5	0.013
FEV1 %predicted		43.7±19.6	48.8±27.3	0.033
DLCO %predicted		37.9±17.3	39.7%±19.7	0.331
6-minute walk distance [m]		309.2±91.5	316.8±73.9	0.935

SD, standard deviation; ECOG, Eastern Cooperative Oncology Group; SGRQ, St. George's Respiratory Questionnaire; VAS, visual analog scale; mMRC, modified Medical Research Council; BMI, body mass index; IQR, interquartile range; SPPB, Short Physical Performance Battery; ASMI, appendicular skeletal muscle mass index; FVC, forced vital capacity; FEV1, forced expiratory volume in 1 second; DLCO, diffusion capacity of lung carbon monoxide.

Among secondary outcomes, changes in FEV1 (-35 mL *vs.* +40 mL; negative due to higher post-rehabilitation value in adherent) and %FEV1 (-2.0% *vs.* +0.5%; p=0.049) were significantly better in the adherent group, while changes in FVC and %FVC had a trend towards significant improvement (p=0.053) in the adherent group. Sub-group analysis was also done based on primary diagnosis (*Supplementary Table 1*). In the DPLD subgroup, significant improvement was seen in PS using KPS score (p<0.001) and ECOG score (p=0.042), mean SGRQ score (60.8 to 46.9 points, p<0.001), and mMRC grade of SOB (p<0.001).

Discussion

Studies on PR are heterogeneous and mostly hospital-based. Numerous randomized controlled trials and systematic reviews have evaluated the effect of rehabilitation in various CRDs, including COPD [10], DPLD [18], bronchiectasis (cystic fibrosis and non-cystic fibrosis), and asthma with improvement in dyspnea scores, QoL, and exercise capacity [19-21]. Benefit has not been seen in spirometry-based tests (FVC, FEV1, and DLCO). Multiple studies on the effect of PR on LT waitlisted candidates have also been done [3,22-25], with similar findings.

Our study brings forth many unexplored aspects. We studied a novel hybrid hospital-based and home-based tele-rehabilitation intervention in a novel group (subjects eligible for LT). The PR program was under the supervision of a respiratory physiotherapist and a senior pulmonology fellow. Our patient cohort was relatively sicker than those previously included in most studies. Medical management was optimized before enrolment, and no major change in treatment was allowed during the intervention, except during an exacerbation. Patients who had an exacerbation during the intervention had to restart their PR after improvement. Lastly, the effect of tele-rehabilitation on increasing eligibility for inclusion in the transplant waitlist has not been studied to date.

In our study, patients who completed the intervention showed significant improvement in the primary outcome of KPS score, as well as other outcomes like ECOG, QoL (SGRQ), symptom severity scores, proportion (%) of patients requiring supplemental oxygen, sarcopenia, and SPPB score. Sarcopenia is an important, although sparsely studied, parameter in patients listed for LT. It is independently associated with increased disability, risk of delisting, and even death [26]. Our intervention has shown benefit in key factors that decide outcomes in patients with end-stage lung diseases who are LT candidates. Significant change was not observed in spirometry-based tests (FVC, FEV1, and DLCO), which is consistent with existing evidence. There was no change in the 6MWD, showing that exercise capacity was maintained during the period of rehabilitation. A similar finding was observed by Li *et al.* [22], where 345 pre-transplant candidates underwent hospital-based PR while on the LT waitlist. The final 6MWD was 15 m less than that at listing (no significant change), which was considered a successful outcome in LT listed patients, where a decline in 6MWT is expected due to the severity of their illness. In another study, 4-week tele-rehabilitation was conducted on 78 LT candidates and 33 LT recipients at the Toronto LT program, and a decrease in 6MWD was observed [27]. Our patient cohort was a relatively sicker group, with the majority (56%) of patients being on continuous supplemental oxygen, explaining the lack of improvement in 6MWD.

Subgroup analysis of adherent and non-adherent patients

Table 4. Primary and secondary outcomes [non-adherent to the intervention (n=26)].

Clinical variable [mean±SD or n (%)]		Pre-rehabilitation	Post-rehabilitation	p
Karnofsky Performance Status score	Complete assistance	2 (7.7)	0	
	Partial assistance	22 (84.6)	16 (61.5)	0.006
	No assistance	2 (7.7)	10 (38.5)	
ECOG score	1	2 (7.7)	7 (26.9)	
	2	17 (65.4)	13 (50)	0.069
	3	7 (26.9)	6 (23.1)	
SGRQ score (quality of life)		62.7±19.4	48.7±23.4	<0.001
Cough VAS		5.4±2.1	4.2±1.5	<0.001
SOB	VAS	7.0±1.9	5.6±2.0	<0.001
	mMRC grade 0-2	7	17	0.001
	mMRC grade 3-4	19	9	
Patients with oxygen requirement at rest		13 (50.0)	10 (38.5)	0.179
Hand grip strength [kgf] (IQR)		21 (11-29)	21 (13-28)	0.824
SPPB score (0-12)	Mean score	8.8±3.2	9.2±3.0	0.265
	<9	9	6	0.083
	≥9	17	20	
Patients with sarcopenia		16 (61.5)	12 (46.2)	0.050
ASMI [kg/m^2]		5.6±1.2	5.3±1.1	0.079
FVC %predicted		40.4%±13.7%	40.3%±17.0%	0.965
FEV1 %predicted		36.8%±17.5%	36.3%±21.1%	0.605
DLCO %predicted		25.8%±15.9%	33.2%±19.3%	0.117
6-minute walk distance [m]		306.8±107.5	296.5±108.6	0.275

SD, standard deviation; ECOG, Eastern Cooperative Oncology Group; SGRQ, St. George's Respiratory Questionnaire; VAS, visual analog scale; mMRC, modified Medical Research Council; BMI, body mass index; SPPB, Short Physical Performance Battery; ASMI, appendicular skeletal muscle mass index; FVC, forced vital capacity; FEV1, forced expiratory volume in 1s; DLCO, diffusion capacity of lung carbon monoxide.

showed significant improvements in both subgroups in terms of KPS Score, as well as most secondary outcomes. However, ECOG score, FVC%, and FEV1% improved in the adherent subgroup only. Criterion for adherence was strict (2/3rd attendance needed individually for both center- and home-based PR), and patients labelled as non-adherent still participated consistently in the tele-rehabilitation sessions, explaining the improvement in their outcomes.

Tele-rehabilitation has emerged prominently after the COVID-19 pandemic [28,29]. A systematic review and meta-analysis by Cox *et al.* [30], comparing tele-rehabilitation and center-based PR in a COPD population, found no difference in outcomes like exercise capacity (6MWD), QoL (SGRQ), or dyspnea scores. PR program completion rates were higher for tele-rehabilitation *vs.* center-based PR (93% *vs.* 70%). This study almost exclusively studied COPD (~99%). Multiple such systematic reviews, including patients with COPD, have been published that showed home-based PR to be as effective as center-based PR, in improving exercise capacity and QoL [31-33]. There is, however, a paucity of evidence on the role of tele-rehabilitation across different respiratory illnesses or among those with end-stage lung diseases who are LT candidates. As mentioned above, the Toronto LT program used a smartphone app for home-based PR on LT candidates and recipients [27]. However, real-time tele-rehabilitation sessions were not conducted in these studies, and pre-recorded videos were used to guide PR. Bourgeois *et al*. studied 20 potential LT candidates who underwent supervised tele-rehabilitation for 12 weeks, followed by an unsupervised maintenance phase [34]. No significant change was seen in 6MWD, SPPB, or SGRQ score at 12 weeks. The authors concluded that preventing further fall in 6MWD and SPPB in a frail LT eligible cohort is a mark of success of any PR program.

The major advantage of tele-rehabilitation is that patients can perform exercises specific to their respiratory comorbidities from the comfort of their homes. Patients with CRDs often require oxygen continuously and find it difficult to travel to the hospital. Many patients lack financial or social support and find tele-rehabilitation cost-effective. However, limitations of this model exist, like difficulty in ensuring correct technique of exercises, effective communication with the physiotherapist, and difficulty in monitoring the patient's vitals. Also, the elderly or less educated may face issues with advanced technologies, as often observed in the Indian demographic. We overcame this by using a smartphone-based video call. India has one of the cheapest internet data plans in the world, and smartphone utilization is impressive.

Lastly, a key and unique aspect of our study was to see the effect of our hybrid rehabilitation program on increasing LT waitlisting. In our cohort, 18 out of 35 patients who initially met the ISHLT listing criteria and also had poor PS and poor rehabilitation potential completed the PR program. They demonstrated significant improvement in their KPS score and important secondary outcomes like SGRQ score and symptom severity scores (VAS and mMRC grade of dyspnea). Consequently, 12 of these patients became "fit" for listing, of whom 7 were waitlisted. Additionally, 8 patients from our PR program were waitlisted who either already had good PS before enrolment or continued to have poor PS after our PR program, making a total of 15 patients to be added to the waitlist over a 2-year period. Previously, from 2019-2021, our LT program was able to waitlist 5 patients. This further underlines how our PR intervention boosted the LT program of our hospital. This aspect highlights the need for a strong PR program at any LT center, with inclusion into the PR program being mandatory before LT listing.

Our study had a few limitations, namely, a small sample size and high loss to follow-up due to death or disease-related morbidity. Adherence to our intervention was ~50% due to challenges in visiting the center physically, although adherence to tele-rehabilitation remained high (90.2%). This further emphasizes the high adherence rates with home-based PR programs. Our patient cohort was heterogeneous, with fewer COPD and bronchiectasis cases. A similar finding was noted by Rathi *et al*. in a cohort of 103 patients referred for LT at our institute, where 57.2% cases were of DPLD [17].

Conclusions

Patients with end-stage lung disease eligible for LT benefit from a hybrid (hospital- and home-based) PR program, with improvement in PS, QoL, and sarcopenia, and enhancement in the eligibility for LT wait-listing.

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Online supplementary material:

Supplementary Table 1. Disease-specific analysis of primary and secondary outcomes.

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