Research Article

Effectiveness of Telerehabilitation on Pulmonary Function in Children with Duchenne Muscular Dystrophy: A Pre-Post Intervention Study

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ABSTRACT

Introduction: Duchenne muscular dystrophy (DMD) is an inherited neuromuscular disorder caused by mutations in the dystrophin gene, leading to progressive muscle weakness. This study aimed to evaluate the efficacy of telerehabilitation in improving pulmonary function in patients with DMD.

Materials and Methods: An interventional study was conducted among boys aged 5-12 years with DMD enrolled in the Pediatric Neurology Clinic from September 2023 to February 2024. Telemedicine-based respiratory exercises were explained to patients and their parents every 15 days for a 3-month period, and the patients were encouraged to exercise for at least 5 days a week. Pulmonary function tests (PFTs), including forced vital capacity (FVC) and forced expiratory volume in 1 second (FEV_1), were recorded before and after the intervention.

Results: A total of 67 children participated in the study. There was significant improvement in FVC (P<0.001, Cohen's d=1.93) and FEV_1 (P<0.001, Cohen's d=1.06). The FEV_1/FVC ratio, a parameter that can be elevated in restrictive diseases, was also significantly decreased (P<0.001, Cohen's d=-0.63). For a one-unit increase in age, the FVC change after intervention was predicted to decrease significantly by 0.24 units, holding other variables constant.

Conclusion: Telemedicine-based pulmonary rehabilitation for 3 months markedly improved pulmonary function, indicating that this intervention is effective in improving pulmonary function in patients with DMD, with greater effectiveness when initiated at an early age.

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Introduction

Duchenne muscular dystrophy (DMD) is an X-linked inherited neuromuscular disorder in children, affecting 1 in 3,500–5,000 boys [1]. It is caused by a mutation in the dystrophin gene, resulting in dysfunction in dystrophin protein synthesis [2]. Dystrophin protein is required for sarcolemma stabilization during muscle contraction; therefore, its absence leads to muscle damage.

The progression of muscle weakness in DMD is stereotypical, with the hip muscles affected first, followed by the shoulder, elbow, and hand muscles, and subsequently, the respiratory muscles [3]. Most boys with DMD lose ambulation in their 20s and become wheelchair-bound [4]. Subsequently, deterioration of arm function occurs, leading to dependence in activities of daily living. Cardiac and respiratory muscle weakness is a crucial cause of morbidity and mortality in DMD; most patients require respiratory support in their early non-ambulatory state. The consequences of DMD include orthopedic complications, gastrointestinal problems, malnutrition, cardiac manifestations, and breathing problems [5]. In the absence of any treatment, a person may die at the end of the second decade of their life due to cardiac and respiratory failure [6].

Despite new and promising treatments, no cure for DMD is currently available. The current standard of care involves a multidisciplinary approach with physiotherapy, steroids, and orthoses, which have improved the survival and quality of life of these children, thereby increasing their lifespan to the late 30s [6, 7].

The evaluation and intervention of respiratory dysfunction are complex in DMD.

Lack of ambulation and deteriorating muscle strength may lead to progressive scoliosis, which, in turn, further compromises the cardiopulmonary system [8]. The compromise in respiratory muscles manifests with sleep-related hypoventilation progressing to daytime hypoventilation and obstructive sleep apnea [9]. Progressive weakness of the abdominal and pharyngeal muscles leads to reduced lung volume, a weak cough, and frequent infections [10]. Progressive deterioration of inspiratory muscle strength and progressive lung restriction lead to declines in FEV and forced vital capacity (FVC) [11]. In DMD, progressive degeneration of skeletal muscle fibers and loss of thoracic wall/compliance and of diaphragm elasticity lead to inadequate airway clearance and ventilation. Progressive weakness of the respiratory muscles limits full inspiration and expiration. It causes a reduction in the FVC and forced expiratory volume in 1 second (FEV_1), resulting in a typical restrictive respiratory pattern [12]. Progressive impairment of respiratory muscle function leads to hypercapnic respiratory/ type 2 failure [10]. Hence, respiratory muscle strengthening is now an integral part of rehabilitation, along with corticosteroid therapy, which reduces respiratory complications, kyphoscoliosis, and upper-limb weakness [13].

Pulmonary function tests (PFTs) are objective measures of pulmonary function. It is widely used as a clinical tool, with various other modes, to identify the progression or regression of diseases and the effects of therapies [14].

While studies in other countries have shown the efficacy of telerehabilitation in DMD, its feasibility and effectiveness in the Indian healthcare context remain unexplored. In India, telerehabilitation is practical and requires fewer resources to provide pulmonary rehabilitation. It also reduces expenditures regarding patient care in rural settings [15]. Thus, this study was planned to assess the respiratory parameters, such as FEV_1, FVC, and FEV/FVC, in patients with DMD after pulmonary telerehabilitation, as they show restrictive-type respiratory disorders. The second objective was to explore the predictors influencing the pulmonary rehabilitation effectiveness in DMD patients.

Materials and Methods

A single-arm, pre-post interventional study was conducted from September 2023 to February 2024 among boys with DMD and respiratory dysfunction. Patients aged 5-12 years enrolled in the tertiary care hospital's Pediatric Neurology Clinic were selected for the study. Ambulatory boys with DMD confirmed by genetic testing and muscle biopsy, who had typical signs and symptoms of DMD, were free from respiratory tract infections and had no episodes of acute respiratory failure, were selected. The other inclusion criteria were that the patient's parents must have basic knowledge of attending video calls and operating e-mails. Basic questions regarding communication via WhatsApp or Skype were asked, and only those patients who were compatible with video calls were included. Patients and parents who provided written informed consent were included in the study. Children who did not respond to video calls and did not attend follow-up after 12 weeks were excluded. A convenience sample of 92 patients was recruited for this study. After exclusion, 67 patients were included in the final analysis.

The age, weight and height of study participants were recorded. The PFT, baseline data were also recorded. PFT was measured using a Spiro Excel spirometry kit (MEDICAID SYSTEMS). Spirometry was performed in accordance with ATS/ERS guidelines. After the demonstration, a minimum of three acceptable maneuvers were performed. The highest value from the three reproducible curves was recorded for analysis.

For the first time, the pulmonary rehabilitation program, including stretching and strengthening exercises, was explained to the patients and their parents/caregivers, and all related instructions were provided. A trained physical therapist demonstrated the exercises via video call and assessed the participant's technique visually to ensure correct performance before proceeding. Subsequently, a trained physical therapist demonstrated the exercises via video calls to patients and their caregivers every 15 days for reinforcement. The boys with DMD were encouraged to perform daily exercises, for 12 weeks, five days a week and 20 repetitions per day. Adherence was measured by maintaining a diary record, and a caregiver report was obtained from patients regarding weekly adherence and exercise repetition.

During video calls following respiratory exercises were demonstrated to the patients:

1. Forced inspiration: Children were asked to take breath, to their maximum limit, hold it for 5 seconds and then exhale. This exercise focused on patients' lung volumes [16].

2. Glossopharyngeal breathing (GPB): Children were asked to take "gulps" of air and propel it to the pharynx using the muscles of the mouth. It augments cough effectiveness owing to respiratory muscle weakness [17].

3. Forced expiration: Children were asked to expand the balloon by exhaling through the mouth and repeat.

After 3 months, the evaluation was performed, and compliance was measured. The procedure for recording the PFT was explained to the patient, and the highest value from the 3 successive attempts was recorded. Spirometry was performed during normal breathing in the sitting position. First, patients were asked to perform forceful inspiration followed by forceful expiration. These were represented as litres on the Y-axis and seconds on the X-axis as a volume-time curve. The values of FVC, FEV_1, and FEV_1/FVC (%) were recorded and assessed using Spiro Excel software and compared to age-matched patients.

Statistical analysis

Data were recorded in Microsoft Excel, and SPSS (version 26.0) (Armonk, NY, IBM Corp.) was used to analyze the data. Descriptive statistics were presented as Mean±SD, and percentages. Data normality was assessed using the Shapiro-Wilk test. A paired t-test was used to compare pre- and post-intervention PFT data at the 5% significance level ($P<0.05$). The effect size of the intervention was also calculated for each PFT variable using Cohen's d. Univariate and multivariate linear regression analyses (both simple linear regression [LR] and multiple LR) were performed. After adjusting for all other variables using stepwise linear regression, many multiple LR models were obtained between the independent and dependent variables. The best-fit model, determined by its R value, was chosen to report the β coefficient for each independent variable.

Results

Ninety-two boys with DMD were recruited for this study. Fourteen children did not respond after a few video calls, and eleven children did not attend during the follow-up period after 12 weeks; hence, they were excluded. Figure 1 shows the CONSORT flow diagram, and Table 1 presents the demographic characteristics of study participants.

It was observed that there was a significant improvement in FVC and FEV_1 (Table 2). There was a large effect size for FVC (Cohen's d=1.93) and FEV_1 (Cohen's d=1.06), indicating that telemedicine-based pulmonary rehabilitation markedly improves pulmonary function. The pulmonary obstruction (FEV_1/FVC) was also significantly decreased ($P<0.001$) by telemedicine-based pulmonary rehabilitation (pre-intervention value=0.603±0.238 and post-intervention value=0.45±0.114) with a medium to large effect size (Cohen's d=-0.63), which suggests that telemedicine-based pulmonary rehabilitation markedly improves the pulmonary function.

A simple linear regression revealed that age was a significant predictor of change in FVC (β=-0.24, P=0.006). Regarding improvement in FVC after intervention (dependent variable), 11.6% of the variance (R^2=0.116) is explained by age, 12.6% (R^2=0.126) by weight, and 12.9% (R^2=0.129) by height. Neither height nor weight was a significant predictor. The regression model indicated that the intercept was 3.154, and the FVC change decreased by 0.189 units for each one-year increase in age (Figure 2).

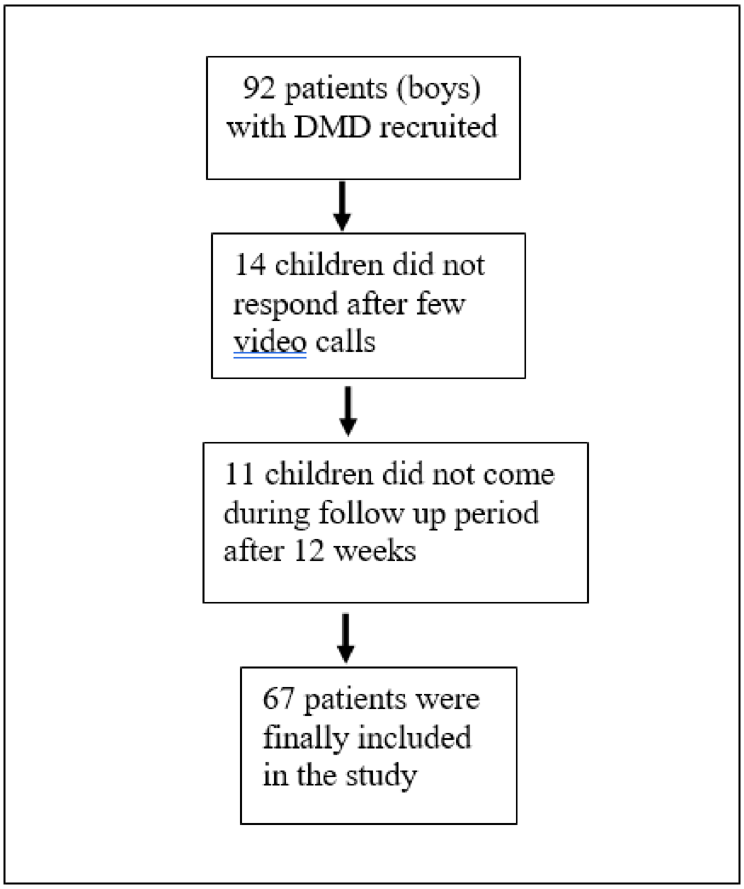

Figure 1. CONSORT diagram to report participant recruitment, attrition and final inclusion in study

Table 1. Demographic details

Variables (n=67)	Mean±SD
Age (y)	7.27±1.65
Height (cm) <-3 Z score <-2 Z score	116.52±10.93 58.2% 41.8%
Weight (kg) <-3 Z score <-2 Z score	19.63±5.68 40.3% 59.7%

Table 2. Pulmonary lung function before and after intervention (telemedicine-based respiratory exercises)

Variables	Mean±SD		t-statistics (df)	Mean Difference	Sig.	Cohen's d (Effect Size)
	Pre-intervention	Post- Intervention				
FVC	1.88±0.78	3.65±0.87	15.8 (66)	1.77	<0.001	1.93
FEV_1	1.06±0.46	1.6±0.42	8.67 (66)	0.533	<0.001	1.06
FEV_1/FVC	0.603±0.238	0.45±0.114	5.19 (66)	0.157	< 0.001	-0.63

FVC: Forced vital capacity; FEV_1, Forced expiratory volume in 1 second.

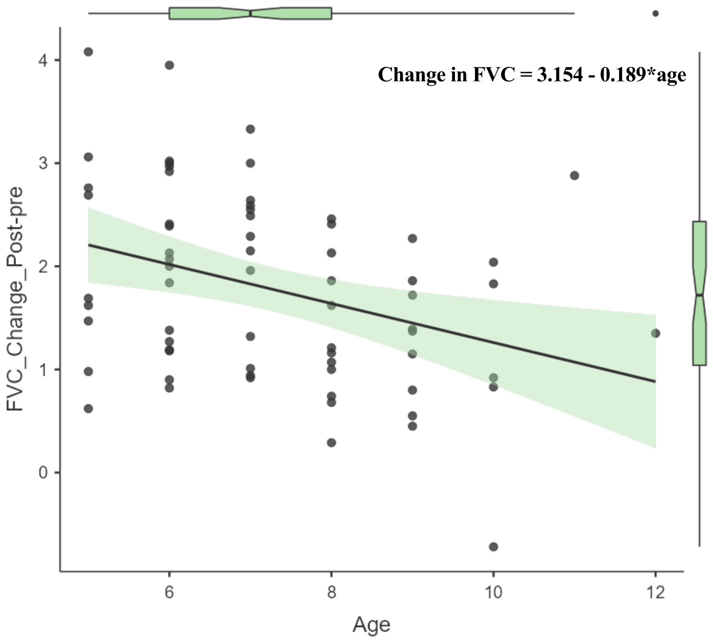

Figure 2. Scatter plot of the change in FVC value after intervention with age

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Discussion

In this pre-post study of 67 boys with DMD, a 3-month telemedicine-based pulmonary rehabilitation program was associated with significant, large-magnitude improvements in FVC and FEV_1. Telerehabilitation is a process to provide rehabilitative care in remote hospital settings, using advances in telecommunication technologies at patients' homes. Evidence shows the efficacy of telerehabilitation in many disorders, with outcomes similar to those of physical consultation and physical rehabilitation. In addition, providing therapies in a homely environment could promote compliance, help them become self-sufficient, and ease their adaptability in real life [18]. The present study also demonstrated a significant improvement in lung function by focusing on respiratory weakness through a short-term telerehabilitation approach in boys with DMD. Kenis – Coskun et al. (2022) depicted in a single blind RCT study that telerehabilitation is effective in significantly improving muscle strength, like neck extension, bilateral shoulder abduction, and left shoulder flexion, bilateral knee flexion and extension, bilateral ankle dorsiflexion, and left ankle plantar flexion strength for children with DMD [19]. Khanna et al. concluded that tele-neurorehabilitation services were feasible, effective, and less resource-intensive care in India [20]. A study by Shaw et al. at New York on multiple sclerosis patients in urban areas found telerehabilitation to be cost-effective and useful through real-time patient supervision via videoconference [21]. Similarly, another study by Akulwar-Tajane et al. on pediatric neurorehabilitation in Indian settings found that telerehabilitation was effective in connecting patients with health care providers, thus ensuring continuity of care to meet the needs of children with disabilities [22]. A recent study conducted in Turkey found that telerehabilitation led to significant improvements in upper- and lower-extremity movement [23].

Conventional respiratory criteria, such as FVC and FEV_1, are universal measures of pulmonary function [24]. Diaphragmatic weakness in DMD is characterized by a drop in FVC (>20%) [25]. The obstructive pattern in DMD shows a decrease in FEV_1/FVC to 70% of the normal value. Reduced inspiratory and expiratory muscle strength also leads to a weak cough, inadequate ventilation, and thus reduced values of FEV, FVC, and the FEV/FVC ratio [26]. Our study demonstrated significant improvements in FVC and FEV_1 in response to breathing exercises in children with DMD. The observed decrease in the FEV_1/FVC ratio, while often associated with obstruction, can also occur in restrictive diseases, such as DMD when FVC declines more rapidly than FEV_1. Our results show a dramatic improvement in FVC, which is the primary goal in restrictive lung disease. The breathing exercises played a pivotal role in improving ventilation and breathing capacity, which is in line with the study by Joo et al. [27] on the efficacy of breathing exercises, which found significant improvements in FEV_1 and FVC. Breathing exercises have been shown to increase lung capacity in a study [28], where improvements in FEV_1 and FVC were observed. One such Polish study by Wasilewska et al. [29] on children with DMD, in which breathing exercises were instructed by electronic spirometry, found improvements in FVC. Similarly, yoga breathing exercises administered for 10 months have improved respiratory function in children with DMD, as evidenced by significant changes in FVC and FEV_1 [30]. A recent study by Dhargave et al also found significant improvement in FVC after breathing exercises, which is in line with the present study [31]. Another study by Wanke et al also found improvements in FEV by respiratory muscle training and breathing exercises [32]. GPB is an autonomous lung expansion techniquespecifically taught to patients in their later stages of disease. This breathing pattern has been shown to enhance lung volume by inflating gulps of air and thus retards ventilator use [33]. A pilot study conducted among children in Hong Kong [34] by imparting a 16-week home training program where telemedicine was used to train patients via videos and follow-up performed via audio calls, video calls, and email depicted that there was significant improvement in maximal expiratory pressure (35.0 vs 47.5 cm H_2O, P=0.028).

Another finding of our study was that as the age increased, the effectiveness of telerehabilitation on FVC improvement decreased by 0.24 times. This suggests that pulmonary rehabilitation should be introduced early, as DMD is diagnosed, to improve outcomes. The study's findings are consistent with Nicot et al.'s study [26], which observed a significant negative correlation between functional residual capacity and age (r=-0.523, P=0.04). Here, age was inversely correlated with minute ventilation (Ve) (r=-0.627, P=0.007) and FVC (r=-0.72, P=0.004). Similarly, a Polish study also reported an inverse relationship between FVC and age (β coefficient=-0.542, P=0.19) among patients with DMD [29].

A limitation of this study was that it was conducted within the same group of study participants. If this study were conducted in two groups, with one group receiving regular training via videoconferencing and another receiving regular physical training in the outpatient department, the results would have been better. The cost-effectiveness of this intervention was not analysed in this study. Another limitation was that FVC drastically reduces in non-ambulatory patients when upright positions are discontinued; therefore, a separate group of non-ambulatory patients could be formed to study the effects of breathing exercises in this population. In DMD, the respiratory muscles are considerably affected, since our electronic spirometer could not monitor the parameters (maximal inspiratory pressure and maximal expiratory pressure), so future studies can be conducted to monitor other respiratory muscle strength parameters.

Conclusion

Thus, the study findings suggest that telerehabilitation is a promising and effective model for delivering pulmonary rehabilitation and is associated with significant improvement in lung function in patients with DMD. Home-based respiratory exercise training for disabled patients delivered via video conferencing has helped patients maintain continuity of care and improve compliance. The second conclusion is that the rehabilitative care should be started as early as possible for better outcomes. Therefore, breathing exercises can be taught to children with DMD through telerehabilitation in India.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Biomedical Research Ethics Committee of Post Graduate Institute of Medical Education & Research (PGIMER), Chandigarh, India (Code: INT/IEC/2023/Study-1550).

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Authors' contributions

Conceptualization, study design, material preparation, writing and final approval: All authors; Data collection: Priyanka Gupta, Seveka Bali, Amrit Pal Singh Sood, Sudhansu Sekhar Baral, Somya Saxena, Rita Upadhyay, and Renu Suthar; Data analysis: Priyanka Choudhary, Amit Kumar Mital, Sudhansu Sekhar Baral, Priyanka Gupta, Seveka Bali, and Amrit Pal Singh Sood;

Conflict of interest

The authors declared no conflict of interest.

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