

Whole Body Vibration - a new therapeutic approach to improve muscle function in Cystic Fibrosis ?

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Abstract:

Background: Disease progression in Cystic Fibrosis (CF) leads to muscle wasting and loss of muscle function.

Objective: The aim of this prospective pilot study was to evaluate the effects of whole body vibration (WBV) on muscle function in adult CF-patients.

Methods: 10 patients (3 m; 7 f) of the CF Center Cologne, Germany, have completed the 3 months' study (age 24-47 years; FEV₁ 17-109 % predicted (49±29) and BMI 16,6–24,4 kg/m² (19,3±2,5). WBV was provided by a vibration platform (Galileo 2000). The patients were standing in an upright position receiving vertical vibration of frequencies between 20-25 Hz. The vibration exercise evokes muscle contractions via stretch reflexes improving muscular activity. The training schedule consisted of three 3-minute sessions twice a day 5 days per week for 3 months. Every 4 weeks the following tests were performed: FEV₁, FVC, BMI, chair-rising-test, one- and two-leg-jump test as well as maximal isometric grip force. The Study has been approved by the local ethics committee.

Results: After 3 months of WBV all parameters in the chair-rising test significantly improved: chair-rising-time (p=0,03), maximal force (p=0,02), maximal power (p=0,01) as well as velocity (p=0,02). The peak-jump-force (p=0,02) and velocity (p=0,01) of the two-leg-jump significantly improved. Parameters in the one-leg-jump as well as maximal isometric grip force showed no significant improvement. Weight and BMI showed a slightly positive trend whereas FEV₁ and FVC did not significantly change. Any change in mechanographic parameters did not correlate with FEV₁ or FVC in the present study.

Conclusion: These results demonstrate that whole body vibration can improve muscle function in CF patients.

Key words: whole body vibration, muscle function, cystic fibrosis, mechanography, peak jump force, peak jump.

Abbreviation list:

BMI: body mass index

CRT: chair-rising-test

FEV₁: forced expiratory volume in 1 sec

FVC: forced vital capacity

MF: maximal force

MP: maximal power

Olj: one-leg-jump

PFT: pulmonary function test

PJF: peak jump force

PJP: peak jump power

MIGF: maximal isometric grip force

SDS: standard deviation score

V_{max}: maximal velocity

V_{mean}: mean velocity

WBV: Whole Body Vibration

Introduction:

Cystic Fibrosis (CF) is the most common chronic hereditary disease in Caucasians. Due to improved therapy and better understanding of the disease, life expectancy has risen to an average of 38 years (1) and is continuing to rise. With this increased life-expectancy it becomes even more important to maintain functional activity as one part of quality of life. Muscle power declines significantly over life span leading to a reduction in physical functioning. Additionally, disease progression in CF aggravates muscle wasting and loss of muscle function resulting in impaired mobility.

Although it is generally accepted that physical exercise positively affects muscle force at all ages in CF, permanent compliance of CF patients with traditional exercise programs has generally been low (2). In addition, CF patients with severely reduced pulmonary function and respiratory insufficiency are not capable to perform sufficient physical exercise.

General objective in chronic disease is preventing or minimizing disease-related muscular decline and restituting functional independence.

Mechanical stimulation in form of whole body vibration (WBV) is a new type of exercise currently tested in sports, geriatrics and rehabilitation (3,4,5). It has recently been found to be a safe and efficient method to activate muscular activity via stretch reflexes (6). The high-frequency postural displacements induced by vibration of the platform produce reflex muscle contractions aiming to stabilize posture. This effect leads to improvement of muscular performance, body balance and physical functioning (7). Thus vibration can be viewed as a special form of muscle training that may particularly affect muscle function. The effects of whole body vibration exercise have not yet been investigated in CF patients although these patients often show a severe loss in skeletal muscle function and reduced mobility during their disease progression.

In the present study this new vibration exercise was tested along with the hypothesis that 3 months WBV can improve muscle function in CF patients.

Subjects and Methods:

Subjects.

The study was performed in the CF Center of the Children`s Hospital, University of Cologne, Germany. 10 clinically stable patients with CF aged 24-47 years (3 males; 7 females) have been evaluated prospectively for a 3 month time period. FEV₁ was 17-109 % predicted (mean 49±29) and BMI 16,6–24,4 kg/m² (mean 19,3±2,5) (Tab. 1). All patients receive standard care containing a nutrition regimen, individualized chest physiotherapy and inhalation therapy as well as antibiotic treatment according to microbiological results. Patients were informed that overall activity including both habitual and sport activity should not be changed during the study period.

The study was approved by the ethical committee of the University of Cologne. Written informed consent was obtained from all individuals.

Test procedure:

Whole body vibration (WBV) was provided by a vibration platform (Galileo 2000, Novotec GmbH, Pforzheim, Germany), which was delivered to the patients` homes. Patients were standing in an upright position receiving vertical vibration of frequencies between 20-25 Hz. The peak-to-peak amplitude was 0,6 mm. The training schedule consisted of three 3-minute sessions twice a day 5 days per week for 3 months.

During vibration on the platform the participants were standing with flexed knees (20-45 degree) to intensify training of muscles of the lower extremities. In addition the following exercises have been made to train muscles of the trunk and back:

- 1) Trunkrotation for abdominal- and backmuscle activity as well as extension of intercostal muscles
- 2) Trunklateralflexion for abdominal- und backmuscle activity and extension of lateral trunk

3) Trunkextension for abdominal- und backmuscle activity and primarily extension and mobility of thoracic spine

4) Trunkflexion for mobility of spine.

During the 3 months period, the patients were seen in 4 week intervals. Pulmonary function (spirometry), auxological parameters and a test programme assessing muscle function including the chair-rising-test, the one- and two-leg jump test as well as maximal isometric grip force were performed.

Pulmonary function test (PFT):

All spirometric measurements were performed using a pneumotachometer system (Masterlab, Erich Jaeger, Würzburg, Germany). The patients were sitting in an upright position and wearing a noseclip. Only prebronchodilator manoeuvres were evaluated. The PFT was performed according to the guidelines of the American Thoracic Society (ATS) (8) .

The most widely used and accepted pulmonary function test (PFT) is measurement of FEV₁ and FVC by spirometry. The reproducibility and variability of FEV₁ are well-defined (8). FEV₁ correlates with mortality in CF, and it is a validated outcome measure for studies in CF (9,10). FEV₁ and FVC values are calculated in percent predicted according to Zapletal.

Measurement of muscle function: Mechanography, a new device for the assessment of muscular function, was applied to assess jumping forces (peak jump force (PJF) and peak jump power (PJP) as well as velocity (Vmax) (11). A platform (Leonardo, Novotec GmbH, Pforzheim, Germany) measures forces applied to the plate over time. Therefore, stationary forces as well as variation of forces over time can be investigated (12). The platform is divided into two sections and can measure the applied forces from the right and left lower limb separately. The detection of force is performed by deformation of detectors that is proportional to the applied force. These data are analyzed by a personal computer recording the change of force measured over time. Therefore kinetic parameters as well as velocity can

be calculated when body weight is known. Software for the detection, storage and calculation of data was also manufactured by Novotec GmbH (Pforzheim, Germany).

Performance of jumping: The patients were standing on the platform and each foot was placed on one section of the jumping platform. The jump was performed as a counter movement jump with freely moving arms, and the patients were instructed to jump as high as possible using both feet and landing also on both feet. The maximum of force of the ascending part of the jump was used for further calculations and is defined as peak jump force (PJF). The patients performed three jumps and the highest peak was selected for further calculations. The peak of the calculated power (force x velocity) is called peak jump power (PJP). Maximal velocity (V_{max}) was defined as the highest velocity of jumping.

One-leg jumping was performed for each leg three times separately with the analysis of the same parameters as with the two leg jump.

Chair-rising test: A seat of the manufacturer was adjusted to the Leonardo platform for the chair-rising-test (CRT) measuring the time interval from rising (no force detection on the chair) until sitting again (force detection on the chair). The test involves rising, with arms folded across the chest, from a sitting position on the chair of standard height (46cm) until an upright position defined as fully stretched knees and returning to the sitting position. Patients were timed whilst performing 5 repetitions of the sit-to-stand test as quickly as they could as a surrogate measure of their muscle power. The 1-chair stand test was used to determine time, maximal velocity (V_{max}) to stand up as well as maximal force (MF) and power (MP) of 1 stand-up by adjusting the time interval to one rising instead of five.

Maximal isometric grip force (MIGF):

Maximal isometric grip force was determined at the nondominant hand with a standard adjustable-handle Jamar dynamometer (Preston, Jackson, MI, USA). The handle was adjusted so that the line of the subject's proximal interphalangeal joints rested exactly on top of the adjustable handle. The subjects were seated with the dynamometer held without support being

asked to put maximal force on the dynamometer. The maximal value of two trials was noted. MIGF was calculated by multiplying the dynamometer reading in kilograms by a factor of 9.81 (unit in Newtons).

Statistical analyses. Descriptive statistical parameters were calculated for the entire study population. Peak jump force, peak jump power and related parameters were transformed into height- and gender-dependent standard deviation scores (SD-score) using reference populations by the formula $SD\text{-score} = (\text{rough value} - \text{mean of reference population}) / SD \text{ of reference population}$. SD-scores for height, weight and BMI were calculated with reference to age and gender. Peak jump force (PJF)-, peak jump power (PJP)- as well as maximal isometric grip force (MIGF)- SD-scores are related to height (11,13,14). For parameters tested in the chair-rising test no reference data are available.

SD-scores were compared to the reference population by one-way ANOVA (paired t-tests, one-tailed). Moreover, auxological, spirometric and mechanographic parameters were also compared for differences between before and after exercise treatment by paired t-tests (two-tailed). Linear regression analyses were performed to investigate the prediction of BMI by FEV1 and associations between different auxological, spirometric and mechanographic parameters. Statistical differences were ascribed to be significant at $p < 0.05$. All statistical procedures were performed by the use of PC Statistics 4.0 (Hoffmann-Software, Gießen) and GraphPad Prism 3.00 for Windows (GraphPad Software, San Diego, CA, U.S.A.).

Results

All patients completed the three months study without any objective side-effects. Neither subjective side-effects such as exhaustive fatigue were reported. The training schedule on the Galileo platform at home was well accepted. All patients underwent the follow-up assessments.

Table 1 shows the parameters tested at study start. Subjects affected with CF were characterized by significant lower values of weight, PJP and MIGF in comparison to normal individuals (SD-scores from the reference).

BMI was positively correlated to FEV₁% ($r = 0.72$). Although several parameters were changed after 3 months of exercise, auxological, spirometric and mechanographic parameters were still significant below the reference.

Table 2 displays changes of parameters after 3 months of exercise. Weight and BMI show a slightly positive trend. Parameters describing pulmonary function did not significantly change. All parameters of the chair rising test significantly improved. 8 of 10 patients showed improvement of muscular performance by reducing their chair-rising time (chair-rising 5 times). 9 patients improved in muscle force (MF), 7 in muscle power (MP) irrespectively of FEV₁ and BMI. MF and MP increased independently from a slight but not significant increase of body weight.

In jump performance (two leg jump) PJJF decreased significantly, whereas PJP remained stable. This was accompanied by a significant elevation of $V_{max_{jump}}$. In the one-leg-jump PJJF and PJP showed no significant change.

The development of maximal forces at the forearm assessed by MIGF remained stable. Any change in mechanographic parameters or BMI did not significantly correlate to FEV₁ and FVC in the present study.

Table 1. Anthropometric characteristics of the entire study population at start of the study

Significant differences of SDS from the reference are indicated with an asterisk.

V mean: mean velocity, MF: maximal force, MP: maximal power, PJF: peak jump force, PJP: peak jump power, Vmax: maximal velocity, olj: one-leg-jump, MIGF: maximal isometric grip force, SDS: standard deviation score.

Table 2. Differences of parameters before and after an interval of 3 months of exercise

Significant differences between t1 (study start) and t2 (after 3 months) are indicated with an asterisk.

V mean: mean velocity, MF: maximal force, MP: maximal power, PJF: peak jump force, PJP: peak jump power, Vmax: maximal velocity, olj: one-leg-jump, MIGF: maximal isometric grip force, SDS: standard deviation score.

Fig.1. Changes in chair-rising time (5) at study start and after 3 months of whole body vibration exercise. The numbers of the 10 CF patients are shown.

Table 3: FEV₁, BMI, time (5), MF and MP of the chair-rising test (CRT) of all 10 CF-patients at study start (0m) and after 3 months of intervention (3m)

Discussion

Muscle weakness is a common finding in CF patients and aggravates during disease progression (15,16,17). The aim of this pilot study was to assess the effects of WBV-exercise on muscle function in CF patients. For this small intervention study the patients were chosen very heterogeneously to explore the effects of WBV in all stages of disease progression.

To test physical performance the chair-rising test has been widely used and is well validated (18). In the present study 8 of 10 patients could improve their muscular performance by significantly reducing their chair-rising time after 3 months of WBV exercise. Also velocity showed a significant improvement. The parameters assessed in the two leg jump show similar trends. Velocity also increased significantly, but interestingly, PJF decreased without any significant change of PJP. As muscle power is a product of muscle force multiplied by velocity patients can obtain higher muscle power by improving either muscle force or velocity. The present data indicate that WBV mainly improves muscular power by increasing velocity of inter- and intramuscular coordination. Especially in complex movement patterns such as chair-rising and two-leg-jump with isotonic and isometric movement components the neuromuscular system shows adaptive effects by improving velocity with the positive result of saving muscle force. Velocity can be specially trained with WBV by enhancing the pattern of recruitment of muscle fibers. According to the current view in physiology, vibration applied to the whole body at the frequency of 1-30 Hz induces a tonic excitatory effect on exposed muscles (7). The reflex involves activation of muscle spindles, mediation of the neural signal by afferents and activation of muscle fibers via motoneurons (6). The response to the reflex may also increase recruitment of motor units via activation of muscle spindles and polysynaptic pathways, the effect which is seen as increase in muscle activity.

Blottner et al have also shown that vibration muscle exercise increased the activity-dependent expression of nitric oxide synthase type 1 at myofiber membranes (19). These data provide

further insight into the mechanism of beneficial effects of vibration muscle exercise on a deconditioned muscle system.

Subjects affected with CF were characterized by significant lower values of weight, PJF, PJP and MIGF in comparison to healthy, adult individuals. Assessment of MIGF using a hand-held Jamar dynamometer is a simple, cheap and well-established method to quantify muscle function (14). Using the same dynamometer as in the present study, Elkin et al (17) showed that MIGF of young CF adults was decreased by about 0.9 SD compared to age-matched healthy controls, which is very close to our results. Similar results were also shown by Rauch et al assessing MIGF of 13 cystic fibrosis children (14). Sahlberg et al compared muscular function of thirty-three adult CF patients and also found reduced hand-grip strength compared to healthy controls even in patients with moderate-to-high-activity levels (20). As expected no significant effect was observed in the MIGF after WBV-exercise as this muscle group was not specifically trained. Therefore, MIGF could serve as a control parameter in this study.

For parameters assessed by the one-leg-jump the results are similar to the MIGF; muscle force as well as muscle power increased slightly without any significant effect. As the relation of muscular cross-section that can be trained is much lower compared to the cross-section of the two-leg-jump we might not see a training effect after 3 months.

The patient group included in this study was diverse. The patients' age was 24 to 47 years (mean $35,2 \pm 8,3$). FEV₁ values were between 17 and 109% with one patient having chronic oxygen requirement and another patient having no pulmonary symptoms at all. As expected the same wide range is seen in BMI values of 16,6 to 24,4 (mean $19,3 \pm 2,47$) as FEV₁ is correlating well with BMI. The improvement in muscle function after WBV-exercise is irrespective of FEV₁ or BMI. Pulmonary function (FEV₁ or FVC) showed no correlation to any change of mechanographic parameters tested in this study. Because of the short observation period and the fact that the study was performed during winter time, an improvement in pulmonary function could not be expected. However, despite FEV₁ and FVC

did not improve during the 3 months CF patients could increase muscle power and benefit from better muscular performance in their every-day life. A longer observation period is necessary to evaluate whether WBV has a positive effect on pulmonary function.

The decline in muscle power is a well-recognized problem in adult CF patients contributing to physical disability in every-day-life. The ideal type, intensity, frequency and duration of physical activity for CF patients is unknown (21). We hypothesized that WBV is a special type of exercise that may be particularly suitable for adult CF patients. It does not require much time or effort (exercise could be done at home besides standard CF therapy) and can be adjusted individually by not causing any traumatic injuries. Even patients with chronic respiratory insufficiency and oxygen dependence could perform the WBV exercise. The WBV technique might be especially useful for patients with severely impaired lung function including patients awaiting lung transplantation as conventional physical exercise is difficult to perform. Furthermore WBV could be included in a physiotherapy program for patients whose adherence with traditional exercise programs is low.

The present study has several limitations. The small number of participants and the relatively short duration of the intervention might have prevented us from identifying treatment effects on secondary outcomes such as pulmonary function or weight gain. However, the effect on the primary outcome -muscle function assessed by the chair-rising-test- was significant. Second, the lack of a matched CF control group to consider if the improvement of muscle function is a placebo effect derived from increasing the emphasis on muscular activity training in CF or even a training effect in the chair-rising test. Further studies with a run-in period as well as a matched control group will derive from this pilot study. The training was perceived as very useful by the participants, who uniformly reported an improved mobility and well-being during every-day-life activities, even in cases of severe disease progression.

As the chair-rising-test is a representative test for functional independence in daily activities improvement of muscular performance in this test reflects better functional mobility of daily

living and possibly quality of life in CF patients. The results of this small intervention study show that WBV exercise is a simple, safe, convenient and efficacious training method that can improve muscle function in adult CF patients. The availability of such an intervention shows new perspectives for therapy and prevention of disease-related loss of muscle function in CF patients.

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Table 1:

Parameter	Mean	SD	Median	Range
Age [yr]	35.2	8.3	38.2	23.8-47.0
Height [cm]	172.1	7.5	172	163.0-187.0
Height-SDS	-0.01	0.91	-0.09	-1.07-1.77
Weight [kg]	57.1	6.6	56.8	45.9-67.0
Weight-SDS	-1.23*	1.13	-1.09	-3.23-0.48
BMI [kg/m ²]	19.3	2.47	19.1	16.6-24.4
FEV1 %	49.4	29.1	44.7	16.9-108.8
FVC %	64.5	23.2	58.1	39.2-110.1
Chair Rising(5) [s]	7.07	1.77	6.61	4.78-10.76
Chair Rising(1) [s]	0.70	0.18	0.66	0.48-1.08
Vmean Chair Rising(1) [s]	0.46	0.14	0.42	0.27-0.75
MF Chair Rising(1) [N]	1061	305	969	0.62-1.61
MP Chair Rising(1) [W]	724	196	727	0.38-1.04
PJF [N]	1413	232	1393	1004-1699
PJF-SDS	-0.64*	0.86	-0.66	-1.71-1.15
PJP [W]	2271	506	2338	1506-3203
PJP-SDS	-1.44*	1.05	-1.77	-2.97-0.24
Vmax Jump [m/s]	2.08	0.27	2.01	1.72-2.57
PJFolj [N]	1472	352	1554	1009-1994
PJPolj [W]	1238	422	1159	1159-2022
MIGF [N]	267	56	270	186-392
MIGF-SDS	-1.36*	0.96	-1.1	-2.95-0.23

Table 2:

Parameter	Mean of differences (t2-t1)	SD of differences (t2-t1)	P
Weight [kg]	0.73	1.85	0.12
BMI [kg/m ²]	0.24	0.64	0.13
FEV1 %	-1.3	5.2	0.44
FVC %	-3.5	6.3	0.11
Chair rising(5) [s]	-1.05*	1.64	0.03
Chair rising(1) [s]	-0.10	0.16	0.04
Vmean Chair(1) [m/s]	0.13*	0.18	0.02
MF Chair(1) [N]	438*	567	0.02
MF Chair(1)/weight [N/kg]	7*	9	0.02
MP Chair(1) [W]	135*	150	0.01
MP Chair(1)/weight [W/kg]	2.38*	2.78	0.02
PJF [N]	-122*	141	0.01
PJF-SDS	-0.43*	0.46	0.02
PJP [W]	-5	207	0.47
PJP-SDS	0	0.47	0.50
Vmax Jump [m/s]	0.10*	0.12	0.01
PJFolj [N]	72	197	0.14
PJPolj [W]	119	210	0.10
MIGF [N]	21	38	0.06
MIGF-SDS	0.33	0.62	0.06

Table 3:

patient	FEV ₁ (%)		BMI (kg/m ²)		time(5) (s) of CRT		MF (N/kg) of CRT		MP (W/kg) of CRT	
	0 m	3 m	0 m	3 m	0 m	3 m	0 m	3 m	0 m	3 m
1	17	16	17,7	17,9	7,2	8,2	15,0	15,6	9,9	9,4
2	18	17	16,6	16,6	8,8	5,5	15,1	18,2	13,1	7,2
3	27	25	18,6	19,2	8,1	5,7	14,8	29,5	10,6	13,3
4	30	28	17,1	16,3	10,8	6,6	13,6	18,8	8,3	12,5
5	42	40	19,7	21,0	6,0	5,5	22,8	29,0	14,4	14,7
6	42	37	21,1	20,5	7,3	6,9	20,9	14,6	14,6	14,0
7	51	44	21,8	21,8	6,2	5,5	17,1	24,7	15,8	17,5
8	62	54	20,7	21,4	5,8	5,1	16,1	35,3	16,8	17,1
9	77	85	20,7	21,4	6,0	6,1	20,0	42,9	10,6	18,6
10	109	107	24,4	24,4	4,8	4,7	23,5	34,4	10,7	15,2

Graphs:

