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Whole-body vibration training in children with Duchenne muscular dystrophy and spinal muscular atrophy

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ABSTRACT

Introduction: Whole-body-vibration training is used to improve muscle strength and function and might therefore constitute a potential supportive therapy for neuromuscular diseases.

Objective: To evaluate safety of whole-body vibration training in ambulatory children with Duchenne muscular dystrophy (DMD) and spinal muscular atrophy (SMA).

Methods: 14 children with DMD and 8 with SMA underwent an 8-week vibration training programme on a Galileo MedM® at home (3×3 min twice a day, 5 days a week). Primary outcome was safety of the training, assessed clinically and by measuring serum creatine kinase levels. Secondary outcome was efficacy as measured by changes in time function tests, muscle strength and angular degree of dorsiflexion of the ankles.

Results: All children showed good clinical tolerance. In boys with DMD, creatine kinase increased by 56% after the first day of training and returned to baseline after 8 weeks of continuous whole-body vibration training. No changes in laboratory parameters were observed in children with SMA. Secondary outcomes showed mild, but not significant, improvements with the exception of the distance walked in the 6-min walking test in children with SMA, which rose from 371.3 m to 402.8 m ($p < 0.01$).

Interpretation: Whole-body vibration training is clinically well tolerated in children with DMD and SMA. The relevance of the temporary increase in creatine kinase in DMD during the first days of training is unclear, but it is not related to clinical symptoms or deterioration.

1. Introduction

Duchenne muscular dystrophy (DMD) and spinal muscular atrophy (SMA) are among the most common inherited neuromuscular diseases with onset in childhood, both leading to severe physical disability. The incidence of DMD is 1/5000,[1] that of SMA is 1/6000–1/10000.[2] DMD, an X-chromosomal-recessive disorder, is caused by mutations in the dystrophin

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gene that result in the absence of the cytoskeletal protein dystrophin. This leads to increased permeability of the sarcolemma made apparent by elevation of the serum creatine kinase (CK), a marker of muscle damage. However, the exact pathophysiologic mechanism leading to the increased membrane permeability and ultimately severe muscle degeneration in DMD is not fully understood.[3] SMA is caused by an autosomal-recessively inherited deletion on the *SMN1* gene which causes the alpha motor neurons in the spinal cord to degenerate and neurogenic muscular atrophy. CK levels are within the normal range or mildly elevated in patients with SMA. Despite their different aetiologies and pathophysiology,

DMD and SMA have many clinical characteristics and treatment approaches in common. Main symptom of both disorders is progressive proximal muscular weakness, leading to impaired motor function with loss of ambulation, development of scoliosis and reduced pulmonary function.[4,5] Complications associated with immobilisation such as contractures and osteoporosis[6,7] contribute significantly to morbidity.

DMD and SMA remain incurable; thus the current treatment approaches, published in Standards of Care for both diseases,[8–10] are mainly symptomatic. Although there are no specific guidelines for physical activity in DMD, regular
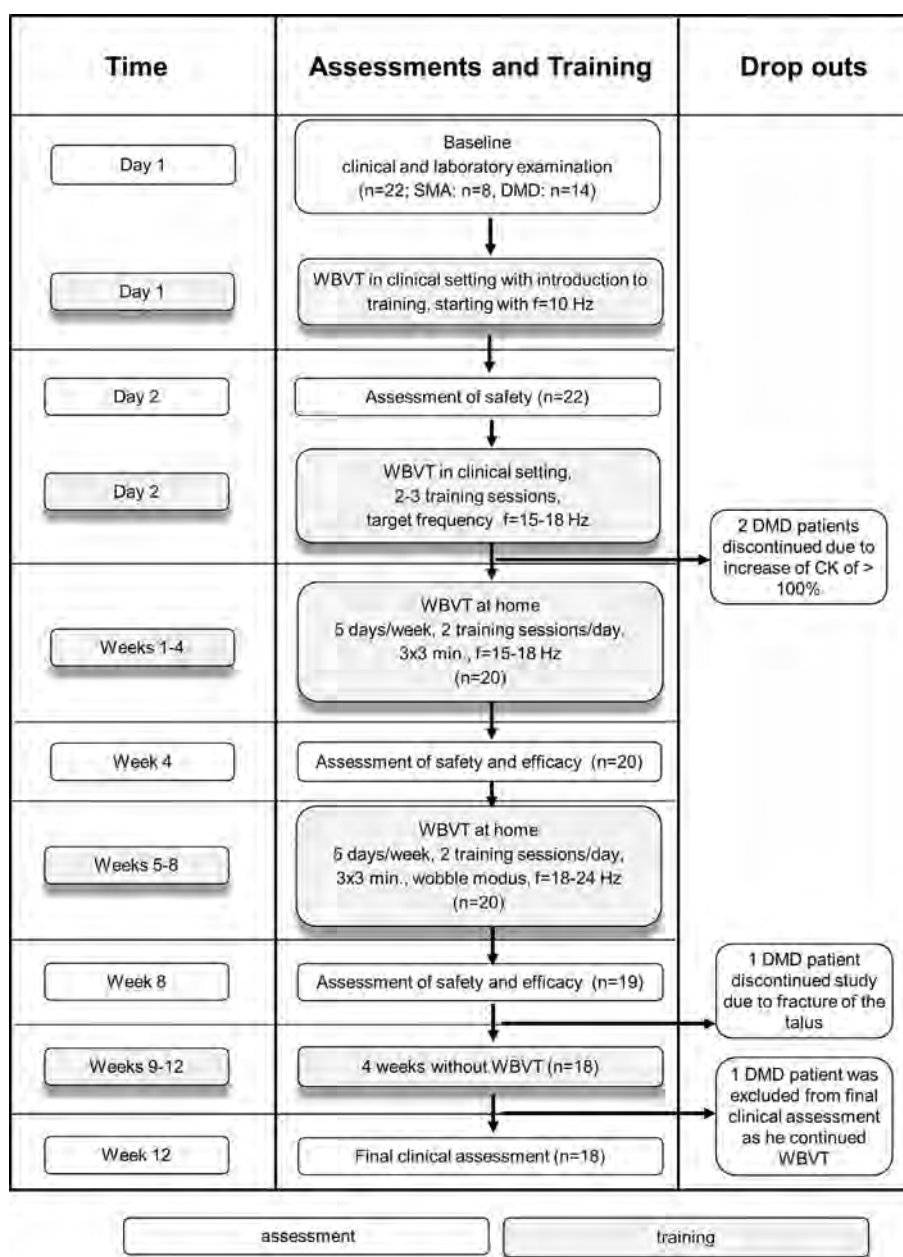

Fig. 1 – **Study flow diagram for the complete study period (12 weeks) with the number of patients (*n*) participating. The training programme and the assessments are shown in the middle. The left column specifies the timing and the right column indicates the patients that did not complete the trial. SMA = Spinal muscular atrophy, DMD = Duchenne muscular dystrophy, WBVT = whole-body vibration training, f = vibration frequency, Hz = Hertz.**

physiotherapy and mild exercise training are recommended[9,11] to decelerate muscle atrophy, prevent contractures and stabilise motor function, which in turn reduces secondary disuse atrophy and weight gain. Mild exercises should be practiced several times per week, ideally daily. However, compliance is often limited because of lack of time and motivation on the part of the families to perform the time-consuming exercises. Compliance could be enhanced by a short and effective physical treatment, easily doable at home and appealing to children.

Whole-body vibration training (WBVT) is a new therapeutic strategy in sports, rehabilitation and preventive medicine. The training consists of mild physical exercises the patient performs while standing on a vibrating platform. Two different types of vibration transmission are available: a synchronous system, where vibration is applied to both feet at the same time, and a side-alternating mode which provokes pelvic movement similar to that of walking. Both vibration-platform types deliver high-frequency mechanical stimuli to the musculoskeletal system that lead to changes in muscle length. The resulting activation of muscle spindles elicits a reflex contraction of the homonymous muscle. The vibratory stimulus therefore leads to cyclic elongation and contraction of the stimulated muscles,[12] which results in measurable increases in muscle strength,[13–17] flexibility[18] and bone mineral density.[19–22] It is hypothesised that the underlying mechanism is increased sensitivity of muscle spindles, which results in a synchronisation of motor units leading to the described clinical effects.[23,24] While WBVT has largely been studied in adults, few trials have been conducted in a paediatric population. Here, positive effects on bone health[25] and functional benefits in children with cerebral palsy[26] have been reported.

These WBVT effects on the musculoskeletal system may also benefit children with neuromuscular diseases, as increases in muscle strength, function and flexibility and bone mineral density are desirable therapeutic effects in this population. However, it is not known whether vibration is well tolerated by damaged muscle. This is especially the case in DMD, where one widely-accepted theory on the pathophysiology, a "mechanical hypothesis", claims that muscle contraction causes mechanical injury to the fragile sarcolemma[27] and thus promotes muscle wasting.

Aim of this trial was to assess the safety and effects on muscle strength and function of an 8-week, intensive, whole-body vibration training programme on the Galileo© vibrating platform in children with DMD and SMA.

2. Patients and methods

2.1. Patients

In this open, bicentric pilot trial, 22 ambulatory children aged 5.7–16.2 years, 8 of whom with SMA (mean age 9.9 years, 5 girls, 3 boys) and 14 boys with DMD (mean age 8.8 years), participated. All but two of the boys with DMD were undergoing long-term steroid treatment. They were recruited between 2010 and 2011 through the TREAT-NMD patient registries for DMD and SMA and the neuromuscular clinics of both participating institutions (University Medical Centre Freiburg, Germany and Children's University Hospital Cologne, Germany). Inclusion criteria were: age 5–18 years, clinically and genetically-confirmed diagnosis of SMA or DMD, the ability to walk at least 10 m unaided, to stand and perform specific exercises on the vibrating platform, and to cooperate on the assessments. Exclusion criteria were: changes in medication having a potential effect on muscle strength 3 months prior to inclusion or during the trial, and any contraindication for WBVT such as epilepsy, renal or biliary stones, bone fractures in the past 6 months, acute inflammation of the musculoskeletal system, acute thrombosis in the past 6 months, acute hernias, acute injuries to the feet, any surgery in the past 3 months, pregnancy and implants in trained body parts. All patients and their parents were informed about the design, goals and possible risks of this study, and written informed consent was obtained. The trial was approved by the German regulatory authorities and responsible ethic committees.

2.2. Methods

WBVT was performed on the side-alternating Galileo©MedM platform without rails (Novotec Medical GmbH, Pforzheim, Germany). A trial flow diagram is displayed in Fig. 1.

Patients and their parents were instructed in the training by the authors and experienced physical therapists on two consecutive days with 2–3 training sessions per day in the hospital. Between each training session, the patient had a break of at least 4 h. For the first training, we chose a low vibration frequency of 10 Hz which was gradually increased to 15–18 Hz as soon as the patients felt comfortable with the training. The target frequency of 15–18 Hz was achieved on the first day in all patients. The vibration amplitude was a steady 4 mm. One training session consisted of three training units, each lasting three minutes, with a break of three minutes between each unit. In each unit, the children performed a physical exercise on the vibrating platform: 1) mild squatting, 2) stretching the gastrocnemius muscle, and 3) alternating slight weight shift from the right to the left leg. Patients were allowed to hold fast onto wall bars for stabilisation during the exercises. After the teaching phase in the hospitals, the patients continued with WBVT at home, 3 × 3 min twice a day with a minimum break of 4 h between both sessions, on five freely-selectable days per week. We decided on this training schedule and not a daily training program for practical reasons, making short family trips or celebrations possible during participation in the trial. There were no changes in preexisting therapies, including physiotherapy, during the study period. Each family received a written detailed description of the training as well as a poster on which the exercises were illustrated for the training at home. During the training at home, patients hold fast onto stable furniture or wall bars. The families were asked to complete a diary noting the exact training times and any particularities. After one week, all families were contacted by telephone to ensure that training was being performed properly and to see if there were any complaints. After the first 4 weeks of training at a constant frequency of 15–18 Hz, a wobble modus was programmed with the vibration frequency undulating

between 18 and 24 Hz. The training then continued with the same exercises using the wobble modus for another 4 weeks at home. To summarise, patients performed the WBVT during 8 weeks, followed by another 4 weeks without training.

2.3.   Outcomes

<u>Primary outcome</u> was safety, assessed clinically and by laboratory parameters. Clinical evaluations after the first day of training and after 4, 8 and 12 weeks included a thorough general and neurological clinical examination including blood pressure, heart rate and body temperature, as well as questions on symptoms of muscular damage such as muscle pain, indicated on a 10-point scale, muscle cramps or muscle weakness. We also asked explicitly for pruritus or skin erythema of the legs. Any adverse events were noted. Laboratory parameters were analysed at baseline (day 1), i.e. just before the first training session in the hospital, 24 h after starting the first training unit (day 2) and after 4 and 8 weeks of training. They included serum markers for muscle damage, i.e. creatine kinase (CK), lactate dehydrogenase (LDH) and myoglobin, as well as a blood panel, serum electrolytes and C-reactive protein. Serum creatine kinase is an important serum marker of sarcomeric damage.[28] In the original study protocol, stop criterion for boys with DMD was defined as an increase in serum CK of ≥100%, irrespective of clinical symptoms. The protocol was amended after starting the study after consultation with external experts and in agreement with the local ethics committee, as two patients with DMD presented an increase in CK of >100% without presenting any major clinical symptoms of muscle damage. In the amended protocol, the stop criterion for DMD patients was therefore defined as a rise in CK of >100% plus clinical symptoms of muscular damage **or** an increase of >100% plus an ongoing increase in CK of ≥20% after three more training days **or** a CK of ≥40.000 IU/l after starting the WBVT. Stop criteria for children with SMA were clinically-relevant symptoms of muscular damage or an increase in CK to >1000 IU/l.

<u>Secondary outcomes</u> were changes in muscle function, strength and range of movement of ankle joints assessed before WBVT, after 4 and 8 weeks of training, and after another 4 weeks without WBVT (Fig. 1, study flow chart). These clinical evaluations were usually carried out by the same experienced physiotherapist in each patient. Time functional tests included the 6-min-walk test, 10 m walking time, the time to climb four stairs and the time to rise from a supine position. We examined muscle strength using the modified Medical Research Council (MRC) scale with scores ranking from 0 (no muscle contraction) to 10 (normal force).[29,30] The following muscle groups of both body sides were assessed at each assessment: hip flexors and –extensors, hip abductors, knee flexors and extensors and ankle dorsiflexors and plantarflexors. A sum score (MRC %) for the lower limb was calculated using the equation: MRC % = sum of grade scores × 100/(number of muscles tested × 10). Additionally, muscle strength of knee extensors, knee flexors and elbow flexors of the dominant body side were assessed by hand-held dynamometry with the Citec©-dynamometer (CIT Technics, The Netherlands) using the "break"

technique. At each assessment, each muscle group was tested three times and the highest score was used for statistical analysis. Strength values of the knee flexors and extensors were used to calculate a mean knee-strength score. The angular degree of dorsiflexion of the ankle joints with extended knees, which reflects the flexibility of calf muscles, was measured with a goniometer. It was assessed because one of the exercises performed on the vibrating platform consisted of stretching of the calf muscles. When dorsiflexion exceeded the neutral zero position, the angle was expressed in positive values, while a negative value indicated that the foot remained in plantarflexion and failed to attain the neutral zero position.

Patients were asked to provide information on whether they experienced any subjective change in their motor function on a three-point scale (improved, unchanged, worsened) at each visit.

2.4.   Statistical analysis

As the pathologies of SMA and DMD differ, the laboratory safety parameters and clinical outcomes of both patient groups are analysed separately.

Statistical analysis was performed with SPSS 20 software. We used the Kolmogorov–Smirnov test to check for normal distribution of data. Student's t-test was used to assess changes in normally-distributed parameters (all laboratory parameters, muscle strength tested manually and with hand-held dynamometry, and time-tests-values). The range of ankle motion in both patient groups and the times to rise from supine in children with DMD were not normally distributed, so that here we applied the Wilcoxon-test to compare the mean ranks between visits. We compared the values of the different outcome criteria at weeks 4 and 8 with the baseline values and those at week 12, i.e. after 4 weeks without training, to the value after 8 weeks of WBVT. We used the Bonferroni correction to account for repeated measurements during the trial and adjusted the p-values accordingly so that statistical significance was achieved with a <0.017 p-value.

3.   Results

Of the 22 enrolled patients, 3 with DMD did not complete the training (Fig. 1). Two of those patients dropped out after the first training day because their creatine kinase increased by >100%. Although this was not accompanied by relevant clinical symptoms of muscular damage, this increase was a stop criterion in the original protocol. We included those patients' laboratory parameters from their baseline visit and after the first training day in the analysis. The third patient had to stop the training due to a talus fracture detected at the visit after 8 weeks of WBVT. His clinical and laboratory data are included in the analysis until the completion of 4 weeks of WBVT. The patients occasionally refused the clinical assessments or taking blood, thus reducing the number of patients for some parameters. This has been indicated in the corresponding tables. Another patient with DMD erroneously continued the training for 4 more weeks. Therefore his clinical data from the final assessments at week 12 is not included in the analysis.

3.1. Performance and subjective tolerance of the WBVT

All enrolled patients were able to perform the WBVT and the exercises. During the first 4 weeks, all patients trained at frequencies between 16 and 18 Hz, and the wobble modus in the following weeks was also done according to the protocol by all patients. The children generally liked the vibrational stimulus, most of them preferring the "wobble" modus. All patients were able to integrate training at home into the daily routine and usually performed it in the morning before school and in the evening before going to sleep. There were no falls off the platform. Symptoms of muscle damage at any time during the study period such as muscle weakness, muscle pain (on a scale ranging from 0 to 10), and muscle cramps were reported by a total of 10 of 14 patients with DMD and 6 of 8 with SMA. These symptoms were most frequent after the introduction and during the first week of training, and are displayed for each assessment in Table 1. The mean intensity of muscle pain of those reporting it was 3.8/10 with a maximum of 6/10 in one patient's thigh. No patient had to interrupt the training or skip the subsequent training session. There were no relevant changes in blood pressure, heart rate or temperature.

3.2. Laboratory changes

After the first training day, the CK of the 14 boys with DMD increased significantly from $11\ 856 \pm 4769$ U/l to $18\ 493 \pm 7430$ U/l ($p < 0.01$) but returned to baseline after 4 weeks of training (9730 ± 4613 U/l). This was accompanied by mild, not compromising muscle pain in 6 patients. After 4 more weeks of WBVT (week 4 to week 8), there was again an increase to $13\ 994 \pm 4047$ U/l, but this was not statistically significant (Table 2, Fig. 2). In patients with SMA, the CK remained unchanged (Table 2). Serum concentrations of LDH and myoglobin showed changes parallel to the CK, providing no further information (data not shown). Blood count, C-reactive protein and electrolytes where normal and did not change in either patient group.

3.3. Effects on muscle function

In the DMD group we noted a small improvement in their 6-min-walk test and the time to climb 4 stairs, while the time to walk 10 m remained stable and the time to rise from supine even worsened during the study period. These changes were statistically not significant. Patients with SMA showed an improvement in all time tests after 8 weeks of training, but only the increase in the distance walked in 6 min after 8 weeks of training was statistically significant ($p < 0.01$). At the final assessment 4 weeks after terminating WBVT (week 12), performance in time tests had worsened. Each subgroup's results for are displayed in Table 3.

3.4. Effects on muscle strength and flexibility

Muscle strength of the legs, assessed manually using the MRC scale and by hand-held dynamometry, showed a mild increase during the training period in both patient groups (Table 4), but the improvements did not reach statistical significance. The angular degree of dorsiflexion of the ankle improved slightly, but not statistically significant, especially in the DMD group within the 8 weeks of WBVT. The changes in the right and left ankles were parallel but more pronounced on the right side, thus for reasons of clarity only the right ankle's values are illustrated in Table 4.

The subjective impression of 11 out of 20 patients (5 with SMA, 6 with DMD) during the training period was an improvement in motor function which coincided with an improvement in gait or climbing stairs, less frequent falls and improved equilibrium. No patient felt any deterioration in strength or motor function. At the last assessment, i.e. after 4 weeks without training, 4 patients with DMD of the 18 patients who finished the protocol reported worsening of neuromuscular symptoms such as increased toe-walking, more frequent falls or muscle weakness.

4. Discussion

This pilot trial demonstrates that an intense WBVT is feasible and clinically well tolerated in children with DMD and SMA. However, we also detected relevant laboratory changes involving a transient CK increase in our DMD patients which might indicate additional damage to muscles through WBVT in that cohort. In interpreting the rise in CK, it is important to consider to what extent the CK usually changes in the course of DMD. It is well known that CK levels are extremely elevated at the time of diagnosis and decline annually by 18%, as

Table 1 – Number of patients with Duchenne muscular dystrophy (DMD) and spinal muscular atrophy (SMA) at each assessment who reported any adverse events possibly related to whole-body vibration training. Some patients reported more than one symptom.

Symptom	Group	After 1st day of WBVT DMD $n = 14$ SMA $n = 7$	After 4 weeks of WBVT DMD $n = 12$ SMA $n = 8$	After 8 weeks of WBVT DMD $n = 11$ SMA $n = 8$
Muscle pain	DMD	6	6	1
	SMA	1	2	1
Muscle weakness	DMD	1	4	0
	SMA	1	2	2
Muscle Cramps	DMD	0	1	0
	SMA	0	0	0
Skin erythema or pruritus	DMD	1	4	0
	SMA	0	2	0

Table 2 – Creatine kinase levels at baseline and after 1 day, 4 and 8 weeks of whole-body vibration training (WBVT) in children with Duchenne muscular dystrophy (DMD) and spinal muscular atrophy (SMA). Compared to baseline, only the DMD patients after 1 day of training displayed a significant increase ($p < 0.01$).				
	Creatine kinase [U/l] Mean ± SD, [range], (number of patients)			
	Baseline	After 1 day of WBVT	After 4 weeks of WBVT	After 8 weeks of WBVT
DMD	11 857 ± 4769 [6070–23 239] (14)	18 493 ± 7430 [6665–32 360] (14)	9730 ± 4613 [4077–18 940] (12)	13 994 ± 4047 [6133–21 000] (10)
SMA	211 ± 129 [91–426] (8)	213 ± 126 [103–425] (8)	196 ± 99 [91–392] (8)	206 ± 86 [97–367] (8)

muscle tissue degenerates,[31] but vary substantially during the daytime and at 6-week intervals.[32,33] The underlying mechanism for these variations is unknown, and there is no indication that the CK levels correlate with the disease's clinical severity. A widely-accepted hypothesis based on studies in mdx-mice claims that exercise, especially eccentric exercise where muscles lengthen as they exert force, exacerbates muscle breakdown.[34,35] This, in combination with a known CK increase after eccentric exercise in healthy adults,[36,37] has led to the recommendation for patients with DMD to perform mild exercise and avoid eccentric contractions.[11,38] However, the hypothesis on stretch-induced muscle injury remains controversial, and several different pathophysiologic
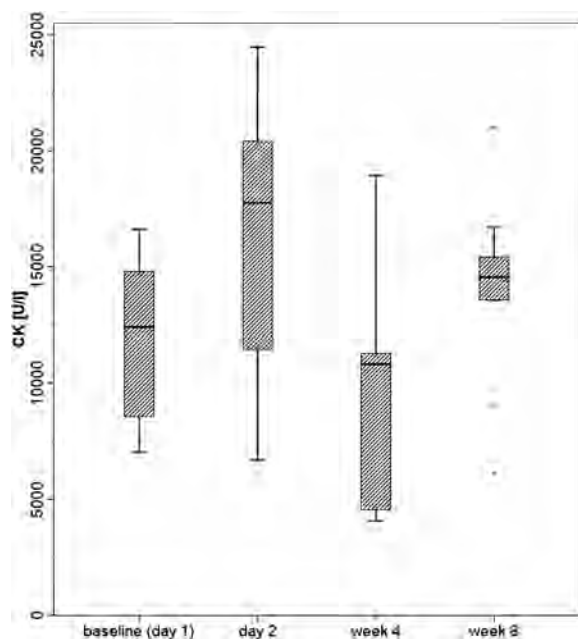

Fig. 2 – Creatine kinase (CK) values of patients with Duchenne muscular dystrophy before the whole-body vibration training and after the first day, 4 and 8 weeks of training. The bottom and top of the box are the 25th and 75th percentile, the band inside represents the median. The ends of the whiskers represent the lowest and highest value still within 1.5 interquartile ranges (IQR). Outliers are represented by circles, extreme values (> 3 IQR) by asterisk.

mechanisms of the disease are currently being discussed.[3,39] Little is known about the influence of exercise on CK levels in children with DMD. To our knowledge, only one study has assessed CK after eccentric exercise in boys with DMD, demonstrating no relevant increase in CK.[32] Our patients performed mild exercises during the vibrations that did not lead to exhaustion, encompassing both concentric and eccentric contractions. The exercise during which the calf muscles stretch while standing on the vibrating platform led to eccentric contractions. This could be responsible for the rise in CK but the stretching exercise was especially well tolerated and preferred by most patients As we did not compare changes in CK after vibration alone and the different types of exercises, we cannot determine whether the stretching performed on the vibrating platform or the vibrations themselves were the origin of the laboratory changes observed after the training's introduction. An increase in CK after WBVT on a synchronously-vibrating platform at higher frequencies has been reported in sedentary adults.[40] However, neither that study nor ours had a control group, so we cannot definitely attribute the observed CK increase to the vibration stimulus.

In summary, due to CK's high variability in DMD, the lack of correlations between CK levels and clinical severity, and the fact the CK levels returned to baseline during continuous training, we should not conclude that WBVT leads to muscle damage according to laboratory parameters alone. It makes sense to interpret laboratory changes in conjunction with the clinical picture. Clinically speaking, WBVT was well tolerated and accepted by our patients. This is in line with previous studies in children with different disorders.[26,41] The observed erythema of the legs after the first few treatment sessions has been described in children with other conditions.[26] Muscle pain was more frequent in boys with DMD than in children with SMA, but muscle pain after activity is a common complaint in boys with DMD.[42] The pain reported after WBVT was mild, transient and led to no interruption in the training. Additionally, our clinical examinations revealed no deterioration in muscle force or function, which one would have anticipated had the training been harmful.

In one patient with DMD, a fracture of the talus was detected during the trial. A question arises as to whether WBVT could have caused the fracture or whether there is an increased risk of falling off the vibrating platform, as patients trained at home on a platform without rails. This small and

Table 3 — Values of different time tests in patients with Duchenne muscular dystrophy (DMD) and spinal muscular atrophy (SMA) prior to whole-body vibration training, after 4 and 8 weeks of training and 4 weeks after termination of training (week 12). Data presented include the mean ± standard deviation, [range] and (number of patients). The number of DMD patients is reduced from week 8 onwards, as one patient with DMD discontinued the study. We compared the parameters at each assessment during the training period to the baseline and those after 4 weeks without training to the values at week 8. The p-values are indicated by[a)] only if statistically significant ($p < 0.017$) and are not shown if statistical significance after Bonferroni correction was not achieved.

	6-min walk test, distance [m]		10 m walking time [sec]		Time to climb 4 stairs [sec]		Time to rise from supine [sec]	
	DMD	SMA	DMD	SMA	DMD	SMA	DMD	SMA
Baseline	400.2 ± 100.1 [157.5—535.0] (n = 12)	371.3 ± 202.0 [25.5—581.0] (n = 8)	5.7 ± 1.0 [3.9—7.3] (n = 12)	9.7 ± 9.8 [3.0—32.9] (n = 8)	5.0 ± 2.4 [2.2—8.7] (n = 12)	10.3 ± 13.8 [2.3—42.1] (n = 8)	8.0 ± 7.6 [2.8—31.0] (n = 12)	7.9 ± 7.1 [2.0—23.0] (n = 7)
Week 4	411.9 ± 60.1 [335.0—523.0] (n = 12)	383.4 ± 205.5 [50.0—603.0] (n = 8)	5.6 ± 1.2 [4.0—8.0] (n = 12)	9.9 ± 10.2 [3.0—33.8] (n = 8)	5.1 ± 3.1 [1.4—11.3] (n = 12)	8.9 ± 10.8 [2.1—31.7] (n = 8)	9.5 ± 8.1 [2.9—28.0] (n = 12)	7.1 ± 7.5 [2.0—23.6] (n = 7)
Week 8	405.1 ± 79.2 [249.1—516.0] (n = 11)	402.8[a)] ± 200.2 [49.7—620.0] (n = 8)	5.6 ± 1.1 [4.0—7.3] (n = 11)	8.9 ± 8.4 [3.0—28.5] (n = 8)	4.5 ± 2.5 [1.7—9.2] (n = 11)	7.6 ± 8.2 [1.8—24.2] (n = 8)	9.5 ± 10.2 [2.8—35.0] (n = 11)	7.2 ± 7.9 [3.0—24.8] (n = 7)
Week 12	398.4 ± 96.7 [204.9—546.0] (n = 10)	394.8 ± 210.0 [52.8—697.0] (n = 8)	6.0 ± 1.8 [4.0—10.0] (n = 10)	9.4 ± 9.3 [3.0—30.8] (n = 8)	5.1 ± 3.3 [2.29—12.54] (n = 10)	9.2 ± 11.7 [2.6—34.1] (n = 8)	11.2 ± 13.4 [3.5—47.0] (n = 10)	8.9 ± 11.9 [2.0—35.7] (n = 7)

light version was chosen for practical reasons such as easy transport and possible storage even in small homes. In this trial, no patient reported any fall off the platform, and we consider the risk of falling as rather low, provided that the patients can hold onto solid furniture as in our trial.

WBVT is performed to increase muscle function in the elderly and, according to the principle of the "muscle-bone unit", is indicated as an adjunctive treatment in patients with osteoporosis due to different underlying diseases.[21,43,44] In children with other diseases leading to severe osteoporosis like osteogenesis imperfecta and cerebral palsy, WBVT has been proven to be a safe therapeutic approach without an

increased risk of fractures.[26,44,45] On the contrary, in these patients, WBVT is used to stimulate the musculo-skeletal system, to improve muscle mass and to reduce fracture rates. Therefore it is unlikely that osteoporosis in DMD patients is worsened due to WBVT. Our patient with the fracture was on steroids and had local pain before starting the vibration therapy, but did not report this when entering the trial. We therefore assume that the fracture was already present when starting the treatment, as osteoporosis typically produces pain once a fracture occurs. Exercises probably worsened the local pain due to the pre-existing fracture. However, screening for bone pain and pathologic fractures is important

Table 4 — Values of strength measurements and angle degree of dorsiflexion of the right ankle in patients with Duchenne muscular dystrophy (DMD) and spinal muscular atrophy (SMA) before starting the whole-body vibration training (baseline), after 4 and 8 weeks of training and 4 weeks after termination of training (week 12). Data presented include the mean ± standard deviation, [range] and (number of patients). MRC = Medical Research Council Scale. We compared the parameters at each assessment during the training period to the baseline and those after 4 weeks without training to the values at week 8. We found no statistically significant differences after Bonferroni-Correction.

	MRC % leg sum score		Myometry knee sum score [N]		Myometry elbow flexors [N]		Angle degree of dorsiflexion of the right ankle [°]	
	mean ± standard deviation, [range] and (number of patients)							
	DMD	SMA	DMD	SMA	DMD	SMA	DMD	SMA
Base-line	60.7 ± 15.7 [37.1—80.7] (n = 12)	59.6 ± 11.1 [47.1—80.0] (n = 8)	52.3 ± 13.3 [31.0—76.0] (n = 12)	45.5 ± 24.3 [16.0—83.5] (n = 8)	39.3 ± 13.9 [22—73] (n = 11)	62.9 ± 33.1 [24—104] (n = 8)	3.3 ± 6.2 [−10 to (+10)] (n = 12)	9.4 ± 4.2 [0—15] (n = 8)
Week 4	63.1 ± 17.4 [40.0—88.0] (n = 11)	59.8 ± 11.0 [50.0—81.4] (n = 8)	55.0 ± 15.3 [34.5—94.0] (n = 12)	46.9 ± 26.7 [19.5—98.5] (n = 8)	41.9 ± 16.7 [26—85] (n = 11)	65.0 ± 32.0 [19—120] (n = 8)	7.5 ± 6.6 [0—20] (n = 12)	9.4 ± 5.6 [0—20] (n = 8)
Week 8	65.8 ± 17.8 [40.0—85.0] (n = 10)	63.0 ± 10.7 [50.7—80.7] (n = 8)	57.7 ± 12.9 [42.5—92.0] (n = 11)	47.1 ± 26.7 [15.5—100.5] (n = 8)	38.8 ± 16.4 [23—81] (n = 11)	71.0 ± 38.3 [23—125] (n = 8)	7.3 ± 6.1 [0—20] (n = 11)	10.6 ± 4.2 [5—20] (n = 8)
Week 12	67.3 ± 16.3 [40.0—95.0] (n = 10)	61.5 ± 11.7 [51.4—82.1] (n = 8)	56.3 ± 11.8 [44.0—85.0] (n = 10)	46.1 ± 27.9 [15.5—93.0] (n = 8)	38.3 ± 11.5 [19—54] (n = 10)	69.6 ± 40.5 [24—123] (n = 8)	7.0 ± 8.6 [−10 to (+20)] (n = 10)	11.3 ± 3.5 [10—20] (n = 8)

before starting the vibration treatment, especially in a high risk population such as DMD boys on steroids.

We conclude that WBVT is feasible in patients with DMD and SMA and that the increase in CK in the DMD group reflects the muscles' reaction to a new stimulus and/or the stretching exercise, but is not indicative of any clinically-relevant muscular damage.

There are several limitations of this trial for the interpretation of the clinical efficacy of WBVT: Our patient cohorts are small and the training period was relatively short. We chose this short time span during which we did not expect relevant clinical changes, because the protocol was designed to assess safety as a primary outcome. Another limitation is the lack of a control group, so that we cannot distinguish between the effects of the vibration itself and the increased exercise. However, the squatting and side-to-side weight shift were so mild, imitating activities of daily life, that we would not expect them to cause any clinical effect.

The findings of this trial with small increases in muscle function and strength in the SMA subgroup therefore suggest that further studies with larger patient cohorts and control groups are needed to investigate the clinical efficacy of WBVT, especially in patients with SMA.

A learning effect of repeated tests seems unlikely to be responsible for the improvements, as most patients were familiar with the measurements, having attended at neuromuscular clinics regularly before entering the study.

In the literature, WBVT's effect on muscle strength and function in people with neurological disorders remains controversial, and there are few trials demonstrating mild improvements[46,47]: one reports an increased range of motion after WBVT in between bouts of conventional stretching exercises.[18] We observed an improved, albeit not statistically significant, dorsiflexion of the ankle after 8 weeks of training in our DMD patients. This clinically-important, enhanced joint flexibility is probably the result of both mechanical stretching due to vibration in general and the specific calf muscle stretching exercise in our protocol; it reinforces the view that daily stretching exercises can increase joint flexibility. Stretching is a key therapeutic procedure for people with DMD and should be performed daily, as developing contractures compromise muscle force and in turn exacerbate weakness. Our findings suggest that WBVT could be valuable to prevent and treat contractures in this patient population.

Although our results on clinical effects are not unequivocal we believe that adding a home-based WBVT training to the frequently practiced combination of professional physiotherapy and exercises under the supervision of relatives at home would be beneficial for both patient groups for several reasons: Most of the participating children enjoyed the vibrational stimulus, which motivated them to perform the training regularly. Our experience has revealed that children are far less likely to show compliance in performing regular stretching exercises at home because they often perceive it as boring and time-consuming. Other advantages of WBVT at home are the facts that it can be done quickly and during other activities such as watching television, making it is easy to integrate into the daily routine and probably further enhancing the children's

compliance. Other positive effects such as the increase in bone mineralisation,[25] reduced blood glucose levels,[48] and cardiovascular benefits[49] have not been addressed in this pilot trial, but these would be additional desirable training effects in our patients who cannot carry out conventional exercises due to their neuromuscular problems.

To summarise, WBVT in a home setting is feasible, clinically well tolerated, and seems to be safe in children with DMD and SMA. We did not detect a clear effect of WBVT on muscle strength, function and flexibility in children with DMD and SMA, but more research in this field with control groups and a longer training period is needed to specify the effect of vibration therapy compared to physical therapy without vibration. Because of the enhanced compliance and a potentially maximum effect within a short time span, WBVT may be considered a low-impact addition to current physiotherapeutic treatment.

Acknowledgements

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ejpn.2013.09.005.

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