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ORIGINAL REPORT

WHOLE-BODY VIBRATION THERAPY IN CHILDREN WITH SEVERE MOTOR DISABILITIES

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Objective: **To study the effect of whole-body vibration therapy on bone mass, bone turnover and body composition in severely disabled children.**

Methods: **Nineteen non-ambulatory children aged 5.1–16.3 years (6 males, 13 females) with severe motor disabilities participated in an intervention programme with standing exercise on a self-controlled dynamic platform, which included whole-body vibration therapy (vibration, jump and rotation movements). Whole-body vibration therapy was performed at 40–42 Hz, with an oscillation amplitude of 0.2 mm, 5–15 min/treatment, twice/week for 6 months. Bone mass parameters and bone markers were measured at the study start, and after 6 and 12 months.**

Results: **Whole-body vibration therapy was appreciated by the children. Total-body bone mineral density increased during the study period ($p < 0.05$). Z-scores for total-body bone mineral density ranged from –5.10 to –0.60 at study start and remained unchanged throughout. Approximately 50% of the subjects had increased levels of carboxy-terminal telopeptides of type I collagen and decreased levels of osteocalcin at the start. Body mass index did not change during the intervention period, but had increased by the 12-month follow-up ($p < 0.05$).**

Conclusion: **Whole-body vibration therapy appeared to be well tolerated by children with severe motor disabilities. Total-body bone mineral density increased after 6 months of whole-body vibration therapy. Higher carboxy-terminal telopeptides of type I collagen and lower osteocalcin values indicated that severely disabled children have a reduced capacity for bone acquisition.**

Key words: bone; cerebral palsy; dual-energy X-ray absorptiometry; fracture; osteoporosis; paediatric.

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INTRODUCTION

Children and adolescents with severe physical disabilities are at risk of developing osteopaenia and, as a consequence, experience more low-impact fractures (1). Children's bone health is of importance, and peak bone mass is reached by 20–25 years of age. Some studies indicate that high peak bone mass reduces the risk of sustaining osteoporotic fractures later in life (2).

Bone mineral accrual during childhood is a critical determinant for developing osteoporosis in later life (3) and a decrease in size-adjusted bone mineral content (BMC) during childhood is related to increased fracture risk (4). Lifestyle factors, such as physical activity and nutrition, as well as chronic disorders and medications, influence bone mineral accrual (2, 5). Muscle weakness is associated with decreased bone development (6), which in turn leads to an increased risk of fractures (7).

Common therapies to prevent bone loss in children with motor dysfunctions include standing exercise, prophylaxis against contractures, stretching of muscles and joint mobility training. It has been shown that non-ambulatory children with cerebral palsy (CP) have a significantly increased fracture risk if no standing exercise is performed (8). However, a review by Fehlings et al. (1) concluded that weight-bearing activities need to be further evaluated prior to inclusion in osteoporosis prevention protocols.

Mechanical loading is osteogenic in children with disabling conditions according to Ward et al. (9). Whole-body vibration therapy (WBVT) has been shown to increase muscle strength in postmenopausal women (10, 11). Semler et al. (12) demonstrated improvements in the mobility of immobilized children and adolescents after WBVT. Furthermore, WBVT, in comparison with resistance training, has been demonstrated to have a positive effect on spasticity, muscle strength and motor performance in adults with CP (13). WBVT may improve mobility in children with CP due to a positive effect on leg muscles (14).

This study was designed to examine the effects on bone mass, body composition and markers of bone turnover in children with severe motor disabilities after a 6-month intervention

programme, on a self-controlled dynamic platform, which offered vibration, jumps and rotation. The children were also examined after a follow-up period of 6 months with no WBVT. We also investigated whether WBVT would be accepted and appreciated by the participating children and a successful intervention would increase BMD without any side-effects.

METHODS

Participants and study design

Children were recruited from the Habilitation Unit of Gothenburg, Sweden from May 2008 to December 2010. The Human Ethics Committee at the Medical Faculty, Sahlgrenska Academy at the University of Gothenburg approved the study. Informed consent was obtained from all parents. Twenty-one children were included initially; however, 2 children were excluded due to severe medical problems. In total, 19 children and adolescents (6 males and 13 females) completed the study. They were between 5.1 and 16.3 years of age (median age 12.5 years) and had severe motor disabilities with different aetiologies. The motor impairment of the child, independent of CP or not, was classified according to the Gross Motor Function Classification System (GMFCS). Only children with motor disabilities equivalent to GMFCS IV and V were included (i.e. they need a wheelchair for transportation). Both children with and without previous fractures were included. In total, 9 of the 19 children had a history of 21 low-energy fractures (Table I) All fractures were documented with X-rays. One child with severe disability of unknown aetiology had a history of 10 fractures. This individual was treated with anti-resorptive bisphosphonates after his seventh fracture; however, the treatment was terminated 1 year before inclusion in this study due to already long-term treatment and side-effects. Exclusion criteria according to the manufacture were: severe lung problems, a vagus nerve stimulator and a pacemaker.

Clinical data for the study group is presented in Table I. Eleven children had CP and 8 had other neurological diseases. Participating children and adolescents performed a standing exercise programme for 6 months on Hoppolek, a self-controlled dynamic platform with vibration, jumps and rotation, which is referred to as WBVT in this study. The device is described in detail elsewhere (15). The participating children used their ordinary standers during WBVT. WBV was carried out at preschool or at school at least twice a week, 5–15 min/treatment, at 40–42 Hz and with an oscillation amplitude of 0.2 mm. By using the manoeuvre panel, each participant could activate jumps and rotations and listen to their favourite music, where necessary with help from staff. Bone mass was measured and blood samples collected at the start of WBVT, and after 6 and 12 months.

Bone and muscle mass measurements

Total-body less head (TBLH), lumbar spine (L1–L4) bone mass were measured by dual-energy X-ray absorptiometry (DXA) (GE Lunar Progidy, Madison, WI, USA). Measurements provided data for BMC (g) and areal bone mineral density (BMD) (g/cm^2), which will be referred to as BMD. From these scans we also received data on body composition and BMD Z-scores from the Lunar international reference database (16). A quality-control programme using a phantom was used. BMC and BMD were assessed in the left calcaneus using a paediatric version of the DXA, and laser (DXL) Calscan technique (Scanflex/Demetech AB, Täby, Sweden), which is described elsewhere (17). Twenty healthy persons (age 6–37 years) were scanned twice to assess the *in vivo* precision. From these measurements, coefficients of variation (CV) were 0.5% for total-body bone mineral density (TBBMD), 0.7% for spine BMD. CV for body fat mass and lean mass was 2.4% and 0.9%, respectively. Intra-individual CVs for BMD in the calcaneus were 9.8% for 2-year-old, 6.5% for 4-year-old and 2.4% for 7-year-old children (17).

Questionnaire

Questionnaires were used to determine the history of fractures. Parents were interviewed 3 months before and during the intervention period, and 6 months after WBVT had ended. Parents answered questions regarding change in appetite, sleeping habits, time spent outdoors

Table I. *Clinical data at study start*

Child number	Diagnosis	Level of movement impairment (GMFCS)[a]	Age, years Gender, F/M	Number of low-energy fractures before inclusion	Cognitive disorder	Epilepsy/AED treatment	Visual impairment	Gastrostomy	Scoliosis
1	CP	V	6.3, F	1	MR	No	Yes	No	Yes
2	CP	V	7.4, F	0	MR	Yes/VPA	No	Yes	No
3	CP	IV	5.9, M	1	ADD	No	Yes	Yes	No
4	CP	V	5.1, M	0	MR	Yes/VPA	Yes	No	No
5	CP	V	8.1, F	1	MR	Yes/VPA	No	Yes[b]	No
6	Rett syndrome	5	8.6, F	0	MR	Yes/LTG	No	Yes	Yes
7	CP	V	7.9, F	0	MR	Yes/VPA	Yes	No	No
8	CP	V	9.8, M	0	MR	Yes/VPA	Yes	Yes	No
9	Rett syndrome	5	16.0, F	2	MR	Yes/LTG	No	Yes[b]	Yes
10	Rett syndrome	5	15.6, F	1	MR	Yes/VPA	No	No	Yes
11	Unclear	4	13.2, F	0	MR	Yes/VPA	Yes	Yes[b]	No
12	CP	V	16.3, F	3	MR	Yes/VPA	No	Yes[b]	No
13	CP	V	13.5, F	0	MR	Yes/LEV, OXC	No	Yes	No
14	CP	V	15.3, F	0	MR	Yes/VPA	Yes	No	No
15	CP	V	12.5, F	0	MR	No	Yes	No	No
16	Unclear	4	15.8, M	1	MR	Yes/VPA	No	No	No
17	Unclear	5	13.8, M	10	MR	Yes/VPA	No	Yes[b]	No
18	Unclear	4	11.8, M	0	MR	Yes/VPA	Yes	Yes	Yes
19	Unclear	4	15.2, F	1	MR	No	No	No	Yes

[a]Roman figures correspond to children with CP and Arabic figures correspond to children with hypotonic conditions.

[b]Children who received vitamin D and calcium supplementation at start.

ADD: attention deficit disorder; AED: anti-epileptic drug; CP: cerebral palsy; F: female; GMFCS: Gross Motor Function Classification System; LEV: levetiracetam; LTG: lamotrigine; M: male; MR: mental retardation; OXC: oxcarbazepine; VPA: sodium valproate.

and medication. The children's experiences of the vibration, jump and rotation movements, as well as comments from the parents and staff were assessed during the study. The purpose was to determine the children's experience of the treatment and to identify adverse events. The questionnaires comprised statements ranging from 1 to 5, where 1 = "Strongly disagree", 5 = "Agree strongly" and also the alternative "No difference at all". During every WBVT session, the total minutes of vibration, number of jumps and the child's mood were registered by staff, who had prior knowledge of the participating child. Mood was registered on a scale of 1 to 4, where 1 = "happy/content", 2 = "neutral", 3 = "discomfort", and 4 = "much discomfort/pain".

Biochemical markers of bone and mineral metabolism

Serum type I procollagen intact amino-terminal propeptide (PINP) was determined by radioimmunoassay (Orion Diagnostica, Oulunsalo, Finland). The serum bone alkaline phosphatase (ALP) activity was determined by quantitative enzyme-linked immunosorbent assay (ELISA) (Quidel Corp., San Diego, CA, USA), and serum osteocalcin by chemiluminescence immunoassay (DiaSorin Inc., Stillwater, MN, USA). Type I collagen degradation was assessed by the serum CrossLaps ELISA (IDS Nordic A/S, Herlev, Denmark), which is reported to measure a cathepsin K degradation product of trivalently cross-linked type I collagen (CTX). Both serum intact parathyroid hormone (PTH) and 25-hydroxyvitamin D (25OHD) were analysed by Elecsys electrochemiluminescence immunoassays on a Modular Analytics E170 (Roche Diagnostics Scandinavia AB, Bromma, Sweden). Serum calcium and phosphate were measured by routine clinical chemistry assays. Paediatric age and gender-specific reference intervals are reported elsewhere (18–22). The lower limit of serum 25OHD has been suggested to be 50 nmol/l to cover the requirements of at least 97.5% of the population; however, upper reference limits for 25OHD are seldom reported. A report published by the Institute of Medicine (IOM) suggests that the upper limit of serum 25OHD should not exceed 125 nmol/l (23).

Statistical analyses

All calculations were made using SAS software release 9.2 (SAS Institute, Cary, NC, USA). For continuous variables, the results are presented as minimum, maximum and median values. For comparison over time the Wilcoxon signed-rank test was used for continuous variables. All the tests were two-tailed and conducted at the 5% significance level.

RESULTS

The mean duration of the WBVT period was 6.5 months. The result of the mean mood registration (scale 1–4) was 1.5 (range 1.0–2.1), which indicates that the children tolerated well and appreciated the WBVT. The number of treatment sessions, standing hours, number of jumps and vibration time are presented in Table II. The interviews with staff and parents showed that WBVT was received positively and that the children did not experience pain during the vibration or jumps. No changes in the children's appetite or sleeping habits were reported during the study. According to the interviews, most children liked the jumping activity best.

Nine of the 19 children had a history of 21 low-energy fractures prior to the study. One of these children and an additional 3 children without previous fractures, experienced a further 5 fractures during the study. This made a total of 26 fractures, 17 of which were femur fractures. The 5 fractures during the study were; 3 femur fractures during lifting procedures, 1 foot fracture during flexion of the foot and 1 femur fracture during the night, unknown cause. The questionnaires showed that the 12 children, who experienced fractures before or during the study, had been outdoors during the summer months for a mean of 7.3 h/week, in comparison with 8.3 h/week for the 7 children without fractures. The corresponding mean numbers for the winter months were of 4.9 h/week and 3.5 h/week, respectively.

Table II. *Detailed description of the 6-month whole-body vibration therapy*

	All patients (n = 19) Mean (range)	Patients without fractures prior to study start (n = 10) Mean	Patients with fractures prior to study start (n = 9) Mean
Number of sessions	51 (18–80)	57	47
Number of standing hours on the plate	21 (6–35)	22	20
Vibration, h	9 (2–26)	10	8
Total number of jumps during each session	374 (138–697)	425	345

Bone mass measurements

Data from the DXA and DXL Calscan measurements are shown in Table III. TBBMD Less Head (LH) and Total-Body BMC Less Head (TBBMC LH) increased after the WBVT period of 6 months ($p < 0.05$) (Table III). The median Z-score was –2.5 for TBBMD LH. It ranged from –5.1 to –0.6 at the start of the study and did not change significantly during the intervention or follow-up period. More children were able to complete the lumbar spine DXA scans ($n = 18$) than the total-body DXA scans ($n = 11$) because of movement artefacts, contractures or metal implants. No significant changes were observed in spine BMD or BMC during the WBVT period. All patients completed the DXL scan, which demonstrated low calcaneal BMD and BMC values at start. No significant change was, however, observed in calcaneal BMD or BMC during the study period.

Participating children were classified into 2 groups, spastic $n = 10$ and non-spastic $n = 9$. No significant differences were found between these groups regarding TBBMD LH, TBBMC LH and lumbar spine BMD. Among the subjects, the difference in duration of WBVT, or in the number of jumps, did not significantly change the assessed bone mass parameters.

Growth and body composition

The participants' weight did not change during the WBVT period; however, at the 12-month follow-up a significant weight increase was observed ($p < 0.0001$). The median weight standard deviation score (SDS) was –1.5 (range –4.0 to 1.0) at start and –2.0 (range –3.5 to 1.5) at 12 months. Height had increased both during the 6 months of WBVT and at the 6-month follow-up period ($p < 0.0001$). The median height SDS was –3.0 (range –5.0 to 0.0) at start and –2.5 (range –5.0 to 0.0) at 12 months. Body mass index (BMI) did not change during the WBV intervention, but had increased thereafter from median 18.0 (range 13.2–25.4) to median 19.0 (14.2–25.8) by the 12-month follow-up ($p < 0.05$).

Table III. *Bone mass and body composition*

	n	Study entry Median (min–max)	Change from start to 6 months Median (min–max)	Change from 6 to 12 months Median (min–max)
TBBMD LH, g/cm^2	11	0.62 (0.52 to 0.72)	0.014 (–0.016 to 0.034)*	0.004 (–0.024 to 0.020)
TBBMD LH Z-score	11	–2.5 (–5.10 to –0.60)	0.000	–0.100
TBBMC LH, g	11	508 (211 to 1099)	33.5 (–34.9 to 112.5)*	20.0 (–19.7 to 105.8)*
BMD L2 – L4, g/cm^2	18	0.62 (0.45 to 0.84)	0.016 (–0.403 to 0.166)	0.018 (–0.113 to 0.544)
BMD L2 – L4, Z-score	18	–2.4 (–4.3 to 0.4)	0.000	0.100
BMC L2 – L4, g	18	16.7 (9.1 to 47.6)	1.200 (–5.40 to 13.80)	2.20 (–2.50 to 20.30)
Calcaneal BMD, g/cm^2	19	0.025 (0.009 to 0.115)	0.004 (–0.014 to 0.030)	–0.001 (–0.025 to 0.114)
Calcaneal BMC, g	19	0.007 (0.001 to 0.083)	0.004 (–0.014 to 0.022)	0.000 (–0.025 to 0.114)
Fat mass LH, g	11	11,839 (5,889 to 22,319)	485.0 (–2,679 to 2,514)	923 (–123 to 3,521)**
Lean mass LH, g	11	14,557 (8,899; to 30,791)	700 (–807 to 1,996)	442 (–972 to 2,548)

*$p < 0.05$, **$p < 0.01$ Wilcoxon signed-rank test.
BMC: bone mineral content; BMD: bone mineral density; LH: less head; TBBMC LH: total-body bone mineral content less head; TBBMD: total-body bone mineral density; TBBMD LH: total-body bone mineral density less head.

Body composition data were attained from the whole-body DXA scans (Table III). Fat mass did not change significantly during the WBVT period, but increased significantly during the follow-up period. Lean mass was unchanged during the entire study period.

Biochemical markers and bone markers

Results of the biochemical markers of bone and mineral metabolism before and after WBV are presented in Table IV. All children started their WBVT during August/September and finished after 6 months. At the start, the median 25OHD concentration was 82 nmol/l (range 26–204 nmol/l), which decreased significantly during the 6-month WBV period to 58 nmol/l (range 17–145 nmol/l, $p < 0.01$). At the 12-month follow-up 25OHD had returned to baseline levels 72 nmol/l (range 18–194 nmol/l). Other biochemical markers of bone and mineral metabolism did not change significantly, except for serum calcium, which decreased from 2.45 mmol/l to 2.37 mmol/l ($p < 0.05$) during the WBV period. Most children had markers of bone turnover within the reference intervals reported for healthy children and adolescents. However, at the start of the study, a tendency for increased bone resorption was observed, as 8 children had increased CTX concentrations (Table IV). After 6 months of WBVT, only 4 of these 8 children had elevated CTX levels. The bone formation marker osteocalcin was below the reference interval for 50% of the children both at start and after 6 months.

DISCUSSION

The current study is one of the few longitudinal intervention studies involving WBVT in children with severe motor disabilities. Fractures, especially in the lower extremities, are common in this group of children, as confirmed in this study. Early interventions to stimulate bone accrual are of clinical importance in preventing osteoporosis. Despite complex clinical circumstances and several medical issues being present in this patient group, the present study indicates that it is possible to treat severely disabled children with WBV and that the children appreciate the treatment. Moreover, WBVT may contribute to increased bone formation and mineral accretion in the skeleton, resulting in increased BMD.

Table IV. *Biochemical markers of bone and mineral metabolism in comparison with age and gender-adjusted reference intervals*[a]

	Study entry					After 6 months of WBV therapy				
	n	Median (min–max)	Patients below the reference interval *n*	Patients within the reference interval *n*	Patients above the reference interval *n*	*n*	Median (min–max)	Patients below the reference interval *n*	Patients within the reference interval *n*	Patients above the reference interval *n*
Calcium, mmol/l	19	2.45 (2.33–2.62)	0	19	0	19	2.37 (2.21–2.57)	0	19	0
Phosphate, mmol/l	19	1.30 (0.93–2.10)	4	14	1	19	1.20 (1.00–1.80)	2	17	0
PTH, ng/l	15	32 (16–109)	0	7	8	16	39 (16–98)	0	6	10
25OHD, nmol/l	17	82 (26–204)	4	11	2	19	58 (17–145)	8	9	2
Osteocalcin, µg/l	18	37.0 (6.7–88.0)	9	9	0	15	31.0 (9.1–70.0)	8	7	0
PINP, µg/l	19	278 (21–527)	5	12	2	19	238 (48–612)	6	13	0
Bone ALP, U/l	19	109 (25–149)	0	18	1	19	107 (26–173)	0	18	1
CTX, µg/l	19	0.87 (0.22–1.92)	1	10	8	19	0.62 (0.26–1.74)	0	15	4

[a]Reported paediatric age and gender-specific reference intervals for markers of bone and mineral metabolism were used in comparison with our study group, see Methods section for details.
25OHD: 25-hydroxyvitamin D; ALP: alkaline phosphatase; CTX: carboxy-terminal cross-linking telopeptide of type I collagen; PINP: type I procollagen intact amino-terminal propeptide; PTH: parathyroid hormone; WBV: whole-body vibration.

Twelve of the 19 children (63%), who had a median age of 12.5 years, had fractures before or during the study. It has been reported that the risk of sustaining a fracture for healthy boys at 16 years of age is 42% (24). For using the term osteoporosis in children, the paediatric official position of the International Society for Clinical Densitometry requires Z-scores below –2.0 and previous fractures (25). In general we found very low Z-scores and low calcaneal BMD values. In an evidence-based review using clinical practice guidelines for children with CP, there was insufficient evidence to support the use of weight-bearing activities, vitamin D or calcium supplementation to decrease fragility fractures or improve BMD (1). However, it has also been shown that non-ambulatory children with CP who perform standing exercise, have a reduction in fractures without trauma compared with those who are not using standers (26). The fact that 4 children experienced 5 fractures without trauma during this study further emphasizes the need for new treatments. However, the small study group and the short follow-up time make it difficult to draw any such conclusion.

The current study demonstrates that WBVT had a modest effect on bone mass, since TBBMD LH and TBBMC LH increased over the 6-month intervention period. This is in accordance with the case report by Dalén et al. (15), who reported increased BMC in children with severe CP, using the same WBVT as in the present study. Another similar study involving WBVT over 6 months showed increased bone mass in ambulant children with disabling conditions (9) and Stark et al. (27) found positive effects on BMD and BMC in children with bilateral spastic CP using a home-based vibration-training programme. The current study also demonstrates that heel bone DXL is a useful complement to whole-body DXA measurements, because of the constraints of spastic movements and metal implants in the patients.

In general, markers of bone formation (i.e. osteocalcin, PINP and bone ALP) were within the reference intervals for most children during the entire study. Osteocalcin was below the reference interval for 50% of the children (at the start and after 6 months of WBV), which could indicate a decreased bone formation rate in comparison with healthy children. CTX, a marker of bone resorption, had increased in 8 out of 19 patients at the start of the study. The low BMD Z-scores (Table III) can, in some patients, be due to increased bone resorption and decreased bone formation. After the WBV period of 6 months, more patients had normalized their CTX levels, which could indicate a decreased resorption and a positive response to WBVT. However, the actual CTX values did not change over the study period. The decrease found in serum calcium could be due to a higher degree of calcium incorporated within the skeleton after WBVT as a result of increased mineralization. Larger study groups, and possibly longer WBVT periods, are needed to elucidate the potential benefits of WBVT on bone mass in children with severe motor disabilities.

In growing children, an increase in height and weight is expected over a period of 6–12 months. In the current study, the participating children did not increase their weight during the WBV intervention period. However, a significant increase in weight was observed at the follow-up period, which indicates that more energy than normal was consumed during the WBV intervention period. This finding is in agreement with the results of a recent study by Milanese et al. (28), where obese women had lower BMI and body fat after 10 weeks of WBVT. Lee & Chon (14) found increased leg muscle thickness after 2 months of WBVT. In the present study, however, DXA measurements showed no changes in lean mass or fat mass. The energy balance needs to be further investigated in disabled children, especially during WBVT, since this it might be comparable to additional energy-consuming physical activity.

The low number of participating children is a limitation of our study. Previously reported WBV studies in children do not, however, comprise large study groups. This demonstrates the challenges when conducting intervention studies among disabled children, and shows there is a need for large standardized multicentre studies. Due to motion artefacts and metal implants, the number of total-body BMD measurements is low. This is a limitation; however, the lumbar spine and the calcaneal DXL scans are useful complementary measurements. It would also have been preferable to have had an age-, pubertal- and gender-matched control group with matching diagnoses. Such a study design is difficult to accomplish due to the low number of patients with matching criteria. It would have been preferable to have more frequent treatment sessions; however, since the study were performed during school hours, when the children already have a full schedule, it was not possible to include additional treatment sessions. The pubertal effect on the skeleton was not recorded.

In conclusion, although the study group was small, this study contributes new knowledge about WBV intervention therapies in children with severe motor disabilities. A high incidence of fractures was observed prior to the start of the study and during the study, which emphasizes the need for strategies for interventions. WBVT appears to be well tolerated and appreciated among these children, and no adverse events were recorded. Low TBBMD LH Z-scores were found throughout the study; nevertheless, we found a positive change in TBBMD LH after 6 months of WBVT. Higher CTX and lower osteocalcin values indicate that severely disabled children have a reduced capacity for bone acquisition in comparison with healthy children.

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