

Marked Improvement in Physical Function through Gains in Muscle Strength and Thigh Muscle Size after Heavy-Load Strength Training in Women with Established Postmenopausal Osteoporosis

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Abstract

Purpose: To test feasibility and effectiveness of a well-controlled strength training program in postmenopausal women with osteoporosis.

Methods: A total of 22 women (56-80 years) with established osteoporosis were recruited. Strength training was conducted three times per week for 15 weeks. After an initial familiarization period of 2 weeks, strength training was performed with one to three 4-12 repetition maximum (RM) sets in squats, standing calf rise, leg press, rowing, chest press and shoulder press. Strength was measured as 1 RM in chest press, shoulder press and knee extension. Physical function was measured through five different activities (stair climb with and without load, chair raise, timed up and go and 6 minute walk test). Cross sectional area (CSA) of thigh muscles was measured with CT. Bone mineral density and body composition was measured by dual-energy X-ray absorptiometry (DXA).

Results: Strength increased by $33 \pm 4\%$ (mean $\pm$ SD) in chest press, $44 \pm 8\%$ in shoulder press and $36 \pm 4\%$ in knee extension ($p < 0.01$). CSA of knee extensors increased by $8 \pm 1\%$ ($p < 0.01$). Performance in stair climb and in chair rise was improved by $7 \pm 3\%$ and $7 \pm 2\%$, respectively ($p < 0.05$). There were no significant changes in bone mineral density or lean body mass, but fat mass was reduced by 1.0 kg ($p < 0.01$). There were no significant changes in well-being indices, but exercise motivation and perceived competence were improved ($ES = 0.54 \pm 0.45$ and 0.55 ± 0.38 , respectively).

Conclusions: Strength training in postmenopausal women with established osteoporosis was feasible and effective in improving muscle mass and strength. Importantly, the increased muscle strength was translated to improved function in activities of daily living and exercise competence and motivation was improved.

Keywords: Resistance training; Body composition; Bone mineral density; Bone mineral content; Osteoporosis; Lean body mass

Introduction

Post-menopausal osteoporosis (OP) is the most frequent population based disease in women above 50 years of age, and more than 40% can expect to experience at least one fragility fracture during their lifetime, compared 20% of men [1]. The disease accounts for approximately 1.5 million new fractures each year in the US alone with annual costs estimated at \$17 billion, and is expected to rise by the year 2025 [1].

In Norway with a population of approximately 5 million, OP is the major cause of fractures in elderly with 9000 femoral neck and 15000 forearm fractures yearly [2]. The Norwegian Institute of Public Health estimates that 140 000 women and 90 000 men above 50 years have suffered vertebral compression fractures, resulting in societal costs estimated at ~4000 M NOK per year [3]. Furthermore, OP patients occupy more hospital beds than any other disease groups in Norway.

OP is defined clinically through measurement of bone mineral density (BMD) which is, so far, the single best predictor of fracture risk [4,5]. Twin and family studies have shown that 50%-85% of the variance in BMD is genetically determined [6,7]. Importantly, OP is strongly associated with reduced muscle strength and mass, and the deterioration in musculo-skeletal performance impairs balance and increase the risk for falls and subsequent fractures. Of the different types of fragility fractures, hip fractures have the highest mortality and morbidity risk [2,3]. Consequently, there is a need to establish effective strategies to counteract and treat the unfavourable combination of low muscle mass and reduced BMD occurring especially in postmenopausal women, but also affect about 1 in 5 men above 50 years of age [1]. Increased muscle

mass and strength in the lower body will be expected to reduce the risk of falling because low muscle mass (sarcopenia) is independently related to increased risk [8], whereas increased bone mineral density will improve the stress tolerance.

In healthy elderly people, heavy-load strength training has been shown to effectively improve muscle strength (25-35%), muscle mass (~ 1 kg) and physical function in interventions typically lasting 10-24 weeks [9-11]. Although the documentation is less convincing for the effects on increasing bone mineral density, two meta-analyses suggest that heavy-load strength training has the potential to increase BMD in postmenopausal women [12,13]. Importantly, it was concluded that progressive resistance training is a safe and effective way to avert bone loss in postmenopausal women [13].

However, there is a lack of information and knowledge regarding the effects of exercise in individuals with diagnosed osteoporosis [14]. The effect of heavy-load strength training in osteoporotic women has so

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far only been investigated in two small studies [15,16]

In addition to improved physical performance, another important outcome of exercise interventions concerns the participants' well-being. A sensation of high well-being has been related to lower risk of disability and mortality, better physical health and performance [17,18]. In addition, feeling well through exercise is likely to enhance the chance of continued participation and thereby increasing future health [19,20].

The aim of this study was to investigate the feasibility and the effects of 15 weeks of strength training on muscle strength and muscle mass, performance in activities of daily living, indicators of motivation and well-being as well as on BMD, in 22 postmenopausal women with established OP and at least one fragility fracture.

Methods

Study design

The present study was a 15-week strength training intervention aiming at improving muscle mass, strength, physical function and bone mineral density in osteoporotic women.

Inclusion criteria were based on BMD measurements at the back and hip showing osteoporosis at both sites (T-scores < -2.5) and at least one fragility fracture. Subjects had been evaluated through additional X-ray examination and blood biochemistry including measurements of 25OH vit D, vitamin K and endocrinological analyses covering calcium/PTH metabolism and thyroid status. No other diseases (kidney, alimentary or inflammatory) or medicine known to affect bone metabolism were allowed (e.g. oestrogen, corticosteroids). All subjects received daily supplements of vitamin D (1000 I.E. D3) and calcium (1000 mg). They were all on antiresorptive treatment (peroral bisphosphonates) and two had finished 2 years prior treatment with parathyroid hormone.

Recruitment

Participants for the trial were recruited consecutively through an outdoor medical clinic and gave their verbal and written consent. The study was approved by the Norwegian Regional Ethical Committee (REK no:2010/2539 [21]) and conducted according to the Declaration of Helsinki.

Participants

Sample size calculations, based on previous research on healthy elderly in our lab [35] revealed that 10 participants were needed to detect 10% increase in strength and 18 participants were needed to detect 5% increase in thigh muscle cross sectional area. A total of 22 women (age 55-80 years) with established OP were included (Table 1). Three participants had been previous smokers and the level of physical activity within the group were from moderate (one hr walking per day) to fair (1-3 hrs walking and attending gymnastics 1-2 times a week), except for one woman who competed in skiing at high level.

Of the 22 included patients three dropped out; one experienced a fracture unrelated to the training program, one withdrew before the start of the intervention and one did not complete the intervention for unknown reasons (Table 1).

Training protocols

The total duration of the intervention was 15 weeks, including two weeks to familiarize the participants to the training protocol using lighter training loads. The focus in this period was correct technique

in all exercises with special emphasis on positioning and stabilization of the hip and spine ensuring neutral and safe joint positions through the range of motion in all exercises. After the familiarization period the training loads were gradually increased to assure that the following thirteen weeks of training was conducted with optimal loading to improve muscle strength and muscle mass.

Strength training in the last 13 weeks was performed as traditional heavy-load strength training: three times per week with one to three sets involving all major muscle groups. The training protocol consisted of three exercises for leg muscles; squat, leg press and standing toe rise, and three exercises for upper body muscles; chest press, seated rowing and shoulder press (Figure 1). In addition, the participants performed self-selected exercises for abdominals and lower back muscles at the end

Variabel		Mean			Range		
		Mean		SD	Min		Max
Age	(years)	68.3	±	6.7	56.4	-	79.4
Body mass	(kg)	63.4	±	12.1	44.5	-	89.5
Height	(cm)	164	±	5	151	-	174
BMI	(kg/m ²)	23.7	±	4.7	18.1	-	35.7
Z-score							
	L1-L4	-1.5	±	0.7	-3.1	-	0.7
	Total hip	-0.6	±	0.6	-3.7	-	0.8
	Femur neck	-0.4	±	0.4	-1.2	-	0.6

Table 1: Characteristics of the participants.

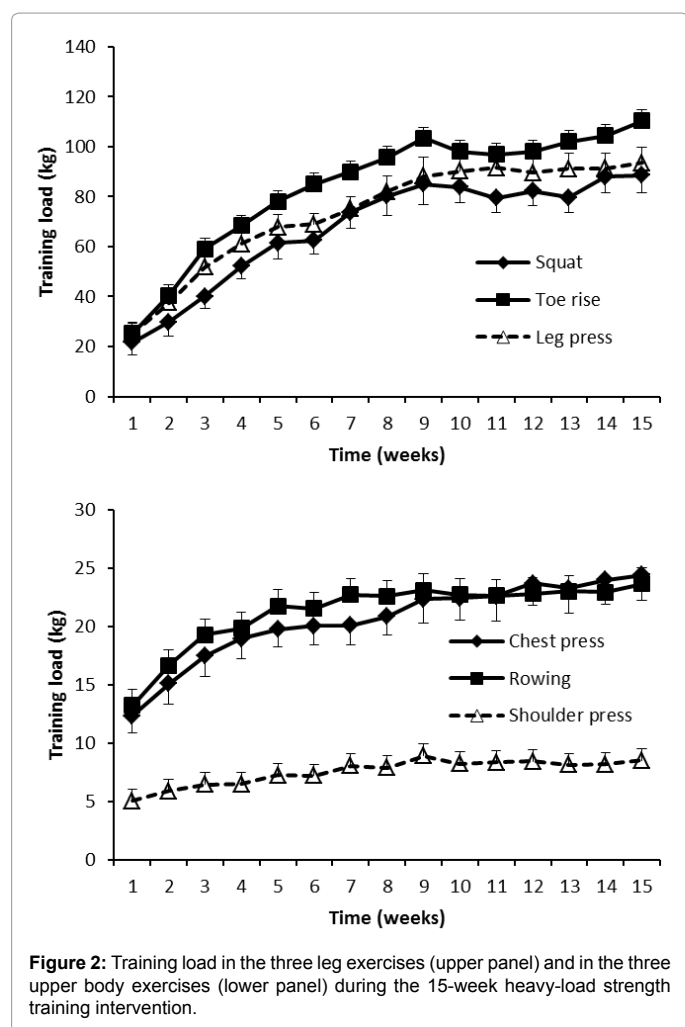


Figure 1: Main exercises in the training program: for lower body in the upper panels and upper body in the lower panels. A) The squat exercise which strengthens knee and hip extensor muscles in addition to core muscles stabilizing the hip and spine. Note that the back is resting towards a stabilizing plate which ensures an anatomically correct position of the spine. B) The toe rise exercise which strengthens the calf muscles and core muscles stabilizing the hip and spine. Both A and B put mechanical loading on the skeleton from the spine to the foot. C) The leg press exercise which mainly strengthens knee and hip extensor muscles. The mechanical loading on the skeleton is mainly focused on the legs and hips in this exercise. D) The chest press exercise which mainly strengthens chest, shoulder and elbow extensor muscles and puts mechanical loading on all bones in the arm and shoulder. E) The shoulder press exercise which mainly strengthens shoulder, neck and elbow extensor muscles and puts mechanical loading on all bones in the arm and shoulder (although considerable less load than the chest press exercise). F) The seated rowing exercise which mainly strengthens back muscles, shoulder muscles and elbow flexors.

of each session. The strength training regime was a mix between linear periodization and daily undulating periodization. The participants started with 8-12 RM (repetition maximum) sets, and ended the 13-week protocol with 4-8 RM sets. In two sessions per week the sets were run till failure (RM-sets) and in the third session, performed between the two maximal sessions, sets were run with a load corresponding to 80-90 % of the actual RM load. The participants performed a general warm up (10-15 min) on treadmill, bicycle, step machine or rowing machine at the beginning of each session. Total duration of training was about 60 minutes per session, and the participants exercised in groups of three with an instructor present. Training under supervision ensured the quality of the exercise and the safety of the participants. The training load was recorded in a training diary and this log was used to check the progression in all exercises for each participant (Figure 2).

Timeline

Baseline assessments: Measures of well-being and exercise motivation were performed the first time participants came to familiarization at the intervention site, while physical tests were performed after two familiarization sessions. Measurement of body composition and CT scans of the thighs was also performed during these two weeks of familiarization and testing, and at least 24 hours after any strenuous physical activity.



Post-assessments: About one week after completing the 15 weeks of strength training the participants repeated the physical and psychological tests and body composition measurements. The tests were conducted at the same time of day and with the same investigator performing the tests as in the baseline assessments. The order of the tests was standardized and identical to the baseline assessment.

Measures

Physiological measures:

Body composition: Lean body mass, fat mass and total body fat percentages were determined by dual energy x-ray absorptiometry (DXA) using a Lunar Prodigy densitometer (GE Medical Systems, Madison, WI). Prior to the DXA scan, subjects were requested to avoid training for 24 hours and to avoid any ingestion of liquid or food 2 hours before the scan. Subjects were lying in a standardized position in the machine according to the instructions of the manufacturer. The measurements were carried out by two skilled bioengineers. Repetitive measurements of the same patients gave a CV of 2.8% at the spine and 2.6% at the hip.

CT measurements: Muscle cross sectional area (CSA) of the anterior compartment of the thigh was measured using a Phillips Brilliance 64 slice scanner (slice width of 3.75 mm, scan time of 0.75 sec, kV of 120 and mA of 50). The subjects were lying in a supine position with legs extended and straps securing legs in a fixed position. Axial CT scans of both thighs were obtained at distances $\frac{1}{4}$, $\frac{1}{2}$ and $\frac{3}{4}$ of the femur length between the greater trochanter and the femoro-tibial joint line, as determined from a coronal scout image. CSA was measured by manually tracing the outline of *m. rectus femoris*, *m. vastus lateralis*, *m. vastus intermedius* (quadriceps muscles/extensor muscle group) and *m. sartorius* using a tracer function in the software [22].

Functional tests: The participants performed different functional tests simulating everyday activities. The subjects climbed stairs (20 steps, 16 cm height) as fast as possible in two different conditions; without any load and with a weight vest of 10 kg (stair climb + 10 kg). Times were recorded using photocells (JBL Systems, Oslo, Norway) placed at the start of the stairs and 70 cm after the last step. Each subject was given two attempts in each condition. The ability to get up from a chair was measured with the chair rise test. The test consisted of five consecutive rises, where the subjects were asked to make sure that their back touched the backrest each time they sat down, and that their feet and back were straight in the upright position. Two attempts were given to each subject, and times were recorded with a stopwatch. The subjects were also tested in the "Timed Up and Go" test (TUG). They were asked to rise from the chair (46 cm height), walk three meters, turn around a cone, walk back and sit down on the chair. Times were recorded using a stopwatch. The six-minute walk test was used to assess walking capacity. The subjects were asked to walk as far as possible in six minutes on an indoor track. The total distance covered in six minutes was recorded.

Strength tests: Strength testing was performed in machines (Technogym, Selection Line, Gambettola, Italy) using a one repetition maximum test (1RM) in three different exercises (chest press, shoulder press and knee extension). In all exercises the subjects performed a standardized warm up protocol consisting of three sets with gradually increasing load and decreasing repetitions (10, 5 and 3 repetitions). The first attempt on 1RM was performed with a load of approximately 95% of predicted 1RM, and after each successful attempt the load was increased with 2-5% until failure. Rest between each attempt was approximately 3 minutes.

Psychological measures

Well-being is a multifaceted phenomenon [23,24] and therefore participants' well-being was measured with several well-validated indicators. *Life satisfaction* was assessed with the Satisfaction With Life Scale (SWLS;[25]). The SWLS is a short 5-item scale designed to measure the cognitive component of subjective well-being. To assess *positive and negative feelings*, a short version of the Positive and Negative Affect Schedule (PANAS;[26]) was used. The scale consists of six positive feelings (enthusiastic, inspired, alert, excited, determined, active), and six negative feelings (upset, nervous, afraid, distressed, scared, irritable). Participants feeling of *vitality* and energy were measured with six items from the Subjective Vitality Scale (SVS; [27]). The measure is considered an important aspect of a person's well-being, but also indicates the function of the participants. High well-being does not necessarily mean the absence of ill-being [24]. Hence, *depression* was also included using the Center for Epidemiologic Studies Depression Scale (CES-D; [28]). The CES-D was originally constructed to measure current level of depression scores in epidemiological studies, but has been used in several intervention studies among elderly (e.g.[29]).

Subjective health (SH) was measured with six items, two from SF-36 [30] and four from [31]. The items reflect participants' satisfaction with own health, whether they were worried about their health or whether their health prevented them in daily life.

Participants' *motivation for exercise* was measured with a 16-item version of the Behavioral Regulation in Exercise Questionnaire [32]. The scale consist of four different reasons for doing exercise, and a sum-score was made by summing the intrinsic (joy) and identified reasons (importance), and subtracting the sum of introjected (guilt) and external (pressure from others) (e.g., [33]).

Perceived competence was measured with an exercise version of the 4-item "Perceived Competence Scale [34], which indicate participants perceptions of ability to be physically active. All scales have proved acceptable reliability (Cronbach's alpha >.70) in a previous larger exercise study among older adults in Norway [35,36].

Statistics

Changes were analysed using paired sample t-tests. Correlations were performed using Pearson's product moment correlation coefficient. Change scores are given as percent $\pm$ standard deviation, or standardized effect sizes (ES) with the 95% confidence interval (CI). An effect <0.20 is considered trivial, 0.20-0.60 small, 0.60-1.2 moderate [37]. Mediation was tested with bootstrapping analyses where the data were resampled 5000 times. Bootstrapping is considered especially appropriate with small samples [38]. All data were analysed using SPSS version 15.0 and statistical significance was set at $p \leq 0.05$ for all analyses.

Results

Training progression and feasibility of the training program

After the initial two weeks of familiarization to the training exercises a gradual progression in training load was observed through the next 7 weeks (Figure 2). During the last 5-6 weeks the training loads stabilized at a level approximately 70-100% and 20-30% above those used in the first week after familiarization (week 3) in the lower body and upper body exercises, respectively. Participants completed $85 \pm 9\%$ of the planned sessions (range: 72%-97%).

The exercises and the training loads were well tolerated by the participants, but one compression fracture in the spine was attained

during an accident in the squat exercise. The patient recovered during 3 months of reduced loading and completed the training intervention with excellent results after that. The progression in the leg exercises from week 3 to week 9 (70-100% increase in load) was reported as "too fast" progression in some participants. Consequently, the progress was slowed down and more focus on correct technique was implemented in the final 5-6 weeks of training.

Body composition (LBM and fat mass) and thigh muscle cross sectional area

Total body mass was reduced by 0.88 kg as function of a 1.06 kg reduction in fat mass (Table 2). Total lean body mass and total bone mass were not significantly changed, but a mean increase of 0.28 kg ($p=0.12$) and 0.03 kg ($p=0.13$), respectively, were observed.

Cross sectional area of the knee-extensor muscles increased by 7-8% in all three measured sites (Figure 3).

Strength

Strength measured as 1 RM increased by $33 \pm 4\%$ in chest press, $44 \pm 8\%$ in shoulder press and $36 \pm 4\%$ in knee extension (Figure 4, $p < 0.01$).

Physical function

Performance in stair climb with 10 kg extra load and in chair rise

Variabel	Pre		Post		Change		p-value
	Mean	SD	Mean	SD	Mean	SD	
Total body mass (kg)	63.43	± 12.08	62.55	± 11.51	-0.88	± 1.40	0.01
Lean body mass (kg)	39.74	± 4.61	40.03	± 4.60	0.28	± 0.76	0.12
Fat mass (kg)	21.38	± 8.79	20.32	± 8.45	-1.06	± 1.17	0.00
Bone mass (g)	1870	± 254	1901	± 281	31	± 86	0.13

Table 2: Body mass and body composition measured at baseline (Pre) and after (Post) the 15 week-intervention including 13 weeks of heavy-load strength training.

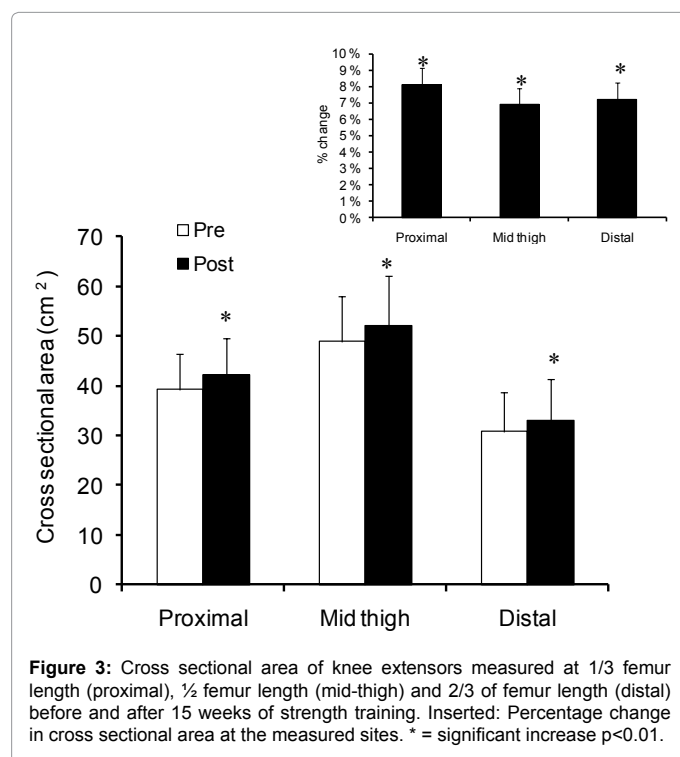


Figure 3: Cross sectional area of knee extensors measured at 1/3 femur length (proximal), 1/2 femur length (mid-thigh) and 2/3 of femur length (distal) before and after 15 weeks of strength training. Inserted: Percentage change in cross sectional area at the measured sites. * = significant increase $p < 0.01$.

was improved by $7 \pm 3\%$ and $7 \pm 2\%$, respectively (Table 3, $p < 0.05$, Figure 4). Preferred walking speed was reduced by $8 \pm 11\%$ (table 3, $p < 0.01$). There were no other statistically significant improvements in the other tests of physical function (Table 3).

Bone mineral density and bone mineral content

There were no significant changes in total BMD or BMC or regional changes at the specific sites measured (Table 4).

Psychological variables

There were no significant changes in the well-being indices or subjective health (Table 5), while perceived exercise competence (ES

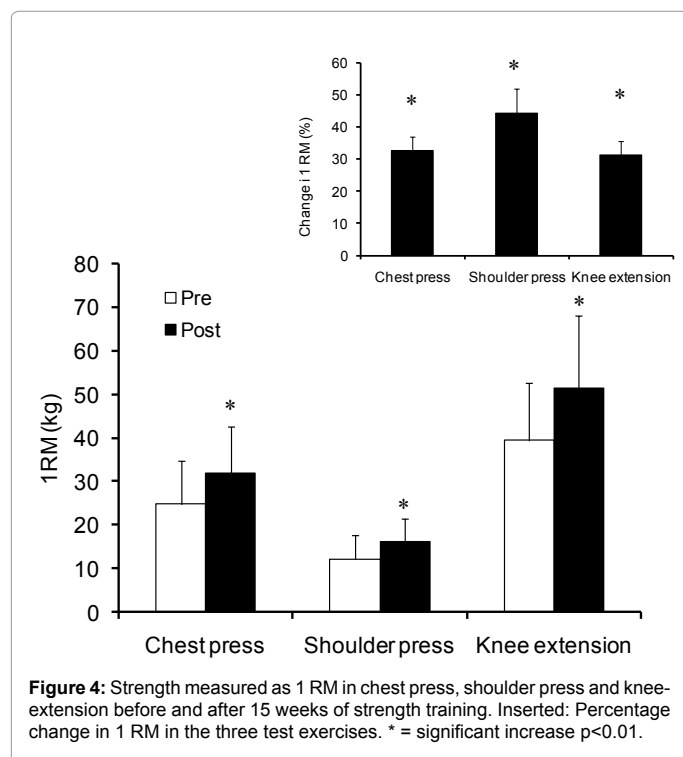


Figure 4: Strength measured as 1 RM in chest press, shoulder press and knee-extension before and after 15 weeks of strength training. Inserted: Percentage change in 1 RM in the three test exercises. * = significant increase $p < 0.01$.

Variable	Pre		Post		Change		p-value
	Mean	SD	Mean	SD	Mean	SD	
Stair climb (s)	8.00	± 1.96	7.55	± 1.92	-0.45	± 1.26	0.14
Stair climb +10 kg (s)	8.27	± 1.77	7.62	± 1.59	-0.65	± 1.10	0.02
Chair rise (s)	11.53	± 1.68	10.74	± 2.05	-0.79	± 1.33	0.02
Timed up and go (s)	6.18	± 0.73	5.95	± 1.09	-0.20	± 0.59	0.13
6 min walk test (m)	629	± 78	635	± 90	5	± 46	0.64

Table 3: Performance in activities of daily living measured before (Pre) and after (Post) the 15 week-intervention including 13 weeks of heavy-load strength training.

Variable	(g/cm ²)	Pre		Post		Change		p-value
		Mean	SD	Mean	SD	Mean	SD	
L1-L4		0.749	± 0.096	0.744	± 0.093	-0.002	± 0.027	0.80
Femur neck		0.741	± 0.066	0.738	± 0.072	-0.004	± 0.015	0.36
Arms		0.743	± 0.086	0.754	± 0.092	0.011	± 0.048	0.34
Hip		0.762	± 0.085	0.762	± 0.093	0.000	± 0.016	0.98
Total		0.963	± 0.084	0.963	± 0.084	0.003	± 0.014	0.43

Table 4: Bone mineral density (BMD) measured at baseline (Pre) and after (Post) the 15 week-intervention including 13 weeks of heavy-load strength training.

Variable	Pre		Post		Change		p-value
	Mean	SD	Mean	SD	ES	95%CI	
Satisfaction with life	5.56	± 1.25	5.57	± 0.94	.01	.25	.94
Subjective vitality	5.52	± 1.17	5.70	± 1.11	.15	.29	.29
Positive affect	3.59	± 0.69	3.50	± 0.74	-.13	.51	.61
Negative affect	1.62	± 0.58	1.74	± 0.88	.20	.62	.52
Depression	1.70	± 0.20	1.74	± 0.26	.19	.53	.47
Subjective health	3.61	± 0.59	3.87	± 0.64	.43	.60	.15
Perceived competence	4.88	± 2.01	5.99	± 1.21	.55	.38	.01
Motivation	3.29	± 1.85	4.29	± 1.75	.54	.45	.02

Note. ES = Standardized effect size, 95% CI = 95% confidence interval

Table 5: Indices of well-being and motivation measured at baseline (Pre) and after (Post) the 15-week intervention including 13 weeks of heavy-load strength training.

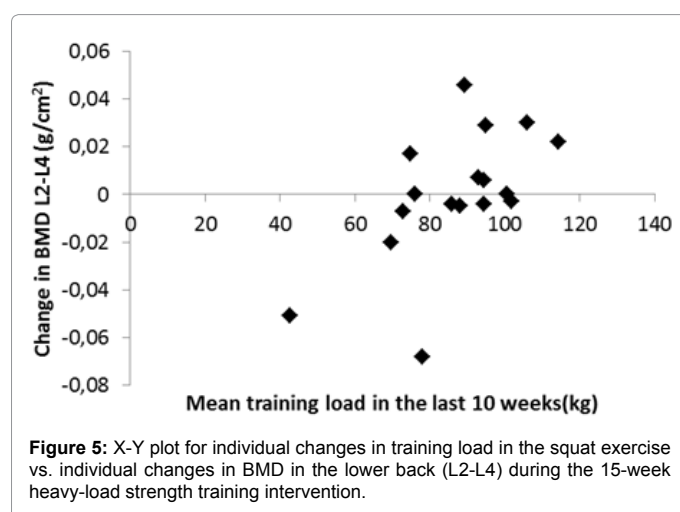


Figure 5: X-Y plot for individual changes in training load in the squat exercise vs. individual changes in BMD in the lower back (L2-L4) during the 15-week heavy-load strength training intervention.

= 0.55, $p = 0.01$) and motivation for physical activity showed significant improvements (ES = 0.54, $p = 0.02$).

Correlations between physical parameters, muscle CT measurements and subjective health Baseline.

At baseline there were significant correlations between relative strength in knee-extension and performance in the stair climb tests ($r = 0.82$, $p < 0.01$), and between the cross sectional area of knee-extensors and the strength in knee-extension ($r = 0.87$, $p < 0.01$).

There was a clear relation between BMC and perceived exercise competence ($r = 0.55$, $p = 0.015$). This may indicate that those with high BMC have exercised more and thereby reported higher competence.

Changes during intervention.

The combined training load in the squat exercise and toe-rise during the last 10 weeks of the intervention was significantly correlated to the individual change in BMD in the lumbar spine (L2-L4) ($r = 0.62$, $p < 0.05$, Figure 5).

Several interesting correlations between change in subjective health and change in physical function emerged; those with improved stair walk (without load $r = -0.61$, $p < 0.01$ and loaded $r = -0.55$, $p < 0.05$), improved TUG ($r = 0.64$, $p < 0.01$) and a higher sum score (%) on functional tests ($r = -0.70$, $p < 0.01$), reported increased subjective health. In addition the change in subjective health was related to reductions in depression scores ($r = -0.48$, $p < 0.05$). These correlations opened up for testing a meditational model through bootstrapping (suggested

for small samples). The analyses indicated a marginal model where subjective health mediated the relation between increased physical function ($PE = -.05, p < .05$) and reductions in depression ($PE = -.067, p < .05$). The model explained 26% of the change in depression scores among the participants.

Discussion

The present study is the first whole body heavy-load strength training intervention performed in a well characterized cohort of women with established osteoporosis. The supervised heavy-load training was feasible; no one dropped out because the exercise program was experienced too tough, and they developed a positive attitude towards the program. The main effects of training were marked improvements in physical performance measured as muscle strength and performance in activities of daily living, increased cross sectional area of thigh muscles, reduced fat mass, as well as improved perception of competence and motivation for exercise. Probably due to the short intervention period, no significant improvements in BMD were observed, but a significant correlation between training load and change in BMD of L1-L4 was present; indicating possibly positive ongoing remodelling changes.

The exercises and the training loads were well tolerated by the participants. It is, however, important to highlight that experienced instructors supervised all sessions to ensure correct technique and loading in each lift; consequently the risk for adverse outcomes was minimized. Furthermore, training load in the first two weeks (first 6 sessions) was submaximal with controlled progressions and with focus on correct lifting technique in each exercise. The exercises and apparatuses were chosen specifically to prevent compression fractures due to uncontrolled movements in spine and hips (e.g. the back support in all leg exercises). Nevertheless, one compression fracture in the spine was attained during an accident in the squat exercise as the subject did not manage to secure the load after finishing the last repetition. Consequently, extra attention to safety routines should be paid at the beginning and the end of each set in exercises where the load has to be secured before entering or leaving the apparatus. Noteworthy, the patient recovered during 3 months of reduced loading and completed the training intervention with excellent results thereafter.

An important observation in the present study was that postmenopausal women with established osteoporosis showed similar gains in muscle size and muscle strength as reported for healthy men and women after comparable strength training intervention [9,10,39]. Similar findings were reported in a group of 8 postmenopausal women with osteoporosis or osteopenia focusing on strength training of leg muscles over 12 weeks [15]. In that study, women with less advanced disease showed an impressive 154% increase in 1 RM in the squat exercise and 52% increase in rate of force development (muscle power), which is suggested to be of high importance for preventing falls [40,41]. Bone mineral content (BMC) increased by 2.9 and 4.9% in the lumbar spine and the femoral neck respectively, but no significant change was, however, observed in BMD. De Matos et al. investigated the effect of 12 months strength training on BMD in the spine and hip region in 59 osteoporotic or osteopenic women. Although no significant increases in BMD was observed, there was a significant intervention effect on BMD in spine as a result of the combination of a slight increase in the strength training group and a decrease in the control group [16]. Effects on muscle mass, muscle strength and physical function were, however, not reported in that study. Consequently, postmenopausal women with established OP seem to have similar potential to respond to strength training as healthy and osteopenic women. It is an open

question whether the low muscle mass associated with OP [42] mainly is a genetically determined comorbidity or a consequence of low levels of high impact or reduced physical activity (and/or suboptimal diet). It should, however, be noted that no significant increase in LBM was observed in the present study. Interestingly, large individual variations were observed for changes in LBM ranging from a loss of 1.2 kg to a gain of 1.4 kg and also the changes in body mass showed large variations (ranging from a loss of 5.0 kg to a gain of 0.9 kg). This highlights the impact of proper nutrition for optimal effects of strength training and the gains in LBM may have been improved if the diet had been optimized with regard to energy balance and protein intake.

The participants all had an average Norwegian diet supplemented with vitamins and minerals [21] and experienced that body and fat mass were reduced by 0.9 and 1.1 kg, respectively. Consequently, body composition was improved despite no significant gains in LBM. This is probably an important finding because the newly introduced term osteosarcopenic obesity highlights the increased risk of metabolic abnormalities and increased risk of falls in obese women with low bone and muscle mass [43].

We were not able to detect any significant changes in BMD or BMC during the 15-week intervention period, which was probably too short to induce significant effects. Interestingly, we observed a positive correlation between the training load used in the squat and toe-rise exercise and the individual changes in and L2-L4 BMD, and it seemed like the load had to exceed 80 kg in order to induce an increase in BMD. Consequently, this might represent the threshold for the mechanical stress on the bones that needs to be exceeded before the osteogenic response becomes significant in short duration interventions. Furthermore, the importance of nutritional status influencing the osteogenic response to strength training was reflected by a woman who lost 5.0 kg body mass during the intervention and she showed the largest decrease in L2-L4 BMD.

Although the effect of training intervention on indicators of well-being and subjective health did not reach statistical significance, it is of importance to notice that our subjects increased their perceived competence and motivation for exercise. These changes increase the likelihood for sustaining strength training after the end of an intervention, an essential requirement for maintaining improved muscle mass, strength and function. Furthermore, we observed several interesting correlations between changes in subjective health and changes in physical function. These findings are essential because perception of health and physical function are important mediators between exercise and better mental health [29,44]. Further support for the importance of improved physical function on mental health was indicated by the mediation of changes in subjective health on the relation between improved function and reduced depression.

Limitations and Precautions in Interpretation of the Results

Even if this study is the largest of its kind, and the participants represent a clinically well-defined cohort [21], it does not include a replication cohort or a non-training control group. In light of previous reports [15,16], we considered it to be not ethically correct to include a non-training group on basis of the progressive nature of the disease. Our results are highly concordant with similar, smaller studies in osteopenic and osteoporotic women [15,16], and the present results may be considered as a needed complementation and supplementation.

None of the participants were treatment naïve, all had received, and

19 were still on bisphosphonate treatment as the major therapy. The impact of medication on the result cannot be evaluated. If anything, one would expect that the effect of training on the skeleton would be less due to the known effect of bisphosphonates to impair bone remodelling and thus initiate anabolic processes.

Perspectives

The heavy-load strength training program was feasible and effective in improving muscle size, muscle strength and physical function over 15 weeks. Consequently, the program can be recommended for osteoporotic women with low muscle mass and muscle strength. The program was, however, intensive and time consuming, and to continue this program for months and years will be challenging. For maintenance of muscle mass and strength over a prolonged period of time, a transfer of training competence to the participants is probably necessary, and a somewhat moderated program with lower frequency (1-2 times per week) and volume (1-2 sets per exercise) is recommendable. However, for optimal effects on BMD and BMC, which probably need more time, training frequency seems to be important [45]. Consequently, the main goal for the planned training should always dictate the choice for the main variables in a training program (frequency, volume and load).

In conclusion, the heavy-load strength training was well-tolerated in postmenopausal women with established OP. Participants showed significant improvements in muscle cross sectional area and strength with corresponding gains in physical function. Furthermore, perception of competence and motivation for exercise increased during the intervention. Consequently, the program was both safe and efficient, and can thus be recommended as an effective countermeasure against the low muscle mass and suboptimal muscle strength strongly associated with OP in postmenopausal women.

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