

The effect of habitual physical activity, non-athletic exercise, muscle strength, and VO_{2max} are not highly correlated with bone mineral density is rather low in early postmenopausal osteopenic women

W. Kemmler¹, J. Weineck², W.A. Kalender¹, K. Engelke¹

¹Institute of Medical Physics, University of Erlangen,

²Institute of Sport Sciences, University of Erlangen, Germany

Abstract

Context: Although the positive effect of well-designed exercise regimes on bone mineral density (BMD) is established the osteo-anabolic relevance of habitual physical activity and non-athletic exercise is still under discussion. **Objective:** To determine the effects of habitual physical activity, non-athletic exercise muscle strength, VO_{2max} and anthropometric parameters on BMD in early postmenopausal women. **Design: Cross-sectional study. Methods:** 150 early postmenopausal women (55.5 ± 3.4 years), which were free of diseases or medication affecting bone metabolism and had no athletic history were investigated. The influence of weight, body composition, physical activity, isometric strength, VO_{2max} , and nutritional intake on BMD was measured at multiple sites using different techniques. Further bone markers (Osteocalcin, CTX) were determined. Activity and weight-bearing activity were assessed by questionnaire. Maximum strength was measured isometrically. Aerobic capacity was measured with a spirometric system in a stepwise treadmill test and dietary intake was monitored over 5 days. **Results:** Slight relationships between physical activity, exercise, muscle strength and VO_{2max} with bone parameters were determined by univariate analysis. After adjusting for confounding variables in a stepwise regression analysis, significant relationships with BMD measured at the hip or the spine could no longer be detected for physical activity, exercise, and physical fitness (strength indices, VO_{2max}). The same was true for osteocalcin and CTX. Arm strength explained 4.5% of the variation of forearm BMD (DXA). At the calcaneal site, osteogenic exercise was significantly related to the quantitative ultrasound index ($r^2 = 0.27$). **Conclusion:** The isolated effect of habitual physical activity, unspecific exercise participation, and muscle strength on bone parameters is rather low in (early-) postmenopausal women. **Clinical relevance:** Women at risk should take specific exercise programs into consideration rather than to increasing the amount of habitual physical activity.

Keywords: Anthropometric Parameters, Physical Activity, Strength, VO_{2max} , Bone

Introduction

It is widely accepted that physical activity benefits the musculoskeletal system but the mechanisms affecting bone mass and density that are set off by physical activity in general and mechanical loading in particular are still poorly understood.

According to the theory of the mechanostat the bone-muscle interaction plays a dominant role. Thus, exercise should mostly affect bone indirectly via the muscle interface. However, there is also clear evidence that an exercise regimen with impact loading has a direct effect on bone¹⁻³. Apart from a particular loading pattern, strain intensity and variation are important parameters for the regulation of bone mass and density. In this context the osteo-anabolic relevance of habitual physical activity and non-athletic exercise is still under discussion. There is no agreement yet whether slightly above average habitual physical activity or non-athletic exercise with low to moderate strain levels constitute an adequate strategy to maintain bone in the elderly population.

Some recent studies in non-athletic postmenopausal females have shown significant correlations between bone mineral den-

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Corresponding author: Wolfgang Kemmler, Ph.D., Institute of Medical Physics, University of Erlangen, Krankenhausstr. 12, 91054 Erlangen, Germany
E-mail: wolfgang.kemmler@imp.uni-erlangen.de

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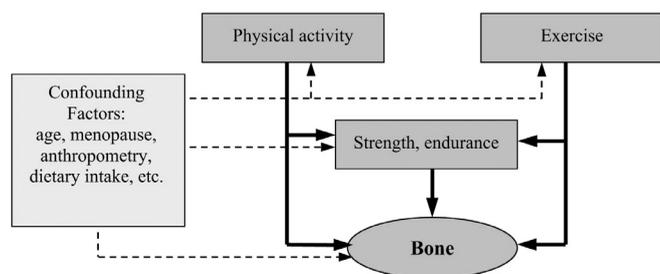


Figure 1. Relationship between variables affecting bone.

sity (BMD) and physical activity⁴⁻⁶, muscle strength⁷⁻¹¹, or endurance (i.e., aerobic capacity)¹²⁻¹⁴. However, the conclusions of these studies are limited because:

1. Most of the investigated cohorts were rather heterogeneous with respect to age, menopausal status, athletic history, or medication and diseases affecting the bone metabolism.
2. Often only a very limited set of parameters was measured. Relationships were frequently analyzed pair-wise instead of using multivariate methods that take into account dependencies among those variables presumably related to BMD. Confounding factors such as age, menopause, and variables of anthropometry or even dietary intake were often neglected.
3. Most of the significant correlations reported in the literature were rather low ($r < 0.3$) indicating, at best a slight dependence of bone mineral density and physical activity.
4. All studies evaluating physical activity focused on frequency (how often) and duration (how long) but not on intensity.

In the current study we proceeded differently. We investigated a rather homogenous population: early postmenopausal women with a non-athletic history. We specifically investigated the hypothesis that differences in bone density cannot be explained by variations in habitual daily activity or low exercise levels. We assumed a general cause/effect pattern shown in Figure 1. Physical activity and exercise can impact on bone indirectly via parameters such as muscle strength (local impact) and endurance (systemic impact). However, there is also a direct impact. In addition one has to consider confounding factors in all relations.

In this cross-sectional study, we measured parameters of bone densitometry at different sites and with different techniques as well as a large variety of ‘independent’ variables that are known to affect bone mineral density (BMD). We used baseline data of the Erlangen Fitness Osteoporosis Prevention Study (EFOPS), an ongoing long-term controlled exercise trials from which complete one-¹⁵ and two-year data¹⁶ have been published so far.

Materials and Methods

The EFOPS Study is a controlled exercise trial in early postmenopausal osteopenic women approved by the Ethics Committee of the University of Erlangen (Ethik Antrag 905),

Exercise discipline	Example	Osteogenic impact factor
Exercises with no or low ground-, and joint reaction forces	cycling swimming	0
Exercises or games with low ground-, and joint reaction forces	bowling walking	1
Exercises or games with moderate ground-, and joint reaction forces	dancing low impact aerobic calisthenics	2
Exercises or games with ground reaction forces > 1000µE	running high impact aerobic tennis squash	3
Exercises with high joint reaction forces	high intensity strength training at machines	3

Table 1. Osteogenic impact factor assigned to exercise disciplines.

the Bundesamt für Strahlenschutz (S9108-202/97/1), and the Bayerisches Landesamt für Arbeitsschutz (13B/3443-4/5/98). All study participants gave written informed consent.

Subjects

150 early postmenopausal (1-8 years) women were recruited from the Erlangen area by media advertisements and individual letters. All women were osteopenic at the spine or hip as defined by the WHO criterion ($-1 > DXA-T-Score > -2.5 SD$). Exclusion criteria for the EFOPS study were secondary osteoporosis, known osteoporotic fractures, and current or recent (within 2 years before study start) use of medication (i.e., bisphosphonates, HRT, PTH, glucocorticoids, thyroxin) or diseases affecting bone metabolism. Further exclusion criteria were inflammatory diseases, history of cardiovascular disease, very low physical capacity at ergometry ($< 75 W$), and athletic history defined as active participation in athletic competitions during the last 2 decades.

Baseline measurements

The following baseline measurements of the EFOPS Study were used for the investigation reported here.

Anthropometric data

We measured body height, weight, and composition. Body composition was determined with the impedance-technique (Tanita BF 305, Tanita, Japan).

Exercise-specific data

Isometric muscle strength

Maximum isometric muscle strength of the trunk extensors and flexors, hip flexors, leg adductors and abductors, and of the

	Mean \pm SD	Minimum	Maximum
Anthropometric Parameters			
Age [y]	55.5 \pm 3.4	46	62
Body height [cm]	162 \pm 7	142	185
Body weight [kg]	68.0 \pm 11.7	38.8	113.4
Body Mass Index [kg \cdot m ⁻²]	25.6 \pm 4.0	19.1	44.3
Body fat [%]	36.0 \pm 6.1	12.9	49.7
Lean mass [kg]	42.9 \pm 4.2	33.8	55.5
Gynecological risk factors of osteoporosis			
Age at menarche [y]	13.4 \pm 1.4	10	17
Age at menopause [y]	50.5 \pm 3.1	43	57
Menopausal age [y]	4.8 \pm 2.2	1	8
Estrogen exposition [y]	37 \pm 3	27	44
Number of pregnancies	2.0 \pm 1.2	0	7
Dietary parameters			
Energy intake [kJ \cdot d ⁻¹]	7726 \pm 1712	4801	12116
Calcium intake [mg \cdot d ⁻¹]	994 \pm 359	390	2358
Phosphate intake [mg \cdot d ⁻¹]	1262 \pm 366	602	3108
Magnesium intake [mg \cdot d ⁻¹]	351 \pm 99	158	802
Vitamin D intake [μ g \cdot d ⁻¹]	5.1 \pm 4.6	0.1	23.9
Further risk factors of osteoporosis			
Ever smoked [%]	27	---	---
Use of glucocorticoides > 3 months during life [%]	5	---	---
Use of contraceptiva > 1 year during life [%]	72	---	---

Table 2. Mean \pm SD, minimum, and maximum values of anthropometric and dietary parameters and of other risk factors of osteoporosis that were measured in this study.

arm flexors and extensors was measured using a Schnell-Trainer-dynamometer (arm flexors and extensors) and a Schnell M-3 isometric tester (Schnell, Peutenhausen, Germany). Only the dominant limb was analyzed. We employed the isometric test protocol from Tusker¹⁷ that is recommended for research. All strength values were recorded as torques in Newton meter (Nm). Grip strength of the dominant hand was assessed with a Jamar dynamometer (Jamar, Bolingbrook, IL). The exact test and positioning protocols of the isometric strength measurements have been described elsewhere¹⁸. From the measured values we derived three strength indices. The upper body strength index (BSI_u) combines muscle strength of the trunk extensors and flexors as well as of the hip flexors. The lower body strength index (BSI_l) combines muscle strength of the hip flexors and the leg adductors and abductors. The arm strength index (ASI) combines the grip strength and the strength of the arm flexors and extensors.

Treadmill ergometry

Aerobic capacity was measured using a stepwise treadmill (Technogym, Gambettola, Italy) test up to a voluntary maxi-

imum. Three subjects were excluded from the data analysis due to poor test compliance defined as a maximum heart rate (HR_{max}) below 155 beats/min. According to the test protocol the intensity was increased in steps of 1 km/h every 3 minutes beginning at 6 km/h (0° slope). Ventilation (VE), carbon dioxide output (VCO₂), oxygen uptake (VO₂), and maximum heart rate (HR_{max}) were measured breath by breath with a Zan 600 open spirometric system (ZAN, Oberthulba, Germany).

Bone densitometry

Bone densitometry was performed by dual X-ray absorptiometry (DXA), quantitative computed tomography (QCT), and quantitative ultrasound (QUS). Areal bone mineral density (BMD_a) was measured by DXA at the lumbar spine (L1-L4), the proximal femur, and the forearm (QDR 4500A Hologic, Bedford, MA). Volumetric bone mineral density BMD was measured by QCT at the lumbar spine (L1-L3) (Somatom Plus 4, Siemens, Erlangen, Germany) using the dedicated low dose Osteo protocol¹⁹. Speed of sound (SOS), broadband ultrasound attenuation (BUA), and the combined quality of ultrasound

	Mean \pm SD	Minimum	Maximum
Present activity intensity index (AI) [h \cdot week ⁻¹]	32 \pm 14	6	89
Present weight bearing intensity index (WI) [h \cdot week ⁻¹]	28 \pm 14	8	81
Present exercise index (EI) [min \cdot week ⁻¹]	200 \pm 171	25	670
Osteogenic exercise index (OI) [min \cdot week ⁻¹]	170 \pm 97	40	600
Subjects not performing any exercise [%]	40%	---	---
Subjects not performing osteogenic exercise [%]	58	---	---
Strength index upper body [Nm]	65.5 \pm 17.6	23.3	137.6
Strength index lower body [Nm]	89.9 \pm 20.3	42.5	141.0
Strength index arm [Nmkg]	48.5 \pm 9.9	31.3	76.7
Rel. VO _{2max} [ml \cdot min ⁻¹ \cdot kg ⁻¹]	25.9 \pm 6.0	12.6	39.9

Table 3. Mean \pm SD, minimum, and maximum values of parameters used to describe physical activity, exercise, muscle strength, and endurance.

index (QUI) were measured by ultrasound at the calcaneus using the Sahara device (Hologic, Bedford, MA).

Markers of bone turnover

Serum Osteocalcin (N-midTM Osteocalcin One Step Elisa) was measured to assess bone formation and serum CTX (CrossLapsTM One Step Elisa; both Osteometer Bio-Tech A/S, Herlev, Denmark) to assess bone resorption. These measurements were only taken in a subgroup of 66 randomly selected women. Inter (intra) assay variation was 2.8–6.5% (5.4–6.8%) for Osteocalcin and 5.4–8.1% (5.0–5.4%) for CTX. Sensitivity was 0.5 ng/ml for Osteocalcin and 94 pmol/l for CTX.

Dietary intake

The individual dietary intake was assessed by a 5-day protocol of the food consumed. For accurate weighting the participants were supplied with digital household scales. The procedure was discussed in detail with each participant and additionally provided as a printed document. For the analysis of the protocols Prodi 4,5/03 Expert software (Wissenschaftlicher Verlag, Freiburg, Germany) was used that extracts a total of 1,500 different basic nutritional ingredients. The analysis was carried out in close collaboration with the Department of Sports Medicine of the University of Bayreuth, Germany.

Questionnaires

Detailed questionnaires were used to assess average daily activity levels due to work, household, and gardening activities as well as historical and immediate pre-study exercise levels. Physical exercise was recorded from childhood on by a structured questionnaire.

Two activity and two exercise indices were calculated from the questionnaires:

1. The activity intensity index AI [h/week] summarizes weekly household, hobby, and gardening activities as well as occupational activities: $AI = \sum_j t_j l_j + \sum_k t_k m_k$

where l_j denotes the intensity of a household, hobby, or gardening activity j which was self rated on a scale from 1 to 7. m_k denotes the intensity of an occupational activity k . The intensity of the occupation given by the study participant was graded independently by two researchers on a scale from 1 to 7 and the average grade was used. t denotes the total duration of a given activity j or k in hours per week.

2. The weight-bearing intensity index WI [h/week] is a subset of AI; it only includes those activities where the feet are involved. Thus, sitting occupational activities are excluded from WI.

3. The exercise index EI [min/week] characterizes weekly exercise frequency and duration: $EI = \sum_j t_j$

where t_i is the duration of an exercise session i in minutes and i runs over all weekly exercise sessions.

4. The osteogenic exercise index OI [min/week] additionally considers the osteogenic relevant intensity of a specific exercise discipline: $OI = \sum_j a_j EI_j$

where EI_j is the exercise index for an exercise discipline j , for example the total minutes of cycling per week. a_j is the intensity factor for exercise discipline j . We termed it osteogenic impact factor and assigned values between 0 and 3 (Table 1).

EI and OI were assessed for the following time intervals: before menarche, during adolescence, during the 3rd, 4th, and 5th decades of life and at the time of the start of the EFOPS study.

The questionnaires were explained to the study participants in detail by research assistants. Concerning the physical activity and exercise section of the questionnaire participants were specifically informed about the character of the questions. Furthermore, the risk factor – and physical activity section of the completed questionnaires were inspected by the assistants together with the study subjects to avoid mistakes. During this

	Mean \pm SD	Minimum	Maximum
BMD _a LS 1-4 [g · cm ⁻²]	0.871 \pm 0.091	0.703	1.220
trabecular BMD LS [g · cm ⁻³]	93.9 \pm 18.9	49.0	152.4
cortical BMD LS [g · cm ⁻³]	252.7 \pm 38.9	169.5	437.9
BMD _a total hip [g · cm ⁻²]	0.855 \pm 0.079	0.644	1.095
BMD _a total forearm [g · cm ⁻²]	0.530 \pm 0.044	0.408	0.658
BMD _a ultradistal radius [g · cm ⁻²]	0.418 \pm 0.052	0.313	0.569
US BUA [dB · MHz ⁻¹]	73.5 \pm 15.0	41.2	124.0
US SOS [m · s ⁻¹]	1543 \pm 30	1486	1659
US QUI	91.9 \pm 17.7	55.8	152.3
Osteocalcin [ng · ml ⁻¹]	25.6 \pm 14.3	8.7	101.0
CTX [pmol · l ⁻¹]	3172 \pm 1818	666	7838

Table 4. Mean \pm SD, minimum, and maximum values of parameters of bone densitometry and of bone markers.

interview subjects were specifically asked about type, intensity and duration of their exercise history which was compared with the data of the questionnaire. The reproducibility of the questionnaires had been tested in an earlier study²⁰. A random sample of 10 women had answered the questionnaires twice within 2 weeks. The mean difference between the first and the second score had been less than 5%.

Analysis strategy and statistics

Baseline measurements are reported as mean values and standard deviations (SD). Normality of the distribution and homogeneity of variance were investigated using the Kolmogorov-Smirnov and Levine's F-tests. According to the data (interval or rank scaled) Pearson or Spearman correlation coefficients were used to investigate univariate correlations between 'independent variables' and dependent bone parameters. Stepwise multiple regressions were used for multivariate analysis. A 5% probability level was considered significant (*). SPSS 10.08 (SPSS Inc., Chicago IL) was used for all statistical analyses.

Univariate correlations

We first investigated univariate correlations of the parameters describing physical activity and exercise as well as muscle strength and VO_{2max} with variables of bone densitometry and bone markers. In detail we univariately correlated the variables listed in Table 3 with those listed in Table 4. We further analyzed the influence of the confounding factors listed in Table 2 such as age, menopausal age, gynecological risk factors, and nutritional intake on bone parameters. Finally we univariately correlated the confounding factors with the independent variables of Table 3 to account for the complex relations among the variables that are associated with a variation of bone density.

Stepwise regression analysis

In the stepwise multiple regression analysis we included all parameters that had shown a significant correlation with densitometric measurements in the univariate analysis.

Results

Table 2 - 4 list mean \pm SD, minimum, and maximum values for the parameters used in the analysis.

Univariate correlations

Significant univariate correlations between physical activity, exercise, muscle strength, and VO_{2max} with variables of bone densitometry are shown in Table 5. Table 6 lists significant correlations between the confounding variables (Table 2) and variables of bone densitometry and Table 7 those between the confounding variables and physical activity, exercise, muscle strength, and VO_{2max}. Correlations that did not reach significance are not shown in the tables.

Stepwise regression analysis

The results of the regression analysis are summarized in Table 8, which again only shows the remaining significant results.

Lumbar spine

16% of the variation of trabecular BMD measured by QCT was explained by body weight and age. The variable years since menopause that also showed a significant univariate correlation with trabecular BMD was no longer significant after the stepwise regression. For cortical BMD only weight but neither the osteogenic exercise index nor did

Variable 1	Variable 2	r
Weight bearing intensity index (WI)	QUI calcaneus	.21
Present Osteogenic exercise index	cortical BMD LS	.28
	QUI calcaneus	.52
Strength index upper body (BSI _u)	BMD _a LS	.17
Strength index lower body (BSI _l)	BMD _a total hip	.21
Strength index arm (ASI)	BMD _a total forearm	.27
	BMD _a ultradistal radius	.24
Rel. VO _{2max}	BMD _a total hip	-.22

Table 5. Significant ($p < 0.05$) univariate correlations between variables of physical activity, exercise, muscle strength, and VO_{2max} with variables of bone densitometry and bone markers.

VO_{2max} remain significant in the model. For the projectional DXA measurement at the lumbar spine the P/Ca intake ratio was the only significant contributor, the upper body strength index dropped out.

Proximal femur

For the total hip BMD_a, weight, and calcium intake remained in the model explaining 20% of the total variation. The strength index of the lower body and rel. VO_{2max} dropped out.

Forearm

Age and arm strength index explained 11% of the variation of the total forearm BMD_a as measured by DXA. Similar results could be observed for the distal forearm.

Calcaneus

The osteogenic exercise index explained 26% of the variation of calcaneal QUI. The weight-bearing index and body weight dropped out.

Markers of bone metabolism

Neither osteocalcin nor CTX showed significant relationships with the independent variables listed in tables 2 or 3. Therefore a stepwise multiple regression was not performed.

Discussion

In this study we investigated the relation between bone density and habitual daily activity levels or non-athletic exercise in early postmenopausal women. Of course many studies have

Variable 1	Variable 2	r
Age	trabecular BMD LS	-.28
	BMD _a total forearm	-.27
Years since menopause	trabecular BMD LS	-.23
Body height	trabecular BMD LS	-.17
	BMD _a total hip	.25
Body weight	BMD _a total hip	.41
	QUI calcaneus	.18
P/Ca intake ratio	BMD _a LS	-.22
	BMD _a total hip	-.17
Ca intake	BMD _a total hip	.21

Table 6. Significant ($p < 0.05$) univariate correlations between confounding factors and bone densitometry.

already addressed this issue in various populations, some of them also in postmenopausal women. However, most studies focused on physical activity or exercise or strength or VO_{2max} with or without adjusting for confounding factors such as age or anthropometric parameters whereas we determined the combined effect on different bone parameters. Furthermore, existing studies assessed physical activity most often only by the amount of physical activity or exercise, i.e., as hours per week. This approach is problematic because at least at physiologic strain frequencies the adaptive response of bone is more sensitive to strain intensity and impact²¹ than to strain number and duration²².

In this study we used the five indices defined in section questionnaires to account for amount, intensity, and impact of various exercise types and daily activities. In order to incorporate strain impact we ranked exercise types according to their osteogenic impact (Table 1) similar to other recent cross-sectional studies in athletes comparing the effect of different sport disciplines on BMD²³⁻²⁶. We did not investigate whether athletic and non-athletic exercise levels require different ranking schemes but used the results for athletes also for our study.

For this cross-sectional analysis we used the baseline data of the EFOPS study, a long-term ongoing exercise trial in which a cohort of early postmenopausal white women from the Erlangen area in Germany is enrolled. At study start the women were osteopenic at either the hip or the spine as defined by the WHO. None had diseases or took medication affecting the musculoskeletal or cardiovascular systems and none had performed athletically during the last 2 decades.

Our group is comparable to other early postmenopausal study cohorts with respect to anthropometric variables²⁷⁻³⁰, physical activity and exercise levels^{4,31}, grip strength^{32,33}, VO_{2max}^{34,35}, and other risk factors of osteoporosis³⁶. Only the dietary calcium intake of almost 1,000 mg per day was higher in our cohort compared to average values of 650-750 mg/d reported by other authors for peri- or postmenopausal women^{30,37,38}.

The overall outcome of our investigation is displayed in Table 8 that shows the stepwise regression results. There is a low ($r^2 < 0.2$)

Variable 1	Variable 2	r
Age	Upper body strength index	-.28
	Lower body strength index	-.23
Years since menopause	VO _{2max}	.20
Body height	Arm strength index	.28
	Upper body strength index	.33
	Lower body strength index	.38
	VO _{2max}	.30
Body weight	Arm strength index	.41
	Upper body strength index	.30
	Lower body strength index	.31
P/Ca intake ratio	Upper body strength index	-.19
Calcium intake	Arm strength index	-.20
	VO _{2max}	.21

Table 7. Significant ($p < 0.05$) univariate correlations between confounding factors and variables of physical activity, exercise, muscle strength, and VO_{2max}.

correlation of bone density with anthropometric variables; for the central skeleton predominantly with weight and for the forearm with age. With two exceptions no correlation of densitometric variables with any parameters describing present or earlier physical activity, exercise, muscle strength, or endurance was found. Some significant correlations for these variables were observed in the univariate correlations but they did not increase the predictability of the stepwise regressions. The two exceptions are a modest ($r^2 = 0.26$) correlation between the (present) osteogenic exercise index and QUI of the calcaneus and an even smaller contribution of the arm strength index in explaining bone mineral density of the forearm. These results clearly demonstrate that it is mandatory to correct for the influence of anthropometric variables and Ca intake when analyzing the effect of physical activities and exercise on bone density.

Age, anthropometric, gynecological, and nutritional intake parameters are known to significantly affect bone^{6,28,39-41}. In our study, body weight is a predictor of total hip BMD_a ($r^2 = 0.16$), and together with Ca intake explained about 20% of the variation of total hip BMD_a. This result is comparable to other studies in postmenopausal woman^{39,40,42} indicating that the low relationship between physical activity and fitness with bone density is not a bias of our osteopenic cohort. At the lumbar spine age and body weight explained 16.3 % of the trabecular BMD variation as measured by QCT. Age again is a significant predictor explaining 6.6% (5.8%) of the variation of total forearm (ultradistal) BMD_a. Furthermore, body weight predicted cortical BMD ($r^2 = 0.057$) and the Ca/P-Index trabecular BMD ($r^2 = 0.059$) at the spine.

Concerning our physical activity and exercise questionnaire all efforts were made to avoid subjective bias. Current exercise and exercise during the last decades was specifically assessed by questionnaire and interview. The short-term reliability of the questionnaire as assessed by a current study²⁰ was high. As stated by several authors⁴³⁻⁴⁵ reliability of long term recall of

Variable	Total r ²	Corrected r ²	p
Lumbar Spine			
Trabecular BMD (QCT)			
Weight	.107	.100	.001
Weight + age	.175	.163	.007
Cortical BMD (QCT)			
Weight	.064	.057	.004
BMD _a (DXA)			
P/Ca intake ratio	.059	.059	.004
Proximal Femur			
Total hip BMD _a (DXA)			
Weight	.168	.162	.000
Weight + Ca-intake	.210	.199	.007
Forearm			
Total Forearm BMD _a (DXA)			
Age	.073	.066	.001
Age + arm strength index	.124	.111	.005
Calcaneus QUI (QUS)			
Present Osteogenic exercise index	.274	.261	.001

Table 8. Results of the stepwise regression analysis.

exercise and physical activity was modest. Hereby recall of vigorous activity was more accurate than for less intensive activities. In our study physical activity levels summarized as activity intensity and weight-bearing intensity indices had no effect on BMD at all. Similar results were reported in other studies in which also the influence of physical activity on BMD was non-significant after adjusting for confounding variables^{6,40,46}. Univariate correlations and regressions result in postmenopausal women are reported in a large number of studies^{4,13,27,41,47-55} but the interpretation of their results is very difficult. This is obvious by comparing the data of Table 5 and 8.

Does an increase of physical stimulus by non-athletic exercise have a larger effect on bone than daily activity levels alone? This question can be answered by relating amount, intensity, and impact of exercise to bone density or by relating primary target parameters of exercise such as muscle strength or endurance to bone density. In Figure 1 this corresponds to the two paths linking exercise with bone. For the direct path typically data from questionnaires are used. For the second path, which has been more frequently pursued in the published literature, measurements of strength and endurance are used.

We followed both avenues. For the direct path we merged the information from the questionnaires into the exercise and the osteogenic exercise indices as described above. After the stepwise regression analysis no significant relations remained between the EI and variables of bone densitometry at any skeletal site (spine, femur, forearm, calcaneus) and

any time period (menarche, adolescence, 3rd, 4th, and 5th life decades, and immediate pre-study) analyzed. Also there were no relations with bone markers. For the osteogenic exercise index a moderate relation ($r^2 = 0.27$) with QUI of the calcaneus was all that remained significant.

Contrary to our results, some authors reported significant effects of current^{4,41,56} or previous⁵⁷⁻⁵⁹ exercise on BMD, even after adjusting for relevant confounding factors. The discrepancy with our results may be explained by a number of reasons: 1. Women with an athletic history during the last 2 decades were excluded from our study. 2. In our cohort the proportion of competitive exercisers during childhood and adolescence was low (< 5%). 3. The average osteogenic impact factor of the exercises carried out in our cohort was below 1, which is obvious by comparing the EI and OI in Table 3. Indeed 65% of our cohort preferred sports with no (swimming, cycling) or little (walking, bowling) osteogenic impact.

Our study results are similar for the second, the indirect path for which we analyzed the impact of strength and endurance on bone. After the stepwise regression only the relation between the arm strength index and areal bone density of the forearm remained significant. These results are supported by investigations^{6,8,11,40,49,60} in which the significance of univariate relationships was also drastically reduced after adjusting for anthropometrical variables. Thus, in particular at weight-bearing sites such as the lumbar spine and the proximal femur, the negligence of body weight may drastically overemphasize the importance of muscle strength for bone density.

Some authors reported significant relationships between strength and/or VO_{2max} and bone parameters in postmenopausal women even after adjusting for confounding factors^{8-11,13,49,60,61} but the adjusted regression or correlation coefficients were almost negligible ($r^2 < 0.1$). Some of these studies actually showed significant correlations between muscle strength at one skeletal site and BMD at another site^{9,61}. This indicates hidden confounding factors because the mechanical impact of physical activity or exercise is predominantly site-specific⁶².

A strength of our study is the large set of parameters assessed for bone densitometry, physical activity, exercise, anthropometry, dietary intake, and other risk factors of osteoporosis. This allowed a detailed investigation of the impact of daily physical activity and non-athletic exercise on bone density in early postmenopausal women. A limitation of our study is the fact that all women were osteopenic ($-1 > DXA$ t-Score > -2.5 SD) at the hip or spine. Thus the range of BMD values in our cohort is narrower than in the total population of this age range. For the total hip the standard deviation (SD) of BMD_a in our population was 0.07 g/cm^2 compared to 0.12 g/cm^2 in the NHANES reference population, for the spine (L1-L4) the SD for BMD_a in our population was 0.09 g/cm^2 compared to 0.11 g/cm^2 in the reference population of our scanner. For trabecular BMD as measured by QCT our SD was 18.9 g/cm^3 compared to 27.9 g/cm^3 in a QCT reference population. 70% of the subjects qualified for the EFOPS study because they were osteopenic at the spine, the other because they were osteopenic at the hip as measured by DXA.

Thus in our study the BMD variation at the spine and hip was slightly smaller than in a normal population but still covered a fairly large BMD range extending well into the normal and osteoporotic domains. Therefore it seems adequate to generalize our results beyond the early postmenopausal osteopenic cohort. Of course a scientific validation of this claim is necessary, in particular in the very old and frail population.

Conclusion

The isolated effect of habitual physical activity, non-athletic low impact exercise, and muscle strength on bone parameters is rather low in (early) postmenopausal women. Even in most other studies demonstrating significant interactions, the amount of variation of bone parameters explained by physical activity, exercise or strength is barely relevant at least after adjusting for confounding factors. As a consequence an increase in the amount of habitual activity or low impact unspecific exercise may be not effective maintaining bone during and after menopause. Instead specific exercise programs are required for postmenopausal women to reduce the osteoporotic fracture risk.

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