Association between muscle force and power with different pQCT and DXA-derived parameters in middle-aged adults

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ABSTRACT

Jumping mechanography (JM) and peripheral Quantitative Computed Tomography (pQCT) have recently gained interest as powerful techniques for the assessment of muscle function and bone geometry. These techniques constitute useful tools for the investigation of the muscle-bone relationship. The aim of this study was to evaluate the association between JM-derived muscle force and power with different pQCT- and DXA-derived parameters. Data was obtained from 568 participants (mean age: 49.8±4.99, 52% female) from a population-based cohort with available data for cross-sectional analysis. Maximum muscle force and power was assessed using single 2-legged jump. pQCT scans were performed at 4% and 66% of the tibial length, measuring bone geometry parameters such as cortical and trabecular bone density, area and circumference. Next, dual-energy X-ray absorptiometry (DXA) was performed and areal bone mineral density (aBMD), lean mass and fat mass were derived. All variables were standardized prior linear regression analyses with standardized β-coefficients presented; corrected for age, sex and weight. Our results showed strong positive association between maximum force and trabecular density at 4% (β: 0.174; 95% CI: 0.033 to 0.315), cortical area (β: 0.192; 95% CI: 0.088 to 0.295) and thickness (β: 0.077; 95% CI:0 .047 to 0.306) at 66%, but not with cortical density at 66% (β: 0.006; 95% CI: -0.127 to 0.139), endosteal circumference (β: -0.022; 95% CI: -0.159 to 0.115) and periosteal circumference (β:0.037; 95% CI: -0.085 to 0.158). Maximum power followed the same trend, and was also associated with periosteal circumference (β: 0.153; 95% CI: 0.023 to 0.282). Finally, muscle force and power were also associated with all DXA-derived bone and body composition parameters. In conclusion, maximum force and power are associated with specific pQCT bone parameters and DXA outcomes. Therefore, they may serve as important clinical markers for musculoskeletal decline in older adults.

INTRODUCTION

Osteoporosis, characterized by loss of bone mineral density (BMD) and deterioration of bone tissue, is a major risk factor for fragility fractures. [1,2] The loss of BMD advances with age, which predisposed towards increased prevalence of osteoporosis and fragility factures in elderly people. Recognition of fracture risk and subsequent fracture prevention among the elderly might be vital for their survival as bone fractures have been associated with increased morbidity and mortality. [3-5] As the elderly population continues to grow, better screening and prevention strategies of osteoporosis and its sequels is needed.

Multiple studies have shown a positive association between muscle mass and bone mass [6-8] as well as between muscle strength and BMD. [9-11] This relationship between bone and muscle can be explained by the mechanostat theory. [12-15] The theory postulates that BMD increases as a result of mechanical load-induced strains, with peak muscle forces thought to be the main cause of strains. This allows for the bone to adapt to the body's own maximum force. For this reason, bone mass and strength increase in individuals with high peak muscle force. [16] On the other hand, low peak muscle force is associated with lower BMD. Muscle dysfunction is highly important in assessing risk of fragility fracture. Muscle weakness not only increases falling risk but also it increases chances of fracture as a result of a fall as well due to lower BMD, thus doubling the risk of future fracture. This acknowledges the importance of the muscle-bone unit as a whole in preventing fragility fractures and presents an opportunity for improvement of screening for fragility. [17]

This theory has led to further investigation of the muscle-bone unit as a possible tool in identifying low BMD individuals. Recent research has used various methods to assess muscle and bone, presenting associations between multiple combinations of muscle and bone parameters. The methods of assessing bone structure are limited to Dual X-ray Absorptiometry (DXA) and peripheral Quantitative Computed Tomography (pQCT). While Dual X-ray Absorptiometry (DXA) has traditionally been the main method in assessing BMD and diagnosing osteoporosis. [18] Where DXA is limited by its two-dimensional nature and primarily produces areal BMD, pQCT scans are three dimensional and more accurate. The pQCT yields volumetric BMD and distinguishes trabecular from cortical parameters. pQCT is a useful tool for research purposes due to its accurate and extensive results and form a good basis for comparing muscle to bone. Although correlations between DXA and pQCT have been found, the techniques seem better suited alongside each other rather than instead of each other. [18] Therefore, the interest in peripheral Quantitative Computed Tomography (pQCT) has increased as it provides more powerful means to assess the bone parameters. [20-22] On the other hand, multiple methods exist to assess muscle functioning such as, questionnaires

to determine current physical activity, pQCT examines muscle cross-sectional area (mCSA), DXA produces lean body mass and various equipment to estimate grip and leg strength and Jumping Mechanography (JM). [23-32] The latter one is used to assess peak jump power/force which, as mentioned before, are assumed to be a main cause of the strains that influence bone makeup. Therefore, a method capable of measuring peak forces is preferred in the assessment of the muscle-bone unit. Additionally, JM is safe and easy and results are easily reproduced. [33-34] This makes JM a promising method in predicting bone mass and strength.

The current method of using DXA's BMD measurements to identify individuals at risk of future fracture are inadequate as most fractures currently occur in individuals who do not have osteoporosis. [35] The combination of pQCT and JM possibly contributes to better predictions of future fracture, but current information about these methods is lacking. Large, population based descriptive data for both methods is missing as well as information about the association between JM and bone parameters, and thus about JM's possible use as a screening too, is limited as well. The aims of this study are therefore 1) to report descriptive information for both pQCT and JM from large population bases cohort and 2) to investigate the association between different pQCT DXA and JM derived parameters.

MATERIAL AND METHODS

Study Population

This present study was embedded within the Rotterdam Study, a prospective population-based cohort that started in 1990[36]. The study investigates risk factors in an ageing population in order to increase recognition of chronic diseases that are frequent among the elderly. Residents of the Ommoord district in Rotterdam in The Netherlands have been recruited for participation since 1990, when the first cohort (n=7,983) started with participants aged 55 years or older. The most recent fourth cohort (n=±4,000) started 2016 and has recruited residents aged between 40 and 55 years. Initially, participants are interviewed at home followed by extensive examination at the study center in the Ommoord district. Follow-up surveys and examination take place in cycles every 3 to 4 years. Examinations focus on imaging and collecting biomarkers, both used for further analysis. The examination procedure is conducted by dedicated research personnel. All data is collected by the research center. Anthropomorphic data are collected at baseline and updated with every round of examinations. These data include age, height, weight and sex. The medical ethics committee of the Erasmus MC (registration number MEC 02.1015) has approved the study design of the Rotterdam Study and written consent is obtained before participation.

Peripheral Quantative Computed Tomography (pQCT)

pQCT has recently been added to the Rotterdam Study's examination protocol. The pQCT scanner (XCT2000 from Stratec Medizintechnik, Pforzheim, Germany) is used to examine bone, muscle and fat characteristics in the lower leg. Scans are performed at distal (4%) and midshaft (66%) of tibia site. Tibial length is measured from inner ankle to the top of the tibia. Scan slices are 3 mm thick. Legs are fixated during scans to prevent movement. Scans are processed by software developed by the manufacturer to produce test results. Trabecular variables are derived from 4% scans, while cortical and cross-sectional area measurements are derived from 66% scans. Density is measured as volume BMD (vBMD). Endosteal and periosteal circumference as well as cortical thickness have been calculated using the average radius of the inner and outer perimeter of the cortical bone. The inner (r) and outer (R) radius was calculated using the formulas:

$$R = \sqrt{((\text{Total bone area})/\pi)}$$

$$r = \sqrt{(((\text{Total bone area} - \text{cortical bone area}))/\pi)}$$

The cortical thickness is the difference between the inner and outer radius. The inner radius was used to calculate the endosteal circumference and the outer radius for the periosteal circumference using the formula:

$$\text{Circumference} = 2 * \text{radius} * \pi$$

To prevent processing errors and inaccurate scans, each scan was visually inspected. Scans with moderate to severe movements were excluded and processing errors were corrected manually where possible. Reported pQCT outcomes are total bone area at 4% (TotA4) and 66% (TotA66), cortical bone area (CrtA), Muscle Cross-Sectional Area (MCSA) and Fat Cross-Sectional Area (FCSA) in mm^2. Endosteal circumference (EndoC), periosteal circumference (PeriC) and Cortical Thickness (CrtTh) are reported in mm. Cortical bone Density (CrtDen) and Trabecular Density (TrbDen) are reported in mg/ccm and Stress-Strain Index (SSI) is reported in mm^3.

Jumping Mechanography (Ground force reaction platform)

A Leonardo Mechanograph Ground Reaction Force Platform (GRFP) was used to test muscle strength through measurements of muscle force and power. The participant is asked to perform a single 2-legged jump (s2LJ), this type of jump is most suitable for determining maximum power output. The participant is instructed to jump as high as possible using both legs and to land upon both forefeet and stand still on both feet for three seconds, completing the single 2-legged jump. Counter movement (knee bending) prior to the jump was allowed to increase jump height. Because of a small

learning curve in performing the jump, the jump is repeated until 3 proper jumps are performed. The highest jump of each participant was used in our analysis. Test outcomes include jump height in cm, maximum force (MaxF) in kilonewtons, maximum power (MaxP) in kilowatts and relative force and power (newtons/watts per kilogram bodyweight).

Dual X-ray Absorptiometry (DXA)

DXA was used to determine areal BMD, lean mass and fat mass. BMD measurements of the femoral neck, the whole femur and the whole body were available. Total lean and fat mass measurements were available as well as lean mass of the arms and legs. DXA outcomes are total lean mass (TLM), total fat mass (FM), arms lean mass (ALM) and legs lean mass (LLM) in kg as well as total BMD (TBMD), spine BMD (SBMD), Femur BMD (FBMD) and Femoral Neck BMD (FNBMD) in g/cm^2.

STATISTICAL METHODS

Before the start of statistical analysis, scatterplots and histograms are checked for distribution and to identify outliers. Outliers are checked for test quality, tests with poor quality are excluded. Descriptives are reported as means with standard deviation for the main outcomes of pQCT, JM and DXA for both male and female in addition to the total population. Partial pearson correlation tests adjusted for age and sex were performed between all major outcomes and correlation coefficients are reported. Multiple linear regression models were used to test for associations between maximum force and power and bone parameters as measured by pQCT and DXA. Model 1 was adjusted for age and sex while in model 2 weight was additionally added. All predictors and outcomes were standardized before regression analysis, thus standardized β-coefficients are presented. Analysis was performed using SPSS (version 24.0.0.1).

RESULTS

Study Population

Data for all three methods was available for 568 participants. The mean age of the study population was 49.48 (SD 4.77) years, 50.8% (n=289) being female. Average weight was 70.79 kg (SD 12.21) and height 167.53 cm (SD 6.57). Study descriptives are presented in Table 1.

Table 1 | Descriptives characteristics of the study population stratified by sex

	Total (n=568)		Male (n=279)		Female (n=289)	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Demographics						
Age (years)	49.8	5.0	50.2	5.2	49.5	4.8
Weight (kg)	79.1	15.5	87.8	13.3	70.8	12.6
Height (cm)	174.2	9.6	181.2	7.0	167.5	6.5
BMI (kg/m^2)	25.9	3.9	26.7	3.6	25.2	4.1
Jumping Mechanography						
Jump height (cm)	33.6	8.0	38.4	6.9	29.0	6.0
MaxF (kN)	1.58	0.36	1.79	0.32	1.37	0.27
RelF (N/kg)	19.9	2.7	20.4	2.5	19.4	2.8
MaxP(kW)	2.73	0.87	3.40	0.69	2.09	0.42
RelP (W/kg)	34.2	7.5	38.8	6.4	29.7	5.5
pQCT						
TotArea4 (mm^2)	1,078	172	1,187	142	973	126
TrbDen4 (mg/ccm)	227	40	242	40	213	34
TotArea66 (mm^2)	975	220	1,101	191	854	173
CrtArea66 (mm^2)	292	66	335	55	251	47
CrtDen66 (mg/mm^3)	1,066	40	1,059	35	1,073	44
CrtTh (mm)	2.9	0.7	3.2	0.6	2.7	0.6
EndoC (mm)	92	14	97	12	86	13
PeriC (mm)	110	12	117	10	103	10
MuscA (mm^2)	6,045	1,224	6,844	975	5,273	904
FatA (mm^2)	3,295	1,358	2,565	892	3,999	1,359
SSI (mm^3)	3,305	858	3888	714	2742	558
DXA						
LM (kg)	49.7	10.4	58.4	6.6	41.3	5.1
FM (kg)	25.8	8.6	25.8	8.5	25.9	8.8
ALM (kg)	64.5	2.0	8.2	1.2	4.8	0.8
LLM (kg)	17.5	3.9	20.6	2.7	14.5	2.2
TBMD (g/cm^2)	1.17	0.12	1.22	0.11	1.13	0.11
SBMD (g/cm^2)	1.01	0.14	1.04	0.13	0.97	0.13
FNBMD (g/cm^2)	0.96	0.13	0.99	0.13	0.93	0.13

Correlation

Correlation between different pQCT, JM and DXA parameters are shown in **Figure 1.** Maximum jumping force showed strong correlation with multiple bone parameters, most notably cortical area (0.39, $p < 0.001$), total BMD (0.40, $p < 0.001$) and cortical thickness (0.26, $p < 0.001$).

Maximum jumping power was also most notably correlated with cortical area (0.36, $p < 0.001$), total BMD (0.37, $p < 0.001$) and cortical thickness (0.23, $p < 0.001$). Interestingly, total lean mass correlated better with most bone parameters than maximum force and power **Figure 1**. Force and power correlated strongly with other muscle parameters such as muscle cross-sectional area, total lean mass, and lean mass of the legs. pQCT and DXA bone measurements correlate strongly as well, as we see in correlations between trabecular density, cortical area and cortical thickness, and total BMD. The different muscle measurements of pQCT and DXA correlate strongly as well, as we see strong correlations between muscle CSA and total lean mass and muscle CSA and lean mass of the legs.

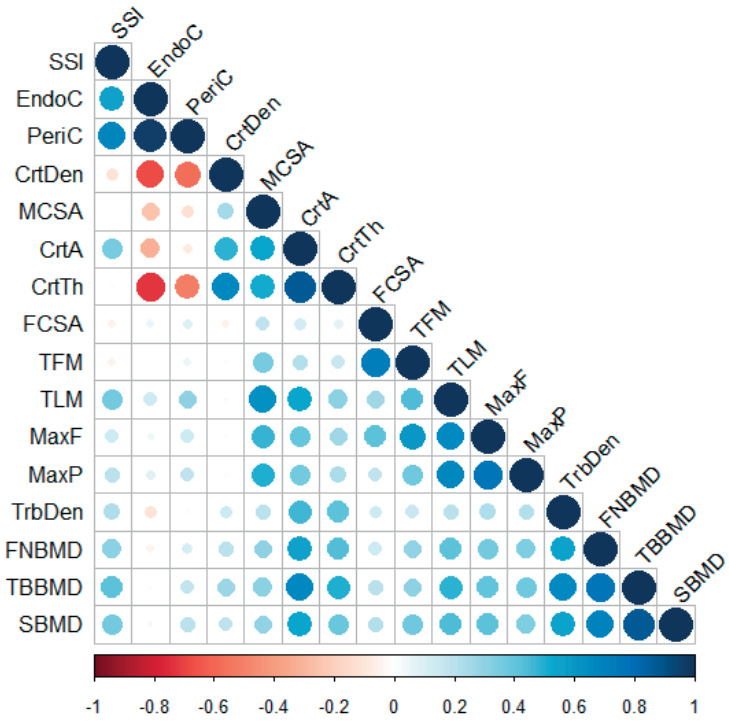

Figure 1 | Genetic correlation between variety of pQCT and DXA parameters. SSI= strength-strain index; endoC= endosteal circumference; PeriC= periosteal circumference; CrtDen= Cortical density; crtA=Cortical area; CrtTh= cortical thickness; trbDen=trabecular density; MCSA = muscle cross sectional area ; FCSA= fat cross sectional area; MaxF= maximal force ; maxP= maximal power; FNBMD=Femoral neck bone mineral density; LSBMD= Lumbar Spine bone mineral density; TBBMD= total body bone mineral density; TFM= total fat mass; TLM= total lean mass.

Table 2 | Association between pQCT and DXA parameters with muscle force and power

N=568	Maximum Force		Maximum Force		Maximum Power		Maximum Power	
	Model 1		Model 2		Model 1		Model 2	
	Beta (95%CI)	P	Beta (95%CI)	P	Beta (95%CI)	P	Beta (95%CI)	P
pQCT parameters								
Trabecular density 4%	0.264 (0.167, 0.361)	< .001	0.174 (0.033, 0.315)	0.012	0.319 (0.196, 0.443)	< .001	0.196 (0.045, 0.347)	0.011
Cortical Area 66%	0.363 (0.291, 0.435)	< .001	0.192 (0.088, 0.295)	< .001	0.438 (0.345, 0.530)	< .001	0.240 (0.129, 0.350)	<0.001
Cortical density 66%	0.005 (-0.086,0.096)	0.914	0.006 (-0.127, 0.139)	0.926	-0.022 (-0.137, 0.093)	0.707	-0.039 (-0.182, 0.104)	0.591
Cortical thickness	0.296 (0.206, 0.385)	< 0.001	0.077 (0.047, 0.306)	0.008	0.328 (0.214, 0.443)	< .001	0.169 (0.029, 0.308)	0.018
Endosteal circumference	0.043 (-0.051,0.137)	0.369	-0.022 (-0.159, 0.115)	0.753	0.110 (-0.008, 0.229)	0.069	0.085 (-0.062, 0.232)	0.259
Periosteal circumference	0.150 (0.067, 0.233)	<0.001	0.037 (-0.085, 0.158)	0.553	0.237 (0.132, 0.342)	< .001	0.153 (0.023, 0.282)	0.021
Muscle CSA	0.471 (0.399, 0.543)	<0.001	0.179 (0.079, 0.280)	<0.001	0.638 (0.547, 0.728)	< .001	0.369 (0.265, 0.474)	<0.001
Fat CSA	0.394 (0.320, 0.467)	<0.001	-0.080 (-0.172, 0.013)	0.091	0.220 (0.120, 0.321)	< .001	-0.326 (-0.422, -0.231	<0.001
SSIp	0.138 (0.064, 0.213)	<0.001	0.083 (-0.023, 0.192)	0.136	0.225 (0.131, 0.319)	< .001	0.180 (0.064, 0.296)	<0.001
DXA parameters								
Total Lean Mass	0.454 (0.410, 0.498)	<0.001	0.153 (0.082, 0.188)	<0.001	0.598 (0.543, 0.652)	< .001	0.305 (253, 0.357)	<0.001
Total Fat	0.617 (0.549, 0.685)	<0.001	-0.115 (-0.167, -0.062)	<0.001	0.482 (0.382, 0.583)	< .001	-0.295 (-0.346, -0.243)	<0.001
Arms Lean Mass	0.345 (0.297, 0.393)	<0.001	0.109 (0.043, 0.174)	<0.001	0.497 (0.439, 0.555)	< .001	0.300 (0.234, 0.336)	<0.001
Legs Lean Mass	0.564 (0.514, 0.613)	<0.001	0.190 (0.132, 0.248)	<0.001	0.745 (0.684, 0.805)	< .001	0.401 (0.346, 0.456)	<0.001
Total BMD	0.411 (0.333, 0.489)	<0.001	0.169 (0.058, 0.280)	0.003	0.485 (0.384, 0.585)	< .001	0.221 (0.103, 0.340)	<0.001
Right Femur BMD	0.317 (0.246, 0.388)	<0.001	0.133 (0.031, 0.234)	0.01	0.405 (0.315, 0.495)	< .001	0.221 (0.113, 0.329)	<0.001
Spine BMD	0.448 (0.364, 0.531)	<0.001	0.147 (0.029, 0.264)	0.014	0.459 (0.350, 0.569)	< .001	0.111 (-0.015, 0.238)	0.084
Right femoral neck BMD	0.392 (0.307,0 .477)	<0.001	0.164 (0.042, 0.285)	0.009	0.461 (0.351, 0.570)	< .001	0.215 (0.084, 0.345)	0.001

Model 1 is adjusted for age and sex

Model 2 is adjusted for age, sex, and weight

Beta-coefficients represent changes in standard deviation for 1 standard deviation increase in maximum force (1SD = 0.36 kN) and maximum power (1SD = 0.87)

Associations of Muscle and Bone

Maximum force and power both showed strong positive associations with trabecular density (force: β = 0.264, p < .001; power: β = 0.319, p < .001), cortical area (force: β = 0.363, p < .001; power: β = 0.438, p < .001), cortical thickness (force: β = 0.296, p < .001; power: β = 0.328, p < .001), periosteal circumference (force: β = 0.150, p < .001; power: β = 0.237, p < .001) and SSI (force: β = 0.138, p < .001; force: β = 0.225, p < .001), but not with cortical density (force: β = 0.005, p = 0.914; force: β = -0.022, p = 0.707) and endosteal circumference (force: β = 0.043, p = .369; power: β = 0.110, p = 0.069), adjusted for age and sex. Various BMD measurements from DXA showed similar associations with both maximum force and power, with slightly larger effects (**Table 2**). Most significant associations remained after added adjustment for weight, although less strong. Changes in significance were observed between maximum force and periosteal circumference (β = 0.037, p = 0.553), maximum force and SSI (β = 0.083, p = 0.136) and maximum power and BMD of the spine (β = 0.111, p = 0.084).

DISCUSSION

Jumping mechanography, pQCT and DXA were used to determine associations between different muscle and bone parameters. pQCT and DXA bone parameters showed similar associations with both power and force, in addition to strong correlations between all parameters. Trabecular density, cortical area and cortical thickness were all strongly associated with maximum force and power. This points to jumping mechanography as a possible predictor of bone health and geometry. Surprisingly, differences in muscle function were not able to predict changes in cortical density. Changes in periosteal circumferences were best explained by changes in power, in contrast to changes in force. The combination endosteal and periosteal circumference, reflected in cortical thickness, was well predicted by both force and power.

A handful of studies have taken a similar approach to investigate the muscle bone relationship. Our results are consistent with previous studies comparing pQCT with jumping mechanography. Similar positive associations between power/force and cortical area have been found in a group of middle-aged adults containing high bone mass individuals as well as control. [23] In a group of 25 to 45-year-old men, power and force have been shown to associate positively with cortical bone, cortical thickness and SSI as well. [25] Furthermore, in a population of 8 to 82-year olds, Anliker et al. [16] found a positive association between maximum force during a m1LH test and volumetric Bone Mineral Content (vBMC) at the multiple sites. Even though this study is in line with our findings, their use of vBMC as opposed to vBMD restricts direct comparisons. Verroken et al. [25] found lean mass of the legs to be the best predictor

of bone characteristics when compared to force, power, MCSA and quadriceps torque. Although the study mentions that only force, not lean mass of the legs, is associated with cortical bone area over total bone area, suggesting force as the best predictor of explicitly cortical bone parameters. Using structural measurements as a predictor of bone characteristics was outside the scope of our study as we decided to focus on the functional muscle parameters provided by JM. Additionally, Rantalainen et al. has found positive associations between maximum jumping force during 2-legged countermovement jump and SSI in pre- and postmenopausal women. [37] These results are very similar to ours in a group of comparable age. In a group of pre-pubertal females and males SSI has been shown to correlate most strongly with power, and force to a lesser degree. [38] Although comparing this with our study might be of limited value due to the enormous difference in age. Whether force or power is more useful remains unclear as sometimes power, [23,38] sometimes force [25] is the better predictor of bone parameters.

In the current study, power was a slightly better predictor for most pQCT and DXA variables, although not statically significant. This difference might originate in our use of a suboptimal test to assess maximum force. As mentioned before, the m1LH test is more suitable for maximum force while a s2LJ is more suitable of assessing maximum power. The s2LJ might underestimate maximum force as discussed by Anliker et al. [16] This underestimation might help explain the difference between this study and other studies.

Moreover, we found that both cortical parameters as well as trabecular density are predicted by force. As cortical geometry seems to be the most important predictor of future fracture, [39-41] pQCT derived cortical thickness and SSI may be useful measurements in identifying at risk individuals. On the other hand, metabolic activity in bone is the highest in the trabecular bone. vBMD measurements might subsequently be used to identify the first signs of decline in bone health. Whether changes in cortical geometry really trail trabecular changes cannot be researched in a cross-sectional design study. Repeated measurements and an increase of sample size in the current cohort could possibly be used for these purposes.

Even though peak muscle forces are believed to be the main force behind changes in bone geometry, the effect of weight might still account for some portion of the changes by putting a load on weight bearing bones.[42-45] As we see in the differences before and after weight adjustment, weight seems to account for a non-negligible portion of the changes in bone geometry. During regression analysis (not shown here) of normal and high BMI groups, we found the jumping mechanograph to predict bone health less well in the high BMI group, as opposed to the normal BMI group. The lower coefficients in the high BMI group expose weight as a mediating factor when predicting bone health with a jumping mechanograph. A rational explanation would be that

with the increases in weight, the weight takes an increasing role in bone geometry due to increases in gravitational loading as opposed to muscle loading. While muscle contractions are believed to be the main cause of changes in bone, weight seems to account for a bigger part of the changes in high BMI individuals as opposed to normal BMI individuals. The importance of weight on bone geometry might be more significant in high BMI individuals, but more research needs to be done to confirm this.

To our knowledge, the present study provides the largest population to investigate the bone-muscle relationship using both pQCT and jumping mechanography. In addition, our population contains both male and female participants in contrast to most other studies. Another advantage of our study is the use of multiple methods of assessing bone characteristics. pQCT is a very accurate way to investigate bone and show different aspects, DXA on the other hand has long been a household method of investigating bone. We reported both with and without weight adjustment to be complete and because most comparable studies did adjust for weight.

We do recognize some limitations in the current study as well. First of all, menopause status has not been used for women. As the menopause has a substantial effect on bone geometry, the absence of information in this regard limits drawing of conclusions. Secondly, we used a single 2-legged jump to assess maximum force. As mentioned before, this type of jump is most suitable in the assessment of maximum power. A multiple 1-legged hopping test would be better suited to assess maximum force. Thirdly, our study population can be considered too young to truly investigate the decline of bone health in relation to muscle function as our population is in the beginning stages of the decline. Still, this study does show the association between the two with less focus on the pathological process. We are missing physical activity so this can be limitation also given it an important predictor of both power and bone.

These findings help us understand the possible mechanisms of changes in bone geometry and might help in the early recognition of bone deterioration. Not only that, the strong link between bone and muscle also provides a possible solution to prevent further decline in both health by encouraging regular exercise with a focus on muscle strength.

In conclusion, our study has demonstrated the ability of the jumping mechanography in explaining variation in bone parameters as measured by pQCT and DXA. In combination with other studies, this solidifies jumping mechanography as a good, low burden tool in the assessment of bone health. In addition, pQCT has been demonstrated as a valuable alternative to DXA. Even though jumping mechanography predicts both pQCT and DXA approximately equally well, the ability of pQCT to deliver more in-depth information about bone geometry is highly valuable in the investigation of underlying mechanisms.

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