MUSCLE POWER AND FORCE MAY INFLUENCE CORTICAL BONE STRENGTH VIA DISTINCT MECHANISMS: FINDINGS FROM A CROSS-SECTIONAL STUDY OF HIGH BONE MASS CASES AND CONTROLS

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Background:

•The mechanostat theory states that the skeleton adapts to loads imposed upon it, including muscle forces[1].
•We aimed to investigate relationships between muscle function, assessed by jumping mechanography, and bone parameters in an adult population including individuals with high bone mass (HBM).
•In particular we wished to determine i) whether peak jumping power and force are related to bone strength measured by mid-tibial pQCT ii) whether these relationships are stronger for power than force and iii) whether peak power and force have distinct relationships with cortical bone size, thickness or density.

Methods:

•Recruitment was from 3 UK sites within the HBM study[2]. Index cases with HBM were identified by screening DXA databases; cases had a summed total hip and L1 Z-score of at least +3.2. Controls comprised unaffected relatives and spouses.
•In the present study, cases and unaffected family controls were pooled for analysis.
•Peak ground reaction force and peak power, during a multiple one-leg jump and single two-leg jump respectively, were recorded using a Leonardo Mechanography Ground Reaction Force platform. Hip BMD was assessed by DXA scanning.
•A subgroup also underwent mid-tibial pQCT (Stratec XCT2000L).
•Linear regression analysis adjusted for age, gender and height (model 1) and age, gender, height and weight (model 2). Force and power were log transformed.

Table 1: Descriptive characteristics of overall study population

	Mean	SD
Age (years)	57.03	13.66
Weight (kg)	84.76	18.17
Height (m)	169.57	9.53
BMI (kg/m2)	29.43	5.67
2 leg max jump power (kW)	2.49	0.96
Relative 2 leg max jump power (W/kg)	29.29	8.92
2 leg max jump height (m) (n=188)	0.27	0.16
2 leg max jump velocity (m/s)	1.81	0.40
1 leg max jump force (kN) (N=182)	2.04	0.50
Relative 1 leg max jump force (N/kg) (N=182)	24.50	4.83
	n	%
Females	119	62.96
Postmenopausal	82	68.91

N=189 except where stated

Table 2: Regression analysis of logged maximum 2-leg jump power *vs* bone outcomes

Outcome	Model	β coefficient	95% CI	p value
Hip BMD (g/cm²)	1	0.48	(0.28,0.67)	<0.01
	2	0.29	(0.07,0.51)	0.01
Cortical area (mm²)	1	0.38	(0.23,0.53)	<0.01
	2	0.29	(0.11,0.46)	<0.01
EC_{PC} (mm)[1]	1	-0.32	(-0.46,-0.18)	<0.01
	2	-0.24	(-0.40,-0.08)	<0.01
Total bone area (mm²)	1	0.18	(0.01,0.36)	0.04
	2	0.10	(-0.10,0.30)	0.33
Ratio cortical:total bone area (%)	1	0.29	(0.03,0.56)	0.03
	2	0.26	(-0.06,0.57)	0.11
Tibial SSI (mm³)	1	0.34	(0.18,0.49)	<0.01
	2	0.26	(0.09,0.44)	<0.01

All outcome and exposure variables standardised. Standardised β coefficient represents SD change in outcome per SD change in exposure (log 2-leg jump power). Model 1= adjusted for age, gender and height. Model 2=adjusted for age, gender, height and weight (as quadratic term). N=189 (hip BMD), n=113 (all other outcomes). [1]EC_{PC} = endosteal circumference adjusted for periosteal circumference.

Results:

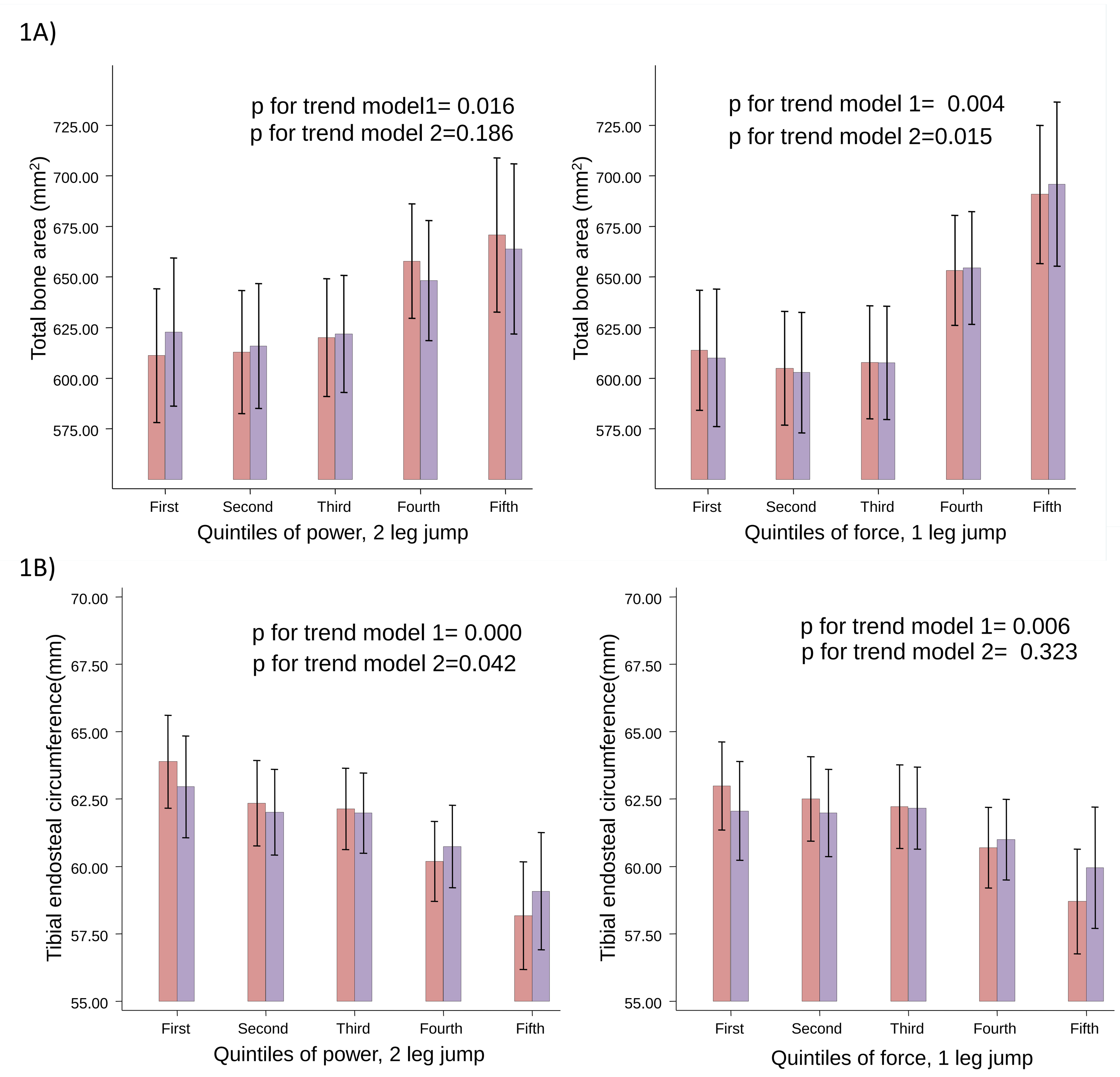
•189 participants completed the 2-leg jump (comprising 113 HBM cases and 76 controls) and 182 the 1-leg jump. Descriptive characteristics are shown in table 1.
•113 participants had both force and pQCT data; compared with those who did not undergo pQCT, this group had a lower height, weight, jump force and jump power (explained by a greater proportion of females). Age did not differ according to whether a subject had undergone pQCT.
•After adjustment for age, gender, height and weight, jump power was significantly associated with hip BMD (table 2, model 2) but jump force was not (table 3, model 2).
•In the participants with both force and pQCT data, both power (table 2, model 2) and force (table 3, model 2) were associated with tibial SSI.
•However, power and force differed in their associations with the other pQCT outcomes. Power was negatively associated with endosteal circumference (adjusted for periosteal circumference, EC_{PC}); no association was seen with total bone area (table 2, model 2). Force was positively associated with total bone area but was not associated with EC_{PC} (table 3, model 2).
•Further analyses were carried out sub-dividing muscle power and force into quintiles (figure 1).
•After adjusting for age, gender, height and weight (model 2), quintile of jump power was not associated with total bone area but was inversely associated with $EC_{PC.}$
•The opposite was true for quintile of jump force which was positively associated with total bone area but not related to $EC_{PC.}$

Table 3: Regression analysis of logged maximum 1-leg jump force *vs* bone outcomes

Outcome	Model	β coefficient	95% CI	p value
Hip BMD (g/cm²)	1	0.21	(0.04,0.38)	0.02
	2	0.03	(-0.16,0.22)	0.74
Cortical area (mm²)	1	0.26	(0.12,0.40)	<0.01
	2	0.17	(-0.01,0.35)	0.06
EC_{PC} (mm)[1]	1	-0.20	(-0.33,-0.07)	0.00
	2	-0.10	(-0.26,0.07)	0.24
Total bone area (mm²)	1	0.21	(0.06,0.36)	0.01
	2	0.22	(0.03,0.42)	0.02
Ratio cortical:total bone area (%)	1	0.09	(-0.15,0.32)	0.47
	2	-0.07	(-0.38,0.23)	0.63
Tibial SSI (mm³)	1	0.26	(0.12,0.39)	<0.01
	2	0.24	(0.07,0.42)	0.01

All outcome and exposure variables standardised. Standardised β coefficient represents SD change in outcome per SD change in exposure (log 1-leg jump force). Model 1= adjusted for age, gender and height. Model 2=adjusted for age, gender, height and weight. N=182 (hip BMD), n=113 (all other outcomes). [1]EC_{PC} = endosteal circumference adjusted for periosteal circumference.

Figure 1: Quintiles of jump power / force plotted against pQCT outcomes



Relationship between quintiles of jump power and force and pQCT outcomes. 1A) Jump power / force *vs*. total bone area 1B) Jump power / force *vs*. endosteal circumference (EC_{PC}). Model 1 (red)=adjusted for age, gender and height, model 2 (purple)=adjusted for age, gender, height and weight.

Conclusions:

•We have studied the relationship between peak force and power, measured by jumping mechanography, and a number of bone outcomes in an adult population comprising HBM cases and unaffected family controls.
•Both ground reaction force and muscle power were associated with bone strength (SSI), as measured by pQCT
•Our pQCT findings suggest that force and power may modify cortical bone strength through distinct mechanisms, peak force being associated with increased periosteal circumference and peak power with reduced endosteal expansion.
•Further studies are required to understand the basis for these differences.

References: 1. Frost, H.M., *Bone "mass" and the "mechanostat": a proposal.* Anat Rec, 1987. **219**(1): p. 1-9. 2. Gregson, C.L., et al., *'Sink or swim': an evaluation of the clinical characteristics of individuals with high bone mass.* Osteoporos Int, 2012. **23**(2): p. 643-54.

The authors declare no conflict of interests

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