Opposing effects of childhood obesity on radial and tibial bone microstructure

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Introduction

The over-representation of overweight and obese children in fracture studies suggests that excess fat in children may alter skeletal microarchitecture or the biomechanical properties of bone. High resolution peripheral quantitative computed tomography (HR-pQCT, isotropic voxel size 82mm) provides the resolution required to accurately determine 3-dimensional *in-vivo* bone microstructure at partially loaded (distal radius) and loaded (distal tibia) skeletal sites at a low radiation dose (<3μSv per scan). Microfinite element analysis (mFE) of HR-pQCT images provides insight into the biomechanical properties of these skeletal sites

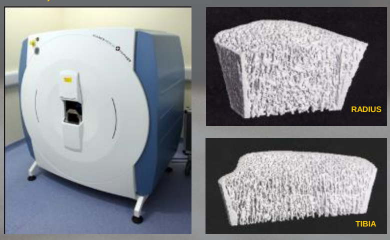
Aim

To determine whether differences in cortical and trabecular bone microarchitecture and the biomechanical properties of the distal radius and tibia exist between obese and lean children matched for pubertal age and gender

Methods

We recruited 18 lean children (BMI <91st percentile) and 18 obese children (BMI>98th percentile) matched for pubertal stage, gender and ethnicity. Height, weight and BMI SD score was calculated using the UK reference values. HR-pQCT image acquisition and analysis of the non-dominant distal radius and tibia were performed using the standard built-in software (XtremeCT, version 6.0, Scanco Medical AG, Brüttisellen, Switzerland – figure 1)

Figure 1: HRpQCT scanner and image of cortical and trabecular microstructure of the distal radius and tibia (resolution 82μm, 110 slices = 9.02 mm)



HR-pQCT measurements included total density (D_{tot}, mg/cm^3), trabecular density (D_{trab}, mg/cm^3 mg/cm^3), cortical density (D_{cort}, mg/cm^3) and microstructural properties including trabecular number (Tb.N, 1/mm), trabecular thickness (Tb.Th, mm), trabecular separation (Tb.Sp, mm), bone volume fraction (BV/TV, %), cortical thickness (Ct.Th, mm) cortical porosity (Ct.Po, %) and mean cortical pore diameter (Ct.Po.Dm, mm)

Microfinite element analysis

Measures of bone strength, for the distal radius and tibia, were determined by micro finite element analysis - bone stiffness (kilonewtons per millimeter), estimated ultimate failure load (kilonewtons), the ratio of the load taken by the trabecular bone in relation to the total load at the distal end (percent) and proximal end (percent), average von Mises stresses in the trabecular (megapascals) and the cortical (megapascals) bone. Bone strength Index (BSI) was calculated using total density (D_{tot}) and total area ($Area_{tot}$): [BSI(mg^2/mm^4) = D_{tot}^2 x $Area_{tot}$]

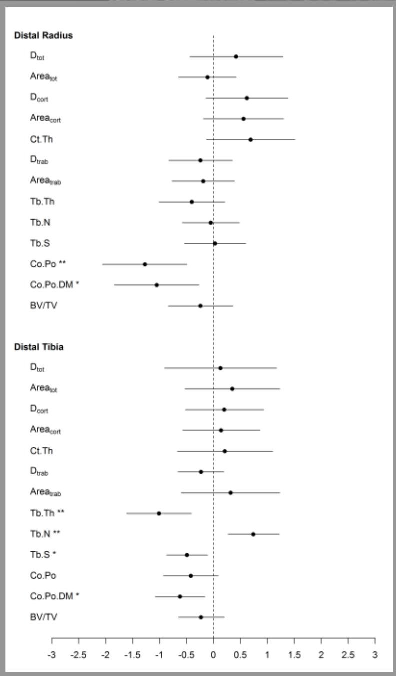
Results

Anthropometric comparison of the groups is detailed in table 1

Table 1: Comparison of anthropometry in lean and obese groups and mean difference (95% confidence interval) matched by gender and pubertal stage. Significance is reached at p≤0.05

	Lean (n = 18) Mean (SD)	Obese (n = 18) Mean (SD)	Mean Difference (95% CI)	P-Value
Age (years)	12.9 (2.0)	12.6 (1.9)	-0.3 (-0.8, 0.2)	0.229
Height SDS	1.12 (1.34)	0.96 (1.41)	-0.16 (-0.96, 0.63)	0.667
Weight SDS	0.55 (0.92)	3.19 (0.87)	2.64 (2.20, 2.99)	<0.001
BMI SDS	0.08 (0.87)	3.14 (0.68)	3.06 (2.68, 3.44)	<0.001
Lean mass (grams)	33129 (9084)	43115 (11166)	9986 (6404, 13568)	<0.001
Subtotal fat mass (grams)	11935 (5133)	38706 (14447)	26771 (20474, 33068)	<0.001
Subtotal percent-age fat mass (%)	26.3 (7.5)	46.6 (5.3)	20.3 (16.5, 24.1)	<0.001
Truncal fat mass (grams)	4767 (2307)	17538 (7441)	12772 (9627, 15916)	<0.001
Truncal percentage fat mass (%)	21.4 (6.6)	43.2 (6.0)	21.8 (18.5, 25.2)	<0.001

Figure 2: Difference in mean and standard deviation score for cortical and trabecular bone microstructure parameters for lean and obese groups.



Results

There was a 1.27 (95% CI: 0.49 to 2.06, p=0.003) standard deviation difference in cortical porosity between groups at the distal radius and cortical pore diameter was 1.05 (95% CI: 0.27 to 1.84, p=0.011) and 0.62 (95% CI 0.16 to 1.08, p=0.012) standard deviations lower at the distal radius and tibia respectively in the obese group. In contrast, mean tibial trabecular thickness and tibial trabecular separation was 1.01 (95% CI: 0.41 to 1.61, p=0.003) standard deviations lower and tibial trabecular number was 0.74 (95% CI: 0.27 to 1.22, p=0.004) standard deviations higher in the obese group (figure 2) .There was no difference in the radial and tibial mFE measurements between the groups.

Correlation with subtotal body and truncal fat (%) and lean mass was determined for cortical and trabecular microstructure that were previously identified as being significantly different between lean and obese groups (table 2). Subtotal and truncal fat mass had the strongest association with cortical porosity and mean cortical pore diameter at the radius and trabecular thickness at the distal tibia.

Table 2:Spearman rank correlations between mass and HR-pQCT cortical and trabecular parameters at the distal radius and distal tibia. Significance is reached at p≤0.05.

	Subtotal Lean Mass		Subtotal Fat Mass %		Truncal Fat Mass %	
	r (95% CI)	P-Value	r (95% CI)	P-Value	r (95% CI)	P-Value
Distal Radius						
Co.Po	-0.34 (-0.61, -0.03)	0.046	-0.57 (-0.79, -0.23)	<0.001	-0.58 (-0.79, -0.25)	<0.001
Co.Po.DM (mm)	-0.04 (-0.36, 0.31)	0.832	-0.41 (-0.72, -0.03)	0.013	-0.41 (-0.71, -0.06)	0.010
Distal Tibia						
Tb.Th (mm)	-0.31 (-0.62, 0.11)	0.064	-0.62 (-0.84, -0.32)	<0.001	-0.60 (-0.79, -0.37)	<0.001
Tb.N (mm^{-1})	0.23 (-0.14, 0.51)	0.177	0.28 (-0.08, 0.58)	0.096	0.30 (-0.07, 0.62)	0.074
Tb.S (mm)	-0.19 (-0.51, 0.20)	0.281	-0.21 (-0.55, 0.16)	0.229	-0.22 (-0.51, 0.07)	0.189
Co.Po.DM (mm)	-0.38 (-0.68, 0.02)	0.024	-0.27 (-0.58, 0.11)	0.115	-0.28 (-0.54, 0.02)	0.103
Tb.VM	-0.09 (-0.43, 0.24)	0.623	-0.39 (-0.68, -0.03)	0.019	-0.37 (-0.66, -0.01)	0.028

Discussion

Fat mass rather than lean mass appears to have a greater influence on the alterations in radial and tibial microstructure in obese children. Despite these changes, there was no difference in the biomechanical properties of the distal radius and tibia between the groups. Bone stiffness refers to the extent to which bone resists deformation in response to an applied force; ultimate failure load relates directly to material failure. As the force imparted from body weight during a fall or twisting injury will be greater in obese children, fracture is more likely to occur due to the lack of biomechanical adaption of the radius and tibia in relation to excessive fat mass. This may in part explain why the incidence of fracture in obese children is greater.