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Original Article

Osteogenic effects of a physical activity intervention in South African black children

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Abstract

Objectives: To determine whether a weight-bearing physical activity intervention improves measures of bone density, size and strength in a pre- and early pubertal cohort of black South African children. **Methods:** Twenty two school children (9.7±1.1 years) were cluster randomised into an exercise (EX; n=12) and control (CON; n=10) group. EX children performed a weight-bearing exercise program for 20 weeks. CON children continued their regular activities. Whole body DXA and tibial peripheral QCT scans were obtained. Urine was analysed for concentrations of cross-linked N-telopeptides of Type I collagen (NTX). **Results:** Changes in 4% volumetric BMD, area and strength were greater in EX than CON. At the 38% site, change in bone area and density was greater in EX than CON. The greater change in periosteal circumference in the EX groups also resulted in a greater change in cortical thickness of the tibia compared to the CON group. NTX concentration was lower in the EX group than the CON group after the intervention. **Conclusions:** This study documents for the first time the beneficial response of trabecular and cortical bone of black children to a weight bearing exercise intervention.

Keywords: Children, DXA, pQCT, Weight-bearing Exercise, Ethnicity

Introduction

Black children and adults have greater bone mass at the femoral neck compared to white children and adults, regardless of physical activity (PA) levels and dietary calcium intake[1-4]. Currently, black African adults have the lowest fracture rates worldwide[5,6] and as such osteoporosis is thought to occur less frequently in black populations[7]. Fractures in the South African black population could however pose a significant problem on an overburdened health care system in the future, as the population continues to age and partake in less physical activity than their white counterparts[8]. In addition, findings of a recent study by Pressley et al[9], suggest that the benefits of better bone mass reported in black children, may be counter balanced through increased exposure to fracture producing injury mechanisms such as accidental trauma. Black children and adults could benefit from the introduction of approaches to increase bone strength. Nonetheless, the response to mechanical loading in a cohort of black children has not been investigated. As such it is unknown whether participation in weight-bearing exercise would offer the same benefits of better bone mass in black children as it does in white children[10-12].

Participation in weight-bearing physical activity is an effective way of increasing bone mass[13]. The best time to partake in this type of physical activity is during the years preceding puberty when bone mass accretion is greatest[14,15]. Pre- and early pubertal children who perform weight-bearing exercise on a regular basis have greater periosteal and endosteal circumferences as well greater strength at the bones of the lower limb[16,17] with significantly higher bone mineral density (BMD), bone mineral content (BMC) and bone area than children who are less active[18-20]. A limited number of cross-sectional studies in black and white pre-pubertal children have

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observed significant ethnic differences in structural bone outcomes[19,21-23]. Black children have greater density and area than white children at cortical sites[21,22]. Indices of strength are also greater in black compared to white children[19,22]. Bone health studies that have taken place in South African black children have been limited in their interpretation due to the sole reliance on dual energy x-ray absorptiometry (DXA) apart from one cross-sectional study conducted in South African 13-year old children that found no ethnic differences in cortical area but greater total area and strength in black compared to white children[23]. The use of pQCT may assist in understanding the mechanisms of bone gain related to physical activity interventions in this unique cohort. Gains in bone mass and structural changes in bone geometry result in stronger bones[24,25], which implies lower fracture risk in children and adolescents. Longitudinal studies have shown that weight bearing activities in early childhood provide sustained benefits to bone health in adolescence[26-28] and lifelong participation in physical activity is now recommended as a means of preventing osteoporotic fracture in later life[29,30].

The cortical bone of black and white children may respond differently to mechanical forces[31], yet physical activity interventions and their effects on bone health in black children have been largely overlooked. There are numerous studies that have examined the role of physical activity interventions in white and Asian children[10-12] and others that have used pQCT to assess change in bone health after a physical activity intervention[20,24,32,33], to our knowledge, none have been conducted with only black children. Therefore the main objective of this study was to determine whether a 20-week weight-bearing physical activity intervention could improve measures of appendicular bone density, size and strength in pre-pubertal black children. Secondary outcomes included DXA derived measures of site-specific areal bone mineral content (BMC) and pQCT derived tibial bone structure and strength. We hypothesised that the change in BMC would be greater in children participating in an exercise intervention program compared with children not taking part in the exercise program. We hypothesised that children participating in an exercise intervention program would show greater changes in bone density and geometry which would confer greater changes in strength compared to children not taking part in the exercise program.

Methods and materials

Study design and participants

Four urban primary schools in the greater Johannesburg area were invited to participate in the study. Three granted permission for the school children to participate in the study. Children in grades 3 to 5 were approached and invited to take part in the study. In order to avoid exercise contamination within each school, schools were cluster-randomized into intervention (EX) and control (CON) groups. To ensure even numbers of children in the two groups, the two schools with the lowest numbers were randomly assigned to the EX group (by drawing the group intervention out of a hat) and one school was assigned to the CON group.

Children between the ages of eight and eleven years participated in the study. Study information sheets were sent home from school for parental consent. Only children whose mother and father were black were included in the study. Thirty seven children who met the inclusion criteria and were attending any of the three different primary schools participated in the study. All children came from similar low-middle income socioeconomic backgrounds as assessed using a validated household amenity questionnaire[34] that has been used in a similar population to that of the current study[35]. Maturational status was self-assessed using breast development (girls), gonadal development (boys) and pubic hair stages as the Tanner five stage classification criteria[36]. The age at onset of menarche was also requested in the Tanner questionnaire for girls. Girls were excluded if they had attained menarche. Children were included in the study if they were classified as Tanner stage I to III. A general health questionnaire was administered to the parents or primary caregivers of each child in order to collect information on the state of health of the child, (including any medication use), as well as history of fractures and family history of osteoporosis. Children were excluded if they had been on corticosteroid medication consecutively for more than seven days in the past year, if they had any milk or lactose food allergies, if they were on a vitamin D or calcium supplement, or if they had been ill or admitted to hospital in the three months prior to participation in the study.

All children who participated in the study had the protocol verbally explained to them and if they agreed to participate signed an assent form. Parents/primary caregivers of the children were required to consent to their child's participation in the study. The study was approved by the Human Research Ethics Committee of the University of the Witwatersrand (protocol no.: M10635) which adheres to the principles of the 1964 Declaration of Helsinki and its later amendments. Children were required to visit the laboratory at the University of the Witwatersrand for various measurements pre- and post-intervention.

Weight-bearing physical activity intervention

The intervention took place between February and June 2012. The 20-week exercise intervention took place after school and was conducted by the same teacher or facilitator that was employed by the school or the after care centre. The teacher or facilitator was advised by the principal investigator on a series of weight-bearing exercises to be performed for two 45 minute sessions per week. Because the intervention took place during the late summer to early autumn months, it was performed outside on the after-care centre's sports field. Each exercise session involved completing an exercise circuit consisting of five activities. A warm up of five minutes was performed before starting the circuit. The warm-up consisted of stretching the upper and lower body. Each activity was then performed for five minutes before moving on to the next activity in the circuit. Exercises included sprinting between cones set a certain distance apart, running and jumping to catch a 1kg medicine ball, ladder hopping (feet together jumping into each space in between the rungs of a ladder), hopping with one or both feet over 30 cm high hurdles, jumping rope for as long as they could. A competition within two or three of the activities was held for the next 10 minutes and children were divided into two groups and performed races to determine a winner of each activity. A cool-down was then performed for another five minutes which again involved upper and lower body stretches. The frequency and intensity of the exercises remained the same throughout the exercise intervention period. On-site monitoring of the exercise intervention was conducted once a month to ensure that the intervention was implemented correctly and consistently. The exercise intervention was performed in addition to any regular activities that the children took part in i.e. mandatory physical education (PE) classes during school hours. These PE classes took place once per week and lasted 35 minutes for each session. The CON group continued with their regular activities throughout the intervention period. These activities included the mandatory PE classes during school hours as well as any structured after school sport as reported on the physical activity questionnaire.

Anthropometry

Height was recorded to the nearest millimetre (mm) using a stadiometer (Holtain, Crosswell, UK) and weight was recorded to the nearest 100 g using a digital scale (Dismed, Halfway House, South Africa). Children were measured without shoes and wearing light clothing. BMI percentile-for-age was calculated using software available from the World Health Organization (WHO, http://www.who.int/childgrowth/software/en).

Dual energy x-ray absorptiometry (DXA)

Bone mineral content (BMC) and bone area (BA) were measured using DXA (Hologic QDR, Discovery W, Bedford, MA, USA) at the following sites: non-dominant forearm (ulna and radius), whole body (WB (less head)), lumbar spine (LS) and hip (total hip (TH), femoral neck (FN), trochanter (T), intertrochanter (IT)) of the non-dominant leg. Fat and lean (fat free soft tissue) mass, as well as body fat percentage, were obtained from the whole body DXA scan. The same trained technician performed and analyzed all DXA scans. The coefficients of variation for BMC and BA over the course of our study were 0.36% and 0.32%, respectively. Intra-observer variation was less than 1% for all skeletal sites scanned by the DXA[37].

Peripheral quantitative computed tomography (pQCT)

Scans of 2.3 mm thickness of the non-dominant lower leg were made at the 4%, 38% and 65% sites of the tibia using pQCT (Stratec XCT 2000 bone scanner, Stratec Medical, Pforzheim, Germany) to measure bone parameters, estimates of bone strength and regional body composition. Tibial length was defined as the distance from the distal end of the medial malleolus to the superior aspect of the medial tibial condyle. A scout view was performed at the ankle for each subject and a reference line placed at the midline of the epiphyseal growth plate of the tibia, clearly indicating the metaphysis. The following measures were obtained from the metaphysis (4%) of the tibia: total bone mineral density (TotD, mg/cm^3), trabecular bone mineral density (TrbD, mg/cm^3), total bone cross-sectional area (TotA, mm^2) and bone strength index (BSI, mg^2/mm^4). Diaphyseal measures (indicative of the geometry and structure of cortical bone) obtained from the 38% site included cortical density (CoD, mg/mm^3), TotA (mm^2) and cortical area (CoA, mm^2), polar strength-strain index (SSI, mm^3), periosteal circumference (PC, mm), endosteal circumference (EC, mm) and cortical thickness (CT, mm). BSI, PC, EC and CT were calculated using formulas described elsewhere[23]. BSI was calculated based on the total CSA of the bone as well as the volumetric density. PC, EC and CT are measures based on the periosteal and endosteal diameters calculated from the bone total and cortical CSA. Muscle (MCSA, mm^2) and fat cross-sectional area (FCSA, mm^2) were obtained from the 65% site as this site is associated with the largest muscle belly. For the metaphyseal (4%) measure, scans were analysed using the CALCBD analysis algorithm with the bone threshold set at 180 mg/cm^3, and contour mode 1 and peel mode 1 were used. For the diaphyseal (38%) site, bone threshold was set at 711 mg/cm^3 (contour mode 1 and peel mode 2) for analysis of ToA, CoA and CoD. Threshold for SSI was set at 480 mg/cm^3 (contour mode 1). MCSA and FCSA were analysed using contour mode 3/peel mode 1. FCSA was calculated as the area with a density below 40 mg/cm^3 while MCSA was calculated as the area with a density between 40 and 180 mg/cm^3. The same independent technician performed all pQCT scans[23]. A QC phantom spine was scanned each morning and the CV for total attenuation for repeat scans on the spine phantom was 0.44% and trabecular attenuation was 0.37% during the study period.

Physical activity questionnaire

All participants completed a physical activity questionnaire with the assistance of their parent or primary caregiver. This questionnaire has been validated against accelerometry in South African children[38] and can be used to collect information on the child's participation in all types of physical activity over the past two years in order to take into account seasonal variation in sport and also to consider those children who had played a sport for one year and then changed to a different sport in the second year. The questionnaire was administered at the baseline visit as well as after the 20-week intervention when post-intervention measures were made. Children and their parents listed all the physical activities that the child had participated in for the past two years for baseline physical activity assessment, and for the past six months for post-intervention physical activity assessment. Information was gathered within four physical activity domains namely, physical activity during school, extra-mural/after-school physical activities, leisure-time activity, as well as transport (walking and/or cycling) to and from school. Children were asked to give details on the number of times per week they performed that activity as well as the amount of time they spent in each activity in order to determine the frequency and pattern of regularity of each activity. Regular participation in a specific activity was classified as the child performing an activity once a week for more than four months of the year (the usual length

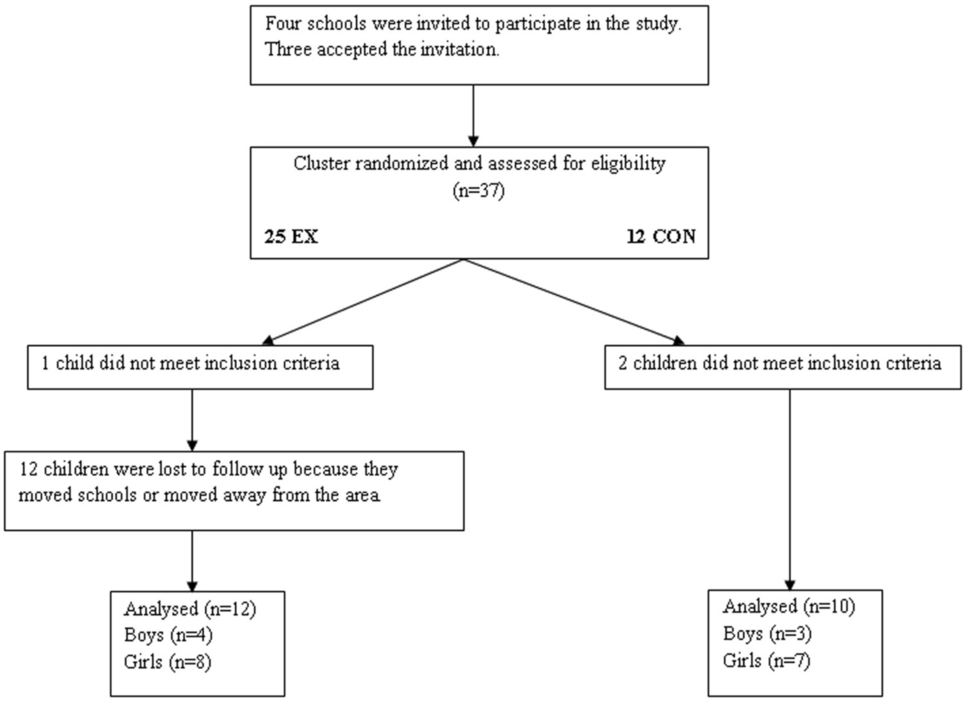

Figure 1. Flow of participants through the study. EX (exercise group), CON (control group).

of a school semester in South Africa). After-school and leisure-time activities were assessed in the same way. Each regular activity was then assigned a bone strain score using a scoring system validated by Groothausen et al[39] by using the ground reaction force produced by each activity to quantify the amount of bone loading of that activity. The sum of the scores for each activity made up the peak bone strain score (PBSS) that was assigned to each child.

Urinary cross-linked N-telopeptides of Type I collagen (NTX)

Children were asked to provide a urine sample for the analysis of urinary cross-linked N-telopeptides of Type I collagen (NTX). NTX concentration before and after the intervention was analysed using a commercially available ELISA kit (Osteomark, Alere Scarborough, Inc., Scarborough, ME, USA). Pre- and post-intervention urine samples from the same participants were analysed on the same plate. Total assay precision was evaluated by testing at two levels at three clinical laboratory sites over a 30 day period. The level I coefficient of variation was 10% and the level II CV was 7%.

Statistical analysis

Unless otherwise specified, data are presented as measures at baseline and follow up [mean (SD)] and adjusted change from baseline [mean (95% CI)] after 20 weeks of intervention. A sample-size calculation showed that we needed to recruit a total of 38 participants in order to obtain a medium effect size (0.2-0.5) for BSI, bone area and SSI with a power of 0.8. The median PBSS between and within the EX and CON groups were compared using a Kruskal-Wallis test. A two-way repeated measures analysis of covariance (ANCOVA) was used to determine time and group effects of the intervention on bone variables and to determine the within group changes over the intervention period. DXA derived BMC was adjusted for sex, follow-up Tanner stage and bone area while pQCT bone outcomes were adjusted for sex, follow-up Tanner stage, height and muscle CSA. Muscle CSA was adjusted for sex, follow-up Tanner stage and height. Five-month absolute change of the bone variables was then compared between groups using an analysis of covariance (ANCOVA), adjusting for sex, Tanner stage at follow-up, and change in bone area for DXA, while pQCT outcomes were adjusted for sex, Tanner stage at follow-up, change in height and change in muscle CSA. A repeated measures ANOVA was used to determine differences in NTX concentrations between groups before and after the intervention. Statistical analyses were based on the per-protocol principle. Data were analysed using SPSS 21.0 (IBM SPSS, NY, USA). Statistical significance was considered as $p \leq 0.05$.

Results

A participant flow chart is shown in Figure 1. Thirty seven children were recruited into the study. Two children from the control group and one child from the exercising group did not meet the inclusion criteria. Twelve children recruited into the exercising group moved away from the area or moved to a dif-

	Control (n=10)			Exercise (n=12)		
	Baseline (SD)	Post-intervention (SD)	Δ (95% CI)	Baseline (SD)	Post-Intervention (SD)	Δ (95% CI)
Age	9.3 (0.9)		-	9.7 (1.2)		-
Boys (n)	3	3	-	4	4	-
Tanner stage I/II/III (n)	9/1/0	5/3/2	-	5/7/0	5/6/1	-
Height (cm)	135.1 (8.2)	136.9 (8.6)	1.8 (1.2-2.4)	135.9 (8.7)	139.0 (9.2)	3.1 (2.1-4.2)[a]
Weight (kg)	30.6 (4.7)	31.6 (4.7)	1.0 (0.2-1.7)	30.0 (5.1)	31.6 (5.7)	1.6 (0.7-2.4)
BMI percentile	57.4 (22.4)	52.3 (23.9)	-5.1 (-15.0-4.9)	39.7 (20.1)	36.6 (21.8)	-3.1 (-8.6-2.4)
Fat mass (kg)	7.5 (1.9)	8.0 (2.2)	0.4 (-0.1-1.0)	6.7 (1.8)	7.0 (1.7)	0.3 (0.04-0.7)
Whole body lean mass (kg)	21.4 (3.9)	22.7 (4.1)	1.2 (0.8-1.7)	21.9 (3.8)	23.5 (4.2)	1.6 (0.9-2.3)
% body fat	25.2 (5.4)	25.2 (5.7)	-0.02 (-1.3-1.3)	22.5 (3.8)	22.2 (3.1)	-0.3 (-1.3-0.7)
Leg muscle CSA (mm^2)	3281.0 (432.2)	3298.2 (421.5)	58.1 (-6.4-122.5)	2948.5 (414.9)	3142.4 (494.2)	193.9 (112.8-275.1)[a]
Leg fat CSA (mm^2)	1684.4 (129.1)	1645.8 (172.4)	-5.6 (-13.3-2.0)	1538.0 (222.0)	1534.4 (225.3)	-3.6 (-13.1-5.9)
Tibial length (mm)	313.7 (24.4)	321.6 (22.4)	7.9 (2.3-13.4)	319.3 (28.4)	319.6 (24.5)	0.3 (-4.7-5.4)

[a] Change is significantly greater in the intervention group, p<0.05. Cross sectional area (CSA).

Table 1. Baseline and change (where relevant) descriptive characteristics for control and exercising groups.

ferent school and could not be followed up. Thus data are available for twenty two children (CON: n=10; EX: n=12). Seventy eight percent of children in the EX group completed all (100%) of the exercise sessions. The median peak bone strain score (PBSS) was similar between the two groups at the start of the intervention (median, 95%CI; EX: 4.5, 3-8; CON: 4, 1-11; p=0.53). As expected, the median change in PBSS was significantly greater for the EX group compared to CON group (median, 95% CI; EX: 3, 2-5 vs. CON: 0, -1-1; p<0.0001) and the PBSS for the EX group after the intervention was significantly greater than that of the CON group (median, 95%CI; EX: 7, 5-11 vs. CON: 4, 1-10; p=0.004) (Figure 2).

Baseline and 20-week change in the anthropometric characteristics of each group are shown in Table 1. The change in height over the 20-week intervention period was significantly greater in the EX group (p=0.03). There was a difference in the proportion of children who were classified as being either Tanner stage I or II between the groups at baseline (p=0.03). Neither group were more pubertally advanced at follow up (p=0.68).

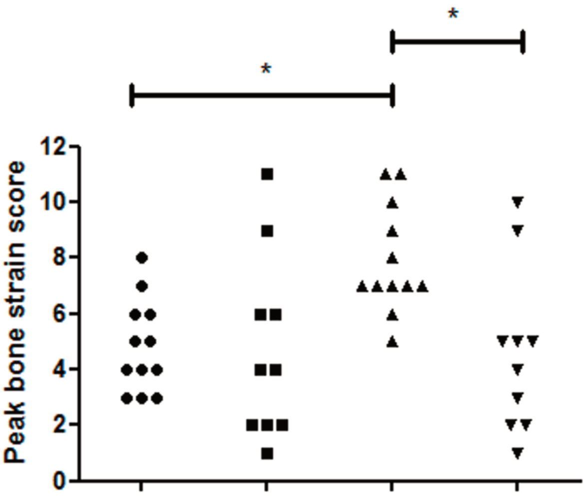

Figure 2. Peak bone strain score (PBSS) for the exercise (EX) and control (CON) groups before and after the 20-week intervention. PBSS was similar before the intervention between groups (p=0.53) but was significantly higher in the exercising group (* p<0.001) after the 20-week intervention. ● = EX baseline, ■ = CON baseline, ▲= EX post-intervention, ▼= CON post-intervention.

DXA

Table 2 summarises the DXA data from each group at baseline and change after the 20-week intervention. There were significant time effects on the BMC of the hip, spine, radius, ulna and whole body (all p<0.001). There was also a significant overall interaction of time and group on the BMC of the total hip (p=0.04). There was no difference in the change in bone mass for any of the sites measured by DXA over the 20-week intervention.

pQCT

Data obtained from the pQCT scans were compared between groups and the group and time effects are summarised in Table 3. There was a significant interaction of time and group on ToD (p=0.004) and TrabD (p=0.003) of the 4% site of the tibia. There was also a significant time and group effect on the BSI of the 4% tibia (p=0.006). When post-hoc tests were performed on the variables, ToA at the 4% site after the intervention was significantly greater in EX than in CON. The absolute changes in ToA (p<0.001), ToD (p=0.003), TrbD (p<0.001) as well as BSI (p<0.001) were all significantly greater for the EX group compared to CON (Table 3). There were significant overall interactions between group and time for cortical area (p=0.05) and

	Control			Exercise			Adjusted p-values		
	Baseline	Post-intervention	Δ (95% CI)	Baseline	Post-intervention	Δ (95% CI)	Time	Group	Time*group
Femoral neck BMC (g)	2.7 (0.4)	2.7 (0.3)	-0.01 (-0.1-0.1)	2.9 (0.5)	3.0 (0.5)	0.1 (0.01-0.1)	0.04	0.19	0.25
Hip BMC (g)	16.3 (2.9)	16.5 (3.1)	0.2 (-0.5-1.0)	17.6 (4.9)	18.7 (5.5)	1.0 (-0.01-1.9)	<0.001	0.45	0.04
Spine BMC (g)	23.4 (4.6)	24.4 (4.7)	1.0 (-0.03-2.0)	23.1 (5.5)	24.3 (6.2)	1.3 (0.5-2.1)	<0.001	0.77	0.44
Radius BMC (g)	3.4 (0.5)	3.6 (0.6)	0.2 (0.1-0.2)	3.6 (0.8)	3.8 (0.8)	0.2 (0.1-0.3)	<0.001	0.35	0.69
Ulna BMC (g)	2.3 (0.4)	2.5 (0.4)	0.2 (0.1-0.2)	2.5 (0.6)	2.7 (0.6)	0.2 (0.1-0.2)	<0.001	0.11	0.57
Whole body BMC (g)	753.7 (103.6)	792.9 (116.7)	39.3 (23.2-55.3)	778.4 (164.0)	822.6 (195.5)	35.3 (17.3-53.3)	<0.001	0.62	0.55

Baseline and follow up data are unadjusted mean (SD). DXA change data are represented as mean (95% CI) and are adjusted for sex, Tanner at follow-up and change in bone area.

Table 2. Site-specific baseline and 20-week change in bone mineral content (BMC) measures by DXA.

	Control			Exercise			Adjusted p-values		
	Baseline	Post-intervention	Δ (95% CI)	Baseline	Post-intervention	Δ (95% CI)	Time	Group	Time*group
4% Tibia									
ToA	738.5 (86.8)	741.3 (99.7)	2.8 (-7.1-12.7)	802.0 (136.9)	847.8 (146.3)	48.8 (37.0-60.5)[a]	0.13	0.22	0.34
ToD	319.6 (46.7)	306.2 (41.2)	-13.4 (-19.5- -7.3)	304.6 (22.1)	306.2 (19.7)	2.3 (-5.5-10.2)[a]	0.10	0.23	0.004
TrbD	291.4 (59.1)	264.1 (54.1)	-27.3 (-36.9- -17.6)	270.2 (29.2)	277.2 (24.6)	8.9 (-2.8-20.6)[a]	0.13	0.23	0.003
BSI	7685.4 (2470.6)	7095.6 (2270.7)	-589.8 (-828.0- -351.6)	7503.6 (1753.1)	7978.2 (1688.1)	545.6 (209.2-882.1)[a]	0.82	0.61	0.006
38% Tibia									
CoA	160.9 (17.5)	170.1 (17.2)	9.1 (6.6-11.6)[b]	165.7 (26.1)	170.2 (25.0)	5.2 (2.2-8.2)	0.001	0.44	0.055
CoD	1071.1 (27.0)	1071.1 (23.6)	0.004 (-3.8-3.8)	1059.8 (51.4)	1073.1 (44.4)	11.1 (6.9-15.3)[a]	0.02	0.74	0.003
SSI	761.6 (77.3)	808.5 (99.0)	46.9 (34.6-59.2)	840.9 (180.7)	888.7 (187.1)	45.0 (31.9-58.2)	<0.001	0.21	0.46
ToA	269.2 (19.0)	279.4 (21.6)	10.2 (7.7-12.7)	294.9 (48.8)	304.1 (48.2)	9.8 (6.9-12.8)	<0.001	0.19	0.23
PC	59.6 (1.8)	60.2 (1.6)	0.6 (0.3-1.0)	59.4 (3.3)	60.7 (3.8)	1.2 (0.8-1.6)[c]	<0.001	0.90	0.99
EC	38.8 (1.1)	39.2 (1.0)	0.4 (0.1-0.6)	38.3 (2.7)	39.1 (3.0)	0.7 (0.4-0.9)	<0.001	0.79	0.93
CT	3.3 (0.1)	3.4 (0.1)	0.04 (0.03-0.06)	3.4 (0.2)	3.4 (0.3)	0.08 (0.06-0.10)[c]	<0.001	0.27	0.28

Baseline and follow-up data are unadjusted mean (SD). Change data are represented as mean (95% CI) and are adjusted for sex, Tanner stage at follow-up, change in height and change in muscle CSA. ToD, total density; TrbD, trabecular density; ToA, total area; BSI, trabecular bone strength index, CoD, cortical density; CoA, cortical area; SSI, strength strain index, PC, periosteal circumference, EC, endosteal circumference, CT, cortical thickness. [a]change is significantly greater in exercise group, $p<0.01$. [b]change is significantly greater in control group, $p<0.05$. [c]change is significantly greater in intervention group, $p<0.05$.

Table 3. Trabecular (4%) and cortical (38%) baseline and 20-week change in tibial bone measures by pQCT.

cortical density (p=0.003) at the 38% site of the tibia. There were no between group differences for baseline and follow up values, when post-hoc tests were performed although ToA at the 38% was not quite significantly different between EX and CON after the intervention (p=0.08). However the absolute change in CoA (p=0.04), CoD (p<0.001), PC (p=0.03) and CT (p=0.01) at the 38% tibia were all greater in the EX group than in CON. The change in muscle CSA was also greater in the EX group compared to the CON (p=0.01).

NTX

There were no differences in NTX concentration at baseline between the EX and CON group, or within each group at follow-up (EX: p=0.77; CON: p=0.06). After the 20-week intervention, however, the CON group had a significantly higher NTX concentration compared to the EX group (p=0.04) (Figure 3).

Discussion

Positive changes in bone density, size and strength in response to an exercise intervention have been repeatedly shown in white children[10-12,20,24,32,33]. Although Black children have greater bone mass than their white peers, there are currently no studies that have considered the effects of an exercise intervention on the bone mass of black children. In our study, black South African children who participated in a 20-week

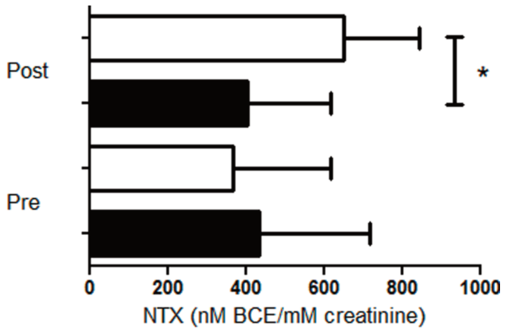

Figure 3. Urinary concentrations of cross-linked N-telopeptides of Type I collagen (NTX) before and after the 20-week intervention. White bars are CON, black bars are EX. *p=0.04. Pre= before intervention, post= after intervention.

weight bearing exercise intervention had significantly greater gains in hip BMC, as well as in density, area and strength at trabecular sites and density, area and structure at cortical sites of the tibia when compared to a non-exercising control group. As populations become increasingly sedentary and adopt poor dietary habits, genetic protection may not offer adequate protection against bone loss[14,40]. Our study has shown the possibility for black children to improve their bone health by taking part in a weight-bearing exercise program that may be easily incorporated into a school curriculum.

The inability of the DXA scans to detect changes in BMC in the present study (apart from at the hip) supports others who have suggested that the two dimensional DXA scan is limited in detecting a bone response to mechanical loading[41]. Children in the CON group had relative increases of between 1 and 9% in DXA derived bone mineral content over the intervention period whereas the children in the EX group showed similar increases of between 3 and 7%. The use of pQCT in our study enabled us to elucidate small structural changes as a result of the weight-bearing exercise intervention. No studies have used pQCT to assess the efficacy of an exercise intervention in black children, although the intervention studies that are available from other ethnic groups show similar results to those observed in the present study. Increases in tibial bone strength at the trabecular site but not the cortical site were seen after an 11-month-long weight bearing intervention in exercising prepubertal boys[20,41]. Similarly in the present study there was no significant difference in the change in strength of the cortical site of the tibia between the EX and CON groups. In the studies described above no other structural changes were observed, while in the present study, area and density changes were greater in the EX compared to CON group and were likely contributors to the greater change in bone strength seen at the trabecular site of the tibia. Whereas responses to a longer intervention than was conducted in our study have been observed[20,41], five months appears to be have been long enough to elicit significant bone gains in our cohort of black children.

Interestingly, the children in the CON group tended to have a decrease in total and trabecular bone density with an overall (although not significant) decrease in BSI. There was a decrease of between 0 and 10% from pre-intervention to post-intervention in the CON group compared to an overall increase of between 0.5 and 6% in the EX group. Although not significant, MacDonald and co-workers[42] have also reported a decrease in tibial total density after a school based-intervention in 10-year old children. Furthermore, the same author found that total density and BSI of the distal tibia was 2% and 1% lower respectively in early compared to pre-pubertal boys[43]. We suggest that this decrease in density may be possible due to one of the following reasons. The first is that the decrease in density may be due to a lag in the time it takes to deposit bone on the trabecular surface after the bone has grown in area. Indeed there is a peak in fracture rates which occur in boys and girls between the ages of 11 and 14 years which is approximately the age at which peak height velocity has occurred[44]. The weight-bearing exercise intervention in the present study may have been preventing this apparent bone loss in the EX group. The greater concentration of urinary cross-linked N-telopeptides of Type I collagen (NTX) in the CON group following the intervention may also in part explain the mechanism for the decrease in trabecular density. Only one other study that has documented NTX concentrations in children, showed that NTX accounts for only a small, but significant percentage of variation in change in BMD in peripubertal girls with exercise[46] while maturity status is a large determinant of NTX levels[47]. The difference in NTX levels between groups in the present study also suggests that the inhibition of bone resorption in the presence of a weight-bearing intervention may contribute to bone gain. Lastly there is always the possibility of measurement error as the decreases observed were greater than the CV's of the machine. Nevertheless, the anomaly of a decrease in bone density warrants further investigation and mechanisms of bone deposition due to growth and participation in weight-bearing exercise interventions need to be considered.

Bone's response to mechanical loading is site-specific[10] and in the present study the cortex of the tibia of children in the EX group exhibited structural changes when compared to the CON group. Our intervention targeted bones of the lower body and a greater change in tibial periosteal circumference and cortical thickness occurred in the EX group compared to the CON group. The increase in endosteal circumference was not quite significant in the EX compared to CON group (p=0.06) and may have been a reason why significant changes in strength at the cortical tibia were not observed. After completing nine months of a jumping intervention, 8-12 year old white boys and girls showed no difference in the increase in periosteal circumference between exercising and control groups at the midshaft of the tibia however the change in endosteal circumference was less in the intervention group compared to their control group[24]. This suggests that the exercising children may have resorbed bone on the inner surface at a slower rate compared to the control group and therefore they may have had thicker cortices even though cortical thickness was not measured in that study. Wang and co-workers (in an observational study) showed that Finnish girls who had the highest levels of leisure time physical activity, had greater cortical thickness at the tibia compared to girls in the lowest tertile of leisure time physical activity[17]. Overall however, it must be noted that both groups had similar relative increases in cortical bone variables of the tibia of between 1 and 6%.

It is also possible that ethnic differences may exist in the way that bone is laid down in response to exercise between black and white children. Currently, no studies have looked at an ethnic comparison of bone apposition due to an exercise intervention in black and white children and further comparative studies need to be done to delineate the changes in bone geometry after an exercise intervention. In an observational study, Leonard and co-workers reported greater tibial periosteal and endosteal circumferences and strength in black compared to white children but they did not report differences in cortical thickness[19]. Black children have been shown to have thinner cortices than white children[8], but it appears from the present study that an exercise intervention in black children has the ability to promote bone apposition at the periosteum, which may have contributed to a greater change in cortical thickness in the EX group. That said there was no difference in absolute cortical thickness between the groups after the intervention. Absolute differences in bone geometry may have been observed if the intervention period was longer but the significantly greater changes in all bone outcomes in the EX group show promise for future research on bone gain as a consequence of exercise in black children.

The change in muscle CSA over the 20-weeks, was greater in the EX group than the CON group but the gain in total lean mass was not different between groups. The weight-bearing intervention was effective in increasing MCSA and this is a likely explanatory mechanism as to how bone area and strength increased at a greater rate in the EX group compared to the CON group. It is widely accepted that muscle CSA (an increase in which is highly attributable to the amount of physical activity that one partakes in) plays a role in determining the amount of bone density gain as well as the beneficial changes in bone geometry and structure[1,48].

Although there was a difference in the proportion of children classified as being in Tanner stage I and II at baseline, all children were considered as being pre- to early pubertal at the start of the intervention. Pubertal status however is closely associated with bone gain, and it must be acknowledged that the change in pubertal status may have resulted in the greater rate of change seen in some of the bone variables in the EX group. It is difficult to control the change in pubertal status that may occur over a period of time but we attempted to minimize this limitation by adjusting for post-intervention sexual maturity in our analyses. Although it wasn't within the scope of the study to assess physical fitness, we acknowledge that a difference in physical fitness between and within groups may also have influenced the results. The more relevant measure however for the present study was the level of participation in weight-bearing physical activity which was assessed using a questionnaire. The fact that the change in height was greater in the EX group compared to the CON group also suggests that this group was more mature than the CON. This may have influenced the rate of change in bone variables in the EX group. The authors acknowledge the importance of stratifying samples by sex as well as sexual maturity for future studies. We did not include other ethnic groups in our study therefore our results may only be applicable to black pre- to early pubertal children. A number of children in the EX group could not return for their post intervention scans due to moving away from the area or school and thus our sample size was reduced. The biochemical interpretation of bone remodelling is also limited due to the fact that we only obtained blood data for bone resorption and not formation markers.

To our knowledge, pQCT has not been used in a cohort of black children who have undergone an exercise intervention. After a 20-week weight-bearing intervention, black children showed greater absolute gains in trabecular and cortical volumetric bone density compared to controls. In addition, structural changes in periosteal circumference and cortical thickness were observed in response to the intervention. Our results demonstrate the possible efficacy of weight bearing physical activity on the trabecular and cortical sites in black children. Similar to what has previously been observed in white and Asian children, this study contributes to the current knowledge on the attainment of bone in response to an exercise intervention. The present study is an ideal example of how a simple low-cost, exercise intervention improved bone health in pre- and early pubertal black children. In a low-middle income country such as South Africa, physical activity models and interventions need to be feasible, affordable, sustainable and relevant to the population that they are being conducted in. Primary schools are an important environment where large numbers of children can be encouraged to participate in exercise interventions. Further exploration into the ethnic specific effects of weight-bearing physical activity interventions in children is needed.

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