The Association of Environmental and Lifestyle Factors with Bone Mass Acquisition in South African Children by Sex, Race and Age

By

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Declaration

I certify that the thesis entitled 'The Association of Environmental and Lifestyle Factors with Bone Mass Acquisition in South African Children by Sex, Race and Age', submitted for the degree of Doctor of Philosophy is the result of my own work and that where reference is made to the work of others, due acknowledgment is given.

I also certify that any material in the thesis has not been submitted for degree or examination purposes to any other university or institution.

Joanne Alexandra McVeigh

Signed ....

August 2007

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"When once you have tasted flight, you will forever walk the earth with your eyes turned skyward, for there you have been and there you will always long to return"

— Leonardo da Vinci

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What a privileged journey this has been. To have worked with the beautiful children that partook in this study, all shapes and sizes. We truly are a rainbow nation and I am so grateful to have had the opportunity of doing my PhD here in sunny South Africa, with so many beautiful South Africans. I wish to thank God, my family, friends and colleagues who have contributed to this culmination of a long voyage and significant accomplishment. My sincere appreciation to the following people:

Preface

The work presented in this thesis is based on the following publications and presentations which have emanated from data collected for this thesis.

<u>Peer Reviewed Publications:</u>

1. **<u>McVeigh JA</u>, Norris SA, Cameron N and Pettifor JM.** Associations between physical activity and bone mass in Black and White South African children at age 9 yr. *Journal of Applied Physiology* 97: 1006-1012, 2004.

2. **<u>McVeigh JA</u>, Norris SA and de Wet T.** The relationship between socio-economic status and physical activity patterns in South African children. *Acta Paediatrica* 93: 982-988, 2004.

3. **<u>McVeigh JA</u>, Norris SA, Pettifor JM.** Bone mass accretion rates in pre- and early pubertal South African Black and White children in relation to habitual physical activity and dietary calcium intakes. *Acta Paediatrica* 96: 874-880, 2007.

<u>Conference Presentations:</u>

1. 2nd International Conference on Child Bone Health, Sheffield, England, June 2002: Poster Presentation.

2. 11th SEMSDA, NOF Conference, Drakensburg, South Africa, April 2003: Oral Presentation.

3. 31st Annual Congress of the Physiology Society of South Africa, Potchefstroom, South Africa, September 2003: Oral Presentation (1st place winner Cyril Wyndham competition)

4. 32nd Annual Congress of the Physiology Society of South Africa, Coffee Bay, Eastern Cape, South Africa, September 2004: Oral Presentation

5. XXXV congress of the International Union of Physiological Sciences (IUPS), San Diego Convention Centre, California, USA, April 2005: Poster Presentation

6. 12th SEMSDA, NOF Conference, Sandton, South Africa, April 2005: Oral Presentation

7. 33rd Annual Congress of the Physiology Society of South Africa, Cape Town, South Africa, September 2005: Poster Presentation

Published Abstracts:

1. **McVeigh JA, Norris SA, Cameron N, Pettifor JM.** Associations between physical activity and bone mass in 9 year old Black and White South African children. *Calcified Tissue International*, 70, 379, 2002.

2. **Norris SA, Cameron N, McVeigh JA, Pettifor JM**. Factors impacting spine and hip bone mineral content and density in pre-pubertal urban South African children. *The Journal of Endocrinology, Metabolism and Diabetes of South Africa*, 8, 20, 2003.

3. **McVeigh JA, Norris SA, Pettifor JM.** Associations between physical activity and bone mass in Black and White South African children at age 9 years. *The Journal of Endocrinology, Metabolism and Diabetes of South Africa,* 8, 20, 2003.

4. **McVeigh JA, Norris SA, Pettifor JM**. Physical activity and bone mass accumulation patterns differ in Black and White South African children. *The Journal of Endocrinology, Metabolism and Diabetes of South Africa* 10(1) 43, 2005.

5. **McVeigh JA, Norris SA, Pettifor JM**. Physical activity and bone mass accumulation patterns differ in Black and White South African children. *FASEB Journal* 19 (4) A568-A569,Part 1 Suppl, 2005.

<u>Honours, Grants and Awards:</u>

1. 1st place winner Cyril Wyndham Competition for best oral presentation. 31st Annual Congress of the Physiology Society of South Africa, Potchefstroom, South Africa, September 2003

2. University of the Witwatersrand Research Committee Award (URC), 2004 and 2005

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Abstract

While osteoporosis is a major public health concern in the developed world, little research regarding factors influencing bone mineral accrual in children has been conducted in developing countries. South Africa is of particular interest since the incidence of hip fractures in South African Blacks has been reported to be amongst the lowest in the world (32; 253). In this thesis, the association of lifestyle factors; in particular physical activity (PA), socio economic status (SES) and dietary calcium intakes on the growing skeleton of Black and White South African children is investigated.

After using accelerometry to validate a physical activity questionnaire (PAQ), in a convenience sample of South African Black, White, male and female children (n=30), fitness levels were assessed in a larger group (n=69) of similarly aged children, stratified by race and gender. Fittest subjects had significantly greater physical activity scores (p=0.022) as reported on the PAQ, lower body mass index's (BMI) (p=0.001) and least percentage body fat (p=0.001) (as assessed using Dual Energy X-ray Absorptiometry (DXA), than least fit subjects. White males who reported to be significantly more active than all other groups on the PAQ were significantly fitter (p<0.001) than White females and Black males and females.

The next study sought to determine whether differences observed in physical activity levels between groups showed an association with bone mineral content (BMC), density (BMD) and area (BA) (as assessed using DXA). PA was analyzed in terms of a metabolic (METPA; weighted metabolic score of intensity, frequency, and duration) and a mechanical (MECHPA; sum of all ground reaction forces multiplied by duration) component for 386 children aged 9.5 (0.04) years recruited from a longitudinal birth cohort study. White children expended a significantly greater energy score (METPA of 21.7 (2.9)) than Black children (METPA of 9.5 (0.5), p< 0.001). When children were divided into quartiles according to the amount and

intensity of sport played, the most active White children had significantly higher (p<0.05) whole body BMD and higher hip and spine BMC and BMD after adjustment for body size than less active children. White children in the highest MECHPA quartile also showed significantly higher (p<0.05) whole body, hip, and spine BMC and BMD after adjustment for body size than those children in the lowest quartile. No association between PA and bone mass of Black children was found. No significant differences between METPA and MECHPA quartiles and BA were observed for any group.

Given the disparate backgrounds from which many South African children come, the next study sought to determine whether differences in socio-economic status between Black and White South African children influence PA patterns. This study explored the relationship between socio-economic status, PA anthropometric and body composition (via DXA) variables in 381 children aged (9.5 (0.04) years) recruited from a longitudinal birth cohort study . Children falling into the highest socio-economic status quartile had mothers with the highest educational levels, generally came from dual parent homes, were most physically active, watched less television, weighed more and had greater lean tissue than children in lower socio-economic quartiles (p<0.001). Significantly greater levels of lean mass (p<0.001) with increased activity level were observed after controlling for television watching time and fat mass. There were high levels of low physical activity and high television watching time among lower socio-economic status groups. White children were found to be more active than Black children, more likely to be offered physical education and to participate in physical education classes at school and watched less television than Black children.

The final study sought to investigate the association between habitual PA patterns and dietary calcium intakes with bone mass acquisition over a one year period in 321 pre-pubertal South African children recruited from a longitudinal birth cohort study. Data were analyzed by regressing change in BMC and BA from age nine to ten years, against BA (for BMC), height

and body weight. The residuals were saved and called residualized BMCGAIN and BAGAIN. Residualized values provide a good indication of weight, height and BA-matched accumulation rates. White children had significantly higher PA levels and calcium intakes than Black children. Most active White males had significantly higher residualized BMCGAIN and BAGAIN at the whole body, hip and spine but not at the radius, than those who were less active. Most active White females had significantly higher residualized BAGAIN at all sites except the radius than less-active girls. No such effects were seen in Black children. There was no interactive effect on residualized BMCGAIN or BAGAIN for calcium intake and PA in boys or Black girls, but an interactive and possible synergistic effect of calcium and physical activity was observed at the spine, radius and hip in White girls. In this population, PA has an osteogenic association with White children, but not Black children, which may be explained by the lower levels of PA in the Black children. Despite this, Black children had significantly greater bone mass at the hip and spine (girls only) ($p < 0.001$) even after adjustment for body size.

In conclusion, differences between White and Black children's PA levels were observed, with White children reporting higher PA levels and exhibiting higher fitness levels than Black children. Physical fitness correlated well with self reported physical activity levels on the PAQ and objectively measured body composition. Socio-economic status differences between White and Black children are highly related to differences in physical activity patterns and body composition profiles. Bone mass and area gain is accentuated in pre- and early-pubertal children with highest levels of habitual physical activity. Limited evidence of an effect of dietary calcium intakes on bone mass in boys and Black girls was found. The role of exercise in increasing bone mass may become increasingly critical as a protective mechanism against osteoporosis in both South African race groups, especially because the genetic benefit exhibited by Black children to higher bone mass may be weakened with time, as environmental influences become stronger.

Operational Definition of Terms

g: Grams

cm: Centimetre

BMC: Bone mineral content (g)

BA: Bone area (cm^2)

BMD: Bone mineral density. Bone density refers to areal bone density (g/cm^2) throughout the thesis

DXA: Dual energy X-ray absorptiometry

pQCT: peripheral Quantitative Computed Tomography

PBM: Peak bone mass

Physical Activity (PA): Any bodily movement resulting in energy expenditure above the basal level. PA can bee seen as an umbrella term for human behaviour with multiple dimensions and sub categories such as exercise, sport, leisure activities, dance and transportation (30; 38; 266).

Physical Fitness: A set of attributes that individuals possess or achieve that relates to their ability to perform physical activities (52).

PAQ: Physical activity questionnaire

Race[1]**:** The term race attempts to distinguish one population or group of people from another. The most widely used human racial categories are based on visible traits (especially skin color, facial features and hair texture), genes, and self-identification (19). Throughout the thesis, 'Black' and 'White' are capitalised as has been suggested by Bhopal (2004) (26).

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[1] The word 'race' is used throughout the thesis and "…does not refer to any biological attributes but rather to the compulsory classification of people into the Population Registration Act" (21). Although the act has been repealed, these categories are still powerful and commonly used by the South African government and statistical services.

Ethnicity: An ethnic group is referred to a population of humans whose members identify with each other, usually on the basis of a presumed common genealogy or ancestry. Ethnic groups are also usually united by certain common cultural, behavioural, linguistic and ritualistic or religious traits (26; 270).

Socio-economic Status (SES): SES is typically a composite of measures such as occupation, education, income, type of residence, and access to certain amenities in the home (e.g., telephone, TV, motor car). For the purpose of this thesis, children's SES is regarded as that of their parents/caregivers.

Chapter 1

Introduction

Chapter 1: The Problem

This chapter presents an introductory overview and foundation to the thesis, a brief literature review is provided, as well as the justification and study aims.

1.1 Introduction

Osteoporosis is a disease characterised by a low bone density and deterioration of the structural quality of bone, leading to weakness and fragility, which results in an increased risk of fracture (137). Common sites for fracture are the thoracic and lumbar spine, femoral neck, distal radius, pelvis and humerus. Our understanding of the factors responsible for bone fractures in older adults is restricted by our limited knowledge regarding bone mineral acquisition during childhood and adolescence. A thorough understanding of the endogenous and exogenous factors associated with bone gain has implications for preventative health measures, since maximizing peak bone mass (PBM) protects against a later osteoporosis risk (48).

The morbidity and mortality, and their associated costs accompanying minimal trauma fractures have made osteoporosis a major public health problem in the developed world. Prevention and risk identification of this disease remain the most desirable way of managing it. It is suggested that maximizing the attainment of PBM during skeletal maturation is the best protection against a later risk of developing osteoporosis and a subsequent higher risk of fractures (131). Preventative strategies against osteoporosis must therefore capitalise on both the maximization of PBM, as well as the retardation of later loss of bone (139).

If age-adjusted incidence rates for hip fracture remain stable, the estimated number of hip fractures worldwide per year will rise from 1.7 million in 1990 to 6.3 million in 2050 (250). The extrapolated prevalence of osteoporosis and related conditions in South Africa in 2005 according to the US Census Bureau was 2,941,442 (±7% of the population) (296). The situation however is quite unique, in that South African Blacks have among the lowest hip fracture rate in the world. The age-adjusted hip fracture incidence is 50% lower in African American women than in Caucasian women (32) and what limited information there is, suggests that South African Blacks also have markedly lower hip fracture rates than South African White adults (253; 274). Very few of the factors influencing osteoporosis have been well studied between race groups. As lifestyle and dietary patterns change with urbanisation and there is a shift towards westernised diets and sedentary behaviour, fractures in elderly South African Blacks may become more prevalent. With these rapid lifestyle changes, it will become increasingly important to prioritise osteoporosis and its related conditions as a major public health concern in South Africa.

1.2 The Assessment of Bone Strength and Risk of Fracture

Fractures, occurring as a result of osteoporosis are events which can be measured. However, bone strength and the risk of fracture are not as easily established. The strength of bone is influenced by bone geometry, trabecular architecture, micro fractures and bone density. Of these characteristics, areal bone density (BMD) is the most easily measured and accounts for 60 to 80% of the variance in the ultimate strength of bone (65; 104; 239). BMD is therefore used as a surrogate measure of fracture risk and rate of bone loss in adults.

Several techniques, including Dual X-ray Absorptiometry (DXA) (43), quantitative computed tomography (QCT), peripheral quantitative computed tomography (pQCT) (108), micro quantitative computerised tomography (µQCT), ultrasound (188) and magnetic resonance

imaging (MRI) (322) have been used to assess bone geometry in humans and animals. The DXA technique has been widely used and is an acceptable method for assessing bone mass in children both for clinical and research purposes. This is chiefly due to DXA's high speed, precision, availability and low radiation exposure (94). DXA measurements are limited however because they do not measure volumetric bone density. By convention bone density measures are reported as bone mineral content (g) (BMC), area (cm) (BA) or areal BMD (g/cm^2). Areal bone density is however are highly influenced by body size and as a result DXA may overestimate bone mass in larger children and underestimate it in smaller children (14; 195). These are important considerations for bone mass research, particularly in children of different sizes. The World Health Organisation panel has used bone density to categorise osteoporosis in White postmenopausal women. Normal bone density as measured by DXA is defined as 1 standard deviation (SD) of the young adult reference mean (age 20 to 45 years); low bone density (osteopenia) is defined as -1 to -2.5 SDs below the young adult reference mean; and osteoporosis below -2.5 SD. Severe or established osteoporosis is defined as bone density below -2.5 SD in the presence of a fracture (323). It is estimated that a decrease in bone density of -1 SD is associated with a 1.5 to 2.5 fold increased risk of fracture.

Recent technological advances have seen the introduction and use of QCT allowing for the discrimination between trabecular and cortical components of bone and giving precise cross sectional information on the geometry of the bone (108). The use of QCT has helped circumvent the measurement artefacts of DXA by measuring volumetric BMD. On the other hand QCT exposes children to a higher dosage of radiation than DXA and published paediatric normative values for QCT are still limited at this stage (195). The use of pQCT is children is a promising prospect in future studies as the smaller gantry sizes of the device offer decreased radiation exposures with effective does similar to that of DXA.

1.3 The Importance of Peak Bone Mass

According to general engineering principles, the strength of a structure varies according to the square of its structural density (113). Bones of lower density will therefore break more easily. Peak Bone Mass (PBM) achieved by the third decade of life has been established as an important determinant of the lifetime risk of osteoporosis (13). The peak level of bone attained during skeletal growth and the subsequent rate of bone loss determines the bone mass of any person at any stage in adult life (57). Fehily et al. (1992) states:

> "the greater the PBM, the longer the period of bone loss that is required before the fracture threshold is reached" ((75), pg579).

Our lack of understanding regarding bone mineral acquisition during childhood and adolescence limits our knowledge with regards to bone mineral loss and skeletal fragility in older adults (16). Recognition of the importance of attaining PBM has led to a proliferation of paediatric bone studies. Studies have suggested that a low PBM may be a more important contributor to osteoporosis than rapid loss of bone during ageing (117).

A human foetus at full term contains 21g (range 13-33g) of calcium, which rises to approximately 1000g in the typical adult (95). Calcium accumulation is particularly intense during puberty (95), while approximately 500g (in women) is lost during ageing. Therefore the amount of calcium gained during growth is greater and more rapid than the amount lost during ageing. These findings suggest that PBM may be a more important contributor than bone loss, to the risk of osteoporosis later in life. Nevertheless several aspects of bone mineral acquisition during childhood and adolescence remain controversial (14).

The timing of the precise realization of PBM is disputed (10), although the childhood and adolescent periods have been identified as the most critical for skeletal mineralization (57). PBM is largely achieved at the end of the second decade of life (108), a few years after the fusion of the long bone epiphyses (195). There are number of factors influencing the attainment of PBM. Factors influencing peak bone mass accrual may be divided into those that may be modified, and those that may not.

1.4 Environmental Influences on Bone Mass

Among the many risk factors for osteoporosis, lack of physical activity may play an important role. Evidence that physical activity may be an effective strategy for the prevention of osteoporosis has been inferred from cross-sectional investigations of retired athletes, showing increased bone mass in those with a history of childhood weight bearing physical activity (18; 23; 173). Disuse and weightlessness of a limb are well known causes of considerable loss of bone mineral. Results from both rodents and humans after returning from space flight show that bone is lost at different rates from different sites of the skeleton (303). Conversely, bone mineral density in physically active people has been shown to be significantly higher than in age-matched non-active controls (271). Physical activity (PA) is increasingly being suggested as an adjunct therapy in the prevention and treatment of osteoporosis, particularly as it relates to postural stability and the subsequent prevention of falls (141). Bone consolidation may also be augmented by greater habitual physical activity.

A number of studies have shown mechanical loading to be the strongest modifiable factor to influence BMD (117; 139; 156). Weight bearing physical activity is an adjustable determinant of PBM accrual and is therefore targeted as an important area of research (130). The assessment and promotion of childhood physical activity is consequently advocated as one of

the most effective strategies for enhancing peak bone mass during childhood, thereby developing a stronger skeletal foundation in order to counterbalance age-related bone loss.

Physical activity is also essential in order to combat the growing obesity epidemic. Early lifestyle habits of physical activity should be established so that they can be sustained into adolescence and adulthood. There have been few studies that address habitual loading activities in healthy children and adolescents. Most studies relating to childhood physical activity and bone mass have been undertaken in elite sporting populations rather than the normal paediatric population and the results of these studies are therefore not applicable to normally active children (130). Cross-sectional studies generally report a positive association with mechanical loading and higher bone mineral densities, yet the long term effects of physical activity on bone mineral accretion in healthy paediatric populations are not fully understood (130).

Habitual physical activity behaviours and patterns are influenced by a number of external factors. These factors in turn have an impact on bone mass acquisition whether it is directly or through the effect they exert on physical activity patterns. Although we may commonly assume that physical activity is a normal part of childhood, a number of studies in developing countries have shown that children and adolescents are often very inactive (114; 287). In recent years, Western developed countries have positioned the promotion of physical activity in childhood and adolescence high on their agenda (294; 318). Developing countries however have not paid as much attention to this problem. In South Africa in particular, very little research has focused on physical activity patterns.

Socio-economic status (SES) has been identified as an important factor influencing physical activity participation (55). The current social and economic situation of South African

children and how this relates to children's physical activity patterns have not been examined. It is well known that children that come from low income families often have limited access to resources supporting physical activity (248). It has been found that habitual PA in childhood is related to maternal education levels (149). Studies have shown that the family has an important role to play with regards to a child's quantity of exercise through creating access to facilities and encouragement of team and sport class participation (193). Many physical educators and scientists believe children of active parents tended to more active themselves (84; 189). The influence of demographic factors such as gender, race and SES provide us with information on variations in physical activity levels and allow for the design and implementation of appropriate programs for different sub groups (248).

For many years the consumption of calcium in the diet has been linked to better bone health. Yet, there is little empirical evidence to show that this is the case. Recommended dietary intakes of calcium in developed countries such as the United Kingdom, Australia and the United States range between 350-800mg per day for children (228). In South Africa, the recommended daily intake of calcium for children is 500 mg per day. In a national food consumption survey conducted in 1999, less that 50% of South African children met this requirement (150). The justification to implement such recommended intakes in developed countries was to encourage a match between calcium intake and 'requirements' in order to curb the high rate of osteoporosis in later life (153). This might not be appropriate in South Africa, where Black South Africans have among the lowest fracture rates in the world (253; 274) .

1.5 Statement of Purpose

Definitive answers to questions relating to bone mineral accrual, mechanical loading and other physical activity patterns in normal South African children are required. No study

comparing habitual physical activity levels and their impact on bone mass has been undertaken on normal Black children compared to a geographically and age matched sample of White children living in South Africa.

Broadly, the purposes of the studies conducted for this thesis are:

- To develop a valid and reliable physical activity questionnaire (PAQ) for assessment of physical activity patterns in large numbers of South African children

- To determine whether there are racial differences in physical activity patterns and fitness levels in South African children

- To specifically explore the relationship between habitual physical activities, socio-economic status, dietary calcium intakes and bone mass status in pre and early pubertal South African Black and White children.

The information and knowledge gathered from these observational studies will provide new information on South African children living in an emerging economy regarding their physical activity patterns, SES and bone mass status. The majority of the data gathered for this thesis is based on observations made on a group of children involved in a longitudinal study. The findings from these data will contribute to the scientific literature and enable realistic conclusions regarding children living in post apartheid South Africa to be drawn up. Applicable and tailor made interventions and child health policy decisions affecting physical activity and bone health can be based on these conclusions.

Chapter 2

Literature Review I

Chapter 2: Literature Review I

This chapter explores the anatomy and physiology of bone, discusses measurement techniques used to determine bone mass, the concept of peak bone mass, as well as non-modifiable influences on bone mass acquisition during childhood. The review concludes with an introduction to the modifiable factors which may influence bone mass acquisition during childhood and these are expanded upon in Chapter three.

2.1 Introduction

Physical activity has been reported as the most pronounced lifestyle determinant of peak bone mass in children and adolescents (57). Over the course of the following two chapters (chapters two and three), this review aims to explore, in some depth the nature of the relationships between physical activities, lifestyle factors such as nutrition (specifically dietary calcium intake), socio-economic status, and bone mass acquisition in South African children. Pertinent research linking these associations will be examined and discussed. Methods used in past studies are described, and findings of these studies are highlighted. A critical review of the contemporary literature regarding physical activity, lifestyle factors and bone mass acquisition follows in chapter three.

The literature review for this thesis is divided into two chapters. This chapter (Chapter Two) will focus mainly on bone mass acquisition and the non-modifiable factors which play a role in skeletal development. The chapter will conclude with a brief overview of the modifiable influences on bone mass acquisition. Chapter three consists of an in depth focus and review on physical activity in children. Factors influencing physical activity patterns in children will also be examined. In particular, Chapter Three examines the role of physical activity and exercise with regards to bone mass in children.

2.2 Overview of the Anatomy and Physiology of Bone

2.2.1 Bone Histology

Anatomically, the skeleton can be divided into two parts: i) axial skeleton (vertebra, pelvis, skull, scapula-predominantly flat bones) and ii) appendicular skeleton (long bones of the arms and legs). Each long bone consists of two wider extremities called epiphyses, a cylindrical shaft (diaphysis) and a zone in between them (the metaphysis), both of which undergo modeling of the bone during growth and development. In a long bone that is growing, the epiphysis and metaphysis are separated by a layer of cartilage (epiphyseal cartilage or the growth plate). This layer of proliferative cartilage cells and expanding matrix is responsible for the longitudinal growth of bones.

Five types of bone cells regulate bone metabolism by responding to various environmental, chemical, mechanical, electric and magnetic stimuli. These include osteoprogenitor cells; osteoblasts; osteocytes; osteoclasts and bone lining cells. The differentiation of mesenchymal cells into osteoprogenitor cells and the eventual calcification of cartilage and bone matrix result in bone development (295). Osteoprogenitor cells occur in the endosteum, the inner surface of the periosteum and within the bone's medullary cavity and remain capable of mitosis. Osteoprogenitor cells are therefore stem cells that can divide and differentiate to produce osteoblasts.

Osteoblasts are bone-lining cells responsible for the production of bone matrix (collagen and ground substance). They are found in clusters of about 100-400 cells per bone forming site. The structure of the osteoblast (round distal nucleus and prominent golgi complex) allows the

cell to synthesize various proteins. Osteoblasts produce a layer of bone matrix called osteoid. Calcification of the osteoid layer begins about 10 days after its production. The plasma membrane of the osteoblast is rich in alkaline phosphatase (serum concentrations can be used a marker of bone formation), and has receptors for parathyroid hormone (PTH), among other hormones. PTH has a mediatory effect on amino acid transport, stimulates cyclic adenosine monophosphate (cAMP), and regulates collagen synthesis and binds to specific receptors (158). Osteoblast function is controlled by endo-, para- and autocrine factors. Osteoblasts also express steroid receptors for oestrogens and 1,25-dihydroxyvitamin D in their nuclei. Towards the end of an osteoblast's secreting period it becomes either a flat lining cell or an osteocyte.

Osteocytes are mature bone cells implanted in osteocytic lacunae. Osteocytes have long interconnecting processes, which permit them to form a complex network throughout the bone matrix (20). This organization enables the osteocytes to provide a means of communication required in the process of mechanotransduction. The role of osteocytes is thought to be responsibility for the detection of stresses in bone and control of the movement of ions in and out of the matrix. Osteocytes are phagocytized and digested with other components of bone during osteoclastic resorption. More than 90% of the bone cells in the mature human skeleton are osteocytes.

Osteoclasts are the cells responsible for bone resorption. They are giant, multinucleated (2-4 nuclei) cells, usually found in contact with a calcified bone surface and within a lacuna. On microscopy, a ruffled border and a ring of contractile proteins characterize osteoclasts. The integrin ring attaches the osteoclast to the bone surface and creates a sub-osteoclastic bone resorbing compartment. Synthesis and release of lysosomal enzymes and H^+ ions into the

bone-resorbing compartment occur. An acid environment is created, which dissolves the mineral and the secreted enzymes break down the demineralised collagen matrix.

2.2.2 Cortical and Cancellous Bone

Bone tissue may be divided into woven and lamellar bone. Woven bone (immature bone) consists of randomly arranged collagen in contrast to the uniform structure of lamellar bone. At birth, woven bone makes up all of the bone in the body, but is only found at sites of fracture healing in later years, or in response to mechanical loading, or under such states as Pagets disease. By the age of four years most of the woven bone has been replaced by lamellar bone consisting of collagen fibres arranged in the direction of lines of force enabling cortical bone to have anisotropic properties. Both woven and lamellar bone can be organized into compartments as either cortical (compact) or cancellous (trabecular) bone.

Calcified tissue comprises the external part of bone (cortex/compact bone). The cortex becomes progressively thinner towards the metaphysis and epiphysis where the internal spaces are filled with a network of thin calcified trabeculae (cancellous /spongy/ trabecullar bone). Maze like arrangements of horizontal and vertical interconnected plates ensure mechanical strength. Bone loss occurs more rapidly in this type of bone thereby increasing its vulnerability to fractures. Haematopoietic bone marrow fills the spaces enclosed by the trabeculae and is in continuity with the medullary cavity of the diaphysis. Articular cartilage, which does not calcify, covers the bone surfaces of the epiphyses (20; 137).

An important difference between cortical and trabecular bone is the way the bone matrix and cellular elements are arranged, resulting in different function. Approximately 80-90% of cortical bone volume is made up of mineralised bone. This is in comparison to only 15-25%

of trabecular bone volume. Trabecular arrangement allows bone marrow, blood vessels and connective tissue to be in contact with the endosteum, which has an active metabolic role. The main functions of cortical bone are for structure and protection. The two surfaces of cortical bone (endosteum and periosteum) are lined with osteogenic cells organized in layers. Endosteal cells are metabolically active and are involved in bone formation and resorption. The cambium layer of the periosteum contributes to appositional bone growth during bone development.

2.2.3 Bone Modeling and Remodeling

Bone modeling is an organized event that allows for bone growth and adjusts bone strength primarily through the action of periosteal osteoblasts depositing new bone on an extended surface area, without being interruption by osteoclasts (222). In general, modeling adds mass to the bone and refers to changes in the shape of the bone, while remodeling refers to an organized bone cell activity involving the basic multicellular unit (BMU). Remodeling replaces damaged or old tissue with an equal amount of new bone (80).In the first years of life, the removal and replacement of bone occurs at a rapid rate. Later on, in childhood, the rate of bone turnover slows down to 10% of the amount in the first year, and either stays at the same rate or decreases throughout life (250). Bone formation during childhood and adolescence mostly results from bone modeling, although bone remodeling continues in the background. Once bone growth ceases in early adulthood, an equal amount of bone is resorbed and replaced, so bone mass neither increases nor decreases, and bone shape remains much the same. During old age, the rate of remodeling increases and results in bone loss as osteoclasts remove more bone than osteoblasts replace.

2.2.3.1 Bone modeling transient

During bone remodeling, some BMU's are in the resorption phase, while others are in the formation phase. The bone remodeling transient is a temporary change in the balance between bone formation and bone resorption, brought about by any factor that affects bone remodeling (111). The remodeling space is the space where temporary loss of bone is occurring (±2% of the skeleton in adults). This bone is either temporarily absent or undermineralised and is not able to be measured using DXA. Therefore the greater the number of remodeling sites, the greater the underestimation of strength and bone mass by DXA. The importance of this phenomenon is often missed in intervention studies (80). Calcium for example inhibits bone resorption, thus during a calcium intervention study, there would be fewer remodeling spaces in the skeleton of subjects on higher calcium intakes. Thus as long as the new calcium intake is maintained, there would be an increased BMC. When the calcium intervention is stopped however, the bone resorption rate would increase again and result in a transient decrease in the amount of measured mineral (80). In order to determine the consistent effect of an intervention, factoring in the component of the change due to the transient out of the total bone response is required. Altering calcium intakes will always induce a remodeling transient, since calcium intake influences PTH secretion and PTH is the primary regulator of bone remodeling activity (111). These factors need to be taken into account in intervention studies and in studies which involve agents that reduce bone resorption (e.g. calcium, bisphosphonates or hormone replacement therapy (in postmenopausal women)) (110).

2.3 Measurement of Bone Mass

The pattern of skeletal growth during childhood and adolescence has been extensively studied using various techniques. The most debated issue in paediatric bone research centres on finding the most accurate technique for determining bone mineral status. The DXA technique

(introduced in the late 1980's) has been widely used and accepted as a preferred method for assessing bone mass in children both for clinical and research purposes. DXA instrumentation is currently more widely available in South Africa than other instrumentation used for measuring bone mass, and was used for all bone mass measurements conducted for this thesis.

The speed, precision, availability, low radiation exposure and ability of DXA to provide data regarding soft tissue composition as well as bone mineral has made it a popular method to assess bone mass (94). The accuracy of DXA measurements has been shown by studies which have examined the correlation between the DXA specified BMC value and ashed content of cadaver specimens (118; 159; 175). DXA also permits assessment of the whole body bone mass and bone mass at other important sites such as the lumbar spine, femoral neck and radius. DXA does not provide a separate measure of cortical and trabecular BMC, but rather a combination of both. By convention bone mass is reported as BMC (g) or areal BMD (g/cm^2). Expressing BMC per unit area provides a partial correction for bone size. BMD however is highly influenced by size and as a result DXA may overestimate bone density in larger children and underestimate it in smaller children (14; 195). Adjustment for body size is therefore important. DXA is unable to measure the depth of the bone and therefore a bone with a greater depth will be reported as being denser. The bone does not actually have a greater amount of bone within the periosteum; it is simply a larger bone (262). Figure 2.1 provides an example of the problem. If two bones, made of the same material but of differing sizes, are measured by DXA, the larger one will be measured to have a greater BMD than the smaller one, even though they have the same material volumetric density (137).

Longitudinal studies in adults making use of DXA measurements of BMD are useful since serial measurements in the same individual will reflect changes in bone mass, since size and shape of the bone are unlikely to change significantly over time in adults. However, the size and shape of bone varies considerably in children and adolescents, making it difficult to attribute changes in BMD to an increase in size, mass or density. Volumetric bone density is

useful for comparing children of different sizes because it adjusts BMC for overall bone volume.

	Block A	Block B
	1 cm	2 cm
Volumetric BMD (g/cm³)	1 g/cm³	1 g/cm³
BMC (g)	1 gram	8 grams
Bone area (cm²)	1 cm²	4cm²
Areal BMD (g/cm²)	1 g/cm²	2 g/cm²
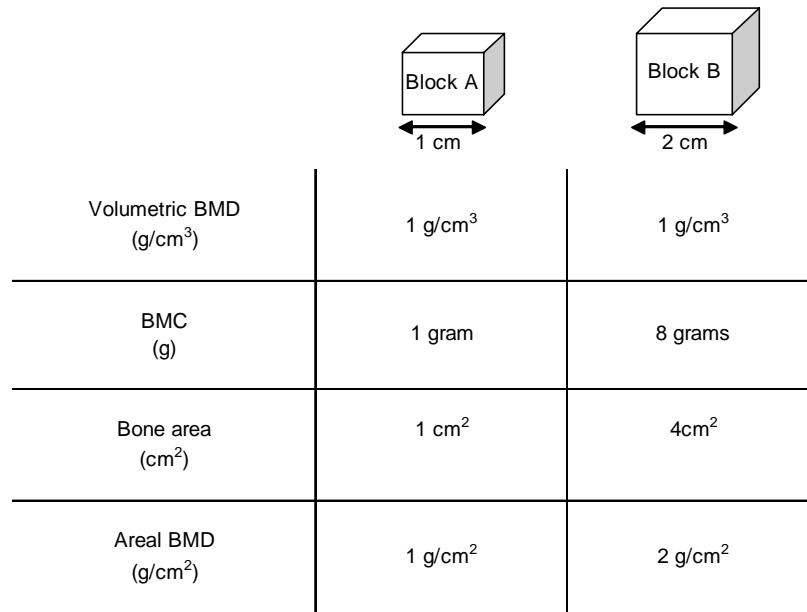
Figure 2.1 Schematic illustration showing the effect of bone size on BMD. Areal BMD measured by DXA is size dependant. The BMD of the larger bone cube (as measured by DXA) is double the value in the smaller bone, despite having the same vBMD. Source: Adapted from Khan et al. (2001), (137).

Recent technological advances have seen the introduction and use of QCT, which allows for discrimination between trabecular and cortical components of bone and gives precise cross sectional information on the geometry of the bone (108). QCT has not been widely used on the femoral neck site due to its complex geometry (137). The peripheral QCT (pQCT) scanner is a smaller more portable version of a QCT machine, and it is built specifically to measure density of the peripheral skeleton. Volumetric bone density can be used as an indicator of the bone's structural stiffness/strength. Avoiding the measurement artefacts of DXA by measuring volumetric density (g/cm³) directly is made possible with the use of the pQCT. On the other hand pQCT exposes children to a higher dosage of radiation than DXA (94), which is an important consideration in longitudinal studies or any study where repeat measurements need to be made on a child for serial comparison. Additionally published paediatric normative values for pQCT are still limited at this stage (195).

2.4 Peak Bone Mass

As highlighted in Chapter One, maximizing the attainment of PBM at the end of the growing years provides the best protection against a later risk of osteoporosis and a subsequent higher risk of fractures (14). Many studies have concluded that bone density reaches its peak by the age of 20 years (133; 145; 243; 269; 283), but there are others who have suggested that PBM is only attained between the age of 30 to 40 (225; 282). Nevertheless, the childhood and adolescent periods have been identified as the most critical for skeletal mineralization (57). Variations in the findings of these studies may be as a result of differences in study design, small sample sizes and different adjustments for maturational land marks.

Apart from the mass of the skull (which increases throughout life) (113), bone mass increases throughout childhood, reaching peak levels by late adolescence or early adulthood (figure 2.2). Once PBM is reached, osteoclastic bone resorption equals that of osteoblastic new bone formation (65). A longitudinal study conducted by Thientz et al. (1992) was one of the first to observe that DXA measurements taken over the period of growth indicate an increase in bone mass throughout childhood and a noticeable acceleration in accumulation at puberty (283). Figure 2.2 shows a graphical representation of bone mass changes with age. The increase in BMD that occurs following the onset of puberty has been confirmed by QCT (98; 195) and is mainly due to an enlargement in bone size but also due to a small contribution by volumetric density (195). Areal bone mineral density increases during the pre and early pubertal years due to the increase in size of long bones. Cortical volumetric bone density however, remains the same throughout life and is similar in males and females (137). Thus it is imperative that bone mass measurements are adjusted for bone size during growth, otherwise the impression that bone density is increasing will be obtained (97).
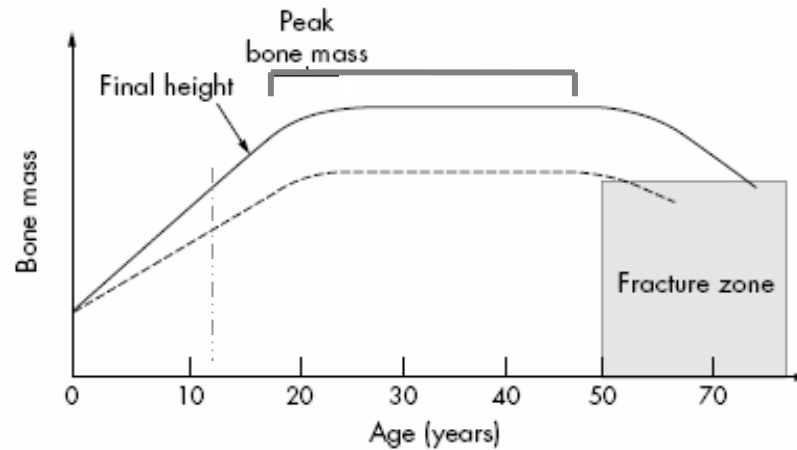
Figure 2.2 Schematic representation of the changes of bone mass with age as measured by DXA
The dotted line shows the theoretical consequence of a reduction in peak bone mass. The magnitude of the difference between the two curves is not intended to be to scale. Adapted from Heaney et al. 2000 (113) and Davies et al. 2005 (65)

There are number of factors influencing the attainment of PBM. These factors may act during intrauterine life, childhood or adolescence (58; 305). Factors influencing bone mass may be divided into those that may be modified, and those that may not.

2.5 Non Modifiable Influences on Bone Mass Acquisition during Childhood

Factors such as genetic make up, gender, race, hormonal status, parental smoking history, parity, chronic diseases, intrauterine life experiences, birth weight and length, and breastfeeding history are considered to be non-modifiable factors which may influence bone mass acquisition. This section of the review will focus on genetic determinants of bone mass acquisition as well as the influences of age, gender, race and hormones.

2.5.1 Genetic Determinants of Bone Mass

Familial and twin studies have shown that genetic predisposition accounts for up to 80% of PBM, and the remaining 20% is modulated by environmental factors and sex hormone levels during puberty (104; 137). BMD has been found to be reduced in daughters of osteoporotic

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women (263). A paradox in the literature regarding the genetic determinants of bone mass is evident in studies which have attributed more than 100% of the variance in BMD to the sum of genetic and environmental factors. Some have estimated that physical activity and calcium intakes account for 40% of the variation in BMD (214; 316) while others have stated that heritability accounts for 80% of the variation in BMD (65; 104). Khan et al. provide examples and explain this apparent contradiction by giving three situations: 1) a gene-environment interaction (e.g. if genes determined a persons lifestyle choices); 2) an environment-environment interaction (e.g. people doing more physical activity also had higher calcium intakes); or 3) a common set of controlling genes for BMD and factors such as lean muscle (which could also be considered as a lifestyle category) (137). A large number of candidate genes have been implicated to be responsible for determining bone mass (for example: Vitamin D receptor (VDR) gene; oestrogen receptor (ER) gene; apolipoprotien E4 gene; interleukin genes; the parathyroid hormone receptor gene; collagen genes). Polymorphisms of many of these genes have been suggested to influence bone mass, but the size of the effects of most of these polymorphisms on bone density in childhood have not been evaluated.

2.5.2 Age, Gender and Racial influences on Bone Mass

Data from the University of Saskatchewan Paediatric Bone Mineral Accrual study (16; 17; 82; 83) provide comprehensive data from a seven year period of velocity curves for bone mineral accrual rates in male and female children living in a developed or first world country. Data from this study showed that after controlling for size differences males accrued more bone at PBM and during the two years around this period than females. Another finding from these data showed that there is a lag period between the time of maximum growth in height (peak height velocity) and PBM accrual, with PBM being attained approximately six to twelve months after the timing of peak height velocity for both genders (Figure 2.3) (18). This lag

period has been shown to partly explain the increased fracture incidence noted around this time in adolescents (268). It should be noted that data from this study were largely based on Caucasian children; data such as these are limited for other race and ethnic groups. Peak height velocity occurs at approximately 12 years of age in girls (317). By the time girls reach menarche at approximately 12.7 years of age, their skeleton is within 97% of its final height; and adult height is usually attained within 2-3 years after this period (22). In boys, peak height velocity occurs approximately two years later, resulting in an additional gain of 10cm in height during the childhood period of growth. The sexual dimorphism of skeletal growth results in a mean 13cm difference in adult height between men and women (95).
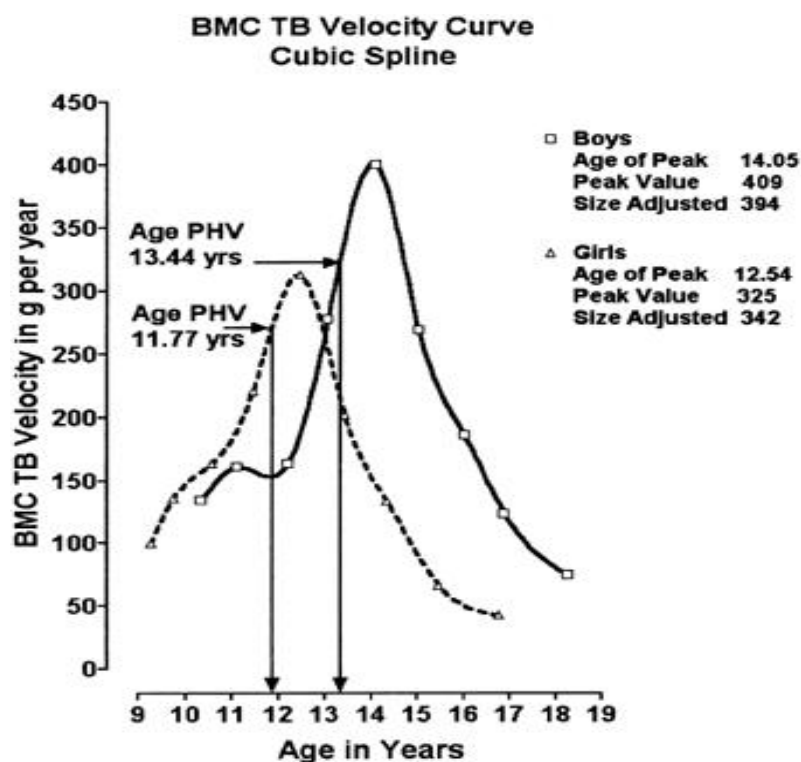
Figure 2.3 The disassociation between whole body BMC and peak height velocity in the University of Saskatchewan Bone Mineral Accrual Study. Reproduced from Bailey et al. 1999 (18).

Peak BMC is approximately 10% higher in males. It is not clear at what age these gender related differences become evident. In 2000, Armstrong et al., reported that young men tend to accrete bone until the age of 22 years, several years after cessation of linear growth, thereby providing an opportunity to maximize accretion of bone during the late teen and early adult period (10). Reports in the literature have been inconsistent. Gilsanz et al. (1997) using

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QCT measurements and Theintz et al. (1992) using DXA measurements have reported that there are no gender differences in lumbar spine BMD during the pre-pubertal years (97; 283) while others (using DXA) have found a higher BMD in girls (128; 145). A large longitudinal study conducted by Nelson et al. (1997) indicated that while there were no significant gender differences in whole body measurements at ages nine and 10, results for the lumbar spine region were greater in females than males (194). The inconsistencies are also found for other sites measured such as for the femoral neck BMC, where some pre-pubertal studies have shown males to have a higher femoral neck BMC than females (74; 146) and others have not (328). Maynard et al. (1998) report that up until the age of 13 years whole body BMC increases are similar in girls and boys, after which boys show sharp increases in BMC, with girls only increasing slightly. Maynard et al. (1998) also state that whole body BMD values do not differ significantly between boys and girls before the age of 15 (174), however these data were not corrected for size or maturity differences. Nguyen et al. (2001) showed that there were no sex differences in BMC or BMD pre-pubertally, although females had significantly higher BMD of the pelvis and BMC and BMD of the spine during puberty (197).

Most studies mentioned above have compared gender groups by chronological age and failed to control for confounding factors such as maturity and body size differences. It is therefore likely that some of the differences observed could be attributed to differences in maturation rates, which are known to be different for males and females. The results presented may therefore simply be a reflection of differences in rates of growth. Differences with respect to body size adjustment techniques are also evident in the literature. While some authors present BMC data, others report BMD data. As mentioned earlier, BMD is a two-dimensional measurement of the amount of bone, in a three-dimensional structure. Thus, adjusting BMC for body and bone size differences can provide insight into the effect bone size has on BMC accrual during growth. Some studies have taken these growth differences into account.

Subjects' data from the University of Saskatchewan Paediatric Bone Mineral Accrual Study (16-18) were aligned with the same maturational land mark - peak height velocity. Where peak height velocities are not available, adjustment for maturity using skeletal age and Tanner staging can also be made.

Studies that have measured pre-pubertal changes in BMC and have adjusted BMC for bone and body size have shown that BMC increases in proportion to the enlarging length and depth of the bone (74; 98). Data from these studies suggest that gender related differences in bone and body size may account for the observed differences in BMC during the pre pubertal period.

Race implies that a particular population has genetic similarities. One of the first studies to observe race differences in bone mass was conducted in the early 1970's. Choi and Trotter (1970) reported that Black foetuses had longer and heavier bones than their White counterparts before birth (54). Since this study, others have corroborated these findings and the prevalence of osteoporosis and fracture occurrence is now known to be lower in Black than in White subjects worldwide (99; 163; 184). What is not known is to what degree racial differences are present in childhood. Bachrach et al. (1999) recommend the use of race and gender specific standards for the interpretation of paediatric bone densitometry data (14). In their study comprising of subjects aged between nine and 25 years, it was found that African Americans had greater mean BMD and bone mineral apparent density (BMAD) than White Americans at all sites. Bachrach and colleagues (1999) and others have observed that depending on skeletal site, age and gender, African American youths have between five to 23% greater bone mass than Whites (98; 99; 194; 306). A more recent finding in South African children, that bone mass at the femoral neck, total hip and mid-radius is greater in 10-year-old Black children than White children (304) is consistent with findings from the USA

(14; 306), but in South African children no differences were found at the spine or distal radius. These data are of particular interest as Black South African children are exposed to many environmental factors known to impact negatively on bone mass. These include living under poor socio-economic conditions, compromised growth (lower birth weight, shorter stature and later onset of pubertal development) poorer nutrition patterns, and less physical activity (181-183; 304; 305). Additionally there are clear race and gender differences in the growth of axial and appendicular skeletons in pre pubertal children. This has been observed in both South African (202) and children from developed countries (99; 170; 261), suggesting that these patterns are more genetically than environmentally influenced.

Biro et al. (2001) found that African American girls had a mean age of menarche of 12.0 years, whereas White girls began menstruating at 12.7 years (28). Early maturation has implications for height and weight, which in turn have inferences for bone mass. While studies of childhood differences between race groups are scarce, a few adult studies have confirmed that Black Americans and South Africans have greater BMD at the proximal femur and that Black Americans have greater BMD at the lumbar spine than Whites (7; 64). Currently, there has been only one study which has compared whole body BMC of Black, White and mixed ancestral origin children from the USA and South Africa Whole body BMC was found to be lower in children of European ancestry compared to African ancestry and South African children had significantly higher whole body BMC compared to their US peers (187).

The pre-pubertal years represent a time of large increases in BMC, contributing to almost half of total peak BMC. There are discrepancies in data regarding males and females, Blacks and Whites and whether or not they accrue a similar amount of bone during the pre-pubertal years. Whether these differences can be attributed to bone size, genetic make up or environmental factors remains to be determined.

2.5.3 Hormonal Influences on Bone Mass

The endocrine system is highly involved in the regulation of bone metabolism and growth. During childhood, the major systemic hormones involved in skeletal development are: growth hormone (GH), insulin-like growth factor 1 (IGF-I), oestrogen and androgens (50; 226). The pre-pubertal years consist of the period of growth from birth until the end of Tanner stage 1 (approximately age 10 in girls and 12 in boys). Levels of GH and IGF-1 increase dramatically during puberty and are augmented by the increasing levels of sex steroids (65). Increases in IGF-I levels have been shown to parallel increases in BMC during growth, suggesting a relationship between IGF-I and BMC accrual (129; 319). Mora et al. (1999) reported that IGF-I levels are the best predictors of cross-sectional bone area at the femoral mid-shaft (190). Growth hormone action on bone is mainly mediated through IGF-1, which stimulates osteoblastic activity and also acts directly on the division of chondrocytes on the growth plate (65). Children, who are GH deficient, have been found to have reduced bone size and a lower bone density than healthy age matched peers (21). Bachrach et al. (1998) found normal bone density, but smaller bones in adults with who were GH deficient as children and had low IGF-I levels (15).

Sex hormones such as testosterone and oestrogen also play an important role in skeletal development during puberty and a strong relationship between GH, IGF-I and these hormones exists. New bone formation around puberty is aided by the anabolic effects of the sex hormones on bone accretion (283). Between seven and eight years of age, the secretion of androgens increases, associated with an increase in height, known as the mid-growth spurt. Sex hormones act in synergy with GH and IGF-I during puberty to induce a growth spurt in height and BMC (327). The oestrogen-related increase in GH and IGF-I appears to be the main mediator of the increases in linear growth and BMC during puberty in boys and girls

(61). While the role of hormones in BMC accrual is not completely understood, it is known that during the pubertal period, oestrogen has important effects, not just by increasing volumetric bone density but also by decreasing bone modeling at the endocortical surface by suppressing bone resorption leading to an increase in cortical thickness (307).

2.6 Introduction to Modifiable Influencers on Bone Mass Acquisition during Childhood

Peak bone mass is principally determined by genetic factors and over the past decade, researchers have pursued genetic approaches to understanding the basis of skeletal fragility (31). However, recent prospective trials have begun to lend strong support for the contention that lifestyle factors such as weight bearing physical activity, muscle strength and nutrition can augment bone mineral in the growing skeleton (23; 191), accounting for approximately 20% of the variation in PBM (14; 57). Additionally genetic markers which have been implicated in osteoporosis risk have been shown to account only for a small proportion of variance in bone mass and fracture risk (58). Owing to the fact that bone mineral acquisition at all sites occurs reasonably early in life, exogenous modifiable factors favouring the attainment of PBM need to be more precisely identified and characterized (173).

Nutrition, in particular adequate calcium intake, is considered a lifestyle factor necessary for good bone health and much of the literature in the past focused on this association. Calcium, the most common mineral in the body, is present in all foods we consume and high dietary intakes during childhood and adolescence have been associated with an increased PBM (47; 65; 113). Conversely, low calcium intakes of approximately 300 to 400mg per day as reported in data from developing countries, have been shown not to have immediate deleterious effects on the skeleton in children (113). This has not been the case in reports from developing countries where children with daily dietary calcium intakes estimated at approximately 200mg

per day presented with rickets in the face of normal serum 25(OH) Vitamin D concentrations (73; 210). Vitamin D is vital for the transport and absorption of calcium through the gastro-intestinal system (113). The human body cannot store a dietary surplus of calcium, thus it is termed a threshold nutrient, i.e. effects accrue up to a threshold intake value, after which no additional benefits are observed with increasing intakes (112). Threshold intakes in children have been reported in the literature (123; 172).

Low dietary calcium intakes have traditionally, in adults, be thought to produce osteoporosis through secondary hyperparathyroidism and an increased bone turnover (210). In Africa, the prevalence of osteoporotic related fractures has been documented to be lower than prevalence rates reported in the USA and Europe, despite habitual calcium intakes which are routinely lower than recommended daily intakes in Africans (211). A comprehensive meta-analysis conducted by Winzenberg et al. (2006), assessed whether calcium supplementation was effective in increasing BMD in healthy children. In the 19 studies that the investigators included in the review, comprising 2859 children, calcium supplementation was found to have no residual positive effect on BMD at any site measured, except for a small effect which was noted at the whole body and upper limb. Additionally, there was no evidence to show that the effect of calcium was modified by gender, baseline calcium intake, pubertal stage, race groups or level of PA (321). Winzenberg and colleagues (2006) concluded that alternative nutritional interventions such as Vitamin D, fruit and vegetables be explored in children. While this was a well conducted review, it is important to note that using BMD as an outcome variable might not necessarily account for the effect that calcium supplementation may have on bone size, as has been demonstrated in other studies (33; 216). Be that as it may, these and other studies which have documented increases in bone mass with calcium supplementation (35; 105; 160; 238), have not been able to show that benefits are maintained after withdrawal of the

supplement. There have also been reports of no association between calcium intake and bone mass (133; 145).

The effect of the bone remodeling transient as highlighted earlier in this review is often missed in intervention studies. True effects of any nutrition supplementation can only be established by measurements made after the bone remodeling transient has passed (111). One follow up study conducted by Bonjour et al. (2001) three and a half years after a calcium intervention, did document sustained bone mass accrual benefits after calcium supplementation had stopped (34). Nevertheless, the calcium supplementation used in Bonjour et al.'s (2001) study was a milk supplement and therefore also contained phosphate and protein. In a randomized controlled trial by Specker and Binkley (2003), a significant increase in cortical thickness and bone area was observed in children whose diets were supplemented with calcium and were involved in a gross motor PA program (275). A follow up to this study conducted 12 months later revealed that children, who were randomised to the gross motor PA program, maintained a greater periosteal circumference even after the calcium supplementation and physical activity intervention had stopped. It is possible that this was due to the fact that children who were involved in the gross motor physical activity program continued to be more physically active of their own accord compared to those children who were assigned to a fine motor activity group, therefore its is not known whether the maintained bone mass effect was due to the residual effect of activity program or continued increased levels of PA (27).

It therefore appears that the effect of calcium supplementation in normal healthy children over and above usual daily intakes has a marginal effect on bone mass. The effect observed in intervention studies is more likely to be a transient effect on bone mass which is unlikely to be maintained after the intervention has stopped.

Weight bearing physical activity is a modifiable determinant of PBM and is therefore increasingly targeted as an important area of research. Many investigators agree that it is during the growth phase that the skeleton may be most responsive to exercise (106; 117; 132; 165; 269). Physical activity during early childhood and adolescence is an important predictor of PBM (65). The positive relationship between physical activity and bone mass has been shown in studies which have mainly been conducted in developed countries. Developing countries such as South Africa are faced with different challenges and obstacles to those found in the developed world. These challenges include massive differences in socio-economic status between population groups, poor access to health care, poor nutritional intakes and compromised growth patterns. These burdens present a major public health challenge. Intensive efforts to promote healthy lifestyles are desperately needed as has been pointed out in a recent review of risk factors related to diseases of lifestyle in Black South Africans (42). While physical activity and dietary habits may both be considered to be modifiable factors, children are able to exert a greater degree of control over their physical activity habits than their diet and socio-economic status.

While many conclusions drawn from studies conducted in the USA and Europe are clearly applicable to a South African population, others are not. There is a paucity of literature on South African children's physical activity patterns, dietary habits and bone mass accrual. Further understanding of the factors affecting PBM accrual and the timing of the achievement of PBM is necessary for the improved understanding and development of preventative strategies against osteoporosis.

2.7 Conclusion

This chapter has examined the literature with respect to the composition and structure of bone. It has highlighted the advantages and limitations of different methods of assessing bone mass.

The importance of attaining a high PBM was underlined along with the non-modifiable factors which may influence the process of bone mass acquisition during childhood. The chapter concluded with an introduction to the modifiable factors influencing bone mass acquisition, physical activity in particular will be expanded upon in Chapter Three.

Chapter 3

Literature Review II

Chapter 3: Literature Review II

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This chapter examines the modifiable influence of physical activity on bone mass. Physical activity as a concept is reviewed; its assessment and the factors which may influence physical activity patterns and their relationship with bone mass are discussed. The review concludes with a summary and critique of existing literature, followed by a brief discussion of specific research questions and hypotheses suggested by this review.

3.1 Introduction

Physical activity can be seen as an umbrella term of human behaviour with multiple dimensions and sub categories such as exercise, sport, leisure activities, dance and transportation (30; 38; 266). Many people link being physically active to rigid organised activities and do not consider enjoyable informal activities such as playing cricket with the family as physical activities (37; 124). Current epidemiological research into the link between disease and physical inactivity concerns "habitual physical activity"- activity performed on a regular basis (37). Habitual physical activity comprises activity at work, around the home, during leisure time and as a mode of transport (30; 37; 266). Little energy over and above resting metabolism is expended during sleep thus sleep is not a form of activity. However it is important to account for the inactive period associated with sleep for research purposes as most people spend at least six hours a day sleeping.

Physical activity research is particularly sparse for those living in developing countries such as South Africa. We know very little about racial differences in these countries, particularly with regards to physical activity levels, bone mass, body composition and obesity. Although the prevalence of obesity is higher in developed countries (164), it is nevertheless a serious

emerging problem in developing countries (71). Other chronic diseases of lifestyle, such as diabetes and hypertension are also increasing, but little is known about the changing prevalence of osteoporosis and fragility fractures in developing countries.

3.2 Assessment of Physical Activity

Growing interest in the study of physical activity and its relation to various health outcomes has been reflected by the proliferation of a variety of self report measures of physical activity. Determinants of physical activity participation, activity patterns of the population and the relationship between health, disease and physical activity may all be described with the use of physical activity data (37).

Due to the random nature of habitual physical activity, it is difficult to assess. Assessments performed in the laboratory may not adequately reflect natural behaviour. Field studies are thus more representative of normal conditions. However, studying activity in an uncontrolled natural environment presents challenges. Physical activity may be assessed directly or indirectly (219). The direct measurement of activity is more accurate and objective and includes the use of doubly labelled water (56); heart rate monitoring via telemetry (25; 219); oxygen consumption; and activity measurement by activity monitors such as pedometers and accelerometers which measure the number of steps or movements (counts) during a specific time period (265). A drawback to measuring activity directly is that behaviour may be altered during the study due to the setting, design of the experiment, invasive nature of the direct observation or interference of natural movement by the equipment. Much of the equipment needed for direct physical activity measurement is expensive and difficult to administer to a large group of subjects. A favourable method is the use of activity monitors which are relatively small devices that can easily be attached to a waistband or strapped to the wrist or ankle. Due to their limitations, direct measures of physical activity are mainly used when

sample sizes are small, or to validate indirect activity methods. In large samples or population studies, indirect activity measurement is more practical. Logging methods such as diaries, logbooks, and physical activity questionnaires (PAQ) are the most commonly used methods used to assess activity indirectly (56).

3.2.1 Physical Activity Questionnaires

Questionnaires are the preferred method of indirect habitual physical activity assessment in large studies (151; 219). Major characteristics of PAQs that favour their use in studies with large sample sizes include the low cost of producing and administering the questionnaires, the relative simplicity of administering the questionnaire and their applicability of use in any setting and their validity in terms of measuring activity (29).

The Harvard Alumni Activity Survey conducted by Paffenberger (1978) remains the most recognised physical activity questionnaire study (204). Paffenberger's questionnaire focused on two domains of activity: activity: as a mode of transport and leisure time activity. Activities within each domain may vary between population and country. For example, walking several kilometres to school is less likely in a developed country, but more likely in developing countries such as South Africa. Hence, questionnaires must be carefully designed for use in a specific population (311).

Although data from a South African population are limited, results from the first National Risk Behaviour Survey conducted in 2002, indicate that less than one third of South African children aged 13 to 19 years old, participate in sufficient (defined as participation in activities such as soccer, netball, rugby, basketball or running for 20 minutes or more on at least three of the seven days preceding the survey) physical activity on a weekly basis (227). A greater

percentage of Black youths (37.5%) were found to be insufficiently active compared with White youths (29.4%). Currently there has only been one study in South Africa in which the authors have made use of a historical physical activity questionnaire, and reported on lifetime physical activity in relation to bone mass in non-Caucasian women. This study was conducted in a South African group of Black and mixed ancestral origin women and found that indeed physical activity during childhood and adolescence is related to BMD in later life in these race groups (186).

3.2.2 Questionnaire Design

Currently, there is no standardised method for designing questionnaires and they are therefore available in several formats. There are basic design characteristics which vary from questionnaire to questionnaire. These include: method of administration; questionnaire length; length of assessment period; domains assessed within the questionnaire; aspects of physical activity assessed (type, intensity, duration); scoring protocol; validation method and repeatability testing.

A domain is a broad category into which several activities taking place in the same environment or serving a particular purpose can be grouped (37). In order to obtain an accurate representation of activity habits, most physical activity questionnaires assess activity in every area of daily life rather than studying domains in isolation. Activities within each domain can vary from country to country and as a consequence questionnaires must be designed carefully to ensure that activity is appropriately assessed within a particular context. Most questionnaires are designed for use in a specific population (310), or a population sub group for a specific purpose. Modification may involve translation of the questionnaire (62); including culturally relevant examples of activity (4; 62) and age relevant activities (320).

3.2.3 Methods of Administration

Administration of physical activity questionnaires generally takes two forms: by self completion or by an interview conducted over the telephone or face to face (62). Self completion of questionnaires very often depends on age, literacy and language ability of respondents. When participants are interviewed, queries can be addressed immediately by the interviewer provided the interviewer and participants are able to converse. Additionally, interviewer administered questionnaires are considered more appropriate in rural settings where subjects may not have access to mail or where such systems may be unreliable and subjects are more frequently illiterate. However, it is essential that interviewers undergo extensive training in order to learn how to ask questions properly, prompt participants where necessary, clarify answers and extract relevant information (242). Intra- and inter-interviewer error also needs to be tested if more than one interviewer is being used for the same sample of participants. Differences in interviewing style may affect some answers obtained from respondents. The best method of administration for physical activity questionnaires depends largely on the research design and the objectives the study is trying to achieve.

3.2.4 Questionnaire Length

Time constraints are one of the main determinants of the length of a questionnaire. Attempts have been made to shorten questionnaires to as little as one question (313). It is important to note that the length of a questionnaire does not necessarily reflect its ability to assess activity accurately. Literature generally concludes that it is the logical order of the questions, not the length of the questionnaire that ultimately determines its validity as a physical activity measurement device (124).

Questionnaire length largely depends on what the researcher is trying to assess as well as the study sample in question. Physical activity questionnaires may be better at providing crude or proxy estimates of physical activity behaviours in children rather than providing absolute values. Questionnaires are especially useful in large longitudinal studies, where subjects can be 'ranked' or categorised into varying activity levels, depending on their responses. Currently there are no agreed guidelines on PAQ design; this is an area needing to be addressed in the literature.

3.2.5 Length of Assessment Period

The length of the assessment period depends on the purpose of the questionnaire and may range from the past 24 hours to the past season, year or lifetime (1; 30; 62; 124; 232; 247; 310). Shorter assessment periods usually assess current behaviour whereas extended periods of assessment would assess long term behaviour patterns. If the purpose of the research is to track changes or to observe trends in activity patterns over time, yearly assessments are common practice. Alternatively if a group of participants is exposed to an intervention or a new physical activity routine, a shorter assessment may be more useful.

Again, deciding on the length of the assessment period that a PAQ should cover will largely be determined by the research objectives. It is important to decide on the length of assessment period and the reasons for using that period, before using a physical activity questionnaire.

3.2.6 Type, Intensity, Duration of Activity

The most commonly assessed aspects of physical activity are frequency, duration and intensity (62; 124; 247). Frequency is usually assessed as days per week, weeks per month and months per year. Seasonal variations in frequency of activity are an important aspect to consider as many sporting activities are seasonally based. Activity duration is either calculated as the total number of minutes spent in activity over an entire day (266), or as the number of bouts of activity lasting longer than a specified period. Reporting of duration of activity (bouts or minutes) is an important consideration when providing activity guidelines to the public. Intensity of activity is the most difficult attribute to assess as very often it is subjective. Questionnaires may ask the participant to rank their own intensity (easy- very hard) or may make use of intensity thresholds to categorise activity when analyzing responses (220).

Since exercise has been shown to have a dose response effect on health, it appears that activity must occur above a certain threshold for maximal health benefits to be observed. With respect to bone mass, results of animal studies have shown dose response relationships between strain magnitude and BMC (236). Thus, type, intensity and duration of physical activities are important considerations.

3.2.7 Scoring Protocol

It is well established that a direct connection between work or activity intensity and energy expenditure via metabolic processes exists for physical activities in which the weight of the body is moved around (5). Intensities of activities can be classified as multiples of one MET or the ratio of the associated metabolic rate for the specific activity to the resting metabolic

rate (RMR). One MET is defined as the energy expenditure for sitting quietly, which for the average adult is 3.5 ml of oxygen.kg body weight^{-1}.min^{-1} or 1 kcal.kg^{-1}body weight.h^{-1} (3; 4). For example a 4-MET activity (e.g. walking briskly) requires four times the metabolic energy expenditure of sitting quietly. MET values are multiplied by the hours reported by the participant, spent performing each activity and the products are summed to give total kcal.kg^{-1}.day^{-1}. This value can be used to quantify the amount of physical activity reported independent of body size. This figure can be multiplied by the body weight in kg to arrive at an estimate of total energy expenditure.

Ainsworth et al. (1993 & 2000) have developed a Compendium of Physical Activities to facilitate the coding of physical activities as well as to promote comparability of coding across studies (3; 4). Each activity reported by a subject can be coded by function, specific type and intensity. The Compendium can be used for epidemiological and clinical purposes by allocating a MET score to every activity indicated in the questionnaire. MET scores are then summed for each category or domain of assessment and a total MET score (hereafter referred to as METPA (summed MET score)) can be allocated to each subject for the period on which they are reporting.

Resting metabolic rate varies with age, weight, height and gender and presents a limitation to using MET scores (3; 25; 219). Additionally Ainsworth's Compendium scores are based on adult resting metabolic rates, and therefore have limited use in assigning absolute values in children. Nevertheless as mentioned earlier, METPA scores can be assigned to rank subjects according to activity levels. This is useful in large studies involving children, where indirect observations of physical activity are made. The purpose of a MET score should be seen to provide an estimate of energy expenditure, and not necessarily a fixed absolute value.

When PAQs are used for bone research, a mechanical physical activity (MECHPA) score can also be calculated to measure the mechanical components of physical activity from the responses provided. The score is based on the concept that bone adapts to the loads applied to it. A concept largely based on 'Wolff's Law' which has recently come under scrutiny and some researchers have suggested that the term be changed to *bone functional adaptation* (237). Groothausen et al. (1997) developed peak strain scores for a variety of activities based on the ground reaction forces of different physical activities (103). In their study, it was hypothesised that activities with a high peak strain (higher loads, fewer repetitions) would have a greater effect on bone mass than activities with higher repetitions and lower loads. This hypothesis was based on observations made from animal experiments (154; 155; 235) which have shown that that bone's osteogenic response to loading is a response that becomes saturated. The crucial factor in the stimulation of bone therefore does not appear to be the number of loads, but rather the effect of the load magnitude (103). Groothausen et al. (1997) assigned all activities that involved jumping a peak score of 3; activities with explosive actions such as turning and sprinting received a score of 2; weight bearing activities received a peak score of 1 and all other activities received a peak score of 0. Their study, did not take into account frequency and duration of activities, but did report a significant and positive relationship between the peak strain score during adolescence and adulthood and lumbar spine BMD at age 27 years.

In a similar manner to calculating METPA scores, a MECHPA score can also be calculated from a PAQ. This can be done by multiplying the peak bone strain scores (developed by Groothausen et al. (1997)) by duration (hrs/wk) of activities recorded by the subject. Kemper at al. (2002) validated their PAQ to measure the effect of mechanical strain on bone mass and concluded that MECHPA scores (mechanical components) are more important than METPA scores (metabolic components) for the healthy development of bone mass (134). A

significantly positive relationship between MECHPA scores and BMD at weight bearing sites (lumbar and hip BMD), but not wrist BMD (non-weight bearing) has been observed (135; 277).

3.2.8 Validation and Repeatability of Questionnaires

The accurate and detailed measurement of physical activity is a crucial prerequisite for exploring its relationship with health and disease. There are numerous methods to measure physical activity in both short and long term research, but their applicability varies greatly in epidemiological and observational research. The most common method of physical activity measurement- questionnaires, allows for low subject burden and cost, qualitative and quantitative information, and quick administration (29). Limitations to PAQs include erroneous recall of time, intensity or frequency of activities and deliberate misinformation. While researchers acknowledge that children may have difficulty in recalling their physical activity, PAQs are popular in epidemiological studies. A PAQ needs to be able to elicit the same valid information from a subject on more than one occasion. In general, correlation between repeated questionnaire administration has been shown to be high (1; 310; 311), indicating that questionnaires are a reliable measure of activity.

There is no current 'gold standard' against which to validate physical activity questionnaires. All physical activity assessment techniques offer their own advantages and disadvantages. In general, METPA scores are compared and correlated with a direct measure of energy expenditure, such as oxygen consumption, activity monitoring or heart rate monitoring (266). Others have compared METPA scores with indices of fitness (124; 310). Physical activity and physical fitness are terms that are often used interchangeably in the sense that subjects who report being more physically active would be assumed to be physically fitter. This is not

always the case. Common measures of physical fitness include body fat percentage, body mass index (BMI), maximal oxygen consumption (VO_2), flexibility, run tests of a specified distance, and number of sit ups performed in a specified time. Validation studies performed in children and adolescents that have compared PAQs with heart rate monitoring, accelerometry and other physical activity measures, have in general shown good validity of PAQs (1; 6; 36; 244; 286).

3.2.9 Current and Future work with Physical Activity Questionnaires

Under the guidance of the World Health Organisation, researchers worldwide are currently involved in a collaborative effort to devise a suitable questionnaire which will be able to assess all domains of activity in all population groups. The first such questionnaire, devised in the late 1990's (International Physical Activity Questionnaire) has been used (324) and tested in a South Africa population (62). The questionnaire's short form has been reported to overestimate activity, the long form was found to be too complex (66; 242). Currently, a questionnaire called the Global Physical Activity Questionnaire (GPAQ) is being tested and validated in several populations (66). If the GPAQ is proven to be an acceptable measure of activity in diverse populations, it will make the comparison of physical activity results between studies possible. There is however some reluctance to covert to the Global Physical Activity Questionnaire due to the incompatibility of future data with past findings (241). Nevertheless, the advantages of having one standard physical activity questionnaire assessment could in certain situations outweigh the disadvantages associated with the loss of past physical activity data.

3.3.1 Accelerometry -An Objective Physical Activity Measure

Accelerometry based devices have been used for over 30 years (29). The Caltrac Personal Activity Monitor (Muscle Dynamics, Torrence, CA) was the first accelerometer or activity monitor to be validated for research purposes (245). There is now a number of different activity monitoring devices available to researchers. The Actical accelerometer (Mini-Mitter; Bend, OR) is currently the smallest accelerometer available and has been validated against other measures of physical activity (115; 219; 220; 314) and other accelerometers (314), and has been used in children as young as three years of age (212).

Accelerometers are a useful tool for the classification of levels of physical activity in children (220). They can be worn continuously for an extended period of time. Accelerometers measure body movement in terms of acceleration (the rate of change of speed), which can be used to estimate PA levels over a specified time. Accelerometers are able to do this with the use of a piezoelectric sensor which detects movements in three planes (medio-lateral, antero-posterior, and vertical). The piezoelectric sensor consists of an element and a seismic mass which is stimulated through acceleration, causing the element to experience deformation. These changes in the piezoelectric element cause a displaced charge to build up on one side of the sensor which can generate a variable output voltage signal proportional to the applied acceleration (53). A limitation of most accelerometers is that they only reliably detect dynamic events. They are better at estimating energy costs associated with activities that involve ambulation than activities such as rowing and weight lifting (53). When an accelerometer is held still, all it senses is gravity. Tilting the accelerometer is an example of how it senses static acceleration. Accelerometer's inability to detect the static component of acceleration means they are not well suited to measuring movements such as weight lifting and standing vs. sitting. The Actical accelerometer is designed for the measurement of whole

body movement and is sensitive to movements in the 0.5 – to 3 Hz range (53). Recording one minute epochs of data is accepted as standard protocol, although it has been noted that this may miss shorter bursts of vigorous activity especially in children (313). Acticals sum 32 counts as values in a 1 second window and divide the sum by four, in order to reduce the size of the value and accommodate the numerical limitations of accumulated activity values. This value is then added to the accumulated value for the epoch. Total energy expenditure and physical activity energy expenditure for each subject can be estimated using Actical output. This is done via the manufacturer's equation which uses data entered by the researcher about the participant (age, height and weight). It has been suggested that it may be more appropriate to use the count data from accelerometers, rather than the energy expenditure output, as converting counts to units of energy expenditure may be inaccurate due to the additional measurement error of the built-in regression equation (63; 267). Crouter and colleagues (2006) have recently compared published regression equations designed to predict energy expenditure from Acticals against indirect calorimetry of activities over a variety field activities. They report that the Actical regression equations used to predict energy expenditure overestimate the cost of walking, but underestimate the amount of energy used in most other activities. This is a limiting factor in establishing the Actical's ability to measure energy expenditure across a range of categories (63). In general however, a high correlation (r=0.94) between counts per minute and METs measured during treadmill walking, running and other activities performed in a laboratory has been reported (115).

Accelerometers do however; allow for the detection of a wide range of movements of differing intensities movements. On the whole, accelerometers have been shown to have good correlations with other measures of PA (312), including the gold standards of energy expenditure such as the doubly labelled water method and are considered to be a valid estimate of overall PA (78). In children, the Actical has been shown to be a valid tool for

measuring PA as shown in a recent study by Pfeiffer et al. (2006) where Actical activity counts were found to be highly correlated with oxygen consumption (VO$_2$) (212).

Standardised protocols for determining the number of days that accelerometers should be worn, placement of the accelerometer and analysis of output do not exist. Accelerometers are however being used increasingly in physical activity research and as a result a scientific meeting aimed at closing the gaps in accelerometry knowledge was held in 2004. From data presented at this meeting, best practice and research guidelines were developed for using accelerometers for research purposes (308). The number of days needed for monitoring largely depends on the setting of the research, population of interest, funding resources and research objectives (289). A number of review papers have presented guidelines with regards to the best placement of the accelerometers and number of days of monitoring needed (308; 312). It is generally recommended that for studies involving children, accelerometers be worn for between three and five days in order to achieve a reliability of 0.7 (290). While no calibration studies have been conducted to derive equations for interpreting accelerometry data from sites other than the hip, placement at the hip or lower back has become the most common sites for placement (308). When positioned on the hip, accelerometers are extremely sensitive to vertical movements of the torso.

Accelerometers have not been used very extensively in bone research. However in a study conducted with children, minutes spent in vigorous activity were found to be highly associated with body size and age adjusted bone measures (BMC and BMD) at the hip and spine (125). The limited number of studies examining bone mass and accelerometry may be due to the fact that there is a considerable cost issue involved in using a device such as the Actical in a large study cohort. Large observational or intervention studies can however, still make use of accelerometers in a sub sample of a large study population by using

accelerometry as a direct assessment method of PA in order to validate self report or proxy report PA questionnaires.

3.4.1 Physical Activity and Physical Fitness

There is controversy as to whether a relationship exists between the activity levels of children, their aerobic fitness and their level of fatness (233). Furthermore gender and racial differences in fitness levels have been shown (8; 9; 148). The vertical jump test seen as the first 'physical test of a man' was developed by Sargent in 1921 (251), but nowadays physical fitness is acknowledged to be comprised of a number of components including flexibility, muscle strength, muscular endurance, explosive strength, balance and cardio-respiratory fitness. While there is plenty of research that has examined the relationship between physical activity and bone mass, few studies have studied fitness and bone mass. Some of the studies that have been conducted however, have found close relationships between physical fitness related variables and BMD (301; 302), but the relationship has not been examined extensively.

There are a number of different types of individual fitness tests available to test different aspects of physical fitness, but few comprehensive batteries of fitness tests exist. Several years of co-ordination of European researchers resulted in the identification of an effective means of accurately assessing physical fitness in children. The EUROFIT battery of fitness tests were developed over a period of 15 years and have been shown to be reliable, simple to administer and relevant in respect of taking into account the school/classroom environment (59). The EUROFIT battery of tests include performance and health related fitness components testing aspects such as agility, power, cardio-respiratory endurance, strength, muscular endurance, body composition, flexibility, speed and balance. These tests seem well suited for use in non-European populations too.

The relationships between physical activity, physical fitness and health are multifarious. A theoretical approach to these relationships has been suggested by Bouchard and Shepard (41). The model is shown in figure 3.1 below. Health related fitness refers to physiological and morphological characteristics defining risk levels or factors for lifestyle diseases associated with being sedentary. Bouchard and Shepard's model indicates that physical activity shows an interaction with health related fitness and health. Their conceptual approach proposes that exercise has a direct influence on fitness (endurance, strength, co-ordination) as well as on health parameters (BMI, blood pressure, glucose, bone mass) (41). The authors argue that all of the above elements should be included in the definition of fitness. This model holds particular relevance in developing countries where the social environment and economic factors play a large and reasonably fixed role in many children's lives.
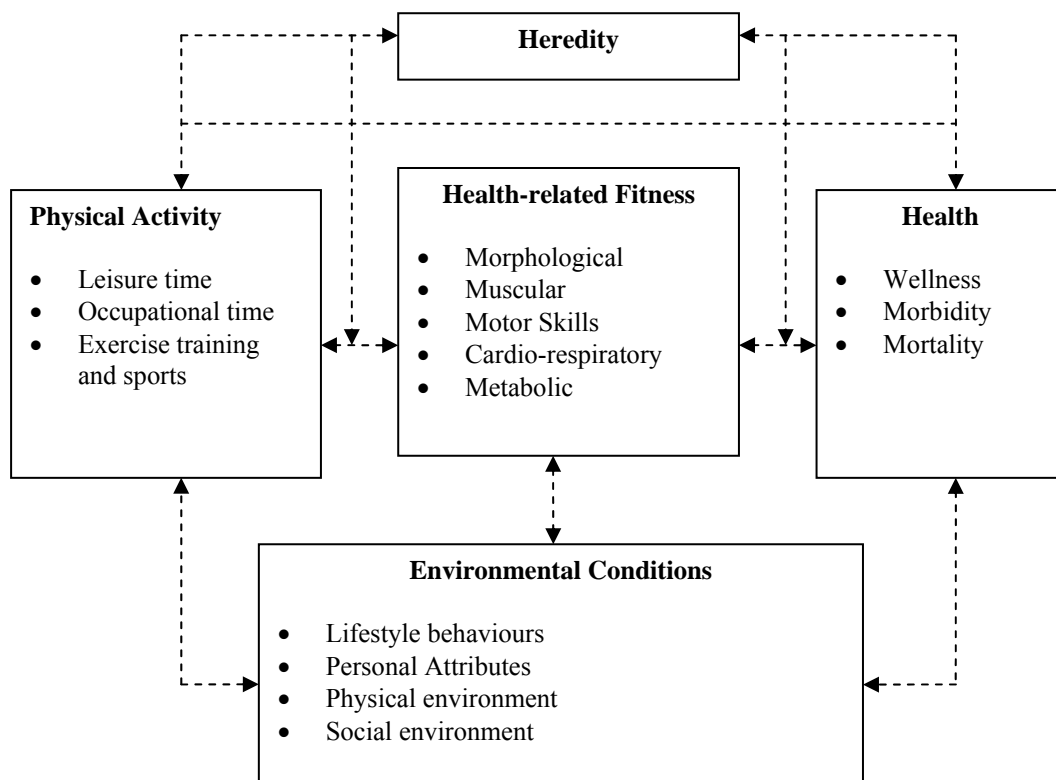
Figure 3.1 Bouchard & Shepard's conceptual approach to the relationship between physical activity, fitness and health. Adapted from (41).

3.3 Socio-economic Status and Physical Activity

Africa is the second largest and most populous continent in the world. It is also the poorest. In South Africa, there are major differences in income and wealth distribution between the White and non-White populations. Thirteen percent of the estimated 50 million South African population lives in 'first world' conditions, while about 22 million people (±44%) live in 'third world' conditions. South Africa has high unemployment (26 percent according to the narrow definition) and 24 percent of the population lives on less than US$1 per day (203). The World Bank is working closely with the South African Cities Network (nine city municipalities) in partnership with the South African Local Government Association to promote pro-poor city development strategies, with a focus on upgrading urban renewal and informal settlements, implementing the Extended Public Works Program, and developing urban economic indicators. Nevertheless, the current degree of unemployment, poverty, and wealth inequality in South Africa is a major influencing factor on people's lives.

The influence of social factors is widely recognized in public health and health behaviour research and has also been formally recognised as an important determinant of health (180). Promotion of physical activity minimizes the development of chronic diseases of lifestyle, aids in injury prevention by decreasing fall propensity, contributes to quality of life, and improves psychological health (276). Adolescents with a healthy participation in PA are more likely to continue being active into adulthood (299). Thus, understanding the factors that may influence the adoption of good PA patterns in youth is crucial in order to establish good life long patterns of PA throughout adulthood. In South Africa, much of the secular trend toward increased body size in adults has been attributed to the process of urbanisation and associated socio-economic change. A shift from agriculturally based economies to cash based economies has minimized the need for physical labour and increased the demand for sedentary or less intensive physical work. Kruger and colleagues (2002), found a significant positive

association between household income and obesity measures in South African Black women. However, physical inactivity was found to have the strongest association with obesity in this study (147). This finding was substantiated by Senekal et al. (2003), who identified physical inactivity as an important risk factor for overweight/obesity in South African adults (264). Although the literature regarding the relationship between PA and obesity in South African children and adolescents has been both scant and controversial, some authors have concluded that obesity in adolescents can only be altered by increasing PA and decreasing dietary intake at the same time (279). A recent study by Rush et al. (2007) which examined body composition in women from five different ethnic groups in South African and New Zealand, found that there is an ethnic specific relationship between BMI and percentage body fat. For the same percentage body fat, interethnic BMI was found to differ by more than 10 BMI units (greater and smaller) (240). Body composition is an important aspect to consider in the context of child and adult health. Wells (2003) reported that lower PA levels may lead to reduced lean and increased fat mass and that both of these occurrences may epitomize pathways of increased risk of adult disease (315). The link between low levels of PA and an associated increase in the risk for developing obesity emphasizes the need for these problems to be addressed in childhood.

Although we commonly assume that PA is a normal part of childhood, a number of studies in developing countries have shown that children and adolescents are often very inactive (114; 287). In recent years, Western developed countries have positioned the promotion of PA in childhood and adolescence high on their agenda (294; 318). Developing countries however have not paid as much attention to this problem. In South Africa in particular, very little research has focused on PA patterns. Specifically, South African children's current social and economic situation and how this relates to their PA patterns has not been examined. Socio-economic status (SES) has been identified as an important factor influencing PA participation

(55). It is well known that children who come from low income families often have limited access to resources supporting PA (248). The influence of demographic factors such as gender, race and SES provide us with information on variations in PA levels and allow for the design and implementation of appropriate programs for different sub groups (248). It has been found that leisure time PA in childhood is related to maternal education levels (149). Studies have shown that families have an important role to play with regards to a child's quantity of exercise, creating access to facilities and encouragement of team and sport class participation (193). Many physical educators and scientists believe that children of active parents tend to more active themselves (84; 189).

In summary, there are many influences of and ways to assess physical activity and physical fitness. This section of the review has highlighted the strengths and weakness of some of the methods used. The collection of physical activity data for this thesis used a combination of methods (Acticals, physical fitness testing and PAQ). The physical activity data collected however was largely based on the PAQ developed for these studies. This was the most appropriate resource to use in this study considering the research objectives, large sample, setting and budget constraints. In addition, data gathered from PAQs are useful for determining the types of activities children are doing. This is an important consideration for South African policy makers and managers, so that proper planning of facilities and other services can be accomplished.

3.4 Introduction to Biomechanics and the Adaptive Response of Bone to Loading

When a load is applied to bone, deformation will occur, resulting in the generation of internal resistance to the applied force. This internal resistance is known as stress. Stress is defined as the amount of force applied to a unit area of bone (138). The measurement of deformation,

normalized by the original length is called strain. The slope of the stress-strain curve represents the stiffness of a bone (amount of force required to deform the bone) (138). Both strength and stiffness of a bone are functions not only of bone density, but also of bone geometry and trabecular patterns.

In 1892, Wolff proposed that the function of cells responsible for mechanically adaptive bone modeling is to ensure that bone mass, geometry and material properties are appropriate to the load applied (155). A more recent revision of Wolff's law is the Mechanostat Theory proposed by Frost (88). The Mechanostat Theory describes a window of mechanical usage that should be considered normal or physiological, such that the bone has a system of control in which a minimum effective strain (MES) is necessary for bone mass to be maintained. When mechanical strains exceed the upper boundary of the MES, bone will undergo modeling and change its structure to reduce the local strains to below the MES. In 1999, Turner challenged Frost's Mechanostat Theory in a number of ways. Turner proposed that the following assumptions made by Frost do not conform well with experimental observation: 1) bone loss, due to disuse declines rapidly to zero- Turner correctly points out that this is not the case as in fact bone loss due to disuse slows down with time; 2) the physiological window is the same for every bone including non-weight-bearing sites such as the skull; 3) bone resorption occurs at the neutral axis; and 4) the loss of oestrogen is considered similar to a state of disuse (292). Turner developed a new theory founded on the principle of cellular accommodation, based on the assumption that bone cells react strongly to transients in their environment, but eventually "accommodate" to steady state signals. Turner postulated that weight bearing and non weight bearing sites would have different points at which the cellular accommodation would be activated. Nevertheless, Turner does not provide evidence for the mechanism involved in cellular accommodation.

Approximately two thirds of the variability in bone strength is explained by differences in BMC, while other geometric characteristics of bone, such as periosteal diameter and distribution of bone explain the remaining third (12; 152). In females, oestrogen inhibits periosteal apposition late in puberty but stimulates the acquisition of bone on the endocortical surface (293). In contrast, males show an increase in bone strength that is greater than the gains observed in BMC, this difference is attributed to greater periosteal bone expansion in males compared to females (257).

3.5 Physical Activity and Bone Mass

Most studies that address loading activities in children have been undertaken in elite sporting populations, the results of which are not necessarily applicable to normally active children (18). In a systematic review of 21 randomized clinical trials in adult women conducted by Ernst in 2000, little doubt was left that regular weight bearing exercise could delay or halt bone loss in postmenopausal women (72). Fuchs et al. (2001), advocate that one of the most cost effective ways to prevent osteoporosis is to increase BMC during childhood, thereby developing a stronger skeletal foundation to offset age-related bone loss (90). Peak bone mass appears to be influenced by the level of physical activity prior to the age at which the peak is reached (16). A recent study conducted by Rideout et al. (2006) demonstrated that physical activity of a moderate intensity undertaken in the teenage years has long lasting effects on the lumbar spine and femoral neck BMD in postmenopausal women (231). A review by Ducher and Bass (2007) concluded that the evidence in support of the contention that skeletal benefits from exercise attained during growth, are maintained into old age is limited (69). While a reduction of habitual physical activity appears to be an important risk factor for the later development of osteoporotic fractures, dose response studies and studies observing the relationship between habitual physical activities in childhood and bone mass and fracture incidence in adulthood are needed.

Studies have shown improved levels of biochemical bone formation markers in exercise intervention studies conducted in adults. After 12 weeks of resistance training in older men, osteocalcin concentration increased and remained high after 16 weeks (326). In a similar study conducted by Lohman et al. (1995), pre-menopausal women showed increased osteocalcin concentrations with five months of resistance exercise training and these levels remained elevated after 18 months (162). Fujimara et al.'s (1997) study found similar findings viz., increased serum levels of osteocalcin and bone specific alkaline phosphotase (B-ALP) after a period of resistance exercise training in men. They concluded that a program including resistance exercise augmented markers of bone formation while transiently suppressing a marker of bone resorption (92). Yet the effects of exercise on bone in the younger population and more specifically during childhood are less well documented. Uncertainties remain with respect to the type, intensity and duration of physical activity that lead to an increase in bone mass.

Since bone modeling occurs during childhood, exercise is more likely to have a greater effect on bone mass during growth than in adulthood. Physical activity is known to have an anabolic effect on tissue (60). Sports including heavy loads/loading sports (e.g. gymnastics) are associated with greater BMDs than sports generating mechanical loads without additional gravitational loads/non-loading sports (e.g. swimming). Courteix et al. (1998) performed a study examining two groups of elite pre-pubertal gymnasts and swimmers. No significant differences in BMD were found between swimmers and controls. Mean BMD values for the gymnasts however, were statistically significantly higher at all sites except for whole body and trochanter. This is surprising and is more than likely due to the fact that the skull BMD (an unloaded site) was not removed from the analyses. It was however, concluded that physical activity in childhood could be an important factor in bone mineral acquisition, if sport can induce bone strains during a long term program (60). Bass et al. (1998) also reported

pre-pubertal female gymnasts to have a higher bone density after adjusting for bone volume, at the femur and lumbar spine compared to age-matched controls (23). Bradney et al. (1998) set out to determine whether moderate exercise may influence areal BMD, femoral midshaft cortical thickness, periosteal expansion, cortical thickness and volumetric BMD in pre-pubertal boys. These investigators found that two groups randomly divided into an exercising (performing a program of readily accessible exercise, games and sport, three times per week for half an hour and for 32 weeks) and non exercising group displayed significant differences in bone mass after an eight month intervention program. The children who exercised showed twice the increase in areal BMD at all weight bearing sites measured (legs, lumbar spine, total body and pelvis) than non exercisers. This group also had increased femoral midshaft thickness and volumetric BMD. Their results show that the growing skeleton is sensitive to moderate bouts of exercise that is easily accessible to the average child or "non-elite" athlete (43). Fuchs et al. (2001) conducted an exercise trial in prepubescent children during which subjects followed a seven month exercise regime of 300 jumps at a ground reaction force of eight times their body weight. After seven months jumpers had 4.5 and 3.1% greater changes in hip and lumbar spine BMD than the controls (90). A follow up study to this showed that indeed the bone mass gains were maintained (91) It is evident that a number of studies have demonstrated that exercise that can be incorporated into physical education classes and everyday exercise regimes for normally active children have beneficial effects on bone mass in the growing child.

Studies of extremes levels of activity (very high level activity/very low level activity) show that the physical load has an effect on bone structures, but this bears little relevance to the effect of physical activity and muscle strength on bone in normal individuals (70). Recent research however has begun to demonstrate that even relatively small differences in bone mass can be very important. The question then arises, whether or not a general increase in a

population's physical activity levels within the limits of a 'normal' lifestyle are sufficient to raise BMD to a level that would significantly lower fracture risk? Duppe et al.'s (1997) data suggest that high levels of PA within limits of a regular lifestyle may preserve BMD in the proximal femur of men (21-42yrs) and contribute to a lower fracture risk (70).

Most of the studies mentioned above have reported changes in BMC and BMD, which are surrogate measures of bone strength and are measures which do not account at all or incompletely for differences in bone size. Additionally most exercise intervention studies have been designed in such a way that they make use of specialized equipment, involve many hours and can be difficult to administer. McKay and her group in Canada have shown in a number of well conducted exercise intervention studies that along with increases in BMC in the femur, there are changes in bone geometry and structural and bending strength associated with loading exercise (166-168; 176; 209). In addition to these studies the group has also devised a quick, easy to administer and novel jumping program. The program called 'Bounce at the Bell' requires only a few minutes a day, no equipment and minimal training. Results from their study showed enhanced bone mass at the hip in children exposed to a three minute, eight month long simple jumping intervention (177). Although the study was conducted with a relatively small sample size and only on White and Asian children, their results are promising. A program such as 'Bounce at the Bell' would be an ideal and sustainable intervention for children living in a developing country, where resources are often limited.

While exercise intervention studies provide the strongest evidence that exercise has a positive effect on BMC during growth, observational studies provide a method of assessing normal habitual physical activity patterns and their associations with bone mass acquisition in children. A limitation of cross sectional studies is that athletes may have a higher bone density

prior to entry into the sport, but this can be circumvented in longitudinal studies of bone mass accretion.

3.6 Growth and Physical Activity

It has been suggested by Cooper et al. in 1995 that the two components of bone mass i.e. (i) the size of the skeletal envelope (BMC) and (ii) the mineral density within that envelope (BMD) may be determined by different factors (57). Cooper also suggests that endogenous factors (hereditary, hormonal and growth trajectories) influence BMC and environmental factors (nutrition and physical activity) influence BMD within that envelope. Cooper explains that an individual's growth trajectory is the most important determinant of BMC and previous studies have indicated that this trajectory might be determined well before the onset of the pre-pubertal growth spurt. In Cooper's study physical activity was shown to have the strongest influence on BMD. His theory proposes that growth of the skeletal envelope "tracks" from early childhood. Tracking refers to the propensity for children who are small in relation to their peers of the same age to remain small and vice versa. Physical activity was a stronger determinant of BMD in Cooper's study than calcium intake; this is in keeping with Welten et al.'s 1994 study (316). Cooper comments that physical activity appears to adjust the mineral density within the skeletal envelope; this may in turn contribute to the possible consolidation of bone towards the end of linear growth. Cooper concluded that infant growth and physical activity are important determinants of PBM in females. It must be noted however, that in Cooper's study, which involved only females, changes in bone area were not taken into account and appropriate body size adjustments were not made.

A number of researchers concur that there is strong evidence suggesting that it is during the growth phase that the body may be most responsive to exercise (106; 132; 269). Animal

studies have shown that growing bone has a greater capacity to add new bone to the skeleton than does an adult bone (122; 198). In humans, Bass et al. (1998) advocate the pre-pubertal years as the perfect time for exercise to increase BMD (23). Their study showed that the residual benefits of exercise before puberty maintained into adulthood, suggesting a possible reduction in fracture risk after menopause. Bass et al. (1998) propose several reasons why the pre-pubertal years may be the optimal stage for skeletal response to exercise:

- Growth is dependant on growth hormone and IGF-1, and exercise is a potent stimulus for growth hormone secretion.
- Pre-pubertal growth is relatively sex-hormone independent.

Cross sectional data comparing playing and non-playing arms of squash players who began training before the onset of puberty are also in support of this view (106; 132).

Bailey et al. (1999) assessed everyday physical activity levels in a group of children with the use of a physical activity questionnaire (18). Highly active boys and girls in their study accrued nine and 17% greater whole body BMC respectively than inactive children around the time of maximal bone mineral accrual and maintained this at all sites one year post peak bone mineral content velocity (figure 3.2). Their study was one of the first to demonstrate that the growing skeleton responds to normal everyday habitual physical activity by increasing bone mineral accrual. However, it was unclear whether their physical activity questionnaire excluded non-weight bearing activities such as swimming; and it would have been useful had the authors provided some kind of indication as to what kind of activities 'active, inactive or averagely active' children were involved in and how much time each category meant the child was spending being physically active. Additionally, Bailey et al.'s (1999) study only involved children of Caucasian descent.
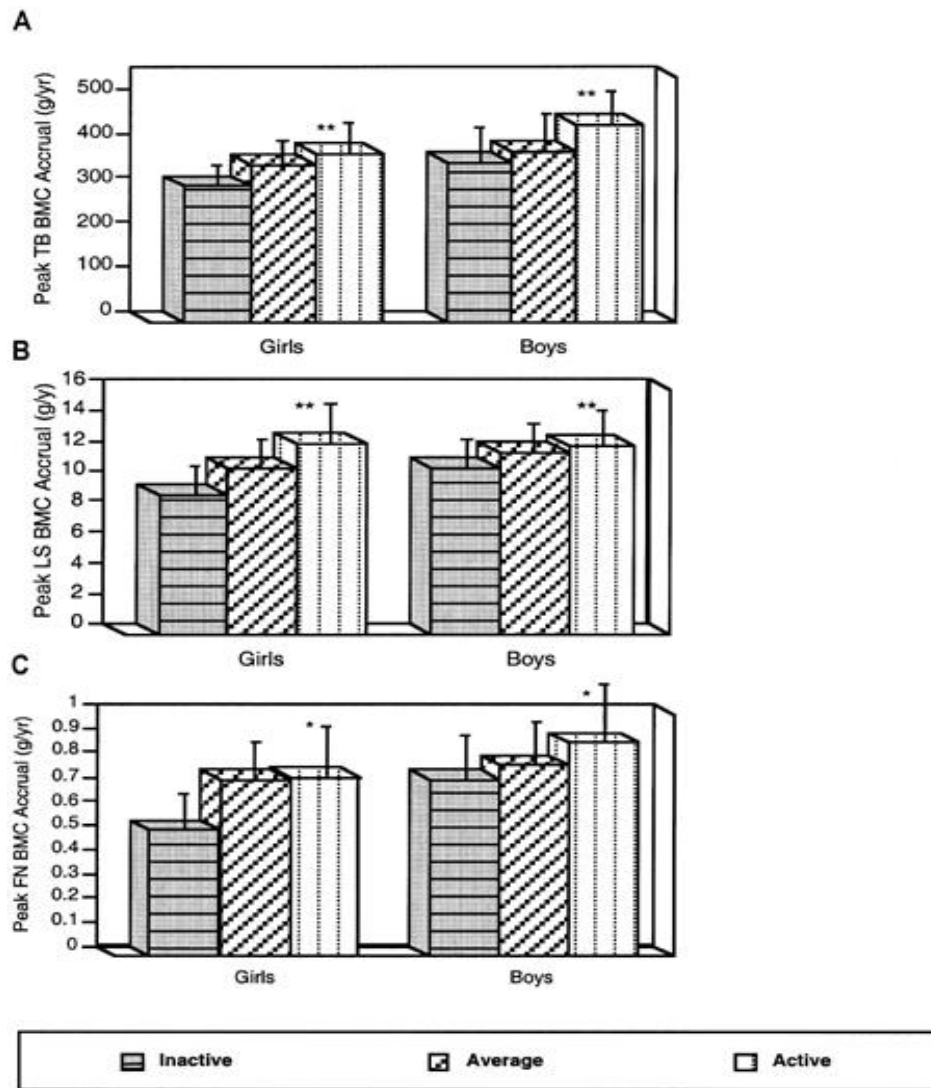
Figure 3.2 Bone mass accrual (g/year) by inactive, average and active groups for boys and girls
*p<0.05, **p<0.001, compared to inactive. Reproduced from Bailey et al. (1999) (18).

A number of studies using a sport which utilizes one side of the body more than the other (unilateral study design) have been conducted and all have shown positive effects on bone mass in the playing or experimental arm (107; 132; 280). Longitudinal unilateral studies have also found that BMC is greater in the playing side of younger starters (107) and is twice as great in children who began playing tennis before menarche than those who started afterwards (132). Unilateral studies are well suited for showing the effects of exercise on BMC. A study using a unilateral design eliminates genetic, endocrine and nutritional confounders and any difference in BMC between each side of the body can therefore be attributed to the increased loading pattern due to the intervention or sport played.

The study of exercise and BMC during growth must take into consideration a number of difficulties. Considerable variability in the rate of maturation between individuals exists. Children matched for chronological age, may differ in their skeletal age or stage of pubertal maturation and therefore in their response to physical activity. Some studies have shown that more mature children show smaller gains in BMC in response to exercise than children who are still growing (116; 269). In Heinonen et al.'s (2001) study, in which pre- and post-menarchal girls participated in a high impact exercise program, only the pre-menarchal girls showed an osteogenic response (116; 269). Loading history of children is another factor which needs to be taken into account; children who have histories of high intensity exercise may not be as responsive to exercise interventions of a lower intensity. Appropriate body size adjustments for outcome measures obtained from DXA also need to be taken into consideration.

3.7 Interactions between Muscle, Bone and Exercise

The basic morphology of the skeleton is determined genetically. Its final dimensions and construction however, are varied by adaptive mechanisms which are sensitive to mechanical factors (81). Physical activity affects bone metabolism, especially skeletal remodeling i.e. cellular mechanisms of bone formation or resorption (271). Bone resorption decreases (inhibits osteoclastic activity) and bone formation increases (stimulates osteoblastic activity) in response to exercise (60). Strains on bone greater than those required for steady state remodeling will cause a modeling response that increases bone mass in order to meet the load requirement. Adaptations in cortical and cancellous bone, reductions in the rate of bone turnover and the activation of new bone formation on cortical and trabecular surfaces may be affected by applied mechanical loads (81).

Rubin et al. (1994) (235) were one of the first groups of investigators to examine the relationship between applied dynamic loads and bone formation. Their study concluded that a diverse exercise regime may stimulate a greater hypertrophic response than a restricted exercise program. Their study showed that only a few cycles of loading were required to induce an osteogenic response.

Muscular disuse causes muscle wasting and bone loss and this has been well documented (140). On the contrary physical activity increases both muscle strength and bone mass. The Mechanostat Theory states that bone gain and loss are determined within ranges of mechanical stimulation, bounded by hormonally or metabolically determined set points (46; 192). The contraction of muscles exerts the major physiological load on the skeleton, and the Mechanostat Theory predicts that increasing muscle force creates a stimulus for an increase in bone strength (223). Several studies have shown that increasing BMD may be a function of greater muscle strength (119; 214; 272). In a meta-analysis conducted by Bérard et al. (1997), physical activity was concluded to be site specific, which is significant in the fact that skeletal modeling and remodeling are directly related to the functional requirements of the tissue being placed under strain (24).

Neither body weight nor physical activity are independent of muscle mass but muscle forces place greater loads on bone than do gravitational forces associated with weight (46). It is well established that muscular contraction primarily results in forces applied to bone. In order to demonstrate that muscle force dominates skeletal adaptation, greater muscle mass or strength would have to be associated with greater bone mass, independent of body size contributions. A number of studies have shown correlations, but have not always demonstrated independence from other body size measures. Burr (1997) argues that in order to demonstrate that muscle forces may govern the adaptation of bone, it may be necessary to show that a

decline in bone strength under conditions of disuse/hormonal insufficiencies preceded decline in muscle mass, and conversely that muscle strength increases before bone mass under conditions of mechanical loading or the re-establishment of hormonal balance (46). Bone mass has been found to be closely related and linearly associated with muscle mass throughout life. In a study conducted by Ferretti et al. (1998) in 1450 subjects ranging in age from two to 87 years, lean body mass was found to be the strongest determinant of whole body BMC (76). This finding was corroborated several years later by Vincente-Rodriguez et al. (2005), who found that lean mass development is the best predictor of femoral BMC and BMD in boys (300). A study conducted by Rauch et al. (2004) concluded that muscle development precedes bone development during the pubertal growth spurt, but that the two processes may be independently determined by different mechanisms (223).

The muscle-bone unit has not been extensively described during growth. The question of whether oestrogen could make growing females add more bone than their physical activity demands in order to store calcium for future gestation and lactation was first raised by Frost (89; 259). Some evidence suggests that the muscle bone relationship is similar between sexes prior to puberty (252). At puberty however, these ratios shift and favour an increase in bone mass and area in females per unit of lean tissue (muscle) (259). Studies conducted by Schoenau and colleagues show that there is a strong correlation between muscle strength and bone geometry, but not between muscle strength and bone mineral density during childhood (255).

A variety of hypotheses exist to explain adaptive responses exhibited by bone. Gibson et al. (2000) suggest that the beneficial effect of mechanical loading on bone acts through a cellular and biochemical pathway, which is amplified by oestrogen, so that when oestrogen is withdrawn, the effect of mechanical loading is diminished (96). This view is supported by

Lanyon et al. (1996) (155). Ernst (2000) believes that the reaction of bone is mediated by strain related electrical responses (72). Kallman et al. (1990) acknowledge that strength, muscle mass and physical activity levels may be partially explained by age (130). Proctor et al. (2000) comment that additional mechanisms such as circulating sex steroid levels may be involved (218). A more recent study conducted by Tobias et al. (2007) on a large cohort of children indicates that physical activity has an effect on lean mass, which in turn has an effect on periosteal bone growth (284). The study's authors propose that physical activity exerts a positive direct effect on both periosteal bone growth (reflected by height-adjusted bone area) and volumetric BMD, and that physical activity indirectly stimulates periosteal bone growth as a consequence of its effects on lean mass. In contrast the tendency of physical activity to reduce fat mass acts to reduce periosteal bone growth. To date, Tobias et al.'s (2007) study is the first comprehensive, well controlled study in a large group of children to propose an inclusive theory of all aspects relating to normal habitual physical activity and exercise and bone mass in children. Tobias et al.'s work fits in well with the functional model of bone development described by Rauch and Schoenau in 2001 (224). The functional model of bone development (Fig 3.3) proposes that bone cell action is coordinated by the mechanical requirements of bone, such that when mechanical challenges exceed a set point, bone tissue is added to the location where it is mechanically necessary. This model is currently the best concept describing bone mass accrual during the growing years.
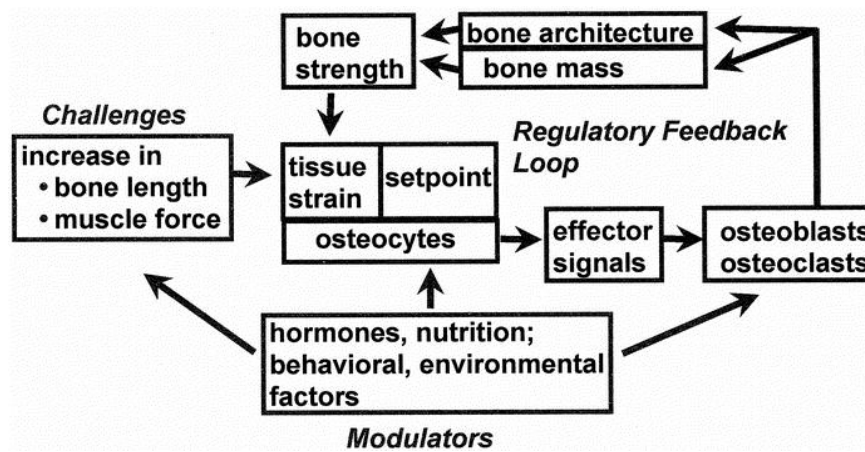
Figure 3.3 A functional model of bone development based on the Mechanostat theory. During growth this system is continually forced to adapt to meet mechanical challenges. Reproduced from Rauch & Schoenau (2001) (224).

3.8 Interaction between Physical Activity and Calcium on Bone Mass

A small number of studies have recently examined the effects of exercise and calcium interventions on bone mass (121; 275; 278). Iuliano-Burns et al. (2003) reported main and interactive effects for calcium and physical activity interventions at the hip in pre and peri-pubertal females (121). Stear et al. (2003) also reported enhanced bone mass with a calcium and physical activity intervention in adolescent females, although the interactive effect (if any) of the two interventions was not reported (278). Another physical activity and calcium supplementation intervention conducted in both male and females children showed that although physical activity stimulated growth in bone width, the actual amount of bone mineral accumulated is dependant on both physical activity level and calcium intake (275). In a 12 month follow up to this trial, no consistent effect of calcium supplementation on BMC was noted (27).

None of these studies have reported on racial effects and all have been conducted in developed countries. Currently, there are no longitudinal observational data on the effects of naturally occurring habitual physical activity and calcium intakes on bone mass accretion in ethnically diverse populations in developing countries such as South Africa. Studies which

have examined naturally occurring habitual physical activity patterns and calcium intakes in other countries, have typically only reported data for short time periods (one week or less) (234). Additionally, most studies have reported on the association between physical activity and BMC, and the issue of whether habitual exercise increases bone size as well has not yet been clarified. Only one other study has examined bone measurements in pre- adolescent girls living in South Africa. Micklesfield et al. (2004) used ultrasound to measure bone density and questionnaires to assess dietary calcium intake and physical activity, they reported that dietary calcium intake was lower in White girls compared with Black girls and reported no difference between ethnic groups for an energy expenditure score, but did report higher bone strain scores in White girls compared with Black girls (188). The calcium data presented in the abovementioned study should be interpreted with caution as children were not asked about specific quantities of calcium rich foods, but only reported on the frequency of eating foods high in calcium. The composite calcium score that the group used may not have been sensitive enough to pick up absolute differences in dietary calcium intake between race groups.

With the rising incidence of diseases of lifestyle, including an exponentially increasing hip fracture rate in the ageing population in developed countries (185), scientists are advocating physical activity and calcium intake as important modifiers of bone mass. This research is particularly important in countries where a more sedentary lifestyle is becoming the norm and where physical education no longer forms part of the school curriculum. The situation in South Africa is of particular interest since South African Blacks are reported to have among the lowest hip fracture rates in the world (253; 274), as well as lower than recommended calcium intakes (211), but life styles are under rapid transition currently.

3.9 Conclusion

A review of physical activity and bone mass literature reveals a wealth of findings. This literature review has examined both adjustable and non-modifiable factors affecting BA, BMC and BMD. It has inspected the literature with regards to energy expenditure, peak strain physical activities and the type, intensity and duration of physical activities best suited to enhancing PBM. Growth and physical activity as well as mechanisms of action have also all been scrutinized. Yet it remains evident that research conducted in a South African context is extremely limited. South African children's physical activity and bone mass patterns have not been established. Before we can make inferences with regards to South African children and their bone development, we must examine these facets in more depth. This study aims to do this by addressing a number of research questions raised by this review.

The major unresolved issues concerning physical activity and bone mass in children living in South Africa include, but are not limited to the following:

1. A comprehensive physical activity questionnaire has not been validated within a population of South African children, nor have normal habitual physical activity patterns been examined in a group of Black and White South African school children.

2. Fitness levels and their relationship with body composition measures and their correlation with physical activity indices as recorded by a questionnaire in South African children are not known.

3. Are there differences in physical activity and bone mass acquisition patterns between racially diverse children living in South Africa?

4. Is the association of exercise on bone mass measures similar in Black and White South African children, despite different calcium intakes?

3.10 Hypotheses

1. The Physical Activity Questionnaire (PAQ) will be positively correlated with objective measures of physical activity (actigraphy and fitness testing), and is a valid and reliable assessment tool in a racially diverse group of South African school children.

2. Fitter children will report higher levels of activity on the PAQ and will have a leaner body composition profile as measured using DXA.

3. Physical activity patterns are influenced by a number of factors including race, gender and socio-economic status. Children from a higher socio-economic background will exhibit higher levels of physical activity.

4. Regardless of gender or race, children who are highly physically active will have better bone mass at all weight bearing sites.

5. Bone mass acquisition patterns over a one year pre-pubertal period will be similar between race groups, but not between gender groups.

Chapter 4

Methodology

Chapter 4: Methods

4.1 Introduction

The Birth to Twenty Study (Bt20) is an observational longitudinal study of child health and development of children living in post-apartheid South Africa (79; 229; 230; 325). It was initiated over a period of seven weeks in 1990, the same year that Mr. Nelson Mandela was released from prison. The Bt20 study is a collaborative study involving academics, researchers, service providers, universities and health departments. All children born within the greater Johannesburg metropolitan area in South Africa over the seven week period were enrolled into the study. During this time there were 5460 singleton births in the area, but only 3273 children were established to have been born to women who were residents in the Greater Johannesburg area for at least the first six months of the child's life (229). Thus the total number of children who were originally recruited totalled 3273. In 1999 a child Bone Health study (approved by the Committee for Human Research of the University of the Witwatersrand, South Africa, Ethics number: M980810 and M050226) was initiated using a convenience sub sample of the original group with an annual follow-up of 623 children. The main aims of the Bone Health study were to investigate a multitude of environmental and hereditary factors which may influence bone mass acquisition in a group of Black and White South African children (200). The children were enrolled into this study at the age of nine years. Cross checks were performed to ensure that there were no significant differences between the Bt20 and Bone Health cohorts for key demographic variables (residential area at birth, maternal age at birth, gravidity, gestational age and birth weight). The Bone Health Cohort was utilised in this study to assess the association of environmental and lifestyles on PA and bone mass accretion.

The methodology described in this chapter is divided into five parts. Parts one and two are primarily methodological studies, while parts three, four and five tackle the main research questions. As a sum however, all parts engage in an attempt to explore the main research question regarding the associations of physical activity, bone mass and lifestyle within a young South African racially diverse population.

Part one (*4.2*) details the methods used in a cross sectional Actical study which was conducted in order to validate our physical activity questionnaire (PAQ). Our questionnaire is based on well established questionnaires in the literature (102; 206; 246) that have been previously validated. However, since we modified our questionnaire to be more appropriate for a South African population and to capture time spent in informal activity, it was necessary to validate it in a South African group of children. Data collection for this part of the thesis took place at a local primary school with children recruited from outside of the Bone Health cohort. Actigraphy was used as an objective measure of activity for this study, and data obtained from the Actical (Mini Mitter Co., Inc., Bend, OR) was compared with data obtained from the physical activity questionnaire (PAQ). The PAQ was used to attain a measure of physical activity throughout the studies. It was easily administered to a large sample of children who were observed annually. Due to budget and logistical constraints, we were unable to use Actigraphy in a larger sample of children.

The second part (*4.3*) of the methodology chapter expands the validation of the PAQ and describes the methods of a cross sectional Fitness Study involving the use of two measures of physical activity (PAQ and a battery of fitness tests) and measures of body composition (DXA and anthropometry). This study was conducted with a sub-set of the Bone Health cohort children and data collection took place both at the Birth to Twenty offices as well as in the Exercise Physiology Laboratory situated in the School of Physiology at the University of

the Witwatersrand Medical School. This study was conducted to assess whether fitness levels in this cohort of children were higher in those children reporting higher levels of physical activity on the PAQ. Additionally, the study sought to examine whether fitter children had leaner body composition and whether there were race and gender differences for these variables within the group.

The rest of the data obtained for this thesis (parts three (*4.4*), four (*4.5*), five (*4.6*)) were gathered from children who are part of the Bone Health study. Data were obtained on an annual visit, whereby children and their primary caregivers came to the Birth to Twenty offices situated in the University of the Witwatersrand Medical School, Johannesburg South Africa for their annual appointment. A team of data collectors and researchers (including myself) would then collect the necessary data. All DXA scanning was done by a qualified DXA technician, and the same technician performed all the scans during the duration of the data collection for this study. Annual visits for data collection followed the same procedures each year.

The procedure was as follows:

- Appointment made with family
- Child and primary caregiver arrive at Bt20 offices
- Informed consent obtained from both child and primary caregiver (example provided in appendices 1 and 2)
- Interviews conducted with both child and primary caregiver (PAQ (Appendix 3), SES questionnaire (Appendix 4), nutritional questionnaire (dietary recall and food frequency), historical data questionnaire, sleep questionnaire)

- Anthropometric measurements (height, weight, skin folds (supra-iliac crest, tricep, sub-scapular, bicep), limb lengths)

- DXA scan (whole body, mid-shaft radius (non-dominant), left hip (femoral neck), lumbar spine (L_{1-4}) , lean and fat mass)

- Blood drawn and urine sample taken (biochemical analyses)- (data not included as this is beyond the scope of this thesis)

The design of the all studies and testing of the hypotheses related to this thesis are shown in Figure 4.1

DESIGN

Part 1

> **Actical Study (n=30)**
>
> **Sample**: 9, 10, 11 year olds recruited from a local primary school
>
> **Measures**: Actigraphy (Actical), PAQ, Weight, Height
>
> **Research Question:** Does the PAQ accurately estimate PA levels in children when compared to the Actical?

Part 2

> **Fitness Study (n=69)**
>
> **Sample**: 11, 12, 13 year olds recruited from the bone health study
>
> **Measures**: PAQ, Anthropometry, DXA, Fitness Testing, Grip Strength, Tanner
>
> **Research Question:** Is there a relationship between fitness level as tested by a battery of fitness tests and activity level as reported on the PAQ?

Part 3

> **Cross Sectional Physical Activity and Bone Mass Study (n=386)**
>
> **Sample:** Bone health study cohort
>
> **Measures:** PAQ, Anthropometry, DXA, Tanner Staging, Skeletal Age, Nutrition
>
> **Research Question:** To examine the association between PA and bone mass within different race groups of South African children.

Part 4

> **Socioeconomic Status and Physical Activity Study (n=381)**
>
> **Sample:** Bone health study cohort
>
> **Measures:** PAQ, Anthropometry, DXA, Tanner Staging, Skeletal Age, SES
>
> **Research Question:** To examine the prevalence of inactivity and activity by gender, SES, maternal education. To explore body composition patterns in relation to sedentary behaviours.

Part 5

> **Longitudinal Physical Activity and Bone mass Study (n=321)**
>
> **Sample:** Bone health study cohort
>
> **Measures:** Annual PAQ, Anthropometry, DXA, Tanner Staging, Skeletal Age, Nutrition
>
> **Research Question:** To examine bone mass changes over a 12 month period in Black and White SA children and to explore these changes in relation to habitual PA levels & dietary calcium intakes.

Figure 4.1 Schematic representation of thesis outline

4.2 Part 1 - Actical Study

The nature of the Bt20 longitudinal study and the large sample size of children involved in the Bone Health study meant that assessment of PA with the use of Acticals was not viable in this sample of children. This was primarily due to the high cost involved in purchasing Acticals as well as logistical issues regarding collection and attachment of Acticals. The children involved in the Bt20 study live in widely distributed areas across Johannesburg, making it difficult for them to come to our offices more than once per year or for them to be visited at home on a regular basis. The PAQ was therefore chosen as an assessment tool of PA in this large group of children due to its ease of administration, low cost and subject burden and applicability in large observational research. As previously mentioned the PAQ that was used, is based on questionnaires which have been previously validated (102; 206; 246), however, some of the questions were modified in order to make them more appropriate to assess the activities of a sample of South African children. It was therefore necessary to validate the PAQ by assessing the relationship between responses provided by subjects and actual Actical measures in a smaller group of children not involved in the Bone Health study. Although Acticals do have limitations as detailed in Chapter 3, they have also been shown to have good correlations with other measures of PA (312).

The aims of the Actical Study were therefore to:

- Determine the relationship between METPA as estimated from the PAQ and activity counts as measured by the Actical.

- Determine the degree of the relationship between time spent in sedentary and vigorous activities as reported by the subjects on the PAQ and time spent in sedentary and vigorous activity measured by the Actical.

- Determine whether the weekly and yearly PA scores obtained from the PAQ are consistent and reproducible.

4.2.1 Subjects

Data for the Actical Study were obtained from a convenience sample of children recruited from a public primary school in Johannesburg. For this study a total of 30 Black and White children aged between nine and 11 years of age volunteered and participated in a four day Actical and PAQ based validation study. As this was an exploratory study, it was estimated that a sample size of 28 (four groups of 7 subjects) was required to detect a 10% difference in activity counts with 90% power at the $p < 0.05$ level. Children who were unhealthy or unable to participate in physical activity were excluded from the study. All children and caregivers gave written informed consent for all studies discussed.

4.2.2 Anthropometric Measures

The height of each child, recorded to the nearest millimetre, was measured using a stadiometer (Holtain, UK), and weight, recorded to the nearest 100 gram, was measured using a digital scale (Dismed, USA). Both devices were routinely checked every three months throughout the study period and no adjustments were necessary to calibrations of the equipment. Subjects were measured with light clothing and no shoes. Height and weight measures were used to calculate Body Mass Index (kg/m^2) (BMI) using the standard method of dividing body mass (kg) by height squared (m). Forearm length, needed for radial and ulna DXA analyses (in later studies presented in thesis), was measured as elbow to wrist length taken between the posterior point of the olecranon and the most distal palpable point of the styloid process of the radius.

4.2.3 Physical Activity Questionnaire

An interviewer-administered PAQ was developed to estimate the time each subject spent doing physical activities in the preceding year. This questionnaire was adapted for the Actical Study to also record the PA of the school aged boys and girls in the preceding week to the interview and the week of the Actical assessment (see fig 4.3 for more detail). The questionnaire measured the total time spent on all habitual PA in relation to school, sports (at school and outside of school), and commuting to and from school and other leisure time activities (including informal activities, sedentary activities such as TV watching etc) during the week and on the weekend (Table 4.1). Physical activity was scored in two ways as calculated from the questionnaire: 1) for all subjects, all activities were rated according to their metabolic intensity based on the method of Ainsworth et al. (1993 and 2000) (3; 4). The metabolic equivalents described in Ainsworth's 1993 paper were used for this thesis. Since the first year of data for the Bone Health study was collected in 1999, the metabolic equivalents described in Ainsworth's initial 1993 paper and not her 2000 paper continued to be used for the purposes of comparison. The metabolic physical activity score (METPA) was calculated by multiplying the intensity (multiples of basal metabolic rate (metabolic equivalents)) by the duration of the activity (hrs/wk); and 2) a mechanical physical activity (MECHPA) score was calculated by multiplying the peak bone strain (ground reaction forces as multiples of body mass) by duration (hrs/wk)). This score is based on the method of Groothausen et al. (103) and has been used recently by Kemper et al. (134), however we modified this by multiplying the estimated ground reaction by duration because the original measure did not include duration or frequency. Thus a sum score for both METPA and MECHPA was calculated as the sum of all METPA or MECHPA scores for each activity (182). Only METPA scores were used for parts one and two of the thesis (The Actical and Fitness Studies), however MECHPA scores were used in parts three, four and five; so the method is explained in this section for purposes of clarity later on in the chapter.

Table 4.1 Summary of main items used in physical activity questionnaire

1. Commuting/transportation
    i. Method of transport to and from school (car/bus/train/bicycle/walk/other)
    ii. Mean daily time taken to school and back from school
    iii. Pace of walking/cycling (if applicable)
        PA SCORE: Mean transport time to school in minutes per week
        METPA SCORE: MET VALUE (for specified activity) * PA score

2. Activities at School
  a. Physical Education
    i. Number of lessons attended per week
    ii. Type of activity performed
    iii. Duration of lesson
        PA SCORE: Mean activity time in minutes per week
        METPA SCORE: MET VALUE (for specified activity) * PA score
  b. Extramural activities at school
    i. Type of sports/activity participation
    ii. Number of months that sport is played for
    iii. Number of practices attended per week
    iv. Length of practice
    v. Number of matches played per week
        PA SCORE: Mean activity time in minutes per week
        METPA SCORE: MET VALUE (for specified activity) * PA score

3. Organised activity outside of school (private extra mural activities)
    i. Type of sports/activity participation
    ii. Number of months that sport is played for
    iii. Number of practices attended per week
    iv. Length of practice
    v. Number of matches played per week
        PA SCORE: Mean activity time in minutes per week
        METPA SCORE: MET VALUE (for specified activity) * PA score

4. Unorganized activity
    i. General leisure activities (e.g. riding a bike, playing in the street)
    ii. Times per week
    iii. Hours per time
        PA SCORE: Mean activity time in minutes per week
        METPA SCORE: MET VALUE (for specified activity) * PA score

5. Sedentary activity
  a. During week
    i. Hours per day spent watching TV and videos
    ii. Hours per day spent drawing, music lessons, homework
    iii. Hours per day spent playing video games
        PA SCORE: Mean activity time in minutes per week
        METPA SCORE: MET VALUE (for specified activity) * PA score
  b. During weekend
    i. Hours per day spent watching TV and videos
    ii. Hours per day spent drawing, music lessons, homework
    iii. Hours per day spent playing video gam
        PA SCORE: Mean activity time in minutes per week
        METPA SCORE: MET VALUE (for specified activity) * PA score

4.2.4 Physical activity monitor-Acticals

Children in this study wore Actical (Mini Mitter Co., Inc., Bend, OR) accelerometers (hereafter referred to as Acticals) affixed on their left hip, slightly above the iliac crest, with an elastic belt for a period of four consecutive days. It was positioned in this way so that acceleration of the displacement of the hip could be measured and so that the Actical would also be sensitive to weight bearing movements. Acticals are the newest and smallest accelerometers (28 X 27 X 10mm, 17g with a battery) currently available. When positioned on the hip, the device is extremely sensitive to vertical movements of the torso. Activity was measured in one minute epochs (the recommended epoch length (53)) over a period of four days. Acticals sum 32 values in a 1 second window, divide the sum by four and then add this result to the accumulated value for the epoch. In this study, sixty, one second values were summed together to generate one resultant raw activity datum (counts) for each one minute epoch (220). The subject's age, weight, height and gender were entered into the Acticals memory so that total energy expenditure and physical activity counts could be estimated using the manufacturer's equation. The Actical is activated when the subject's information is entered into the unit via a computer interface, and inactivated when the information is downloaded to a computer. A new battery was fitted to each Actical before activation. Figure 4.2 represents typical data output using whole day accelerometry, with movement count cut-off points for varying levels of activity. The activities were divided into three categories: sedentary, moderate and vigorous activity. The cut points for defining the boundaries for moderate activity (3 METs) and vigorous activity (6 METs) vary among studies (85). For the purposes of this study 3 MET activities were defined as counts from 1200-2999 and 6 MET activities corresponded to counts equal to or greater than 3000 counts. These values were based on the accelerometer thresholds defined by Treuth et al. (2004) (285).
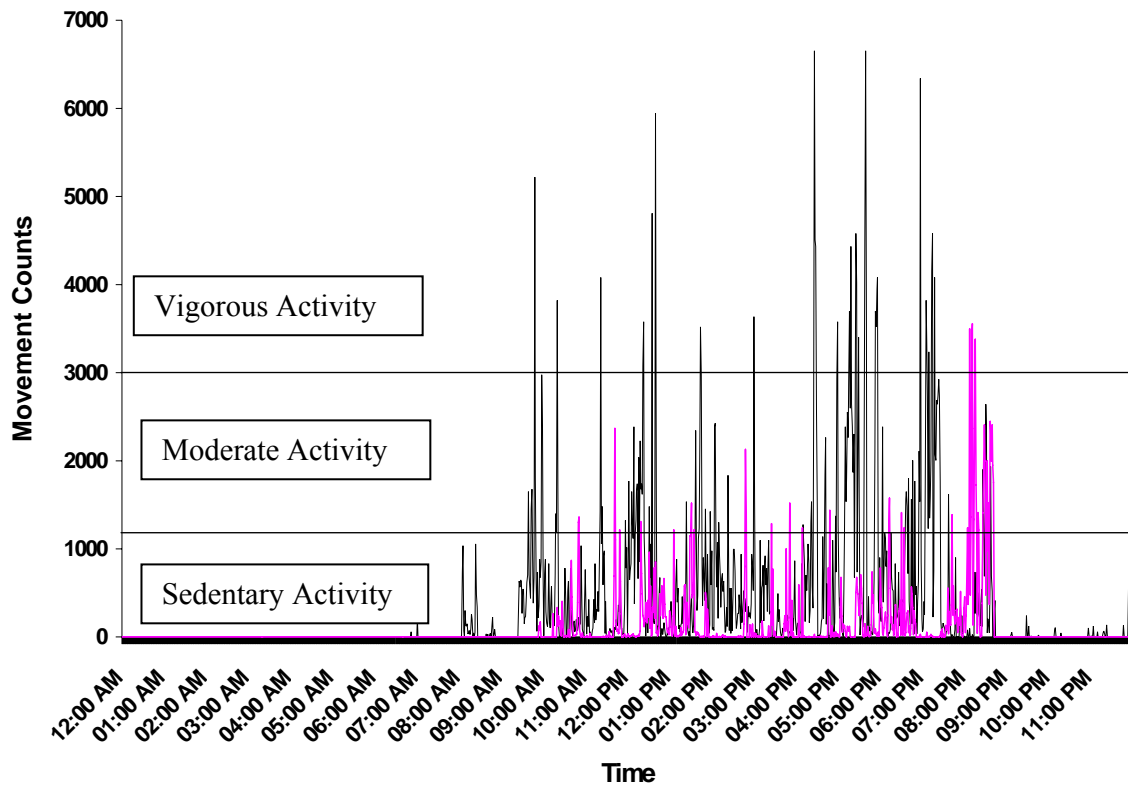
Figure 4.2 Typical Actical data output from whole-day accelerometry. The data shown in Black is indicative of an active child, while the pink lines show counts from a less active child.

4.2.5 Study Design

Data collection took place over a two week period as depicted in figure 4.3 below. The past week PAQ was administered on the Thursday prior to the Actical assessment. This questionnaire examined all activity and inactivity that subjects had undertaken in the past seven days. The past year PAQ was administered the next day (Friday- Day one of the Actical Assessment) and examined all activity and inactivity that subjects had undertaken in the past year. The Actical assessment period then took place over four days, from and including a Friday, Saturday, Sunday and Monday, such that data from both week day and weekend activity was obtained. The data collected from the Acticals were then downloaded onto a computer program (Actical v2.000.7 by Mini Mitter Co., Inc) and comparisons were made with data obtained from the PAQs. Children were asked to behave as they normally would for the four days of the study and to wear the Actical at all times except when bathing or

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showering. The accelerometers were brought to the child's classroom and collected again four days later. All procedures were explained to study participants in detail; they were shown how to attach the Actical to their hips and the PAQ was interviewer administered on both occasions. The past week PAQ was administered for a second time one week after the first administration (following Thursday) in order to assess whether the week during which subjects wore the Actical was representative of a normally active week for the subjects. The past year PAQ was administered again the next day (Friday) to ascertain whether the data obtained on the past year questionnaire was reproducible.
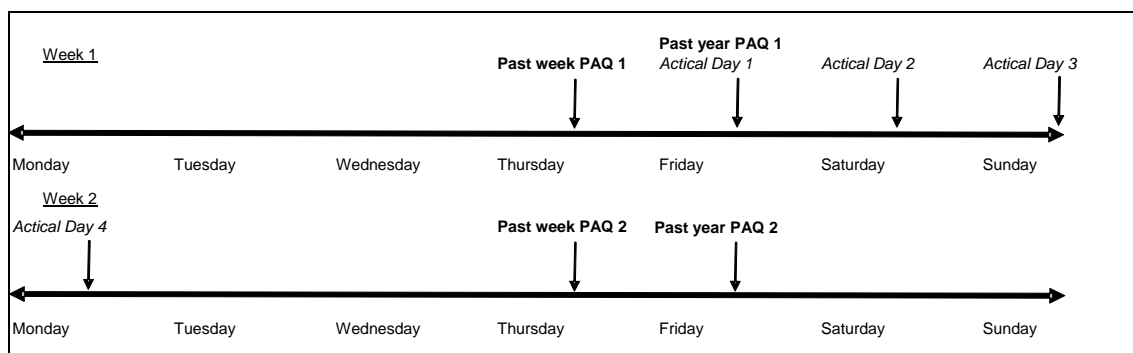
Figure 4.3 Schematic representation of Actical Study design

4.2.6 Data Analysis

All data were analysed using SPSS for windows v12.0 (SPSS Inc, Chicago, IL, USA). Both parametric and non parametric statistical tests were used due to the fact that the distributions of activity estimates were positively skewed. For this part of the thesis, statistical analyses were performed for White and Black males and females together since independent Analysis of Variance (ANOVA) tests revealed no significant differences in physical activity variables between the groups in the present sample. In order to assess the magnitude of the relationship between Actical measurements and those reported by the subjects on the PAQ, Pearson product-moment correlations were performed. Intra class correlation coefficients (ICCs) were utilized to evaluate the reproducibility of the estimates of physical activity obtained from the

PAQ questionnaire. An alpha of 0.05 was set a priori (for all hypotheses tested in the thesis) to determine the level of statistical significance.

4.3 Part 2 - Fitness Study

Physical activity may not necessarily be synonymous with physical fitness. PA is a complex concept which can be separately determined by different indicators (298). Assessment of PA is based on the quantification of these factors. There is controversy as to whether a relationship exists between the activity levels of children, their aerobic fitness and their level of fatness (233). Furthermore gender and race differences in fitness levels have been shown by previous investigators (8; 9; 148). It is therefore important to measure as many factors and facets of physical activity as possible. This study sought to:

- Determine whether there are gender and race differences in fitness levels in a group of 11-13 year old children.
- Determine whether children who report being more physically active (i.e. have a higher METPA score) on the PAQ are fitter and vice versa.
- Determine whether children who are fitter have leaner body composition indices.

4.3.1 Subjects

Data collection for this study took place over a two year period and was comprised of a convenience sample of children. The first 70 consenting subjects from the Bone Health Cohort categorised into selected race and gender groups were used to participate in the Fitness Study. One subject was excluded as her heart rate data could not be retrieved (n=69). A sample size of 64 (four groups of 16 subjects) was required to detect a 6% difference in fitness score with 80% power at the $p < 0.05$ level. A total of 70 subjects were recruited (17-

18 subjects per group) to account for a 10% chance of not being able to retrieve heart rate data properly. Subjects were all healthy and aged between 11 and 13 years at the time of testing. The sample was comprised of 19 White males, 21 Black males, 12 White females and 17 Black females. The following measurements were conducted on all subjects.

4.3.2 Anthropometric measurements

The same anthropometric measures described in section *4.2.2* were conducted on the subjects for this part of the study.

4.3.3 Questionnaires

The retrospective PAQ as described in section *4.2.3* was used. The questionnaire assessed all previous activity in the 12 months prior to the fitness assessment. For this part of the study, only METPA scores were calculated and used from the questionnaire as detailed in section *4.2.3*. Additionally children completed a Physical Activity Readiness Questionnaire (PAR-Q) prior to beginning the battery of fitness tests. This was to ensure that all children were healthy and able to perform in a variety of physical activity tasks.

4.3.4 Fitness testing

A battery of fitness tests, based largely on the EUROFIT battery of tests (59) was conducted on all study participants. The battery of tests that subjects performed included: a 10-metre shuttle run test where subjects ran between two markers placed 10 m apart as quickly as they could (time taken to complete 10 shuttles was recorded (s)) ; sit-ups (maximal number in 30 seconds); and a standard three minute bench step test was used to measure aerobic power of

the subjects. The height of the bench (0.3m) was kept constant throughout the study. Subjects wore a polar heart rate monitor (Polar S120, Polar Electro, Kempele, Finland) for the duration of the stepping test. The bench test was performed at a constant step rate of 25 steps per minute as determined by a metronome. In this way, work rate between subjects remained constant at approximately 50 watts for all subjects. A mean resting heart rate was recorded for a period of five minutes before exercise began; thereafter heart rates were recorded every five seconds during the three minute exercise period as well as for two minutes after exercise had stopped. The time taken to fall to 150 percent of the resting heart rate during the recovery period was termed the *t*-half and was used as the 'performance' marker for this task (109). Grip strength was assessed using a hand held dynamometer (JAMAR Hydraulic Hand Dynamometer, Lafayette Instrument J00105, USA). Subjects performed three trials with each hand and an average of the two hands was recorded. Results were recorded in kilograms. The dynamometer was set at a level most comfortable for each subject and measured in a standing position with the shoulder adducted and neutrally rotated and the elbow in full extension. The shuttle run, sit up and bench test tasks were used in the calculation of a Fitness Score for each participant. The standard performance data (distances, times and repetitions) for each task were included into the calculation of the Fitness score, which was based on the method described by Leyk et al. (2006) (157) in their Physical-Fitness-Test study. Performance on each of the three tasks was scored according to a three point system, whereby zero indicated worse performance (slower time, less reps etc) and three was the best score the participant could achieve on the task. The fitness score cut-off's were determined by dividing the responses from the children into tertiles so they acted as their own assessment of fitness. A child who did a high number of sit ups and completed the shuttle run task in a quick time for example would score a three for both those tasks. A composite score of each subject's total score on each of the three tasks was then calculated resulting in a maximum score of nine and a minimum score of zero. Subjects scoring between zero and two were assigned a Fitness

Score of one, children scoring a three, four or five were assigned a Fitness Score of two and subjects scoring a six, seven or nine were assigned a Fitness Score of three. A schematic representation of the scoring method is presented in figure 4.4.
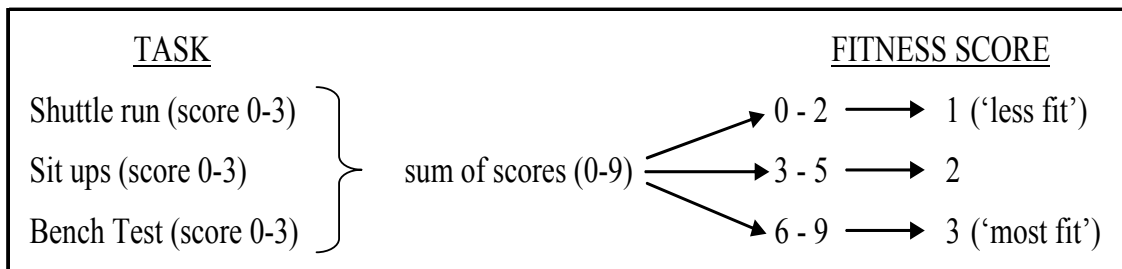
Figure 4.4 Schematic representation of scoring used to calculate Fitness Score for each subject. Based on and adapted from method described in Leyk et al. (157).

4.3.5 Body Composition Measurements

Whole body scans were performed using a Hologic QDR 4500A dual-energy X-ray absorptiometer (Hologic, Waltham, Mass., USA) in array mode according to standard procedures. The data were analyzed with the software supplied by the manufacturer, version 11.2. A spine phantom was scanned daily to determine the intrinsic coefficient of variation of the machine. A trained DXA technician performed all scans, and intra-observer variation in this study was found to be below 1% for all sites measured. The whole body scan enabled the assessment of whole body lean and fat tissue (g) and percentage body fat (%).

4.3.6 Data analysis

The Fitness Score was used as a categorical independent variable in multivariate ANOVA tests to assess if differences in body composition, bone mass and PAQ indices existed between different classifications of fitness levels. Data were analysed for the whole group and separately for each race and gender group as differences between some groups were found for some variables measured. Chi squared tests were used to assess if percentages of

subjects from each race and gender group falling into each category of Fitness Score were equal. An alpha level of <0.05 was considered to be statistically significant.

4.4 Part 3 - Cross Sectional Physical Activity and Bone Mass Study

This section describes the methodology of a study conducted on the Bone Health cohort to assess the associations between physical activity and bone mass in Black and White South African children at age 9 years (182). The purpose of this study was firstly to describe normal habitual naturally occurring physical activity patterns in a group of South African children for the first time, and then to explore the association and relationship between physical activity levels and bone mass in this racially diverse pre-pubertal group of children. This study assessed the association between physical activity (sedentary activity, sports participation and intensity, commuting to and from school (active and passive)) and bone mass in 386 healthy nine-year-old Black and White, male and female South African children.

The study sought to determine whether:

- higher levels of physical activity (a greater METPA score) as estimated from the PAQ would be associated with a higher bone mass;
- the type of sport played influences bone mass (sports with a higher MECHPA score would have a greater osteogenic effect);
- there are differences in activity level between race groups

4.4.1 Subjects

Although 623 children were originally enrolled into the Bone Health Study, complete data for this study were available for 386 children. Subsequent cross checks were performed between

this study sample (n=386) and the Bone Health cohort (n=623) to ensure representation. Subjects were all healthy and aged nine years at the time of testing. Children who had asthma or who were suffering from any other disorder likely to affect bone metabolism were excluded from the study. The sample comprised of 44 White males, 158 Black males, 38 White females and 146 Black female children. The smaller numbers of White children is indicative of the racial distribution in South Africa. Fewer White than Black children were born during the period of enrolment into the study.

4.4.2 Anthropometric measurements

The same anthropometric measures described in section *4.2.2* were conducted on the subjects for this part of the study.

4.4.3 Questionnaires

All subjects completed an interview with the caregiver present. Subjects were asked about past medication, known diseases and pubertal development (by Tanner hair development (201; 281)). Dietary calcium intakes were assessed using a 24 hour dietary recall questionnaire as well as a Food Frequency Questionnaire (169). The PAQ as described in section *4.2.3* was used. Both METPA and MECHPA scores were calculated from the questionnaire and used in the analyses of this study as detailed in section *4.2.3*.

4.4.4 Bone Mass Measurements

We measured whole body and site specific bone mineral content, area and density using a Hologic QDR 4500A dual-energy X-ray absorptiometer (DXA) according to standard

procedures. A lumbar spine phantom was scanned daily to determine the intrinsic coefficient of variation of the machine. During the course of the study, coefficients of variation for BA, BMC and BMD were 0.47, 0.78 and 0.35%, respectively. DXA scans were performed on the non-dominant radius (mid-shaft), left hip (femoral neck), lumbar spine (L_1-L_4), and whole body. The whole body scan enabled the assessment of whole body lean and fat tissue (g) and percentage body fat (%). Sub total whole body values (total body – head) were used as we considered the head to be an unloaded region.

4.4.5 Data Analysis

Two kinds of relationships with bone mass, race group and PA were investigated. Firstly, METPA and MECHPA scores were included as categorical variables (divided into quartiles) and analysed separately for Black and White children. Secondly, METPA and MECHPA scores were log transformed (data were negatively skewed) and correlated with bone mass variables separately for White and Black children using Pearson and Spearman Rho correlation coefficients. All data are presented as mean (standard deviation), unless otherwise noted. Data were analyzed using SPSS v12.0. An ANOVA was performed for all physical activity and bone and body composition measurements. Bone mass differences within METPA and MECHPA quartiles and between race groups were assessed using a multivariate ANOVA. The Bonferroni multiple comparison test was used to assess group differences. Chi-Square tests were used for categorical variables. DXA data is reported both with and without adjustment for height and weight. An alpha level of $p < 0.05$ was considered to be statistically significant.

4.5 Part 4 - Socio-economic Status and Physical Activity Study

This section describes the methodology of a study conducted on the Bone Health cohort to assess the associations between socio-economic status, physical activity and body composition in Black and White South African children at age nine years (183). Physical activity and inactivity patterns in nine year old South African children were examined and the amount of PA by gender, socio-economic status and maternal (primary caregiver) SES characteristics such as marital and employment status, as well as level of education was considered. The study also sought to examine body composition patterns in relation to SES and other sedentary behaviours such as television watching.

The study sought to determine whether:

- access to amenities including electricity, television, motor vehicles etc. is equal across the sample;

- socio-demographic variables such as maternal education, maternal marital status and SES are associated with the subjects' physical activity levels;

- SES is related to body composition profiles, hours spent watching television and PA levels.

4.5.1 Subjects

This study included data obtained from the primary caregiver (defined as the mother for purpose of this study) and children participating in the Bone Health Study. Satisfying these requirements resulted in complete paired data for 381 children and mothers. There were five less children included in this analysis as compared to the study described in *4.4.1* (Part 3) as complete mother and child data were not available for these five subjects. Subsequent crosschecks were again performed between this study sample (n=381) and the Bone Health

cohort (n=623) to ensure representation. Key demographic variables were similar and there were no differences in proportions of children in SES and race groups between this study sample and the original group. Subjects were all healthy and aged nine at the time of testing. The sample for this study comprised of 43 White males, 157 Black males, 38 White females and 143 Black females.

4.5.2 Anthropometric measurements

The same anthropometric measures described in section *4.2.2* were conducted on the subjects for this part of the study.

4.5.3 Questionnaires

All subjects completed an interview with the primary caregiver present. We examined past medication, known diseases, socio-economic and medical history, pubertal development and physical activity. Primary caregivers answered a number of questions regarding their social and economic status. This study utilised an asset indicator approach (44) by formulating a composite score from 11 bivariate factors (house type, electricity, indoor flushing toilet, indoor running water, television, motor vehicle, refrigerator, microwave, washing machine, video machine and telephone) which were asked in the interview. From the asset indicator score the sample was divided into quartiles ranging from low to high SES. Mothers of the subjects also answered questions regarding their marital status and levels of education. The PAQ as described in section *4.2.3* was used. Only METPA scores were used in the analysis of this data set.

4.5.4 Body composition measurements

The whole body scan obtained from the DXA (as described in section *4.3*.5) enabled the assessment of the whole body lean and fat tissue (g) and percent body fat (%).

4.5.5 Data analysis

Descriptive statistics were used to describe the physical features of the sample. Univariate analysis was used to determine racial and gender differences in physical activity. Factors contributing to the asset indicator score were identified as significant contributors through a factor analysis. Figure 4.5 below shows how the SES quartiles were calculated. The asset indicator score ranged from one to 11 and children were divided into four quartiles based on these scores. The analysis compared the prevalence of children falling into each of these quartiles in terms of percentages of PA and inactivity behaviour by socio-demographic background (maternal marital status, maternal education level and socio-economic score). Cross tabs with chi-squared tests were used to assess differences across ordinal variables such as education and support. Multivariate analysis with confounding variables controlled for was used to assess lean mass differences across activity and television quartiles. Number of hours spent watching television was used as indication of sedentary behaviour. These scores were divided into quartiles ranging from less active to highly active. An alpha level of $p < 0.05$ was considered to be statistically significant.

Factor	Amenity	Response	Score
1	House Type	Formal (brick structure)	1
		Informal (non-brick structure)	0
2	Electricty	Yes	1
		No	0
3	Indoor Flushing Toilet	Yes	1
		No	0
4	Indoor Running Water	Yes	1
		No	0
5	Television	Yes	1
		No	0
6	Motor Vehicle	Yes	1
		No	0
7	Refrigerator	Yes	1
		No	0
8	Microwave	Yes	1
		No	0
9	Washing Machine	Yes	1
		No	0
10	Video Machine	Yes	1
		No	0
11	Landline Telephone	Yes	1
		No	0

SCORE RANGE: 0-11

Quartile 1

Quartile 2

Quartile 3

Quartile 4

Figure 4.5 Calculation of asset indicator score

4.6 Part 5 - Longitudinal Physical Activity and Bone Mass Study

This section describes the methodology of a study conducted on children from the Bone Health cohort, to examine bone mass changes over a 12 month period in a group of Black and White South African pre- and early-pubertal children and to explore these changes in relation to habitual physical activity levels and calcium intakes (181).

The study sought to determine:

- whether BA and BMC gains were similar across racial groups and between children with varying levels of habitual physical activity;

- whether residualized BA and BMC values were similar between race and gender groups across varying levels of habitual physical activity, and whether dietary calcium intake has a synergistic effect with physical activity level.

4.6.1 Subjects

This study included data obtained from children in the Bone health cohort, for whom we had complete data at age nine and 10 (n=321). Subsequent crosschecks were again performed between this study sample (n=321) and the Bone Health cohort (n=623) to ensure representation. Subjects were all healthy and aged nine years (9.51 (0.27)) at visit one and 10 years (10.54 (0.27)) at visit two. Children who were asthmatic or suffering from any disorder likely to affect bone metabolism were excluded from the study. Complete data for the two annual visits, spaced one year apart were available for 321 children. The sample was comprised of 31 White males, 141 Black males, 27 White females and 122 Black females

4.6.2 Anthropometric Measurements

The same anthropometric measures described in section *4.2.2* were conducted on the subjects for this part of the study.

4.6.3 Questionnaires

The same set of questionnaires described in earlier sections was completed on both occasions by the children, with their caregiver present. We examined past medication, known diseases, and pubertal development (by Tanner hair development (281)). Girls were asked about their menstrual status. Dietary calcium intakes were assessed using a 24-hour dietary recall questionnaire as well as by a Food Frequency Questionnaire. Total physical activity (METPA and MECHPA) was estimated using the method described in *4.2.3*, taking into consideration all physical activity and inactivity over the previous 12 months. Since the physical activity

questionnaire assessed all previous activity in the preceding 12 months, year 10 data were considered representative of activity in the 12 month assessment period.

4.6.4 Bone Mass measurement

The same bone mass measurements as described in *4.4.4* were used for this study.

4.6.5 Data Analysis

Data were analyzed using SPSS v12.0 and a *p* level of <0.05 was considered to be statistically significant. Since we were interested in examining bone mass accumulation patterns in our sample, percentage gains in BMC and BA (BMCGAIN and BAGAIN) were calculated using the following formula:

% gain= (Measurement at age 10- Measurement at age 9) / Measurement at age 9 * 100

An ANOVA was used to detect differences in BMCGAIN and BAGAIN between race and gender groups from age nine to 10 years and the Bonferroni multiple comparison test was used to assess group differences where appropriate. As BMD is an areal density measurement (g/cm^2), and does not account effectively for diverse body sizes, it has been recommended that the best way of avoiding size related artefact when analyzing bone mass is to include body weight, height and BA as independent variables against BMC as the dependant variable in a multiple regression analysis (93; 217). In this sample of children, height was not significantly related (p=0.891) to BMC, thus it was excluded as a covariate. Height was however, significantly related to BA (p<0.001) at all sites and was therefore included as a covariate for BA analyses. We used a novel method based on Rowlands et al.'s (2004)

technique (234). We regressed body weight and BA against BMCGAIN and saved the residuals to form a new variable called residualized BMCGAIN ($BMCGAIN_{res}$). Given a subject's weight, $BMCGAIN_{res}$ provides a good indication of whether the subject is above or below their expected BMCGAIN for their weight. The same procedure was followed for BAGAIN, whereby body weight and height were regressed against BAGAIN and the residuals were saved to form a new variable called $BAGAIN_{res}$. Given a subject's weight and height, $BAGAIN_{res}$ provides a good indication of whether the subject is above or below their expected BAGAIN for their weight and height. To assess whether the non-bone related components of weight (fat and lean mass) had different effects on BMCGAIN or BAGAIN, a regression analysis was done including the additional covariates.

METPA and MECHPA scores were evaluated over the one year assessment period, which preceded the second DXA scan, and were assessed as categorical variables after subjects were divided into quartiles of activity within race and gender groups. To correct for the possible effects of differing physical activity on BMC and BA accumulation prior to the study period, METPA and MECHPA scores calculated at the subject's first visit (age 9) were entered into the regression analysis as covariates. $BMCGAIN_{res}$ and $BAGAIN_{res}$ at the whole body, radius, hip and spine were assessed within METPA and MECHPA quartiles, between race and gender groups using a multivariate ANOVA. A stepwise linear multiple regression analysis was conducted in order to assess the relationship between past year's physical activity (both METPA and MECHPA), calcium intake and $BMCGAIN_{res}$ and $BAGAIN_{res}$ at all sites measured. The independent variables were entered in the following order: calcium intake, METPA, MECHPA, product of calcium intake * METPA and the product of calcium intake * MECHPA. Independent variables were centered before being entered into the regression analysis, in order to avoid the problem of multicollinearity (234). Centering involves subtracting the mean from each individual score thereby making the mean of the centered

variable zero. The product terms were calculated from the centered variables. All data are presented as means (standard deviation), unless otherwise noted.

4.7 Conclusion

This chapter has described the objectives and methods used for all studies conducted for this thesis. The chapter has described the participants recruited for participation into each study and has given a detailed description of the methodologies and data analyses techniques used to test each research question.

Chapter 5

Results

Chapter 5: Results

5.1 Introduction

The results of the studies conducted for this thesis are presented in the following chapter. The chapter, like the methodology chapter is divided into five parts, each containing data findings relevant to that particular study. Each part begins with a brief summary of aims and methods of that particular study. A final summary of all findings is presented at the end of the chapter. For the majority of the results chapter, comparisons are made between Black and White, and male and female groups. A standard method (using asterisks) to denote significant differences between the groups is used throughout the thesis.

5.2 Part 1 - Actical Study

This study sought to evaluate the correlation between subjects' reported activity on the PAQ and activity as measured by the Actical accelerometer in a group of nine to 11 year old children who were not part of the Bone Health cohort. Thirty children, each wearing an Actical for a period of four days, completed the 'past week' and 'past year' PAQ twice (once before the fitting of the Actical and again one week later). Pearson product moment correlations were used to analyse the PAQ and Actical data and Intra Class Correlation coefficients (ICC) were used to test reliability and consistency of the PAQ. The same four day period that children wore Acticals for, was compared with the corresponding four days of activity reported on the past week PAQ. Data are presented as means (standard deviations) unless otherwise indicated. White, Black, male and female data are presented in tabular form in keeping with the rest of the thesis, however for this study, all groups were analysed

together as there were no significant differences found between the race and gender groups in activity levels or between any of the variables measured in this small sample of children.

5.2.1 Sample Characteristics

Thirty children participated in this study, in which the primary aim was to explore and ascertain a range of responses from the subjects. Sample characteristics are displayed in Table 5.1. The mean age of the subjects was 10.17 (0.80) years. Included in the sample were 12 males and 18 females with equal numbers of White and Black children in each group. The mean height of the subjects was 139.18 (9.01) cm and weight was 35.23 (8.42) kg. Average activity counts per day was 548241 (28933) for the weekdays (Friday and Monday) and 561569 (46710) for the weekend days. Although weekend activity counts were slightly higher; there were no significant differences between the two time frames, although it should be noted that the standard deviation was much higher for the weekend activity. The counts were further divided into percentages of time spent in sedentary, light, moderate or vigorous activity as described in Figure 4.2. Subjects spent an average of 57 % of their time each day in sedentary activity as measured by the Actical (including sleeping). Subjects reported spending 58% of their day in sedentary activity according to the PAQ. This figure comprised 3.83 (0.40) hours per day (16% of day) doing sedentary activities and an average of 10.08 (1.03) hours per day (42% of day) sleeping. These figures included after school and weekend time spent television watching, reading, drawing, doing homework, time spent on the computer, and sleeping, resulting in a mean time of 58% of their day spent in sedentary activity as reported on the PAQ.

In this sample of children, light and sedentary activities were defined to be 2.7 METS or less, moderate activity (2.8-5.9 METS) and vigorous activity were activities which generated MET

scores of 6 and above. Activity that is classified as vigorous on the Actical is approximately equivalent to 3000 counts per minute (125) (refer to figure 4.2). Subjects spent an average of 8.4 (5.6) minutes of their time each day in vigorous activity as measured by the Actical. According to the PAQ, children spent approximately 12.1 (9.7) minutes hours per day in vigorous activities (activities with a MET score of 6 or above).

Average energy expenditure as measured by the Actical was 1256 (55) Cal/ per day over the four day study period. Although children had slightly lower average energy expenditure (1204 (54) Cal/day) over the week day period (Friday and Monday) as compared to the weekend period (1306 (57) Cal/day-Saturday and Sunday), there was no significant difference between these two time frames in this sample of children.

Table 5.1 Sample characteristics for the Actical Study. Data are mean (SD).

	White Male (n=6)	Black Male (n=6)	White Female (n=9)	Black Female (n=9)	Whole Group (n=30)
Age (yrs)	10.17 (0.75)	10.00 (1.10)	10.50 (0.76)	10.00 (0.71)	10.17 (0.80)
Height (cm)	141.00 (8.05)	139.00 (8.03)	140.22 (9.96)	136.75 (10.00)	139.18 (9.01)
Weight (kg)	35.83 (8.11)	37.50 (10.11)	34.56 (7.14)	34.00 (9.73)	35.23 (8.42)
Average total counts/day [week]	657429 (89188)	475573 (25401)	506241 (46698)	562850 (48863)	548241 (28933)
Average total counts/day [wkend]	608392 (91820)	545158 (146816)	520683 (83447)	579646 (76665)	561569 (46710)
Sedentary activity (% time) from Actical	57.65 (3.02)	55.74 (3.32)	57.91 (1.89)	55.06 (1.39)	56.58 (1.12)
Sedentary activity (% time) from PAQ	61.66 (8.83)	54.26 (7.13)	60.91 (6.97)	56.22 (7.01)	57.94 (5.93)
Vigorous activity (% time) from Actical	0.55 (0.05)	0.82 (0.41)	0.58 (0.17)	0.48 (0.11)	0.60 (0.1)
Vigorous MET Score (% time) from PAQ	1.54 (0.58)	0.71 (0.23)	0.77 (0.25)	0.47 (0.08)	0.87 (0.28)
Average total energy expenditure (Cals/day) [week]	1196 (101)	1274 (109)	1133 (96)	1281 (132)	1204 (54)
Average total energy expenditure (Cals/day) [wkend]	1350 (103)	1389 (166)	1238 (89)	1281 (114)	1306 (57)
Average hours sleep/night	10.14 (1.07)	9.84 (1.07)	10.32 (0.90)	10.24 (0.38)	10.08 (1.03)

There were no statistical differences between the groups for any variables.

5.2.2 Validity

An overall significant, positive correlation was observed for total activity counts and total METPA score obtained over the four day period (r=0.53, p=0.004) for all children. In order to determine whether the relationship held true for activities of varying intensities, Pearson correlation coefficients were calculated for time spent in sedentary and vigorous activity as reported by the subjects on the PAQ (for the same four day period as the Actical) and as measured by the Actical. Figure 5.1 shows the relationship between the two observations of sedentary activity. A positive (r=0.66) and significant (p<0.001) correlation was observed between the average percentage time spent per day in sedentary activities as reported on the PAQ and the average percentage of time per day spent in sedentary activity as measured by the Actical. Both measures included time spent asleep.
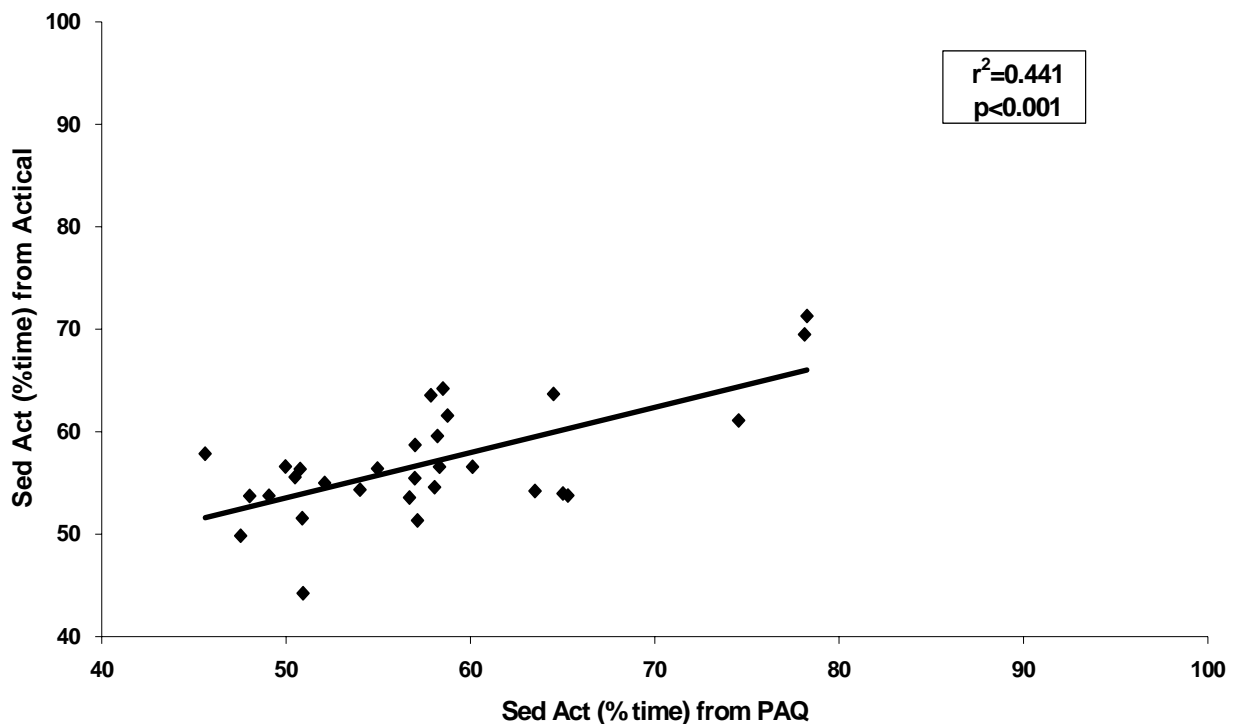
Figure 5.1 Correlation between sedentary activities (% time) as estimated from the PAQ and percentage of time spent in sedentary activity per day as measured by the Actical. (r^2=0.441, p<0.001)

Figure 5.2 shows the relationship between the average daily amount of time spent in vigorous activity (METPA score >6) as reported on the PAQ and the average daily time spent in vigorous physical activity as measured by the Actical. Again, a positive (r=0.70) and significant (p<0.001) relationship between the two variables was observed.
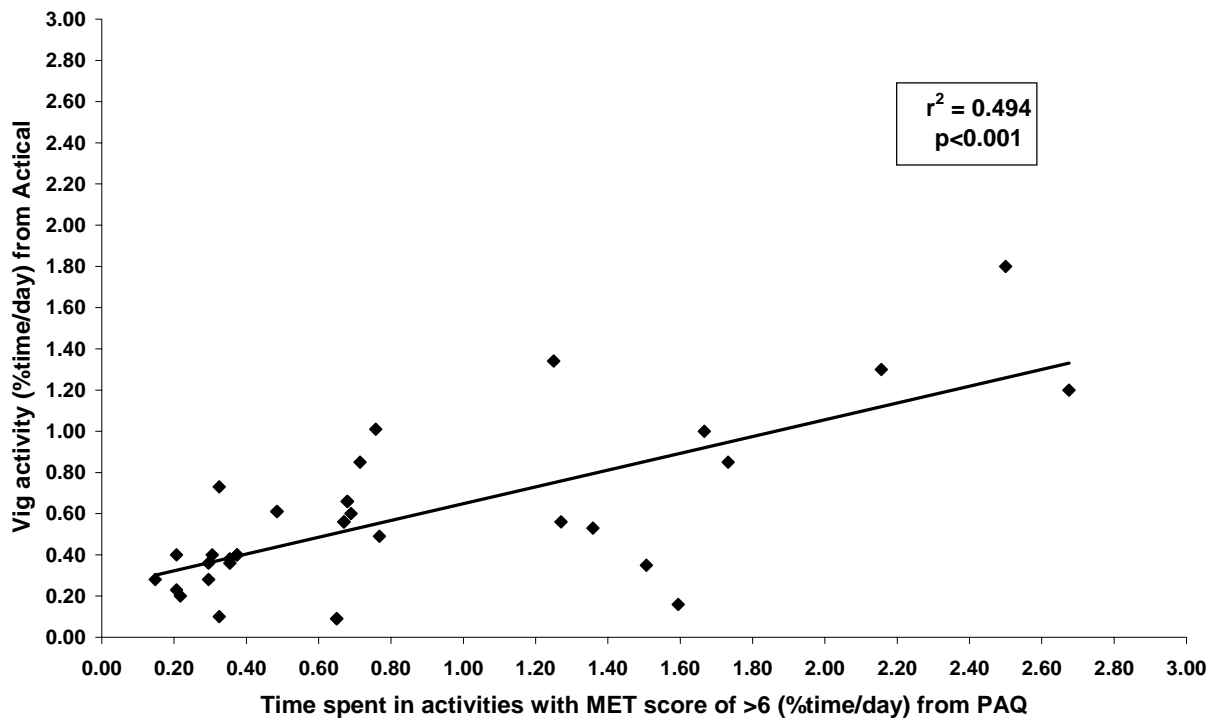
Figure 5.2 Correlation between % time spent in vigorous activity as estimated from the PAQ and percentage of time spent in vigorous activity per day as measured by the Actical. (r^2=0.494, p<0.001)

5.2.3 Reliability

The intra class correlations of the estimates of the past year's physical activity (METPA) and inactivity scores (sedentary activity) as measured twice with a one week interval are presented in Table 5.2.

Table 5.2 Intraclass correlation coefficients comparing two administrations of the past year PAQ one week apart. Data are means (SE)

	1st PAQ administration	2nd PAQ administration	ICC	p Value
METPA (hrs/wk)	6.98 (1.33)	6.83 (1.03)	0.964	p<0.001*
Sedentary activity (hrs/wk)	26.49 (2.72)	25.49 (2.45)	0.975	p<0.001*

*All correlations are significant at p<0.001

To ascertain whether the time period of the Actical assessment period was representative of a 'normal' week of activity and inactivity for the subjects, the short form of the PAQ was also administered twice. While inter week variability in physical activity is expected, it was important to ensure that the week of Actical and PAQ assessment was not different to an average normal week of activity for the subjects. The reproducibility coefficients (Intra Class Correlations) of the estimates of the past week physical activity (METPA) and inactivity scores (sedentary activity) as measured at a one week interval are presented in Table 5.3. The reproducibility coefficients were high, indicating that the week in which the Actical assessment was done, was representative of a normally active week for the subjects or that the children gave average answers irrespective what their actual activity was for that week.

Table 5.3 Intraclass correlation coefficients comparing two administrations of the past week PAQ one week apart. Data are means (SE)

	1st PAQ administration	2nd PAQ administration	ICC	*p* Value
METPA (hrs/wk)	6.76 (1.32)	7.62 (1.14)	0.945	p<0.001*
Sedentary activity (hrs/wk)	28.98 (2.50)	25.97 (2.43)	0.971	p<0.001*

*All correlations are significant at p<0.001

5.3 Part 2 - Fitness Study

This study sought to evaluate the relationship between fitness and physical activity as reported on the PAQ and body composition measures in a sub sample of children from the Bone Health cohort. A Fitness Score was calculated for each subject and compared to body composition and PAQ indices. Data from 69 subjects were used for this study. Descriptive data are presented as means (SD) unless otherwise indicated. Multivariate ANOVA tests were used to assess for group differences (whole group, race, gender) in the tasks performed with Bonferroni multiple comparison tests used as the post hoc test. Chi Squared tests were used to assess whether percentages of children within race and gender groups falling into each Fitness Score category were similar.

5.3.1 Sample Characteristics

Sample characteristics are displayed in Table 5.4. Included in the study were 31 White and 38 Black children, with approximately equal numbers of males and females in each group. There were no significant differences between any of the groups for age, weight, BMI or average grip strength. White females were significantly ($p=0.013$) taller than Black males. White males performed the shuttle run task significantly faster ($p=0.012$) than Black males and females, performed a significantly greater ($p<0.001$) number of sit ups in 30 seconds, showed a significantly quicker time ($p=0.017$) to reach their t-half and had a lower ($p=0.044$) heart rate at t-half than all other groups. White males also scored a significantly higher ($p=0.031$) METPA score as reported on the PAQ than all other groups. There were no other significant differences between variables listed in the table below.

Table 5.4 Sample characteristics for the Fitness Study. Data are means (SD)

	White Male (n=19)	Black Male (n=21)	White Female (n=12)	Black Female (n=17)	Whole Group (n=69)
Age (yrs)	12.69 (0.65)	12.57 (0.14)	12.76 (0.53)	12.60 (0.12)	12.69 (0.65)
Height (cm)	156.79 (11.15)	149.90 (6.40)	159.85 (6.23)*	153.27 (8.65)	154.37 (9.08)
Weight (kg)	46.62 (10.45)	43.69 (10.17)	49.41 (12.91)	44.93 (10.30)	45.82 (10.73)
BMI (kg/m^2)	18.6 (2.5)	19.4 (4.1)	19.2 (3.8)	18.9 (3.0)	19.1 (3.3)
Shuttle runs (s)	45.13 (5.23)**	50.04 (5.03)	48.91 (6.78)	51.05 (4.30)	48.62 (5.68)
Sit ups (n/30s)	21 (5)***	13 (4)	15 (2)	12 (4)	15 (5)
HR (BPM) at t-half	118 (21)***	120 (23)	137 (21)	133 (19)	125 (22)
Time taken to reach t-half (s)	208.6 (8.6)***	216.5 (9.1)	214.1 (4.4)	215.8 (6.7)	213.6 (8.3)
Grip Strength (N)	20.07 (7.7)	16.03 (3.98)	15.12 (4.96)	16.05 (5.76)	16.78 (5.74)
METPA (hrs/yr)	100.72 (7.50)***	78.58 (7.29)	64.11 (8.44)	69.27 (10.78)	79.16 (4.64)
Lean mass (g)	8886.9(5247.2)	9095.9(5014.4)	11220.6(6413.9)	9428.3(4485.8)	9493.8(5208.0)
Fat mass (g)	31848.8 (5300.7)	28224.2 (3490.0)	28814.4 (4625.9)	26471.0 (5509.0)	29051.8 (4946.3)
Percentage body fat (%)	21.1 (5.7)	22.4 (8.2)	26.0 (8.2)	23.4 (4.1)	22.9 (7.0)

* White females > Black males, p<0.05

**White males > Black males and females, p<0.05

***White males > all other groups, p<0.05

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5.3.2 Fitness Testing

As mentioned earlier in the methods section (section *4.3.4*), a point system was used to generate a Fitness Score and classify subjects into different levels of fitness. Each task was assigned a score from 0-3 and a sum fitness score was then generated. Subjects were then classified into three fitness levels and chi square tests were used to assess for differences. Tables 5.5 - 5.8 show the percentages of White, Black, male and female subjects within each fitness level for each task performed.

Table 5.5 shows the percentages of subjects within each point category of the shuttle run task according to group (White, Black, males and females). A score of zero was indicative of the slowest time to complete shuttle runs and a score of three meant that the subject fell into the quickest category for the task. A significantly greater (p=0.04) percentage of White males, compared with all other groups performed the task in the quickest time. There were no Black females able to perform the shuttle runs in the quickest category of time.

Table 5.5 Score table of the shuttle run task. The % columns refer to the distribution of each group within the four categories.

Shuttle Run Points	White Male (%)	Black Male (%)	White Female (%)	Black Female (%)	Whole group (%)
0 (slowest time to complete 10)	11	30	36	23	24
1	6	25	18	54	24
2	22	25	9	23	21
3 (quickest time to complete 10)	61*	20	36	0	31

Reported p-levels are based on likelihood ratio x^2 tests.
*White males > all other groups, p<0.05

The next task that subjects performed was based on the maximal number of sit ups able to be completed within 30 seconds. Table 5.6 shows the percentages of subjects within each point category of the sit up task according to group. A score of zero was indicative of the least number of sit ups completed in 30s and a score of three meant that the subject was able to complete the most number of sit ups in 30s. A significantly greater (p<0.001) percentage of

White males, compared with all other groups; performed the most number of sit ups in 30s. A significantly greater (p<0.001) percentage of Black females fell into the least number of sit ups completed in 30s category.

Table 5.6 Score table of the sit up task. The % columns refer to the distribution of each group within the four categories.

Sit Ups Points	White Male (%)	Black Male (%)	White Female (%)	Black Female (%)	Whole group (%)
0 (least number in 30s)	0	35	0	62[**]	24
1	11	30	56	23	27
2	33	25	45	8	27
3 (most number in 30s)	56[*]	10	0	8	21

Reported p-levels are based on likelihood ratio x^2 tests.
*White males > all other groups, p<0.05
**Black females > all other groups, p<0.05

The third task that subjects performed was a standard bench step test. The test lasted for three minutes and was followed by a two minute recovery period, during which the *t*- half (time taken for the pulse to fall to 150 % of resting heart rate) of the subjects was measured. Table 5.7 shows the percentages of subjects falling into each point's category of the bench step task according to group. A score of zero was indicative of having the longest *t*- half, while a score of three was assigned to those subjects with the shortest *t*-half. There were a significantly greater (p=0.034) percentage of White males in the shortest *t*-half category than any of the other groups.

Table 5.7 Score table of the step test task. The % columns refer to the distribution of each group within the four categories.

Step test Points	White Male (%)	Black Male (%)	White Female (%)	Black Female (%)	Whole group (%)
0 (longest t- half)	17	45	27	42	33
1	22	25	27	33	26
2	11	15	46	8	18
3 (shortest t- half)	50[*]	15	0	17	23

Reported p-levels are based on likelihood ratio x^2 tests.
*White males > all other groups, p<0.05

A composite score of each subject's total score on each of the three tasks was then calculated resulting in a maximum score of nine and a minimum score of zero. These scores were then grouped into categories from one to three. The method of scoring is described in detail in Figure 4.4. Table 5.8 below shows the percentages of subjects falling into each category of Fitness Score from least (score of one) to most fit (score of three). A significantly greater ($p<0.001$) percentage of White males, compared with all other groups were classified as being 'fittest'. There were no Black females that could be classified as being in the 'most fit' category.

Table 5.8 Score table of Fitness Score. The % columns refer to the distribution of each group within the four categories.

Fitness Score	White Male (%)	Black Male (%)	White Female (%)	Black Female (%)	Whole group (%)
1 ('least fit')	0	32	36	46	27
2	25	42	36	54	39
3 ('most fit')	75[*]	26	28	0	34

Reported p-levels are based on likelihood ratio x^2 tests.
*White males > all groups, $p<0.05$

5.3.3 Relationship between fitness, physical activity and body composition

A positive and significant correlation (r=0.60, p=0.022) was found between METPA scores as calculated from the PAQ and Fitness Score as calculated from the battery of fitness tests conducted on the subjects. Figure 5.3 shows the mean METPA scores within each level of fitness (1=least fit, 3=most fit). The mean METPA score of the fittest subjects was significantly greater (p=0.022) than that of the least fit subjects.
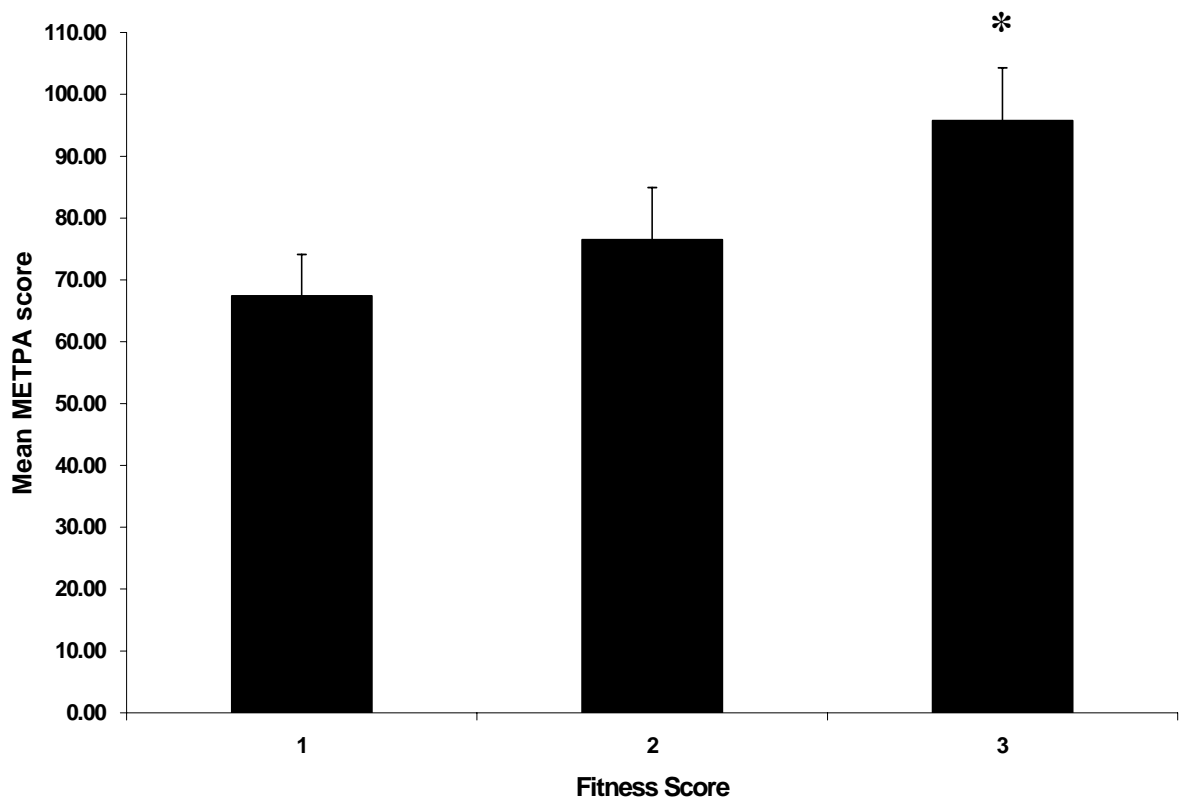
Figure 5.3 Mean (SD) METPA scores as estimated by the PAQ within each tertile of fitness as determined by the Fitness Score. *p<0.05 Level 3> Level 1.

The BMI and body fat percentages of subjects within each fitness level are shown in the figures below (Fig's 5.4 and 5.5). Subjects who had a Fitness Score of one (the least fit), had a significantly greater BMI (21.7 (4.1) kg/m^2, p=0.001) than fitter subjects with a Fitness Score of two (18.3 (2.9) kg/m^2) or three (17.9 (2.1) kg/m^2).
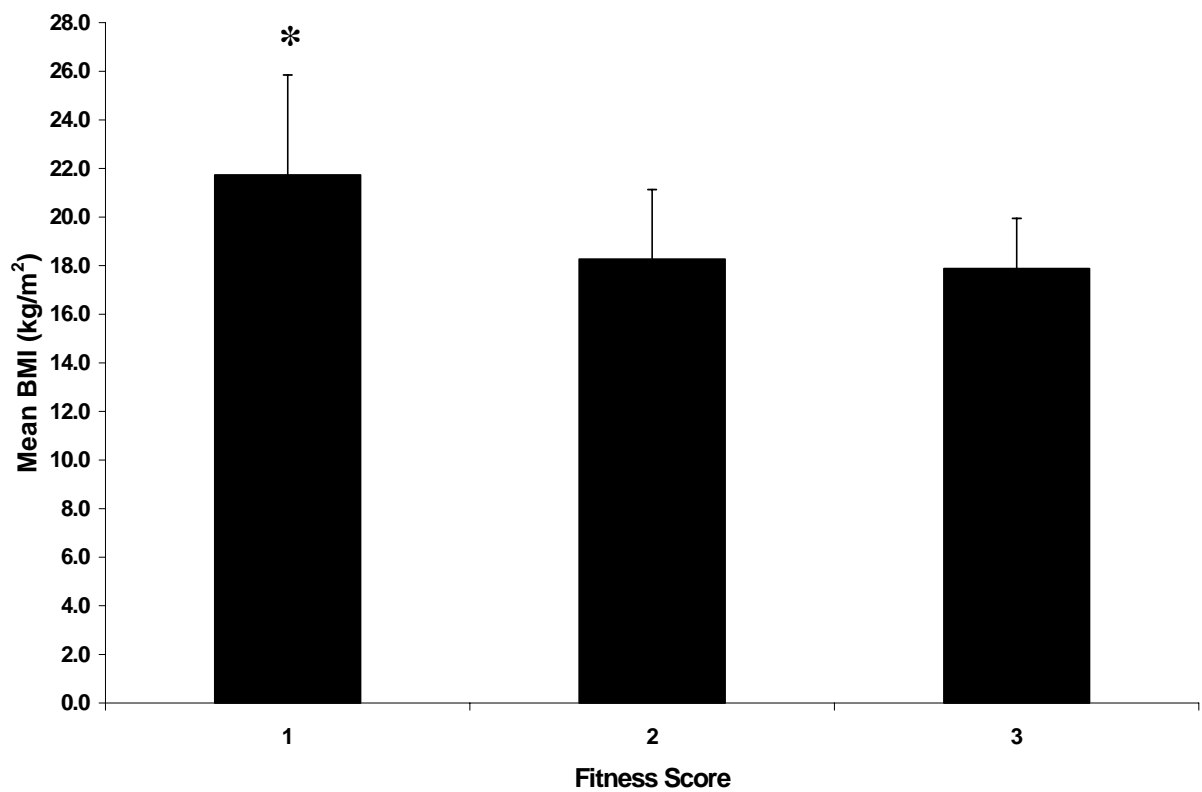
Figure 5.4 Mean (SD) BMI within each fitness level. *p<0.05 Level 1> Level 2 & 3.

Subjects who had a Fitness Score of one, had a significantly greater percentage body fat (29.6 (7.0) %, p<0.001) than subjects with a Fitness Score of two (21.5 (5.7) %) and three (19.7 (5.0) %) (Figure 5.5).
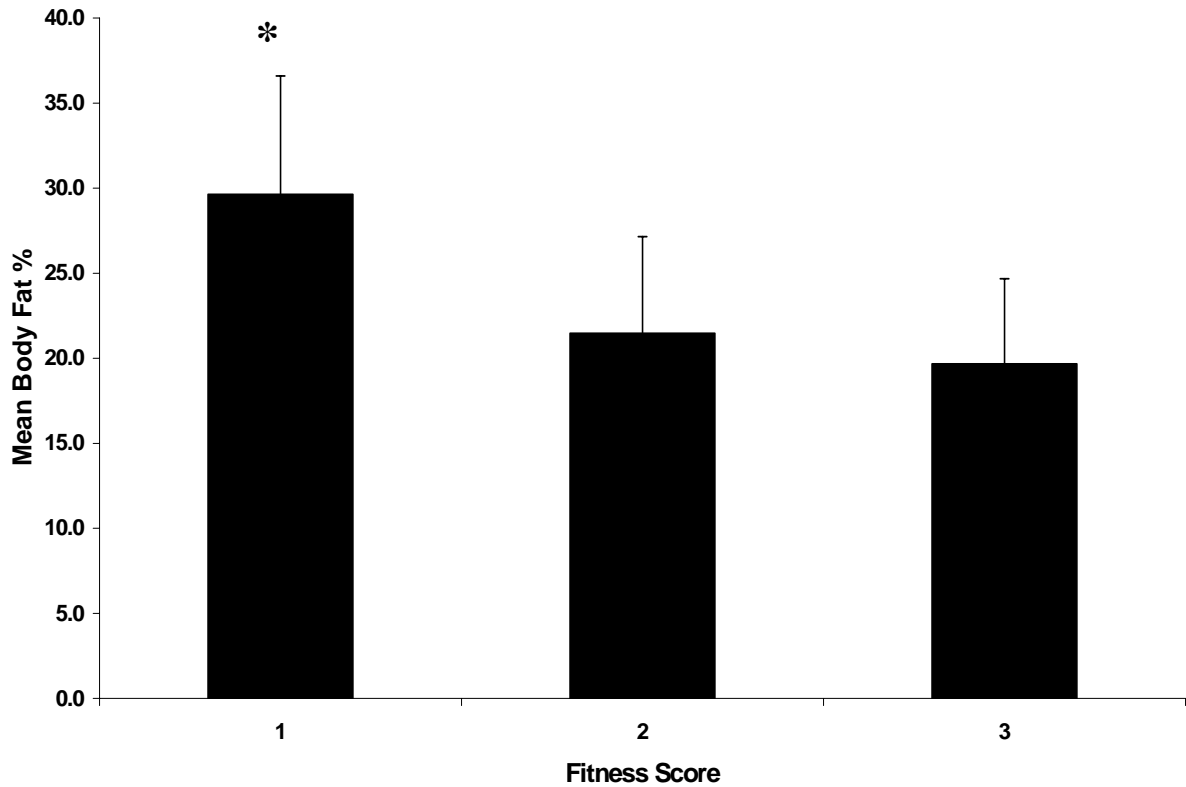
Figure 5.5 Mean (SD) body fat percentage within each fitness level. *p<0.001, Level 1> Level 2 & 3.

5.4 Part 3 - Cross Sectional Physical Activity and Bone Mass Study

5.4.1 Associations between habitual physical activity and bone mass in Black and White South African children at age nine years

This study assessed the association between physical activity (sedentary activity, sports participation and intensity, commuting to and from school (active and passive)) and skeletal mass in 386 healthy nine-year-old Black and White, male and female South African children from the Bone Health cohort. It was hypothesized that: i) higher levels of physical activity (a greater metabolic equivalent physical activity (METPA) score) would be associated with

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higher bone mass; ii) the type of sport played influences bone mass (sports with a higher MECHPA score would have a greater osteogenic effect); iii) race groups would have different levels of PA and possibly, this could translate into different bone mass effects.

5.4.2 Anthropometric and Bone Characteristics

Included in the study were 82 White and 304 Black nine-year-old children, with approximately equal numbers of males and females in each group. All children were pre-pubertal. Table 5.9 shows the results for unadjusted DXA and body composition data. White children had significantly lower hip BMD (p<0.001), and significantly greater hip area (p=0.002) than Black children, and White females had lower spine BMD than Black females (p=0.005). White females and males were significantly taller (p<0.001) and had higher calcium intakes (p<0.001) than their Black peers. White males were significantly heavier (p=0.04) and had significantly greater lean tissue mass (p<0.001) than Black males. There were no significant differences between Black and White children for BMI, fat tissue (g) or body fat percentage.

Table 5.9 Unadjusted bone mass data, height, weight, age, BMI, calcium intakes.

	White Male (n=44)	Black Male (n=158)	White Female (n=38)	Black Female (n=146)
Age (yrs)	9.5 (0.1)	9.5 (0.0)	9.6 (0.1)	9.5 (0.0)
Height (cm)	137.4 (1.0)[*]	133.0 (0.5)	136.3 (1.2)[***]	132.8 (0.5)
Weight (kg)	32.6 (1.2)[*]	29.1 (0.4)	30.4 (1.1)	29.7 (0.6)
BMI (kg/m^2)	16.6 (0.0)	16.7 (0.0)	16.2 (0.0)	16.7 (0.0)
Ca Intake (mg/day)	778 (42)[*]	347 (22)	719 (44)[***]	347 (23)
WB BMC (g)	966.5 (145.8)	927.6 (121.3)	887.0 (183.2)	889.2 (146.3)
WB BA (cm^2)	1176.1 (150.6)	1122.9 (118.7)	1108.5 (176.3)	1112.3 (148.4)
WB BMD (g/cm^2)	0.828 (0.058)	0.827 (0.049)	0.795 (0.051)	0.799 (0.050)
Radius BMC (g)	3.3 (0.5)	3.3 (0.5)	3.0 (0.5)	3.0 (0.6)
Radius BA (cm^2)	8.3 (1.1)	8.4 (1.1)	7.7 (1.0)	8.0 (1.1)
Radius BMD (g/cm^2)	0.403 (0.025)	0.393 (0.032)	0.383 (0.030)	0.379 (0.032)
Hip BMC (g)	14.3 (2.6)	14.4 (2.4)	12.7 (2.8)	13.0 (2.3)
Hip BA (cm^2)	20.5 (2.4)[*]	19.0 (3.3)	21.5 (4.6)[***]	19.4 (2.2)
Hip BMD (g/cm^2)	0.699 (0.079)	0.749 (0.079)[**]	0.603 (0.065)	0.671 (0.079)[****]
Spine BMC (g)	23.5 (4.3)	21.9 (3.5)	20.8 (4.4)	22.0 (3.9)
Spine BA (cm^2)	42.7 (4.3)	40.7 (4.1)	39.4 (4.1)	39.2 (5.0)
Spine BMD (g/cm^2)	0.548 (0.061)	0.536 (0.050)	0.525 (0.065)	0.557 (0.069)[****]
Lean tissue (g)	22791.8 (2966.1)[*]	20718.6 (2700.2)	19916.2 (3183.3)	19720.7 (2746.5)
Fat tissue (g)	8285.1 (5189.6)	6974.4 (3301.7)	9473.9 (4224.4)	9010.0 (4564.6)
Body fat (%)	24.1 (6.3)	23.4 (7.8)	30.0 (7.0)	28.9 (7.9)

*White males > Black males, p<0.05
**Black males > White males, p<0.05
***White females > Black females, p<0.05
****Black females > White females, p<0.05

Table 5.10 shows the results for bone mass data adjusted for height and weight. Bone area data were adjusted for height only. After adjustment, Black children still had a significantly higher hip BMD than White children (p<0.001), Black males had higher hip BMC than White males (p=0.038), and Black females had higher spine BMC (p=0.005) and spine BMD (p=0.004) than White females. White males had significantly greater whole body area than Black (p<0.001) and White females (p=0.002). Black males had significantly greater radial

area (p=0.001) than White females. White males had a significantly greater hip area then Black males and females (p<0.001). White males had a significantly greater spine area than White females (p<0.001) and Black females (p<0.001).

Table 5.10 Bone mass characteristics after adjusting for differences in height and weight for BMC and BMD and height for BA. Data are means (SE)

	White Male (n=44)	Black Male (n=158)	White Female (n=38)	Black Female (n=146)
WB BMC (g)	919.5 (15.3)	943.1 (8.2)	864.2 (16.0)	894.0 (8.2)
WB BA (cm2)	1176.12 (15.63)[*]	1121.60 (12.99)	1108.50 (18.29)	1114.37 (15.53)
WB BMD (g/cm$^{2)}$)	0.824 (0.008)	0.828 (0.005)	0.793 (0.009)	0.800 (0.005)
Radius BMC (g)	3.2 (0.1)	3.3 (0.1)	2.9 (0.1)	3.0 (0.1)
Radius BA (cm^2)	8.04 (0.19)	8.33 (0.10)[**]	7.48 (0.20)	7.96 (0.10)
Radius BMD (g/cm^2)	0.400 (0.005)	0.394 (0.003)	0.382 (0.005)	0.381 (0.003)
Hip BMC (g)	13.6 (0.3)	14.6 (0.2)[***]	12.3 (0.3)	13.1 (0.2)
Hip BA (cm^2)	20.49 (0.42)[******]	19.22 (0.37)	20.87 (0.70)[****]	19.44 (0.50)
Hip BMD (g/cm$^{2)}$)	0.688 (0.012)	0.753 (0.007)[***]	0.598 (0.013)	0.672 (0.007)[*****]
Spine BMC (g)	22.4 (0.5)	22.2 (0.3)	20.2 (0.6)	22.1 (0.3)[*****]
Spine BA (cm^2)	42.69 (0.34)[*]	40.44 (1.08)	39.38 (0.76)	39.23 (0.39)
Spine BMD (g/cm^2)	0.540 (0.010)	0.539 (0.005)	0.521 (0.010)	0.557 (0.051)[*****]

*White males > White females and Black females, p<0.05
**Black males > White females, p<0.05
***Black males > White males, p<0.05
****White females > Black males, p<0.05
*****Black females > White females, p<0.05
******White males > Black females and males, p<0.05

5.4.3 Physical Activity Characteristics

Physical activity data are presented in Table 5.11. Over 90% of White males and females participated in physical education (PE) classes at school compared to approximately 30% of their Black peers. White females spent a significantly greater time sleeping (p=0.006) and playing sports with a higher METPA (p<0.001) and MECHPA (p=0.034) score than Black females. Black females spent a greater time actively commuting to and from school (i.e.

walking/riding) each day than White females (p<0.001). White males also spent a significantly greater time sleeping (p=0.019), had a significantly greater METPA score (p<0.001) and playing sports that generated a higher MECHPA score (p<0.001) than Black males. White and Black children spent similar amounts of time participating in sedentary activities and commuting passively to and from school (i.e. via car/bus/taxi/train). Black children spent a greater amount of time watching TV (p<0.05). After controlling for race differences in PA, boys were significantly more (p<0.05) active than girls (13.11 (0.77) METPA hrs/wk vs. 9.62 (0.81) METPA hrs/wk). There was a significant positive correlation between participation in PE classes and METPA score (r=0.282, p<0.001) and a significantly negative correlation between METPA and hours of TV watched per week (r= -0.145, p<0.001).

Table 5.11 Physical activity characteristics. Data are Mean (SE)

	White Male (n=44)	Black Male (n=158)	White Female (n=38)	Black Female (n=146)
PE (yes)	41/44 (93%)[*]	43/158 (27%)	34/38 (90%)[***]	50/146 (34%)
Sedentary activity including sleep (hrs/day)	10.48 (0.79)	10.63 (0.33)	8.61 (0.54)	9.03 (0.34)
TV watching (hrs/wk)	17.28 (1.67)	26.54 (0.99)[**]	14.87 (1.75)	23.52 (1.02)[****]
Passive commuting (hrs/day)	0.33 (0.03)	0.4 (0.06)	0.37 (0.49)	0.47 (0.06)
Active Commuting (hrs/day)	0.03 (0.01)	0.35 (0.03)[**]	0.04 (0.02)	0.27 (0.03)[****]
Sleep (hrs/night)	10.02 (0.09)[*]	9.24 (0.78)	10.11 (0.14)[***]	9.38 (0.13)
METPA score	27.74 (5.07)[*]	10.65 (0.63)	14.7 (2.07)	8.39 (0.86)
MECHPA score	5.7 (1.05)[*****]	2.96 (0.19)	2.97 (0.56)[***]	2.26 (0.35)

* White males > Black males, p<0.05
**Black males > White males, p<0.05
***White females > Black females, p<0.05
****Black females > White females, p<0.05
*****White males > all other groups, p<0.05

5.4.4 Associations between Bone Characteristics and METPA.

Subjects were divided into quartiles of activity (Q1-least active-Q4-most active) based upon their METPA scores. There were no significant differences between bone mass values (adjusted for weight, height and gender) and METPA quartiles in Black children except for WB BMD (p=0.022). There were however, significant relationships between METPA quartiles and bone mass values (BMC and BMD, but not BA) in White children at the hip (p=0.013; p=0.001) and spine (p=0.019; p=0.003), and whole body BMD (p<0.05) (Figures 5.6-5.9).

Figure 5.6 Mean (SE) whole body BMC and BMD (adjusted for weight, height and gender) across METPA (Mean ± SE) quartiles for Black (●) and White (○) children. Q4 > Q1 & 2 (*p<0.05).

Figure 5.7 Mean (SE) hip BMC and BMD (adjusted for weight, height and gender) across METPA (Mean ± SE) quartiles for Black (•) and White (○) children. Q4 > Q1 & 2 (*p<0.05)**.

Figure 5.8 Mean (SE) spine BMC and BMD (adjusted for weight, height and gender) across METPA (Mean ± SE) quartiles for Black (•) and White (○) children. Q4 > Q1 & 2 (*p<0.05)**.**
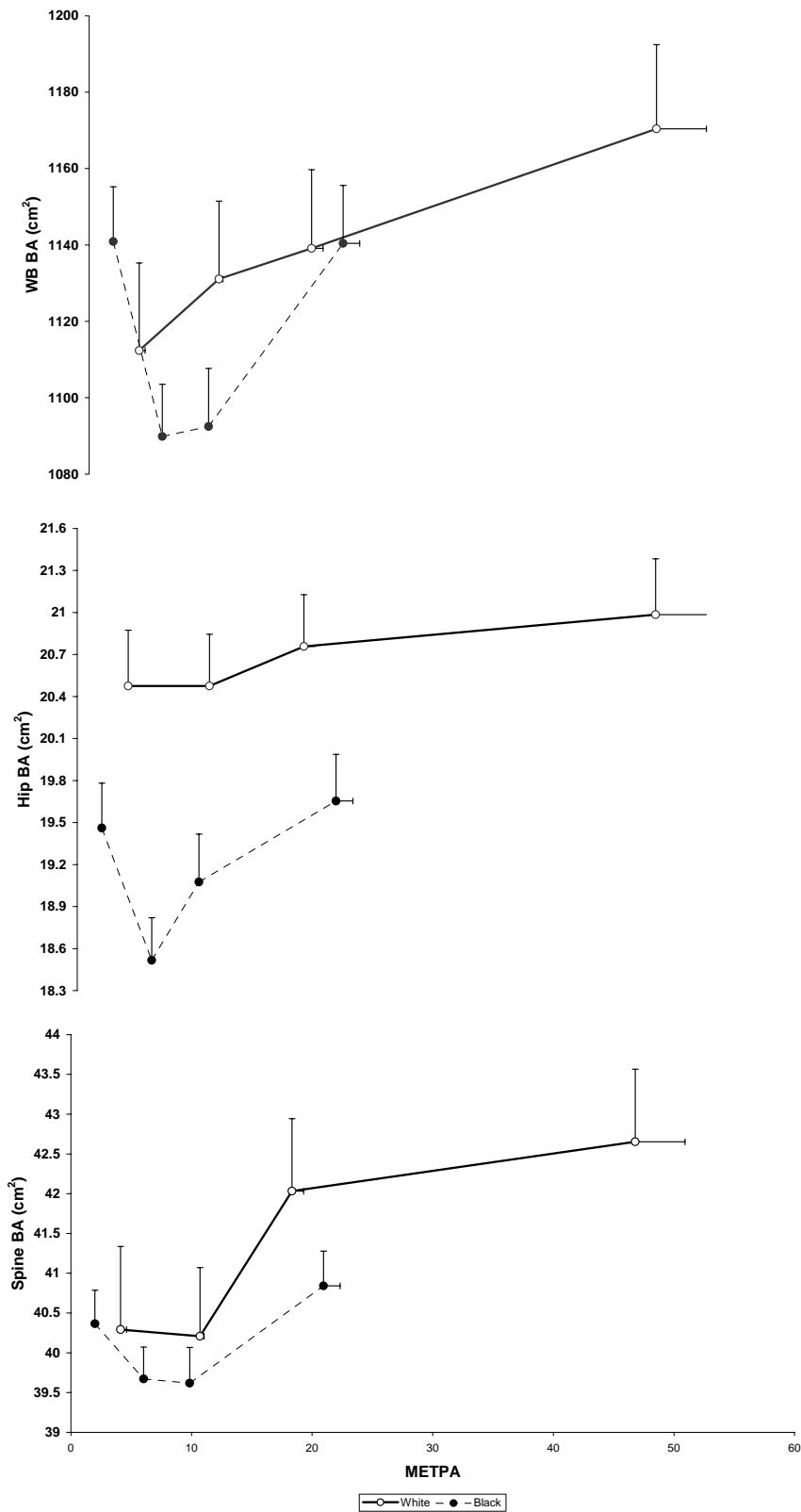
Figure 5.9 Mean ± SE whole body, hip and spine BA (adjusted height and gender) across METPA (Mean ± SE) quartiles for Black (●) and White (○) children.

The two physical activity scores (METPA and MECHPA) were highly correlated. Log METPA scores (adjusted for log MECHPA scores) were significantly partially correlated (shown in bold in table 5.12) with bone mass values at all sites in White children except with BMD at the radius, and with BA at the hip and spine, however in Black children the only significant relationship was between log METPA and WBBMD (r=0.20, p<0.001) and hip BMD (r=0.12, p=0.05).

Table 5.12 Partial correlations between log METPA and MECHPA values and adjusted bone mass measurements in Black and White children

	White Children (r)				Black Children (r)			
	Log METPA	*P*	Log MECHPA	*p*	Log METPA	*P*	Log MECHPA	*p*
WB BMC (g)	**0.32**	**0.01**	**0.29**	**0.02**	0.07	0.26	**0.18**	**0.03**
WB BMD (g/cm^2)	**0.37**	**0.00**	**0.33**	**0.01**	**0.20**	**0.00**	**0.20**	**0.01**
WB BA (cm^2)	**0.28**	**0.02**	**0.24**	**0.05**	-0.03	0.67	0.13	0.12
Radius BMC (g)	**0.26**	**0.03**	0.23	0.06	0.02	0.69	**0.17**	**0.03**
Radius BMD (g/cm^2)	0.14	0.24	0.12	0.33	0.00	0.96	0.07	0.39
Radius BA	**0.25**	**0.03**	0.22	0.08	0.01	0.91	0.13	0.11
Hip BMC (g)	**0.37**	**0.00**	**0.29**	**0.02**	0.10	0.10	0.12	0.16
Hip BMD (g/cm^2)	**0.38**	**0.00**	**0.41**	**0.00**	**0.12**	**0.05**	0.13	0.11
Hip BA	0.19	0.11	0.07	0.58	0.00	1.00	0.02	0.76
Spine BMC (g)	**0.28**	**0.02**	**0.26**	**0.03**	-0.01	0.84	0.04	0.60
Spine BMD (g/cm^2)	**0.36**	**0.00**	**0.34**	**0.00**	-0.04	0.52	-0.07	0.39
Spine BA	0.20	0.12	0.23	0.07	-0.01	0.88	0.11	0.18

*p<0.05. Reported p levels based on partial correlations.

5.4.5 Associations between Bone Characteristics and MECHPA.

Subjects were divided into 'loading' quartiles (Q1-very low loading-Q4-high loading) based upon their MECHPA scores. These MECHPA quartiles were then compared to BMC, BMD and BA at various sites. There were no significant differences between bone mass values (adjusted for weight and height) and MECHPA quartiles in Black children. There were however, significant differences in bone mass (BMC and BMD, but not BA) measures between MECHPA quartiles for White children at all sites except at the radius. For White children the most 'loaded' group (Q4) had significantly higher whole body (p=0.016) and hip (p=0.001) BMD and spine BMD (p=0.004). Most 'loaded' White children also had significantly higher hip (p=0.008) and spine (p=0.024) BMC than the two least 'loaded' groups (Q1 & 2) (figures 5.10-5.13).
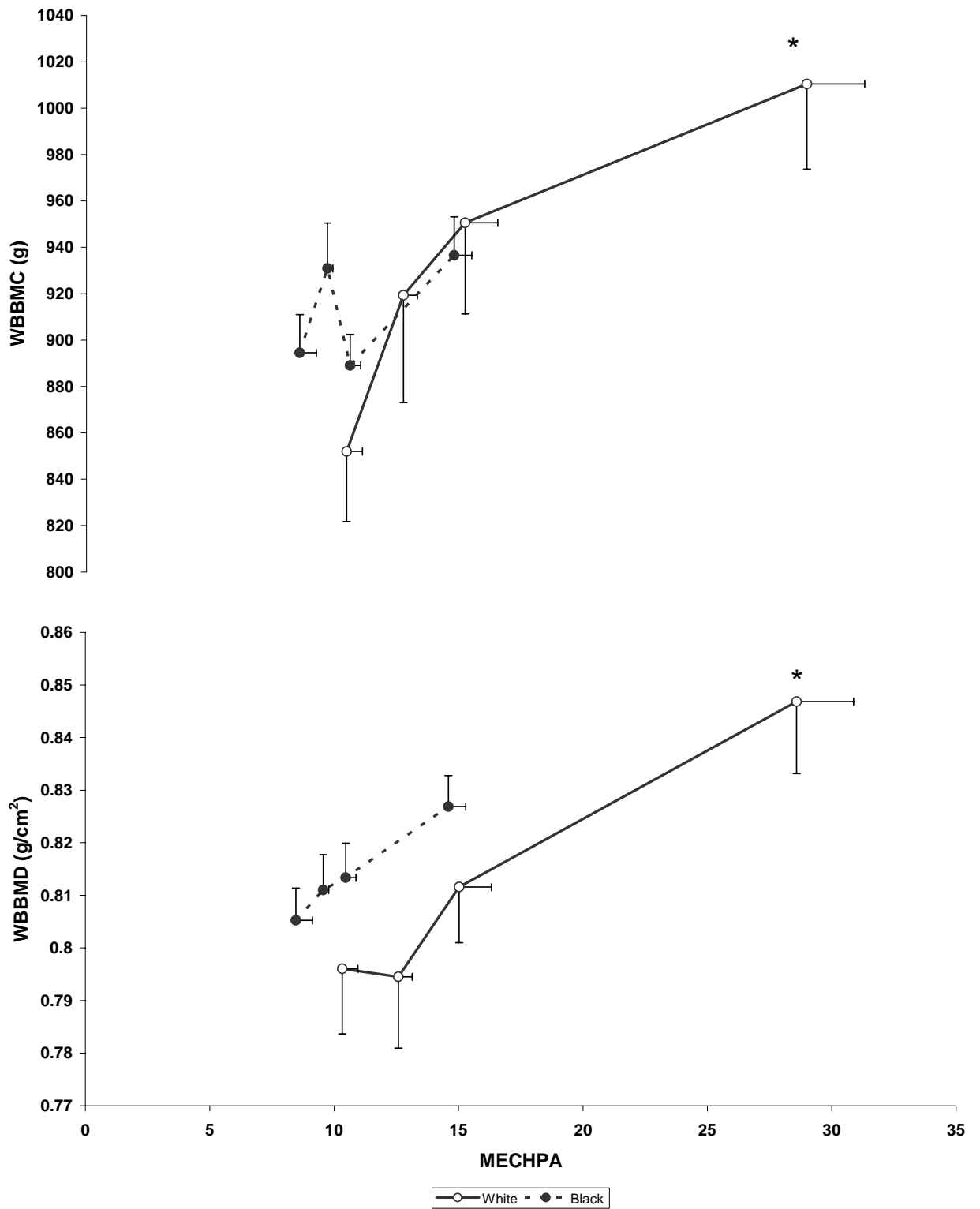
Figure 5.10 Mean (SE) whole body BMC and BMD (adjusted for weight, height and gender) across MECHPA (Mean ± SE) quartiles for Black (•) and White (○) children. Q4 > Q1 & 2 (*p<0.05).
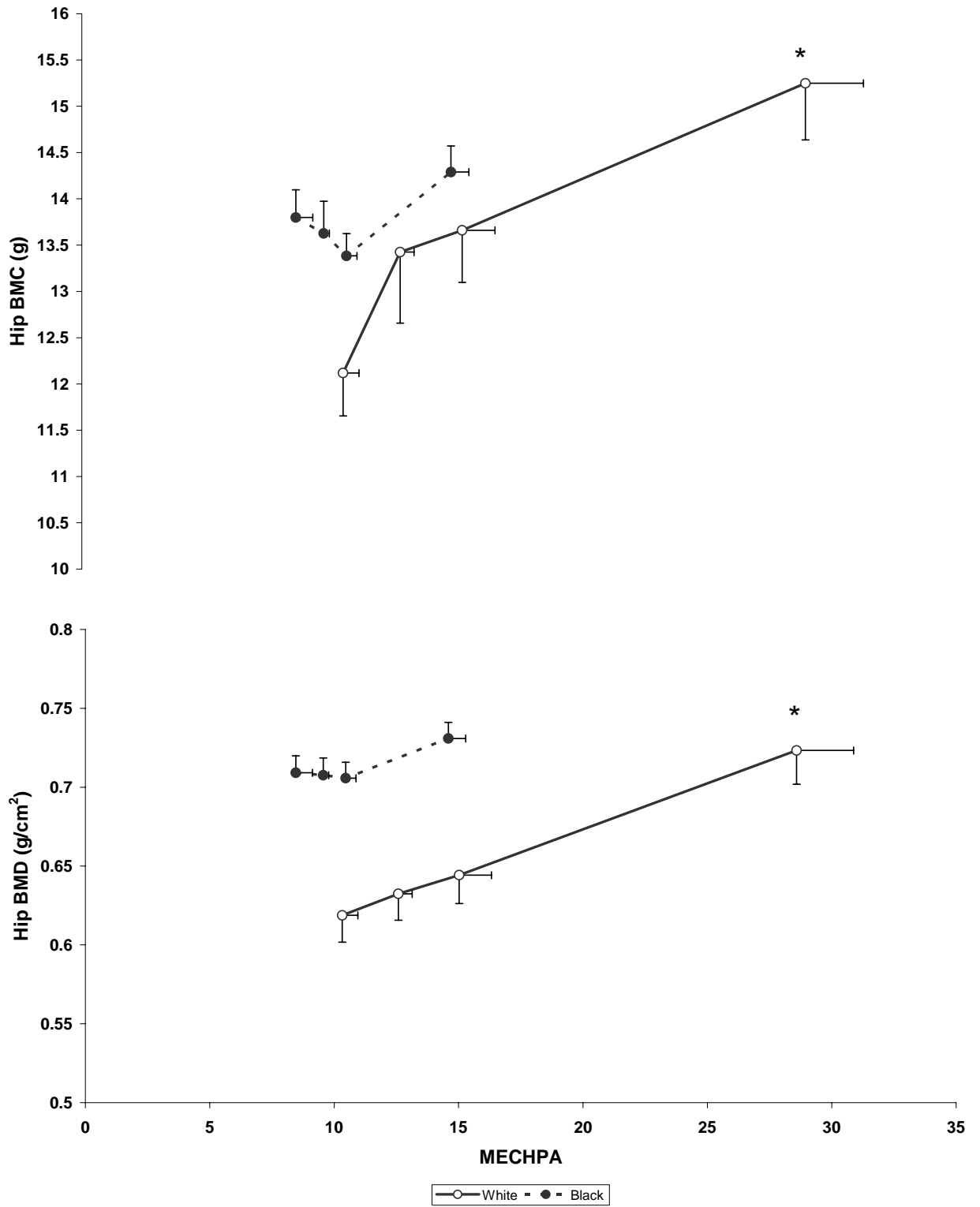
Figure 5.11 Mean (SE) hip BMC and BMD (adjusted for weight, height and gender) across MECHPA (Mean ± SE) quartiles for Black (●) and White (○) children. Q4 > Q1 & 2 (*p<0.05).

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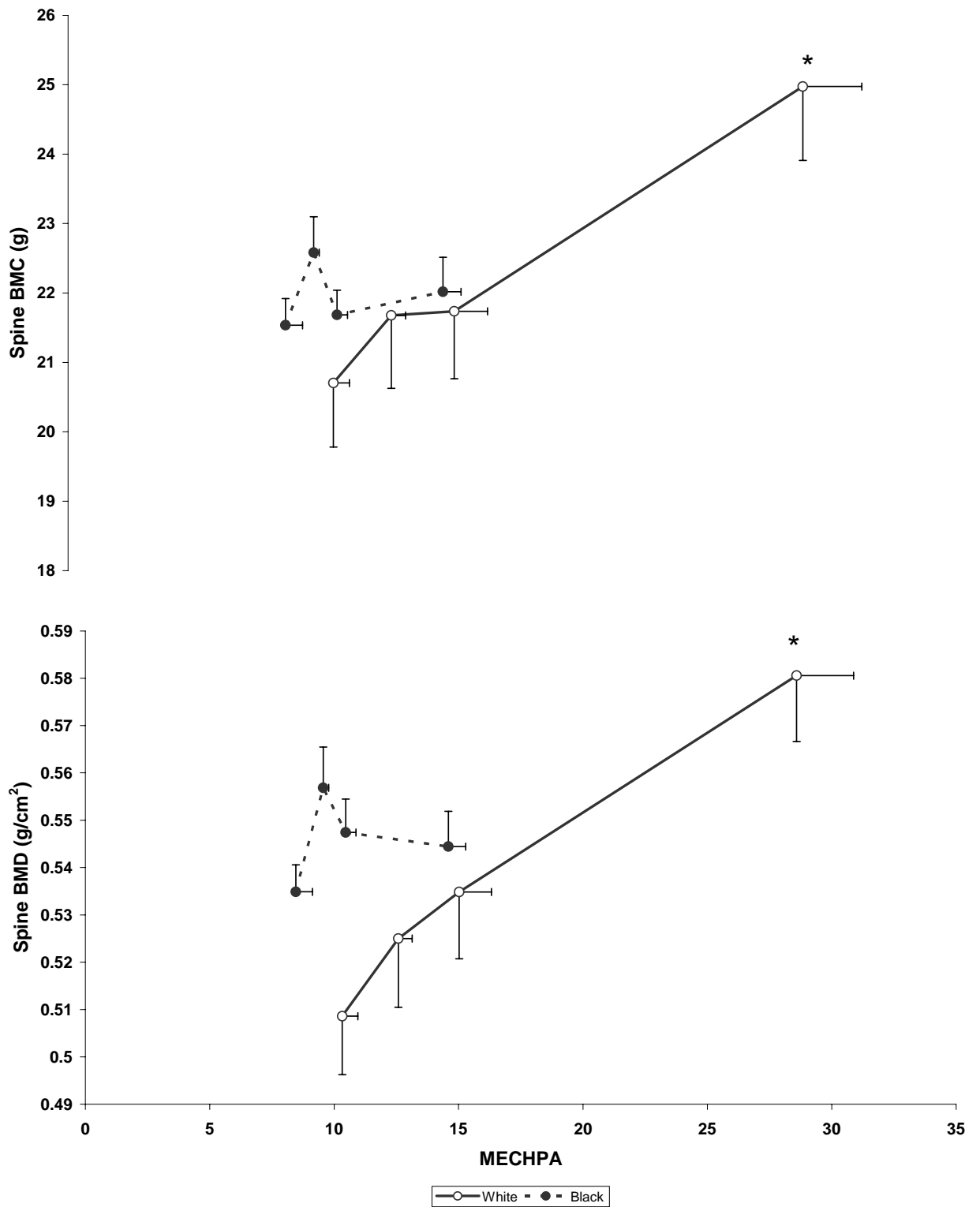
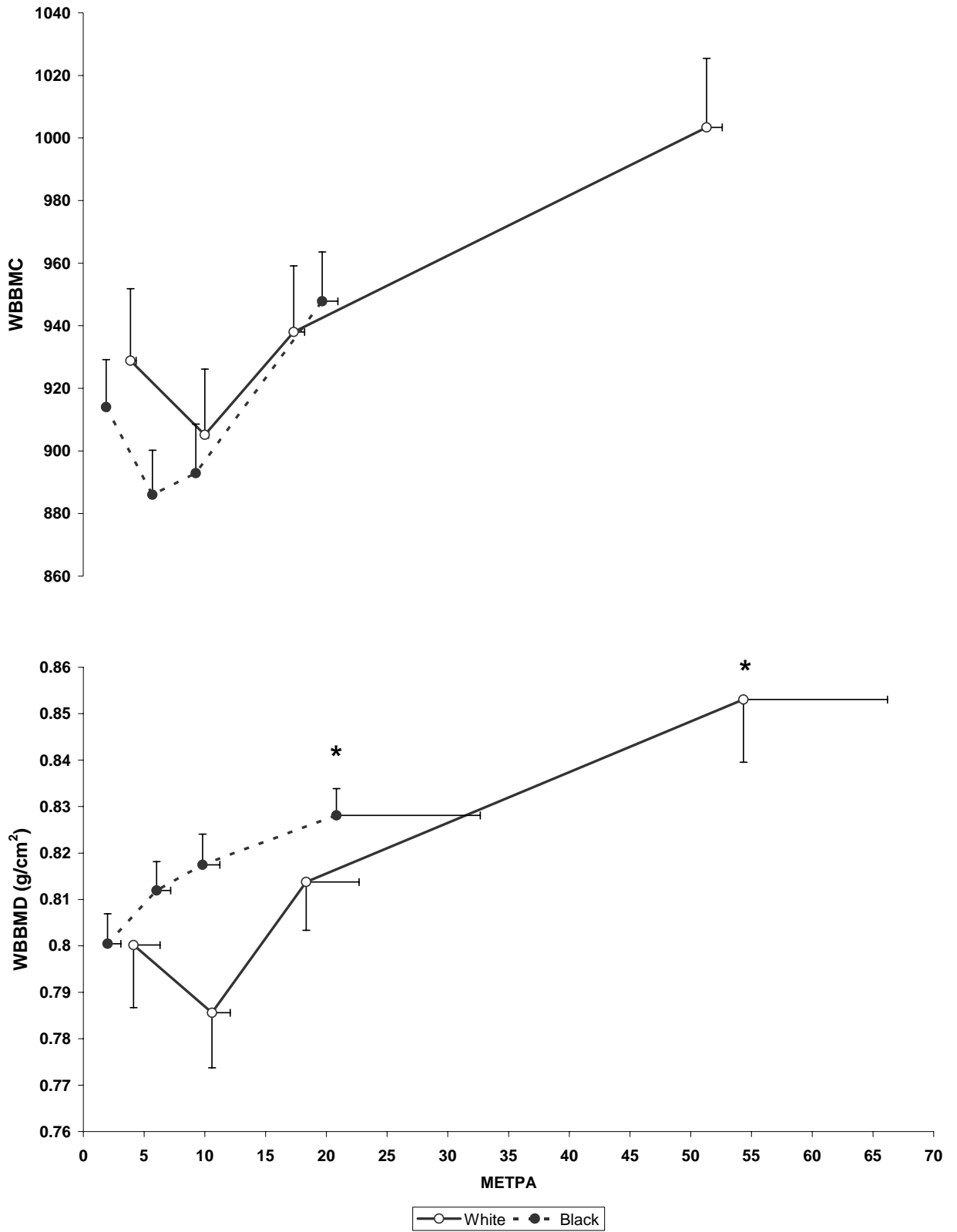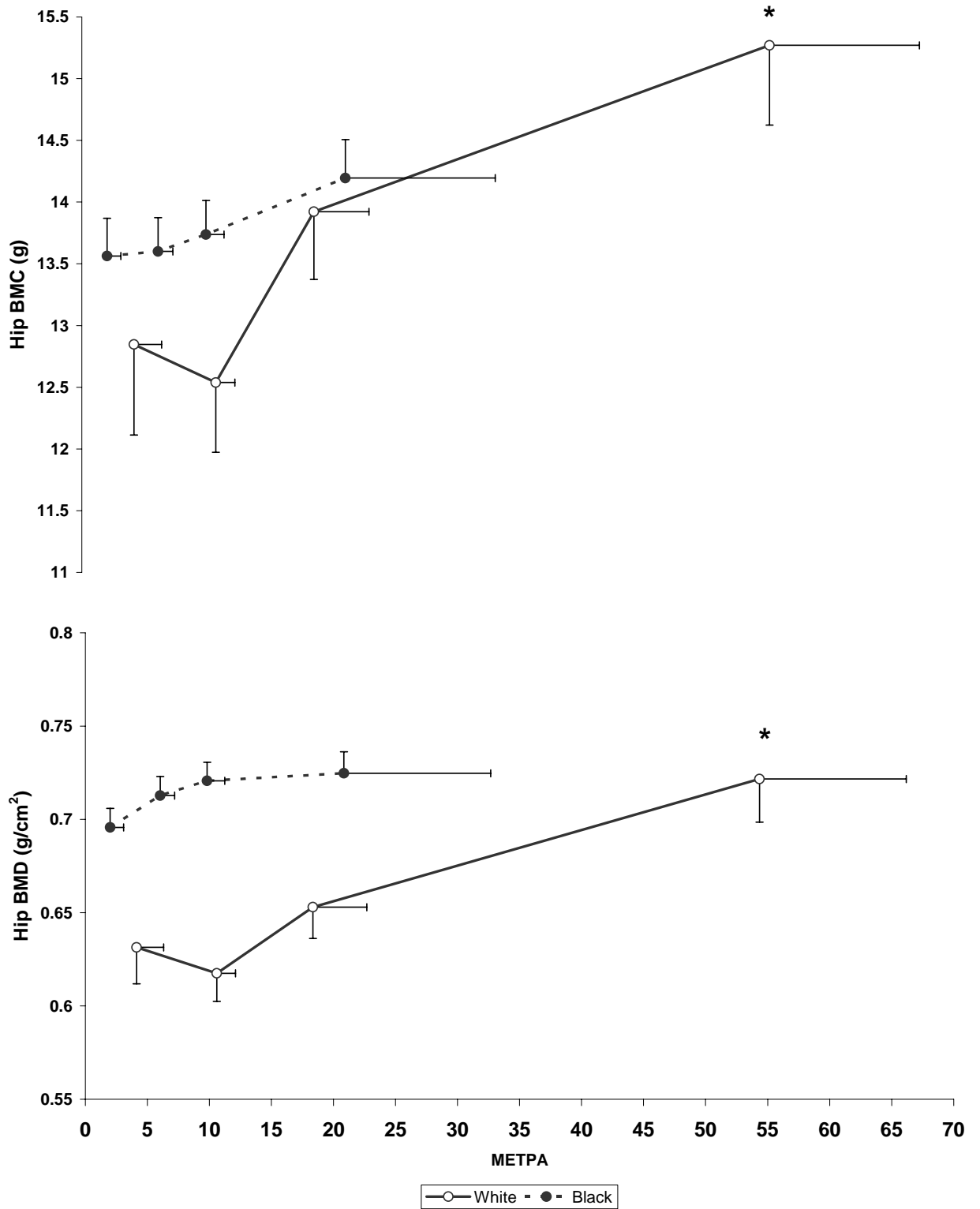**Figure 5.12** Mean (SE) spine BMC and BMD (adjusted for weight, height and gender) across MECHPA (Mean ± SE) quartiles for Black (•) and White (○) children. Q4 > Q1 & 2 (*p<0.05).
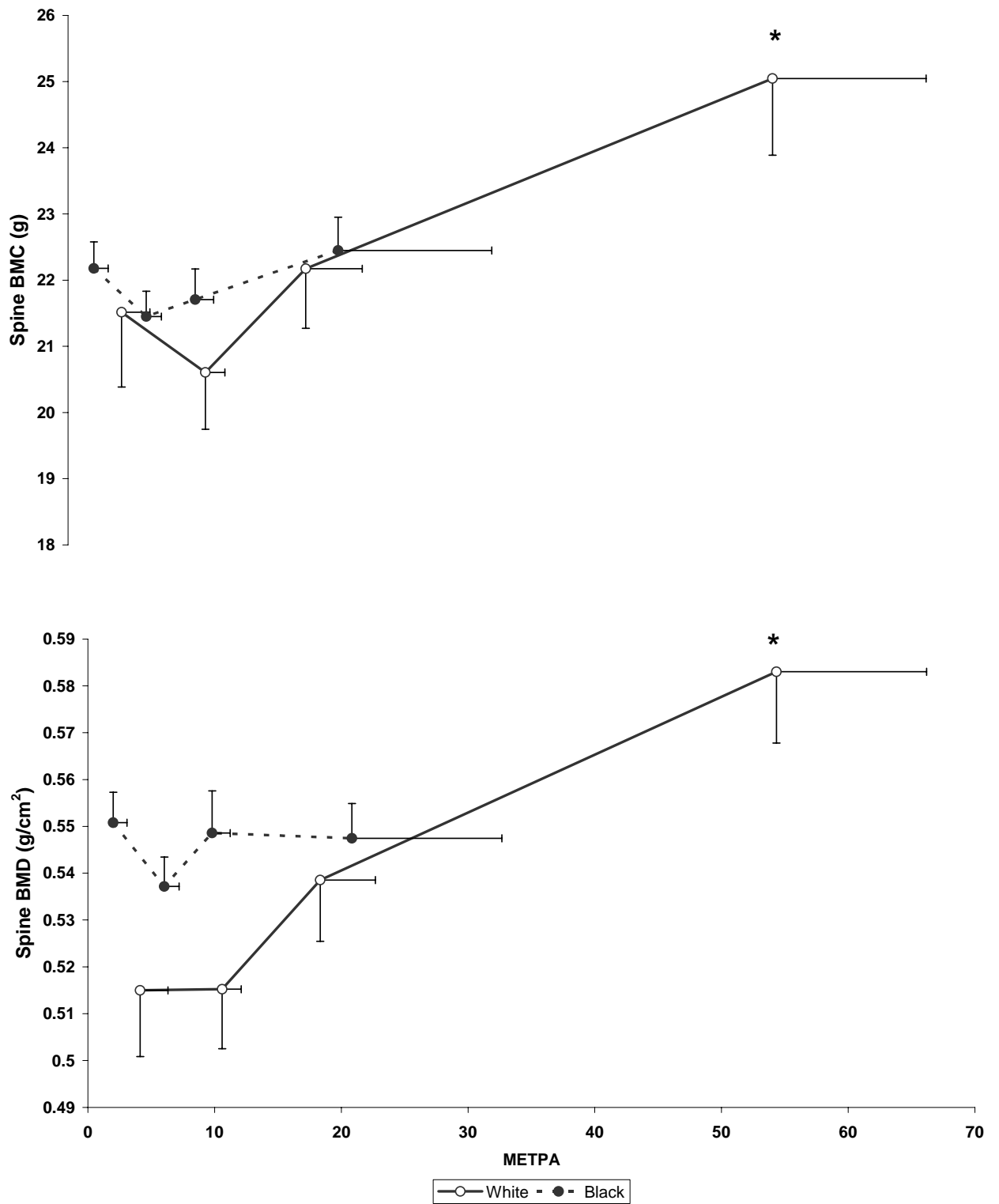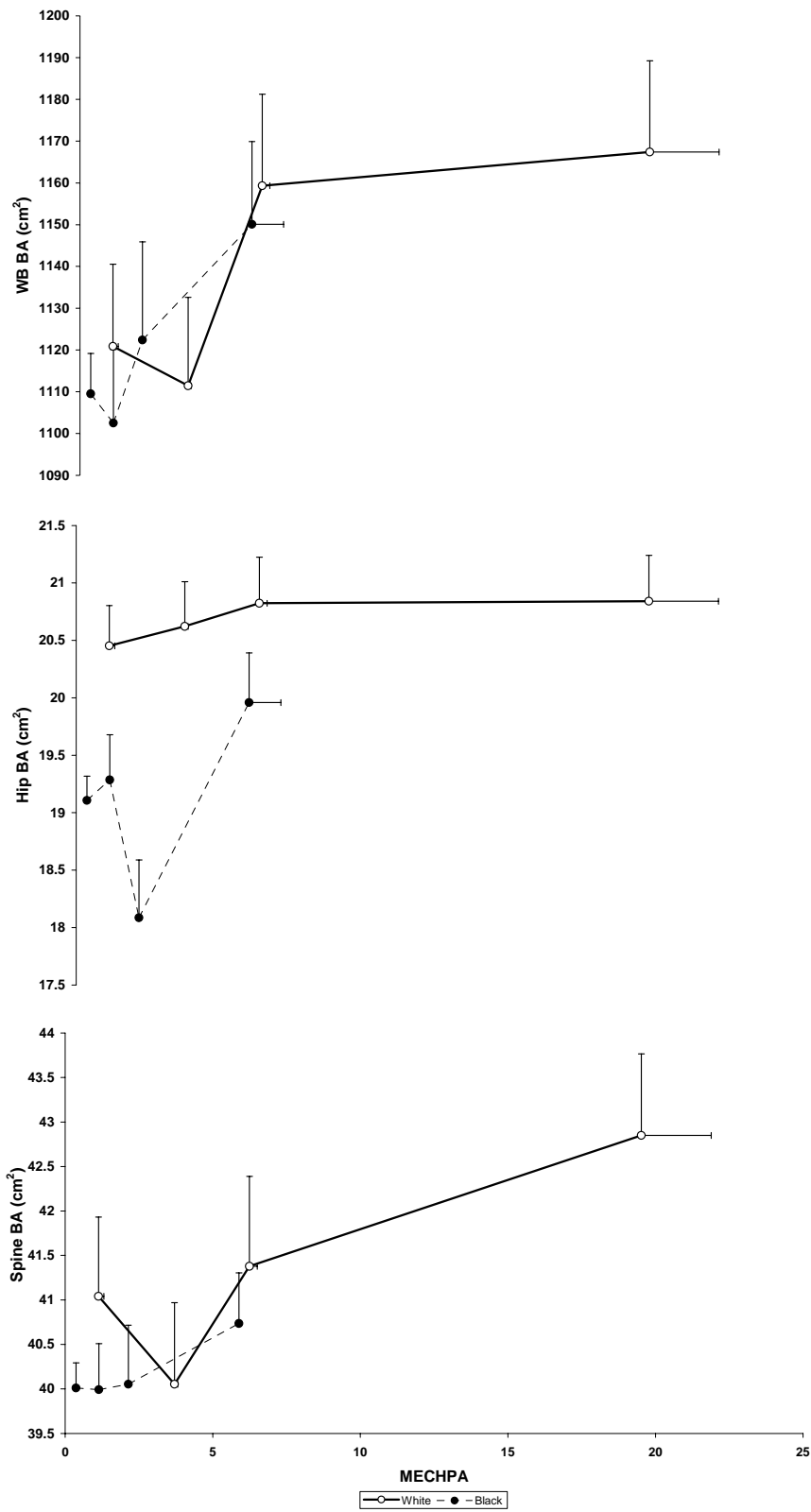
Figure 5.13 Mean (SE) whole body, hip and spine BA (adjusted height and gender) across MECHPA (Mean ± SE) quartiles for Black (●) and White (○) children.

Significant positive partial correlations between bone mass (BA, BMC and BMD) and log MECHPA (adjusted for log METPA) scores were found in White children at all sites except at the radius for BA and BMD, and at the hip for BA (Table 5.12). No significant correlations were found at any site in Black children except for whole body BMC (p=0.03), BMD (p=0.01) and radius BMC (p=0.03).

5.5 Part 4 - Socio-economic Status and Physical Activity Study

5.5.1 The relationship between socio-economic status and physical activity patterns in South African children

This study considered the degree of PA and inactivity in nine-year-old South African children from the Bone Health cohort, focusing on the magnitude of PA by gender, socio-economic status and maternal (primary caregiver) demographic characteristics such as marital and employment status, as well as level of education. Additionally, the study aimed to examine body composition patterns in relation to SES and other sedentary behaviours such as television watching.

5.5.2 Socio-economic Status Results

These results describe the conditions under which the children in this study lived in Johannesburg, South Africa in 2000 (Figure 5.14). Almost all of the children (99%) lived in homes with electricity. Approximately 88% of children lived in brick houses, whilst 12% lived in informal structures. Just over 60% of children had access to an indoor water source and almost 50% had flush toilets inside their houses. Television sets were present in 95% of the houses; 94% families owned a fridge; 76% had a land line telephone; 54% had a video

machine; 44% owned a washing machine; and 39% a microwave oven. Almost 60% of the sample did not own a motor vehicle.
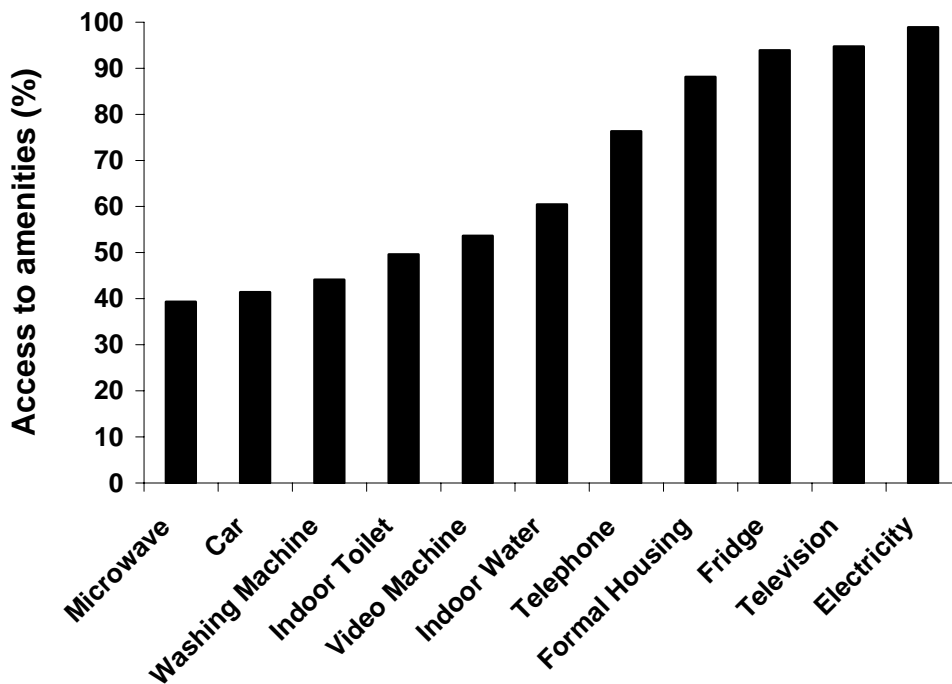
Figure 5.14 Percentages of study sample with access to various amenities

In terms of partner support, 50% of mothers were married and living with their husbands, 4% of mothers were living with their partners, but were not married, while 46% were single. Less than 50% of the children's mothers had completed a grade 12 (final year of school) education or higher. Diplomas were held by 17% of mothers, while only 6% of them held a university (tertiary) degree. At the time of the study 32% of mothers were not formally employed. Average maternal income ranged between R1000-2000 (US Dollar estimate: $140-290) per month. Almost all of the mothers described their children as being healthy, 9% of the mothers described their children's health as fair or poor. Private medical aid was held by 34% of the sample.

5.5.3 Profile of groups

Subjects were divided into quartiles according to their asset indicator score (lowest Q1-highest Q4) as described in detail in figure 4.5. Table 5.13 shows the socio-economic, PA and anthropometric scores across each quartile for Black and White subjects. There were approximately equal numbers of males and females within each quartile. No White children fell into the first three quartiles when the sample was analysed as a whole. Significantly fewer ($p<0.001$) mothers in Q1 had completed high school (17%), whereas over 80% of mothers in Q4 had a high school education or higher. Significantly less mothers (40%) were married and living with their husbands in Q1 compared with over 70% in Q4 ($p<0.001$). The majority of mothers/caregivers in Q1 had no cash income (i.e were not working), whereas the majority of caregivers in Q4 worked and earned an income of >R4000/month (US Dollar estimate: $570 per month), ($p<0.001$). There were no significant differences between maternal reports of their child's health across the quartiles. Maternal health status perception of their child was not associated with PA participation.

Mean METPA scores were significantly greater in Q4 compared with all three other quartiles ($p<0.001$). Percentages of children partaking in PE at school rose significantly ($p<0.001$) from 26% to 79% from Q1-4. Children in Q4 watched significantly less television than children in Q2 and 3 ($p<0.05$) but not Q1. Children in Q1 watched significantly less television than children in Q2 ($p<0.05$).

Significant differences were found across the groups for all anthropometric variables measured. Children in Q4 weighed significantly more than children in Q1 and Q2 ($p<0.05$). They were also significantly taller ($p<0.05$) than all three other quartiles. Children in Q1 weighed significantly less than those in Q2 and 3 ($p<0.05$). There were no significant

differences for BMI between groups except that children in Q1 had a significantly lower BMI ($p<0.05$) than children in Q3. Children in Q4 had significantly greater fat tissue ($p<0.05$) than children in Q1. Lean tissue was significantly greater ($p<0.05$) in children in Q4 than Q2.

Table 5.13 Socio-economic, physical activity and anthropometric variables across SES quartiles for all subjects. Data are means (SE)

	Q1 (n=115)	Q2 (n=78)	Q3 (n=71)	Q4 (n=115)	Whole Group (n=379)
Asset indicator score	4.1 (0.1)	6.4 (0.1)	8.5 (0.1)	10.7 (0.1)**	7.4 (0.1)
Gender (% male)	54	53	49	52	52
Race (% White)	0	0	0	69**	21
Maternal education (% completed high school)	16.5	32.1	43.7	81.7**	43.5
Support (% mothers living with partner or married)	40	41	52.1	70.4**	50.9
Income (% mothers with no cash income)	60	43.6	35.2	27.8**	41.7
Health of child (% good)	86.1	94.9	94.4	92.2	91.9
METPA score of child	10.5 (1.0)	8.6 (1.3)	8.5 (1.3)	16.1 (1.0)**	10.9 (1.1)
Physical Education at school (%yes)	26.1	25.6	32.4	79.1**	40.8
TV (hrs/wk watched by child)	22.0 (1.2)	26.9 (1.4)*	26.5 (1.5)	20.0 (1.2)	23.9 (1.3)
Weight (kg) of child	28.7 (0.6)	28.7 (0.7)	31.1 (0.7)	31.1 (0.6)***	29.9 (0.7)
Height (mm) of child	1326 (5.6)	1322 (6.8)	1333 (7.2)	1360 (5.8)**	1335 (6.4)
BMI (kg/m^2) of child	16.3 (0.3)	16.4 (0.4)	17.5 (0.4)	16.7 (0.3)	16.7 (0.4)
Fat tissue (g) of child	7255 (406)	7575 (483)	9000 (518)	8824 (408)****	8163 (454)
Lean tissue (g) of child	20123 (290)	19839 (344)	20874 (367)	21085 (391)*****	20480 (348)

*Quartile 2 > Quartile 1 and 4, p<0.05
**Quartile 4 > Quartile 1, 2 and 3, p<0.05
***Quartile 4 > Quartile 1 and 2, p<0.05
****Quartile 4 > Quartile 1, p<0.05
*****Quartile 4 > Quartile 2, p<0.05

Since there were no White children within the first three quartiles of socio-economic status, the analysis was repeated using only the Black children in the study in order to determine if the associations observed held true regardless of race. Table 5.14 shows the socio-economic, PA and anthropometric scores across each quartile for Black subjects. Although not significant, the overall mean asset indicator score was lower for the Black children (6.5 (0.1) vs. 7.4 (0.1)) than for the whole group. There were approximately equal numbers of males and females within each quartile. Significantly fewer (p<0.05) mothers in Q1 and Q2 had completed high school (8 and 20%), where as 38% of mothers in Q4 had at least a high school education. Significantly fewer mothers (18%) were married and living with their husbands in Q1 compared with over 30% in Q4 (p<0.05). Twenty five percent of mothers/caregivers in Q1 had no cash income (i.e were not working) compare to 15% of caregivers in Q4. Those in Q4 who worked had an income of >R4000/month (p<0.05). Significantly more caregivers in Q4 perceived their child's health as good (96%) vs. 66% in Q1.

In Black children, mean METPA scores were significantly greater in Q4 compared with all three other quartiles (p=0.001). Percentages of children partaking in PE at school rose significantly (p<0.05) from 28% to 44% from Q1-4. Unlike the cohort as a whole, children in Q4 watched significantly more television than children in Q1 (p<0.05). Children in Q4 weighed significantly more than children in Q1 and Q2 (p<0.05). There were no significant differences for BMI between groups except that children in Q1 had a significantly lower BMI (p<0.05) than children in Q4. Children in Q4 had significantly greater fat tissue (p<0.05) than children in Q1. Lean tissue was significantly greater (p<0.05) in children in Q4 than Q1.

Table 5.14. Socio-economic, physical activity and anthropometric variables across SES quartiles for Black subjects only. Data are means (SE).

	Q1 (n=64)	Q2 (n=94)	Q3 (n=76)	Q4 (n=70)	Whole Group (n=304)
Asset indicator score	3.2 (0.1)	5.4 (0.1)	7.5 (0.1)	9.8 (0.1)*	6.5 (0.1)
Gender (% male)	53	51	54	50	52
Maternal education (% completed high school)	6	20	36	38*	33
Support (% mothers living with partner or married)	18	28	24	30*	43
Income (% mothers with no cash income)	25	34	25	15*	45
Health of child (% good)	66	95	93	96*	88.5
METPA score of child	7.7 (0.7)	7.8 (0.5)	8.0 (0.7)	11.5 (1.1)**	8.9 (0.4)
Physical Education at school (%yes)	28	24	28	44*	31
TV (hrs/wk watched by child)	19.1 (1.6)	26.3 (1.2)	26.5 (1.4)	26.5 (1.2)*	25.1 (0.7)
Weight (kg) of child	29.22 (0.73)	28.57 (0.53)	30.20 (0.70)	30.32 (0.75)*	29.51 (0.33)
Height (mm) of child	1334 (7)	1315 (6)	1334 (7)	1337 (8)	1329 (3)
BMI (kg/m^2) of child	16.3 (0.3)	16.5 (0.2)	16.9 (0.3)	16.9 (0.4)*	16.7 (0.2)
Fat tissue (g) of child	7265 (367)	7441 (409)	8299 (551)	8920 (569)*	7945 (242)
Lean tissue (g) of child	19821 (325)	19943 (275)	20482 (329)	20804 (396)*	20243 (164)

*Quartile 4 > Quartile 1, p>0.05
**Quartile 4> Quartile 1, 2 and 3, p<0.05

On the whole, the pattern observed between White and Black children was similar across all socio-economic, anthropometric and physical activity variables, although the percentages were often different. The remainder of the analyses are therefore presented for White and Black children combined into one group. Socio-economic variables were correlated with physical activity variables. The variables with significant bivariate correlations were then examined further in terms of cross tabulations and chi squared likelihood ratios. Maternal marital status ($r=0.213$, $p<0.001$), maternal education level ($r=0.209$, $p<0.001$) and asset indicator score ($r=0.189$, $p<0.001$) were significant correlates with physical activity level. Table 5.15 shows the results from bivariate cross-classifications of children participating in the various levels of PA by socio-demographic variables. When comparing the two extremes of activity (inactive and highly active), there were significantly ($p<0.05$) more children with single mothers in the inactive quartile of activity (50% vs. 22%). No mothers of inactive children held university degrees, while 14% of mothers of highly active children held university degrees. Significantly more ($p<0.05$) mothers of children in the inactive groups had not completed schooling (53% vs. 23%). On the whole children who were from married households, had medical aid, had mothers with tertiary education and came from higher quartile homes, were more active than children from lower socio-economic households, irrespective of race.

Table 5.15 Analysis of physical activity levels by socio-demographic background. The % column refers to the distribution of the results (the percentage of subjects within each quartile of activity)

Quartiles of Physical Activity	Inactive	Active	Moderately Active	Highly Active
Socio-demographic variables				
Marital Status	p<0.05			
Single	50%	47%	31%	22%
Divorced/separated	7%	11%	4%	5%
Widowed	3%	1%	6%	3%
Married	40%	41%	59%	70%
Education	p<0.05			
Incomplete schooling	53%	70%	55%	23%
Completed high school	31%	21%	21%	42%
Diploma	16%	7%	15%	21%
Degree	0%	2%	9%	14%
SES Status	p=0.001			
Lowest quartiles	19%	17%	16%	12%
Low quartile	22%	31%	30%	16%
Middle quartile	21%	29%	11%	18%
Upper quartile	38%	23%	43%	54%

Reported p levels are based on likelihood-ratio chi-square tests

Lean mass was explored by television watching (hrs/wk) and activity level (METPA score) (Table 5.16). After adjusting for height and activity level no significant differences in lean mass with increased hours spent watching television were found. However, after adjusting for height and TV watching time, lean mass increased significantly (p=0.001) with increased activity.

Table 5.16 Lean mass (g) by television watching and activity level. Data are mean (SE)

	N	Mean lean Mass (SE)	p for trend
<u>TV watching hrs/wk</u> *			
<14 hrs/wk	77	19995 (302)	
14-22 hrs/wk	81	20536 (287)	
23-29 hrs/wk	91	20449 (275)	0.087
30-64 hrs/wk	102	20992 (259)	
<u>Activity level</u>**			
Less Active	85	20444 (279)	
Active	94	19769 (271)	
Moderately Active	87	20446 (273)	0.001
Highly Active	85	21350 (285)***	

*Adjusted for height and activity level
**Adjusted for height and TV watching time
***p<0.05, Highly Active children > all other groups

5.6 Part 5 - Longitudinal Physical Activity and Bone Mass Study

5.6.1 Bone mass accretion rates in pre- and early pubertal South African Black and White children in relation to habitual physical activity and dietary calcium intakes

The aims of this study were an extension of the findings presented in earlier parts of this thesis: to examine longitudinal bone mass changes over a 12 month period in the same group of children (pre- and early-pubertal children from the Bone Health Cohort) and to explore these changes in relation to habitual physical activity levels and calcium intakes.

5.6.2 Anthropometric and Bone Characteristics

Included in the study were 58 White and 263 Black children, with approximately equal numbers of males and females in each group. Pubertal scores at 10 years of age were similar

between Black and White children of the same sex (Table 5.17). None of the girls had begun menstruating and all subjects were considered to be either pre-or early-pubertal. There were no significant differences between the skeletal ages of any of the groups.

Table 5.17 shows the results for percentage gain and actual change in height, weight, and unadjusted BMC and BA from age nine to 10 years, as well as dietary calcium intakes and pubertal stage at age 10. Black males were significantly shorter at age 10 years and had significantly lower percentage BMCGAIN at the spine, BAGAIN at the whole body, dietary calcium intake and physical activity scores than White males ($p<0.001$). Black females had significantly lower calcium intakes than White females ($p<0.001$). Black males had significantly lower gains in weight ($p=0.019$), height ($p=0.004$), BMCGAIN at the whole body, hip and spine and BAGAIN at the whole body and spine when compared with Black females ($p<0.001$). White males had significantly greater physical activity scores than all other groups ($p<0.001$). There were no significant differences in weight at 10 years, BMCGAIN at the radius or BAGAIN at the radius and hip between any of the groups.

Table **5.17** Anthropometric data, Calcium intakes (age 10 yr), physical activity & unadjusted bone mass data, percentage gain BA (BAGAIN) & BMC (BMCGAIN) between ages 9yr & 10yr.Data are means (SD)

	White Male (n=31)	Black Male (n=141)	White Female (n=27)	Black Female (n=122)
Pubertal Stage (Hair) at age 10yr (no in stage1/2)	17/14	94/47	20/7	70/52
Weight at 10y (kg)	35.12 (4.88)	32.82 (6.44)	34.06 (7.51)	34.30 (7.93)
Weight gain between 9-10 (kg)	3.57 (1.26)	3.50 (2.60)	4.03 (1.84)	4.33 (2.08) ****
Weight Gain (%)	12.20(4.55)	11.90(7.58)	13.80(4.82)	14.71(6.14) ****
Height at 10y (cm)	142.71(6.82) *	137.62 (6.08)	142.51 (7.27)	139.09 (6.23)
Height gain between 9-10 y (cm)	5.14 (0.98)	4.69 (1.75)	6.04 (1.88)	5.82 (2.34) ****
Height Gain (%)	4.02 (1.11)	3.61(1.34)	4.55(1.35)	4.49(2.03) ****
BMCGAIN- Whole body (%)	10.64 (3.93)	8.32 (6.63)	10.99 (4.56)	11.67(5.63) ****
BMCGAIN-Radius (%)	12.27 (7.02)	10.21 (9.91)	12.15 (9.15)	12.57 (8.75)
BMCGAIN-Hip (%)	13.26 (7.27)	10.61 (6.97)	16.51 (8.74)	13.89 (10.09) ****
BMCGAIN-Spine (%)	12.40(4.89) *	9.69(4.33)	15.31(6.81)	16.16(7.72) ****
BAGAIN- Whole body (%)	11.31 (4.62) *	8.85 (4.66)	12.42 (4.68)	12.03 (4.43) ***
BAGAIN-Radius (%)	14.46 (6.20)	12.62 (8.15)	14.91 (6.56)	14.14 (7.97)
BAGAIN-Hip (%)	9.72 (4.66)	7.68 (4.83)	6.72 (20.79)	9.65 (6.10)
BAGAIN-Spine (%)	7.91 (3.06)	6.06 (3.28)	8.58 (3.66)	9.60 (4.69) ****
Calcium Intake-age 10 (mg/day)	711(606) *	331(238)	703(479) ***	297(175)
Skeletal Age	10.33 (0.97)	10.18 (1.02)	10.36 (1.29)	10.33 (1.24)
METPA score (yr 10)	21.15 (5.43) **	14.61 (0.88)	13.67 (1.73)	11.27 (0.89)
MECHPA score (yr 10)	8.45 (1.52) **	2.37 (0.19)	3.93 (0.72)	1.89 (0.30)

*White males > Black males, p<0.05

**White males > all other groups, p<0.05

***White females > Black females, p<0.05

****Black females > Black males, p<0.05

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A multiple regression analysis was conducted in order to assess whether the non-bone related components of weight (fat and lean mass) had different effects in BMCGAIN or BAGAIN. The addition of fat mass, lean mass and calcium values to the regression had very little impact on the whole body BMC and area gain values. Each covariate did not contribute significantly more to the model than height and weight alone. The same trend was evident at other sites and for all the groups. These variables were therefore not controlled for in the residual analysis, but body size was.

Table 5.18 shows the results for actual year 10 BMC (adjusted for weight (kg) and BA (cm^2)) and BA (adjusted for weight (kg) and height (cm)) values. Results for percentage gain in BMC and BA after adjustment are also shown. Black males had significantly greater adjusted hip BMC and radius BA at age 10 years (p=0.001) and significantly lower percentage gains in spine BMC (p=0.034) and WB BA (p=0.027) than White males. Black females had significantly greater adjusted hip BMC (p=0.001), WB BA (p=0.03) and radius BA (p=0.002) and significantly lower hip BA (p=0.017) compared with White females at age 10. Black males had significantly greater WB BMC (p<0.001), radius BMC (p=0.037) and BA (p<0.001), hip BMC (p<0.001) and spine BA (p=0.021) at age 10 and significantly lower spine BMC (p<0.001) and percentage gains in WB and spine BMC (p<0.001) than Black females. White males had significantly greater hip BMC (p=0.001) and spine BA (p=0.003) at age 10 years than White females.

Table 5.18 BMC (g) at age 10yr adjusted for BA (cm^2) & body weight (kg). BA adjusted for body weight & height (cm). % gain in BMC (adjusted for body weight &BA) & % gain in BA (adjusted for body weight & BMC) from age 9 to 10. Data are means (SE)

	White Male (n=31)	Black Male (n=141)	White Female (n=27)	Black Female (n=122)
WBBMC yr 10 (g)	1007.92 (9.51)	1015.43 (4.45)***	987.27 (10.13)	987.38 (4.78)
Radius BMC yr 10 (g)	3.65 (0.05)	3.58 (0.02)****	3.55 (0.06)	3.43 (0.03)
Hip BMC yr 10 (g)	14.79 (0.29)*	16.01 (0.14)*****	13.18 (0.32)	14.54 (0.14)*******
Spine BMC yr 10 (g)	24.48 (0.47)	24.03 (0.22)****	24.45 (0.50)	25.44 (0.24)
WBBA yr 10 (g)	1234.00 (11.18)	1252.13 (5.16)	1201.57 (11.76)	1238.34 (5.49)*******
Radius BA yr 10 (g)	8.96 (0.15)	9.63 (0.07)******	8.44 (0.16)	9.07 (0.07)******
Hip BA yr 10 (g)	21.30 (0.30)	21.15 (0.14)	22.25 (0.32)*******	21.18 (0.15)
Spine BA yr 10 (g)	44.15 (0.52)*	44.08 (0.24)****	41.56 (0.55)	43.04 (0.26)
BMCGAIN- Whole body (%)	10.16 (1.07)	8.19 (0.52)	10.70 (1.21)	11.34 (0.54)*******
BMCGAIN-Radius (%)	11.69 (1.56)	11.29 (0.75)	10.56 (1.76)	11.83 (0.79)
BMCGAIN-Hip (%)	10.03 (1.79)	8.09 (0.85)	14.83 (1.99)	11.03 (0.90)
BMCGAIN-Spine (%)	12.80 (1.18)**	9.18 (0.56)	15.12 (1.29)	15.51 (0.61)*******
BAGAIN- Whole body (%)	11.30 (0.84)**	8.92 (0.39)	12.61 (0.91)	11.92 (0.41)*******
BAGAIN-Radius (%)	13.83 (1.47)	12.87 (0.68)	14.49 (1.58)	14.11 (0.72)
BAGAIN-Hip (%)	9.31 (1.47)	7.82 (0.70)	6.37 (1.60)	9.68 (0.73)
BAGAIN-Spine (%)	7.60 (0.72)	6.16 (0.34)	8.26 (0.79)	9.65 (0.36)*******

*White males > White females, p<0.05
**White males > Black males, p<0.05
***Black males > Black females, p<0.05
****Black males > White males, Black females, p<0.05
*****White females > Black females, p<0.05
******Black females > White females, p<0.05
*******Black females > Black males, p<0.05

Parts three and four of this chapter have reported on the descriptive data for this population's physical activity patterns at age nine (182; 183). At age 10, White males still had significantly greater METPA and MECHPA scores than all other groups ($p<0.001$) (Table 5.17). Subjects were divided into quartiles of activity within race and gender groups and levels of activity were then related to BMCGAIN$_{res}$ and BAGAIN$_{res}$ at different sites. Residual values above zero indicate that the subjects' BMC and BA fall above their expected values for their weight, height and bone area and vice versa.

Figures 5.15-5.17 show BMCGAIN$_{res}$ values at the whole body, hip and spine for different quartiles of METPA and MECHPA within race and gender groups. White males in quartile four (highest physical activity group for both METPA and MECHPA) showed significantly greater BMCGAIN$_{res}$ at all bone sites ($p<0.05$) except the radius when compared with the lowest two quartiles. Additionally, White males in the highest quartile of physical activity had BMCGAIN$_{res}$ values well above zero. There were no other significant differences for any of the other groups between race and/or gender.
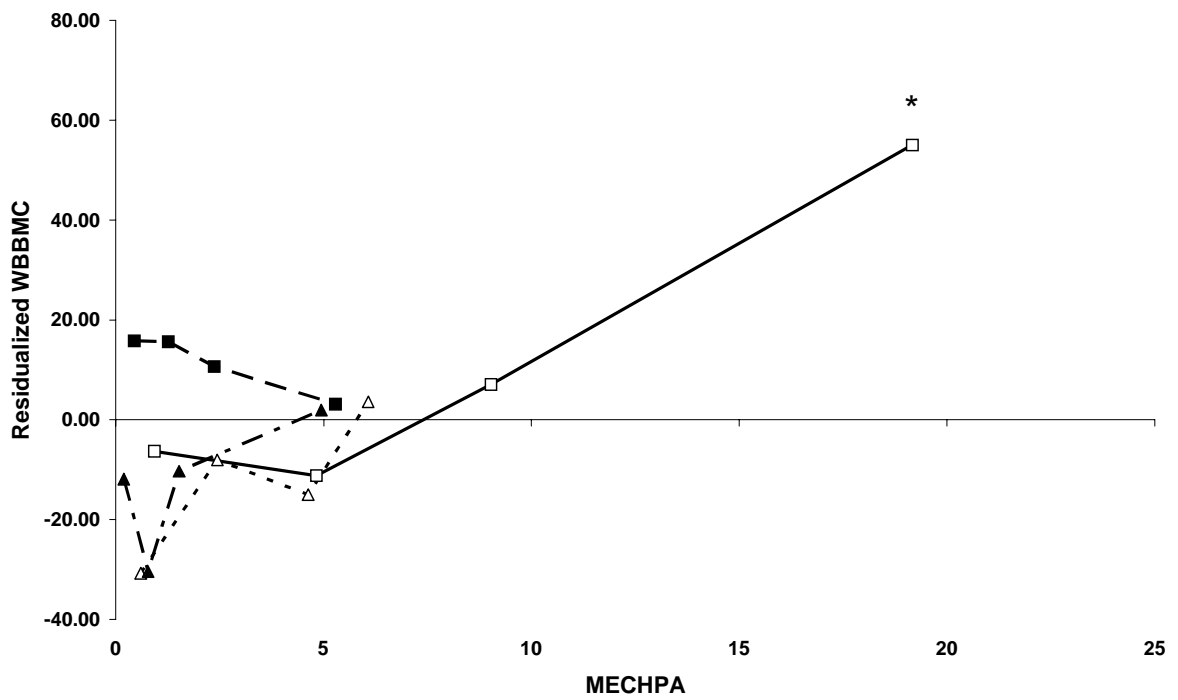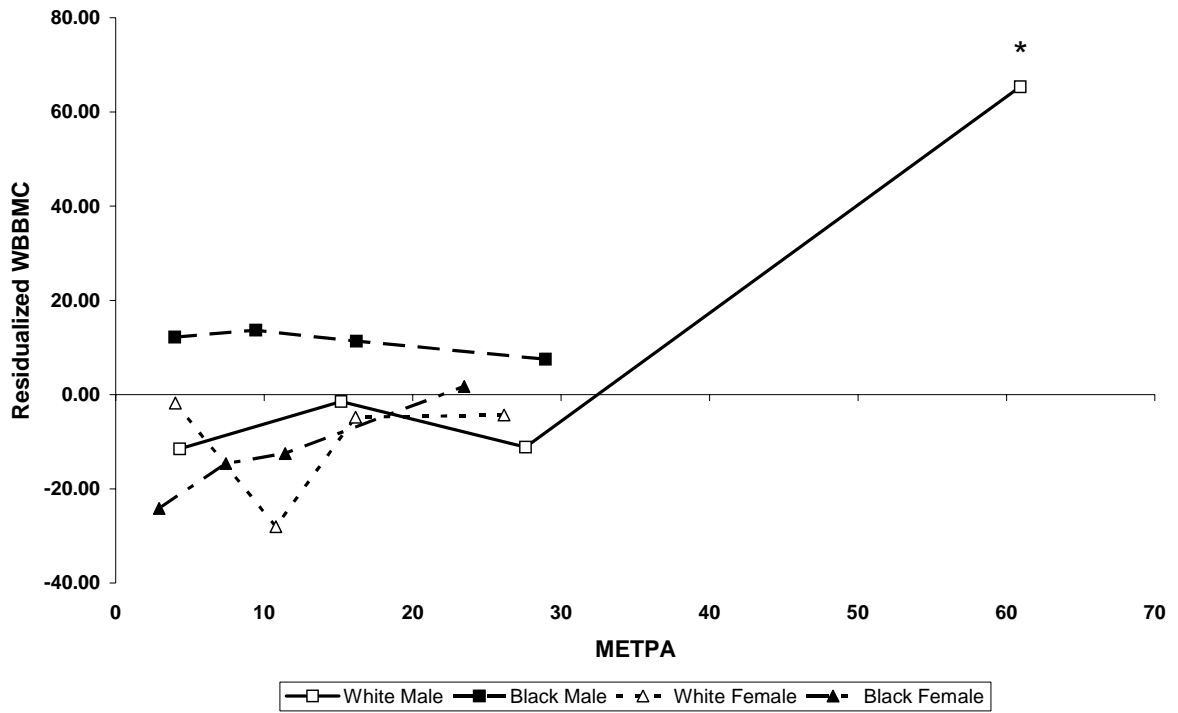
Figure 5.15 Residualized whole body BMC gain (WBBMC) within quartiles of METPA (panel A) and MECHPA (panel B) for Black, White, male and female subjects. *p<0.05, quartile 4>quartile 1 and 2 for White males.
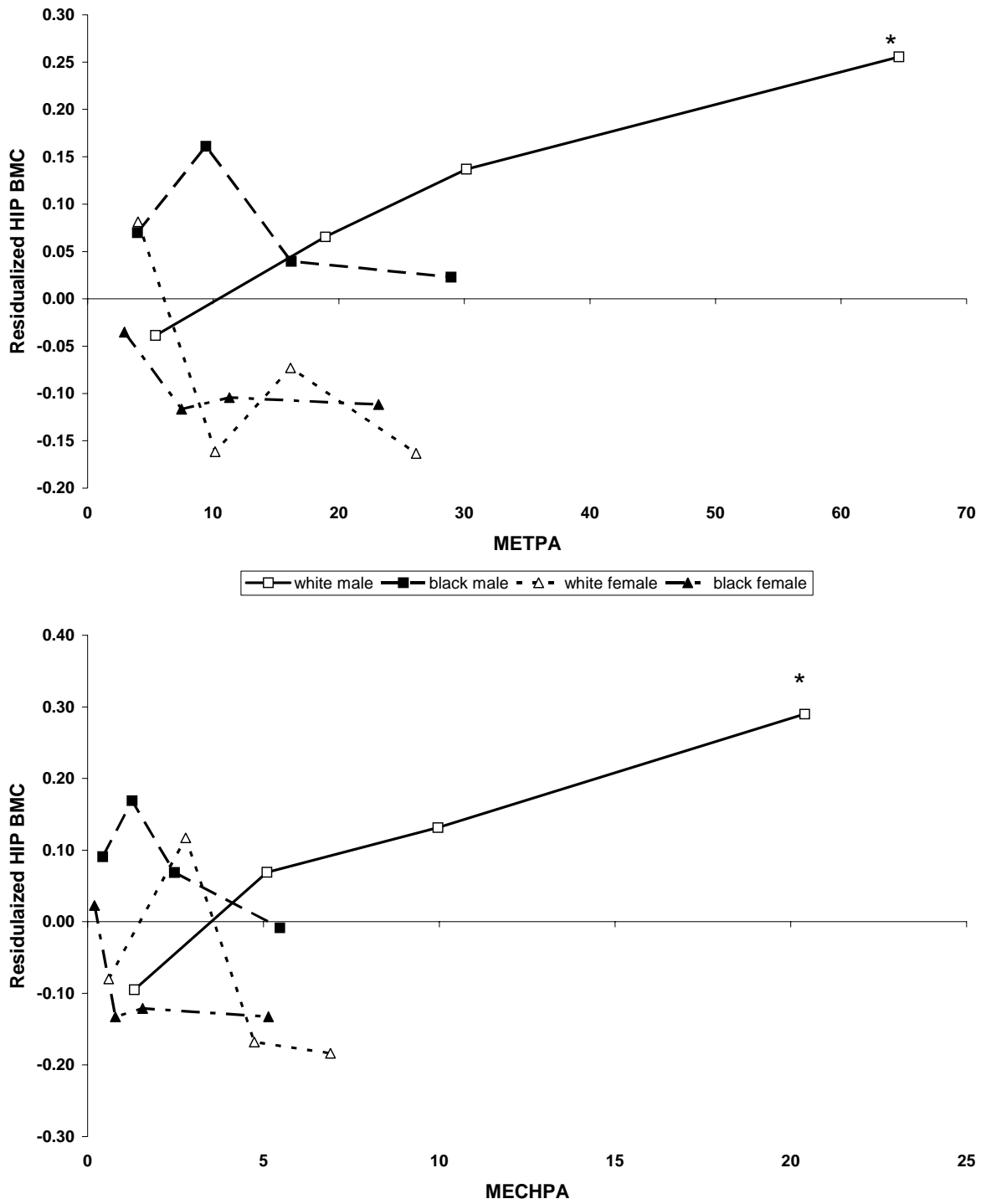
Figure 5.16 Residualized hip BMC gain within quartiles of METPA (panel A) and MECHPA (panel B) for Black, White, male and female subjects. *p<0.05, quartile 4>quartile 1 and 2 for White males.

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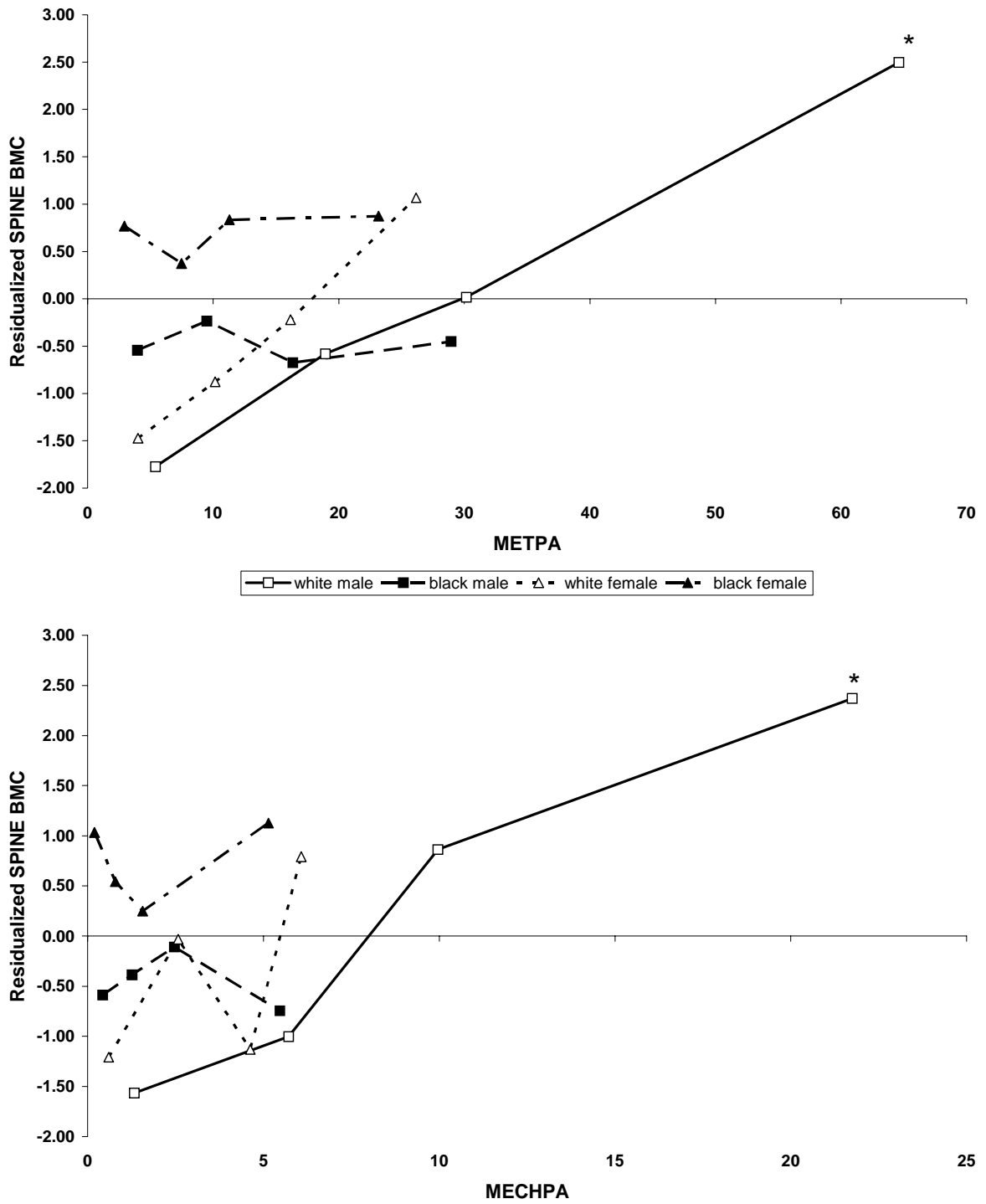
Figure 5.17 Residualized spine BMC gain within quartiles of METPA (panel A) and MECHPA (panel B) for Black, White, male and female subjects. *p<0.05, quartile 4>quartile 1 and 2 for White males.

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Figures 5.18-5.20 show BAGAIN$_{res}$ values at the whole body, hip and spine for different quartiles of METPA and MECHPA within race and gender groups. White males and females in quartile four (highest physical activity group for both METPA and MECHPA) showed significantly greater BAGAIN$_{res}$ at the whole body ($p<0.05$) compared with the lowest two quartiles. White children in quartile four for MECHPA showed significantly greater ($p<0.05$) BAGAIN$_{res}$ at the hip compared with children in lower quartiles. Additionally, White children in the highest quartile of physical activity had BAGAIN$_{res}$ values well above zero. There were no other significant differences for any of the other groups between race and/or gender.
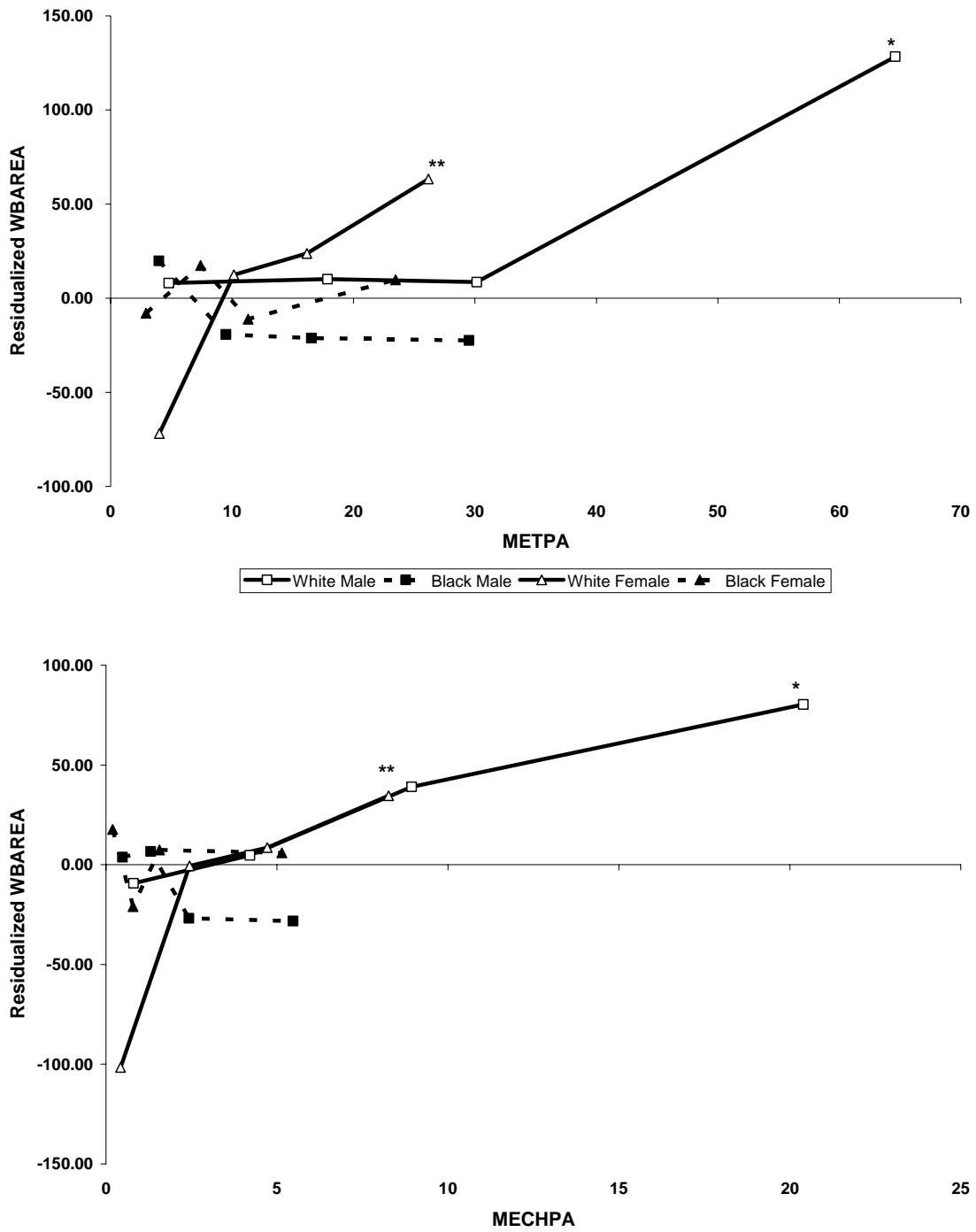
Figure 5.18 Residualized whole body area gain within quartiles of METPA (panel A) and MECHPA (panel B) for Black, White, male and female subjects. *p<0.05, quartile 4>quartile 1,2 and 3 (METPA) and quartile 4> quartile 1 and 2 (MECHPA) for White males. **p<0.05, quartile 4>quartile 1 for White females.

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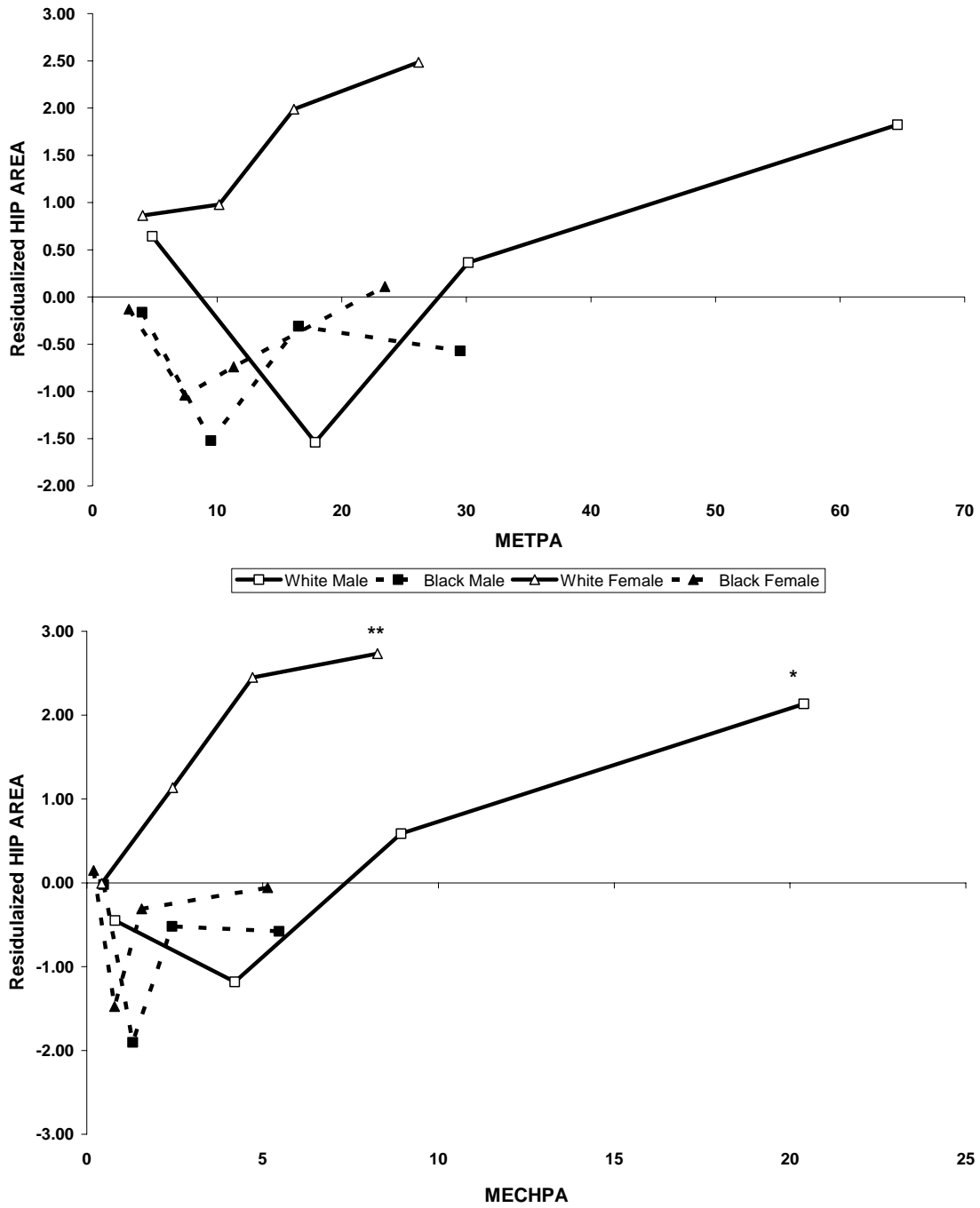
Figure 5.19 Residualized hip area gain within quartiles of METPA (panel A) and MECHPA (panel B) for Black, White, male and female subjects. *p<0.05, quartile 4>quartile 2 for White males. **p<0.001, quartile 4 > quartile 1 for White females.

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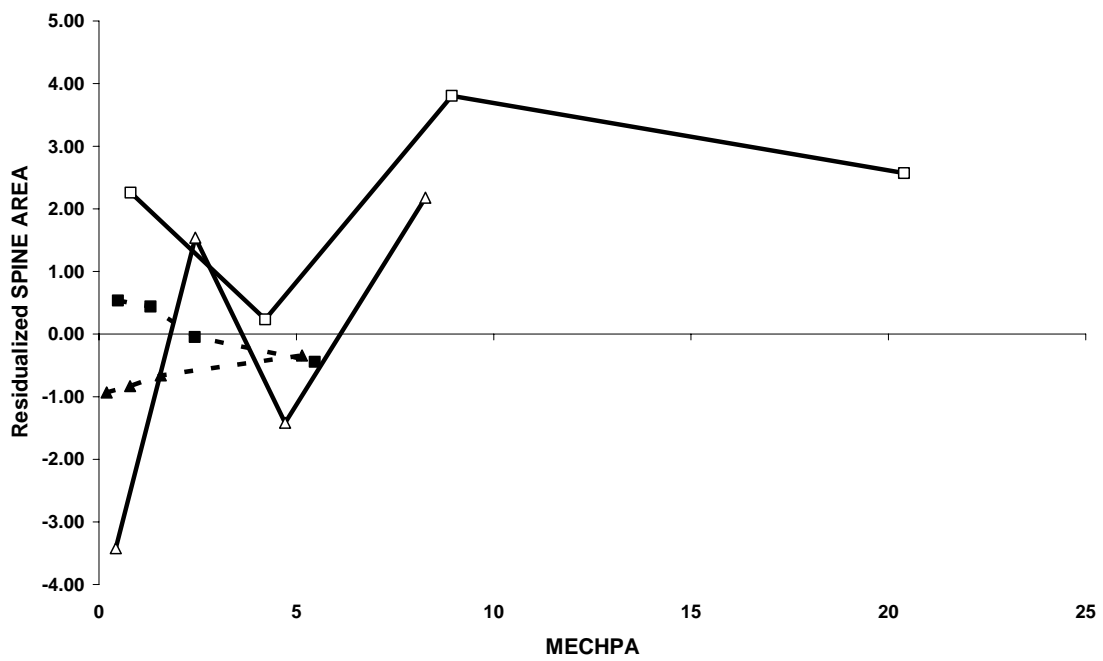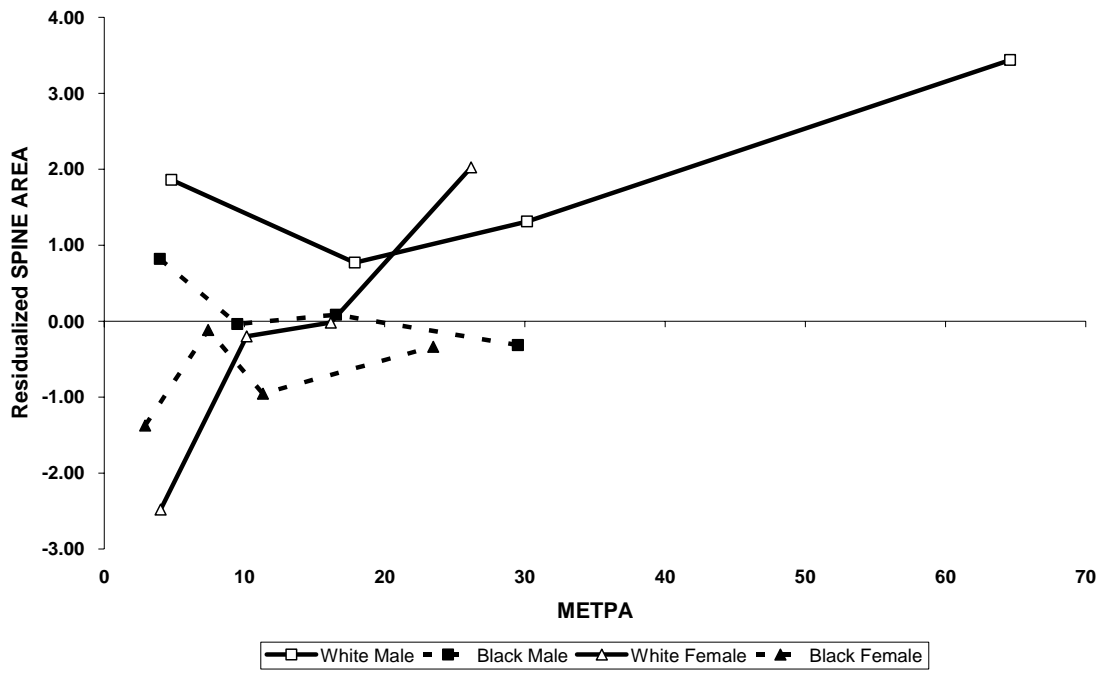
Figure 5.20 Residualized spine bone area gain within quartiles of METPA (panel A) and MECHPA (panel B) for Black, White, male and female subjects. There was no significant relationship between METPA and MECHPA and residualized spine bone area gain.

A multiple linear regression sought to examine the effect of calcium intake and physical activity (both METPA and MECHPA) on BMCGAIN$_{res}$ and BAGAIN$_{res}$ at the whole body, radius, hip and spine. Results are shown in Tables 5.19 and 5.20.

BMC results: There were no significant effects for any of the groups at the radius. No simple effects for calcium were found at any site for any of the groups except in White females at the hip (p=0.012). There were significant effects of MECHPA in White males on BMCGAIN$_{res}$ at the whole body (p=0.03), hip (p=0.002) and spine (p=0.005), and of METPA at the hip (p=0.03). A significant effect of METPA at the spine (p=0.033) were observed for White females. The only significant interaction between calcium and METPA was seen at the spine in White females (p=0.027).

BA results: Simple calcium effects were observed at hip in both male and female White children (p=0.017), as well as at the radius in White females (p=0.009). There were significant effects of METPA observed at the whole body in White males (p=0.044) and females (p=0.02). A significant calcium and METPA interaction was observed at the radius and at the hip in White females (p=0.011 and p=0.044), as well as a significant calcium and MECHPA interaction at the hip in White females (p=0.007).

Table 5.19 Multiple moderated stepwise linear regression analysis for residualized BMCGAIN

Site	Predictor variables in order of entry	White Male		Black Male		White Female		Black Female	
		b	Sig	*b*	Sig	*b*	Sig	*B*	Sig
BMCGAIN$_{res}$-WB	Calcium	0.250	0.17	-0.130	0.192	0.408	0.106	-0.045	0.657
	METPA	0.350	0.35	0.248	0.291	0.293	0.505	0.195	0.284
	MECHPA	**0.397**	**0.03***	-0.368	0.133	0.300	0.460	-0.039	0.839
	Calcium * METPA	-0.005	0.98	-0.287	0.302	0.076	0.882	-0.058	0.748
	Calcium * MECHPA	0.135	0.5	0.337	0.233	-0.027	0.956	0.056	0.772
BMCGAIN$_{res}$-Radius	Calcium	0.167	0.402	-0.079	0.423	2.338	0.031	0.261	0.795
	METPA	0.872	0.276	0.166	0.477	0.005	0.996	-0.270	0.788
	MECHPA	0.970	0.104	-0.335	0.170	-1.081	0.294	0.137	0.892
	Calcium * METPA	-0.185	0.844	-0.077	0.782	-1.441	0.167	-1.612	0.110
	Calcium * MECHPA	0.215	0.772	0.171	0.542	0.888	0.386	2.099	0.038
BMCGAIN$_{res}$-Hip	Calcium	0.261	0.11	-0.139	0.164	**0.496**	**0.012***	0.015	0.880
	METPA	**0.450**	**0.03***	0.245	0.301	0.098	0.620	0.233	0.200
	MECHPA	**0.266**	**0.002***	-0.280	0.257	0.003	0.989	-0.263	0.168
	Calcium * METPA	0.201	0.382	-0.090	0.746	-0.124	0.507	-0.219	0.229
	Calcium * MECHPA	0.223	0.221	0.082	0.771	0.048	0.797	0.224	0.245
BMCGAIN$_{res}$-Spine	Calcium	0.121	0.484	-0.099	0.318	0.225	0.197	-0.008	0.935
	METPA	0.031	0.930	0.236	0.314	**0.392**	**0.033***	0.142	0.442
	MECHPA	**0.497**	**0.005***	-0.279	0.253	0.224	0.214	-0.213	0.273
	Calcium * METPA	0.040	0.837	-0.030	0.914	**0.409**	**0.027***	0.033	0.859
	Calcium * MECHPA	0.094	0.615	0.091	0.747	0.228	0.515	-0.082	0.675

b, Regression coefficient from equation. Calcium intake and physical activity scores were centered before entry into analysis. *p<0.05

Table 5.20 Multiple moderated stepwise linear regression analysis for residualized BAGAIN

Site	Predictor variables in order of entry	White Male		Black Male		White Female		Black Female	
		b	Sig	*b*	Sig	*b*	Sig	*B*	Sig
BAGAIN$_{res}$−WB	Calcium	-0.28	0.89	-0.002	0.992	0.03	0.90	0.114	0.480
	METPA	**0.399**	**0.044***	-0.111	0.567	**0.481**	**0.02***	0.217	0.403
	MECHPA	0.530	0.21	0.150	0.328	0.237	0.903	0.249	0.457
	Calcium * METPA	-0.72	0.75	-0.41	0.882	0.01	0.959	0.096	0.847
	Calcium * MECHPA	-0.15	0.53	-0.128	0.594	0.059	0.807	0.127	0.806
BAGAIN$_{res}$−Radius	Calcium	0.497	0.104	0.09	0.543	**1.607**	**0.009***	0.050	0.759
	METPA	0.186	0.681	0.007	0.971	1.298	0.084	0.135	0.607
	MECHPA	0.239	0.443	0.133	0.479	0.205	0.793	0.193	0.559
	Calcium * METPA	3.882	0.284	0.144	0.593	**2.794**	**0.011***	0.234	0.628
	Calcium * MECHPA	0.154	0.424	0.268	0.255	1.041	0.210	0.166	0.740
BAGAIN$_{res}$−Hip	Calcium	**0.909**	**0.017***	-0.032	0.837	**0.879**	**0.017***	0.229	0.060
	METPA	0.319	0.904	-0.029	0.883	0.174	0.667	-0.103	0.503
	MECHPA	0.888	0.20	0.025	0.902	0.243	0.410	-0.077	0.519
	Calcium * METPA	-0.021	0.967	0.052	0.854	**1.407**	**0.044***	0.239	0.050
	Calcium * MECHPA	1.050	0.06	-0.081	0.746	**2.057**	**0.007***	0.182	0.437
BAGAIN$_{res}$−Spine	Calcium	0.434	0.358	0.049	0.750	0.300	0.135	0.070	0.662
	METPA	0.937	0.754	0.151	0.430	0.376	0.064	0.277	0.291
	MECHPA	0.363	0.878	0.025	0.897	0.153	0.769	-0.382	0.262
	Calcium * METPA	1.021	0.784	-0.019	0.946	1.481	0.292	0.078	0.876
	Calcium * MECHPA	0.511	0.867	0.066	0.785	0.650	0.548	-0.110	0.835

b, Regression coefficient from equation. Calcium intake and physical activity scores were centered before entry into analysis. *p<0.05

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5.7 Summary of Findings

The main purpose of the studies conducted for this thesis was to describe the associations of lifestyle, in particular physical activity, and environmental factors (socio-economic and nutritional) with bone mass acquisition, for the first time in a South African group of Black and White children growing up in post apartheid South Africa.

This chapter presented the results of the thesis in five parts. The first part described the results of the Actical Study which sought to evaluate the correlation between the physical activity scores as generated by responses given by subjects on the PAQ and data obtained from Actical accelerometers. Results showed that the scores generated from the subjects reporting on their physical activity and inactivity on the PAQ were significantly correlated with activity and inactivity measures generated from the Actical. There was also good reliability in the reporting of physical activity and inactivity by the subjects in two separately administered sessions of the questionnaires, one week apart. The results indicate that the PAQ provide a reasonable indication of physical activity levels in pre adolescent children.

The Fitness Study involved a sub-sample of children from the Bone Health cohort and examined fitness levels and their relationship with physical activity as assessed by the PAQ and body composition indices as measured by anthropometry and DXA. White males were found to be the best performing group for all fitness tasks. When children were grouped together and classified into fitness categories, there was a strong correlation between fitness level, METPA score, BMI and body fat percentage. While physical activity has many facets to it, physical fitness in this group of children was shown to correlate well with self reported physical activity level and objectively measured body composition.

The children from the Bone Health cohort were also used as participants for the final three studies conducted for this thesis. The first of which, explored associations between physical activity and bone mass, with particular attention being paid to race differences. The study reported cross sectional bone mass and physical activity data from Black and White nine-year-old children. The vast majority of White children participated in physical education (PE) classes at school compared to less than a third of their Black peers. On the whole, White children reported being more physically active than Black children and males were more physically active than females. Black children spent a greater amount of time actively commuting to and from school (i.e. walking/riding) each day than White children. Black children spent a greater amount of time watching TV than White children. Results showed that whole body BMD, and hip and spine BA, BMC and BMD were significantly associated with increasing levels of activity (i.e. a greater METPA score) and mechanical stress (MECHPA score) in White children. More active White children had a superior whole body BMD (up to 8% greater), hip (up to 17% greater) BMC and spine (up to 17%) BMC (after adjustment for body size), than less active children, even before reaching adolescence and early adulthood. There were no significant associations between activity levels in Black children and bone mass, except for whole body BMD, where most active Black children had significantly greater BMD than their less active counterparts. There were no significant associations between METPA activity levels and BA measures, although a similar trend to that of BMC and BMD was observed between increasing activity level and bone area.

The fourth part of the chapter details findings concerning the relationship between SES and physical activity patterns. A higher asset indicator score among the children was significantly associated with increased maternal education levels, better partner support and higher cash

income. The number of children participating in PE classes at school rose steadily with a higher asset indicator score. Children falling into Q1 (low SES) had a higher METPA score than Q2 and 3, but not 4. The highest METPA score was seen in Q4, which was significantly higher than all three other quartiles and almost double the scores of Q2 and 3. There were fewer children with single mothers in the highly active quartiles. Additionally, there were more children with mothers who held tertiary qualifications in the highly active group than the less active groups. Children who were highly active also had the highest amount of lean mass, regardless of their height or amount of television watched.

The final study examined longitudinal changes over a one year period in the Bone Heath cohort. These data on bone mass changes and physical activity levels provide the only available longitudinal bone mass and physical activity data on normal pre-and early-pubertal children living in a developing country. This study showed that White females and males accumulate BMC, BA, height and weight at similar rates over a 12 month period between the ages of nine and 10 years both before and after adjustment for body size. Black males however had lower height, weight, BMC (at all sites measured) and BA (whole body and spine) accumulation rates compared with the other groups. White males had the highest PA levels and White male children falling into the highest quartile of activity exhibited bone mass benefits at the whole body, total hip and lumbar spine sites. White children consumed approximately twice the amount of calcium than Black children did. Nevertheless, Black children had a higher hip BMC adjusted for body weight and bone area than White children at age nine (182) and 10 years, despite lower calcium intakes and physical activity levels. An interactive effect of calcium and physical activity was observed in White females for BMC at the spine and for BA at the radius and hip.

The findings of this thesis provide a comprehensive picture of normal habitual physical activity patterns and their association with lifestyle and environmental factors affecting bone mass acquisition in South African children by sex, race and age. The results are discussed in greater detail in the following chapter.

Chapter 6

Discussion & Conclusions

Chapter 6: Discussion

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6.1 Introduction

The findings presented in the previous chapter are discussed in both a quantitative and qualitative manner in this chapter. The discussion is again presented in five parts, but data is also discussed in an integrated manner in the final section of the chapter. The results and findings of the studies conducted are reconciled with the findings of other researchers in the area and possible mechanisms and confounders are discussed. The chapter includes limitations of the studies.

While all studies conducted focused on the global research framework, the first two studies were primarily methodological in design. The main purposes of The Actical and Fitness Studies were to attempt to gain a broader perspective of the many complex facets of physical activity, using direct and objective measures (accelerometers and heart rate monitoring) in addition to an indirect measure of physical activity-the physical activity questionnaire (PAQ). Studies three to five were conducted with larger sample sizes of children, and were more in-depth studies directed at describing the associations of lifestyle and environmental factors such as socio-economic status and physical activity with bone mass acquisition in South African children.

While physical activity and bone mass intervention studies are critical for determining cause and effect relationships, they provide limited understanding of the natural effects of habitual physical activity patterns on bone mass development. Longitudinal observational studies in addition to intervention studies are important for describing the cumulative effect of physical activity on bone mass acquisition in addition to the influence of other lifestyle factors, and help ascertain

whether it is possible to increase bone mass through higher levels of habitual physical activity (126).

6.2 Part 1 - Actical Study

This study was designed to determine the validity and reliability of the PAQ during a normal week in nine to 11 year old Black and White, male and female children. Positive and significant correlations were observed for activity reported on the PAQ and measured with the Actical. Time spent in sedentary behaviour which included doing homework, watching television, sleeping and playing on the computer as reported by children on the PAQ was significantly and positively correlated with the percentage of time that children spent in sedentary activity (including sleep) as measured by the Actical. A similar relationship was found at a higher levels of physical activity, whereby METPA hours spent doing vigorous activities (this included sports such as hockey, cricket, soccer etc) were significantly correlated with the percentage of time children spent in vigorous activities per day as measured by the Actical. The PAQ is able to differentiate between different intensities of physical activities and is a useful tool for evaluating physical activity in South African children. However the relationship between the PAQ and Actical assessments of activity is not along the line of identity suggesting that the PAQ overestimates at high values of PA and possibly underestimates at low values. Nevertheless the relationship allows PAQs to be used to divide children into quartiles of activity.

The PAQ provided consistent results over two administrations which examined all activity undertaken in the preceding year. No major differences in reporting of activity levels were observed between the measurements. Additionally the subjects' physical activity behaviour over

the four days of the Actical assessment was representative of a normal week of activity in these children.

A comprehensive comparative study conducted by Puyau et al. (2004), concluded that the Actical provides a valid measure of children's activity and is a good discriminator between sedentary, light, moderate and vigorous activity levels. In the present study, the Actical output was considered as an overall measure of activity and as percentages of time spent within ranges of activity levels (sedentary to vigorous). Three findings are of importance. Firstly, that the PAQ and the Actical are correlated at a low range of activity; secondly, the relationship between the two instruments holds true for activities performed at a higher intensity and thirdly that physical activity as reported on the PAQ was consistently reported on the weekly and yearly recall of activity by the subjects. It is not surprising that although the two instruments were significantly correlated, the correlation was only moderately strong. While PAQs may not be as useful when comparing physical activity between individuals, they do allow one to confidently divide a population into ranges or quartiles of physical activity. There have been a number of reports of validation of self reported PA with measures obtained from accelerometers, a wide range correlations has been reported (r=0.20 − 0.88) (179; 246; 249; 291). Intra class correlation coefficients regarding reliability of PA questionnaires have ranged from R=0.51- 0.98 (179; 246; 267). While these reported ranges are rather wide, the correlations reported in the present study fall well within them and towards the upper end of both ranges.

For the assessment of physical activity in children, a clear understanding of the accuracy of different methods used is important. Children may experience difficulty in reporting their physical activity (51; 213). Accelerometer based activity monitors have become smaller and more

sensitive to monitoring activity over extended periods of time (220). They have been shown to be a valid tool for measuring physical activity in young children (212; 245). A number of review papers have presented guidelines with regards to best practice of placement of the Actical accelerometer and the number of days of monitoring needed (308; 312). Days of monitoring in children using the Actical is generally recommended to be between three and five in order to achieve reliability of 0.7 (290). Placement at the hip and recording one minute epochs of data are also accepted as standard protocol. This study used a four day protocol over two week days and a weekend, placed the Acticals on the left iliac crest of the children and the Acticals were set to record counts in one minute intervals. All subjects wore their Acticals continuously (except during showering or bathing) as evidenced by the continuous data and counts obtained when the data was downloaded.

There are major challenges to measuring physical activity in children particularly in South Africa. The gold standard for measuring energy expenditure in free living humans is the doubly-labelled water technique, which is expensive and has not been used in humans in South Africa. Additionally many questionnaires are specifically designed for use in developed countries and their transfer to other cultures in developing countries may not always be appropriate (309). To date only one study has designed and validated a questionnaire specific to a population in Africa (273), although the Global Physical Activity Questionnaire (GPAQ) is currently undergoing validity testing in a South African population (11). Acticals are an expensive item to purchase, particularly in South Africa and were therefore suitable for activity monitoring in a small group of children only (such as in The Actical study (part one)), but were not a feasible tool to use in the large cohort of children studied in Parts three to five of the thesis. For these reasons, our PAQ

was adapted and modified for appropriate use in a South African population of Black and White children, and used as the primary physical activity assessment tool throughout the thesis.

In summary, the interviewer administered PAQ was found to be a valid and reliable assessment tool in this population of children as evidenced by its good correlation with Actical measurements. The PAQ is an easy to administer, cost effective tool for discriminating more active children from those who are less active. While absolute METPA and MECHPA scores can be calculated from the questionnaire, the better application of the questionnaire appears to lie in its ability to qualitatively rank subjects according to activity level.

6.3 Part 2 - Fitness Study

Fitness levels in a sub sample of Black and White, male and female children from the Bone Health Cohort were assessed and related to body composition and physical activity estimates as calculated from the PAQ. The main findings in this study are that 1) a significant and positive relationship between physical activity levels as estimated from the PAQ and fitness as measured by fitness tests was observed; and 2) a significant and negative relationship between fitness and fatness was observed. These findings support the PAQ as a valid tool, with good evidence to show that the PAQ is accurately estimating what it purports to do.

Physical fitness can be divided into health related fitness, composed of a factors such as cardio-respiratory endurance; body composition; muscular strength and flexibility; and performance related fitness (power, speed-agility, hand-eye coordination etc) (40; 298). While a myriad of tests exist to test health related physical fitness in adults (298), there have been few studies reviewing the best approach for fitness testing in children. Additionally data are also lacking to

show the link between fitness levels in youth and health related physical fitness as an adult (86). Currently, there are no data describing the fitness levels in a population of South African children.

Performance on the shuttle run test has been shown to correlate well with laboratory tests of maximal oxygen uptake (45; 297). The shuttle run test has been used widely in tests of physical fitness; in a large study (1015 children) conducted by Boreham et al. (1997), aerobic fitness as assessed by the shuttle run task was found to be significantly correlated with physical activity as reported from a questionnaire in boys (39). The findings of the present study (Fitness Study) are in agreement with Boreham's results. It is important to note that gender and race distribution was not equal across fitness tertiles, thus it is possible that fatness (BMI) and percentage body fat may reflect race and gender differences instead, rather than be associated with differences in fitness levels.

White males in this study scored significantly higher METPA scores on the PAQ and also performed significantly better on all fitness tasks conducted compared with any of the other groups. The greatest percentage of children classified as being the fittest were White males, while the greatest percentage of children classified as least fit were Black females. Children who were classified as most fit had significantly lower BMI's and body fat percentages. There was also a significant and positive correlation observed between METPA score and fitness level.

The present study provides support for a positive association between activity levels and fitness. The study however does not necessarily attribute decreased fitness to increased body fat. The relationship between these variables could be a self selecting one, whereby fatness may cause a

child to be inactive and therefore less fit. Nevertheless the results of the study agree with those of Rowlands et al. (233) and suggest that inactivity and decreased fitness are linked with increased fatness. This was also found to be the case in a later study conducted for this thesis (part four), in which lean mass was found to be significantly and positively associated with activity level, regardless of height.

The results of fitness tasks conducted for this study were significantly correlated with activity level as estimated by physical activity questionnaire and with body composition measures. Currently there are no representative health related fitness databases of South African children who have been periodically assessed. These simple and easy to administer fitness tasks could be used as a tool for larger studies and provide a good model for inexpensive fitness testing which could be easily implemented and incorporated into schools.

6.4 Part 3 - Cross Sectional Physical Activity and Bone Mass Study

This was the first study to be undertaken in a large population of normal pre-pubertal children living in a developing country which investigated race differences in bone mass and the association with physical activity. The findings demonstrate that physically active children have greater site specific BMC and BMD than their less active peers. Whole body BMD, and hip and spine BA, BMC and BMD were significantly associated with increased levels of activity (i.e. a greater METPA score) and mechanical stress (MECHPA score) in White children. More active pre-pubertal White children had a superior whole body BMD (up to 8% greater), hip (up to 17% greater) BMC and spine (up to 17%) BMC than less active children. These findings are in agreement with Janz et al. (125) and Slemenda et al. (269) who reported 4-7% greater bone mass in pre-pubertal children in the highest quartiles of weight bearing physical activity, as well as

with other epidemiological studies in which physical activity as assessed by questionnaire was found to be positively correlated with bone mass in children and adolescents (100; 135; 136; 161; 196; 284). In the present study, significant positive correlations between PA and bone mass were found only for WB BMD in Black children. When BA, BMC and BMD were plotted against activity quartiles for both METPA and MECHPA scores, an increase in BMC and BMD was seen for White children, but not for Black children. Few studies have reported on the association of habitual physical activity with BA; in the present study no association was observed, although it is likely that with the addition of lean mass as a covariate or other body composition measures, differences may have been observed. In this study PA appeared to have an osteogenic association with bone mass in White children, but not in Black children. It appears that Black children did not reach a high enough "threshold" of activity to induce an osteogenic association. This was evidenced by the Black children's narrower and lower range in activity scores. The highest activity and loading quartiles for Black children had mean scores that were much lower than those of the White children's highest quartiles. Nevertheless lower PA levels in this group of Black children did not appear to negatively impact bone mass; Black children as a whole still had a greater hip and spine (girls only) bone mass than the White children at age nine. The possibility of a genetic protection against low bone mass and fracture in Blacks must be considered, as calcium intakes and physical activity were lower in the Black than in the White children. In Blacks in developing countries such as South Africa, as lifestyle and dietary patterns change with urbanization, so may also the prevalence of fractures in the elderly, thus PA may become increasingly more important as a means of protecting the skeleton in this population.

Physical activity is an exogenous factor influencing bone health and special attention should be given to its role in optimizing bone health. Studies performed in developed countries such as

North America and Europe have shown that inactivity and activity patterns differ by race, with minority groups engaging in less PA (102). Hispanics and African American children have been found to be less active and expend less energy than Caucasian children (67). Obesity and higher body weight are strongly associated with a sedentary lifestyle and lack of physical activity in the adult population of the European Union (171), and the latter are key components of the growing overweight and obesity problem in Western populations. Of the few studies that have been published involving developing country populations (South African and Nigeria), similar findings have been reported (147; 164; 264). Despite differences in physical activity between Black and White pre-pubertal children in the present study, no differences in BMI were noted between the race groups in this study, but White males did have significantly greater lean body mass than Black males. It is possible that BMI units do not correctly reflect real differences in body composition measures as has recently been shown in Rush et al.'s (2007) work, where inter ethnic BMI was found to differ by more than 10 BMI units for the same percentage body fat (240).

The association between activity and bone mass is greatest in the weight bearing regions of the skeleton. In the present study, significant positive correlations were found at all weight bearing sites in White children. Pocock et al. (214) have suggested that a possible reason for the hip being the site most receptive to differing levels of PA is because differences in skeletal load are most pronounced at the hip as a result of the greater increment of load at this than at other sites. It is known that low force activities such as a long distance running, swimming, and cycling increase muscle endurance but not bone mass. Maximal force activities such as weight lifting and sports involving violent acceleration of the body put greater loads on bones than low force exercises (256). Several studies have indicated that bone mass is a function of muscle strength

(70; 199; 258). The positive influence of body weight and muscle mass on bone is well documented (120), but there is still a lack of consensus as to which factors should be correctly entered as covariates in bone and muscle mass analyses. Although a few studies have examined the intensity, frequency and duration of exercise needed to produce a significant effect on body composition and bone mass (18; 127; 166), none have studied children in developing countries. Additionally, most of these studies have been conducted in females only and very few have examined race differences either. Schoenau & Frost (2002) suggest that bone strength adapts to isometric muscle forces (256). Data from the present study substantiate this proposal. White children playing sport with a high bone strain such as rugby and gymnastics (high MECHPA) showed greater BMC and BMD at the whole body and at the hip, with the greatest difference again being observed at the hip (up to 17% greater in the "high strain" group than in the "low strain" groups). This suggests corresponding kinds of exercises during growth could help to achieve greater bone strength and possibly minimise fractures in later life.

Studies have raised the possibility that the sooner children become active, the greater their bone accrual, lean muscle mass and possible peak bone mass. On the basis of current evidence it is clear that bones of growing children benefit most from moderate to high levels of exercise and activity. What is unclear at present is the duration of the effect of habitual exercise on bone once if it is stopped or decreased, and what effect habitual pre-pubertal exercise will have on bone mass following the pubertal growth spurt. Additionally it is not clear whether the same benefits of exercise with regards to bone mass in Black children would be observed, if they were participating at higher activity levels, similar to those of their White peers. What is known however is that rapid changes in dietary patterns, activity levels and the prevalence of obesity are

occurring in populations of developing countries (215) and these changes are associated with an increase in chronic diseases, which will need to be addressed.

Understanding physical activity's impact on bone mass is central to developing primary prevention strategies for osteoporosis. Programs promoting physical education and activity are also desperately needed, specifically in the South African context. The lack of PE lessons at school in predominantly Black schools is cause for concern, as it contributes to the lack of physical activity observed outside of school in Black children. Although fracture rates are relatively low at the present time in elderly Black subjects (254; 274), obesity and associated hypertension and diabetes are major concerns. Thus the development of a culture of exercise is seen as being important in attempting to address these problems.

6.5 Part 4 - Socio-economic Status and Physical Activity Study

This study analysed PA patterns and SES in children and measured the association between these variables. No White children were classified into the first three quartiles of SES when the data were analysed as a whole. Separate race analyses showed that the physical activity trends observed for the whole group were consistent across socio-economic quartiles regardless of race. A higher asset indicator score among the children was significantly associated with increased maternal education levels, better partner support and higher cash income. The number of children partaking in PE classes at school rose steadily with a higher asset indicator score.

PA as analysed by compiling a METPA score showed an interesting trend. Children falling into Q1 (low SES) had a higher METPA score than Q2 and 3, but not 4 (high SES). This was an

unexpected finding as it would have been expected that METPA scores would have followed a "lowest to highest" trend. However, upon further analysis, it was found that almost 20% of the children who fell into Q1, did not own television sets. Consequently these children spent the second lowest amount of time watching TV. Additionally many of the children in this quartile did not have the same luxury items found in households of children from higher SES groups, suggesting that more of their time could be occupied with PA, both informal (on street etc) and formally (at school). Although formal school physical activity is unlikely due to poorer access to facilities in schools of a lower socio-economic status. The children in the lowest quartile also would have had the least amount of money in order to buy snacks of food at school, and perhaps not be able to pay for taxi's or buses to school each day. These children had the lowest weight, BMI and fat tissue mass. This higher level of METPA and lower level of TV watching may be contributing to the healthier body composition patterns evident in the children in Q1. The highest METPA score was seen in Q4, which was significantly higher than all three other quartiles and almost double the scores of Q2 and 3. There is some controversy in the literature regarding SES and PA. A study conducted in the Philippines (77) showed that children from private schools were less physically active and more likely to prefer television to outdoor games. The results of this study in a South African population show the opposite and are in agreement with studies which have found higher PA levels to be associated with a higher SES (143; 144). Children in Q4 had the highest PA scores, were more likely to participate in PE at school and had significantly higher amounts of lean mass, regardless of race.

In the whole sample, weight increased significantly in the third and fourth SES quartiles, compared with the first and second SES quartiles. BMI increased up until the third SES quartile and then decreased in the fourth SES quartile. This appeared to largely be due to the racial

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distribution of the subjects, as there were mostly White children only within the fourth quartile. The fact that all the White children fell into the highest SES quartiles is largely a function of South Africa's historical past. Upon further analysis for the Black children only, BMI continued to increase with increasing socio-economic status. The rest of the trends observed between anthropometric variables, physical activity and increasing socio-economic status remained consistent between the whole group and for Black children alone. Fat tissue and lean tissue mass increased with increasing SES status. There were more married and more highly educated mothers in the most active groups compared with less active groups. Similar findings have been reported in adults where inactivity has been found to be most common in those with a low education level (205).

The physical activity data showed White children were more active than Black children and boys were also found to be more active than girls. These findings are consistent with studies performed in developed countries that have also found similar race and gender differences in PA patterns to those reported here (101). Less than half of the children in this study participated in PE classes at school. The PA score (METPA) was significantly correlated with participation in PE classes; it may be that a lack of PE being offered at school level is translating into low levels of after school or club sport and activity. Low levels of habitual physical activity have serious implications for later health and social development.

No significant differences in lean mass between television quartiles after controlling for activity level and fat mass were found, but a significant association was observed between lean mass and increasing activity levels, after controlling for television watching time and fat mass. This relationship held true for Black and White children. Stafford (1998) explored fat mass by TV and

activity level. She found a stronger relationship between fatness and activity level than between fatness and television watching (276). A similar relationship was found in the present study, specifically when exploring lean mass.

To date few studies have examined factors influencing PA in developing countries. The data presented in the present study suggest important patterns of determinants of PA across groups of varying SES status. It is clear that childhood PA is of a multi dimensional nature and socio-economic and cultural factors have a definite influence on these patterns. In this group of children it appears that physical activity patterns could either be regulated by the primary caregiver or by the school that the child attends. If the school does not provide PE classes or after school sport, parental or caregiver support may act as a stimulus. If the parent or caregiver provides the support, their SES circumstances might influence the children's ability to participate in these extramural activities.

Physical activity is one of the most important modifiable factors influencing the incidence of chronic disease. Abernathy et al. (2002) suggest that it may be possible to cushion the impact of poverty on health through policies that could increase PA levels among those living in poverty (2). In order to develop individual level and policy level interventions, it is imperative that we understand all aspects affecting PA in potentially disparate populations (205).

6.6 Part 5 - Longitudinal Physical Activity and Bone Mass Study

The main determinants of peak bone mass are heredity, gender and race (98), and all of these determinants are associated with differing osteoporotic fracture rates and bone densities. Regardless of race or gender, nutrition and physical activity participation are considered to be the

most modifiable environmental factors influencing bone mass. This is particularly so in the pre-pubertal years, which appear to be the most responsive to these influences (107; 139; 178). There are little longitudinal observational data on the effects of habitual physical activity and calcium intakes on bone mass accretion in children, especially in racially diverse populations in developing countries such as in South Africa. The situation in South Africa is of particular interest since South African Blacks are reported to have among the lowest hip fracture rates in the world, but lifestyles are under rapid transition currently (253; 274).

These data on bone mass changes and physical activity levels over a one year period in a population of Black and White children, together with our other studies (182; 183) currently provide the only available DXA measured bone mass and physical activity data on normal pre- and early-pubertal children living in South Africa. The present study has shown that White females and males accumulate BMC, BA, height and weight at similar rates over a 12 month period between the ages of nine and 10 years both before and after adjustment for body size. Black males however had lower height, weight, BMC (at all sites measured) and BA (whole body and spine) accumulation rates compared with the other groups. White males had the highest PA levels and White male children falling into the highest quartile of activity exhibited bone mass benefits at the whole body, total hip and lumbar spine sites. White children consumed approximately twice the amount of calcium as did Black children. Nevertheless, Black children had higher hip BMC adjusted for body weight and bone area than White children at age nine (182) and 10 years, despite lower calcium intakes and physical activity levels. This racial disparity in dietary calcium intake has also been reported in the first National Youth Risk Behaviour Survey conducted in South Africa in 2002, in which it was found that significantly more White children (70%) had drunk milk on four or more days in the preceding week to the

survey, than had Black children (42%) (227). Although this is a crude estimate of calcium intake it is indicative of racial group differences in calcium consumption. The results of this study conflict with data reported from the only other study examining bone measurements (using ultrasound) in pre- adolescent girls living in South Africa. Micklesfield et al. (2004) reported that dietary calcium intake was lower in White girls compared with Black girls and reported no difference between ethnic groups for METPA score, but did report higher MECHPA scores in White girls (188).

Despite the fact that a significant relationship with physical activity and bone mass in Black children was not observed in this study our results do confirm the well established relationship between physical activity and bone mass in white children (23; 107; 142; 269). This relationship is governed by the degree of physical activity; in order for sizeable bone mass changes to occur, physical activity must be great enough to induce these positive effects (278) . These data show that indeed it does appear that physical activity levels need to be above a certain threshold in order for bone mass benefits to be seen. This phenomenon has been demonstrated in exercise intervention studies but data such as these have not been reported for observational studies of habitual physical activity. In the present study, White males showed both a wider and higher range of scores for METPA and MECHPA compared with all other groups and the benefits of these higher levels of activity are reflected in the greater BMC and BA in highly active children (quartile 4). This "threshold" of activity is important to consider when designing exercise programs aimed at increasing bone mass. Whether this 'threshold' is reached by performing activities with a high enough strain on the bone for a short period of time or performing less strenuous activities for a longer period of time is unclear. The minimum effective dose of weight bearing activity remains controversial, studies have shown bone mass increases from jumping for

as little as three minutes per day (177). In the current study, the most popular sports among White boys were soccer, cricket, tennis and swimming. White boys in the fourth quartile of activity were playing sport for approximately one to one and a half hours per day.

Most studies examining differences in bone mass during the pre-pubertal years have been limited to Caucasians, although McKay et al. (2000) reported lower calcium and physical activity levels in Asian children compared with White children. Racial differences were also observed in bone mass, with Asian boys showing lower femoral neck bone volume and BMD (178). This study confirms the previous findings of lower PA levels in Black children presented in parts two, three and four of the thesis. Similar findings have been reported in developed countries such as the US where African American children were found to have the lowest levels of activity when compared with non-Hispanic White, Hispanic and Asian children (101). When physical activity levels are high and possibly above a threshold or "active" time period, significant bone mass effects are seen. This was evident for White males, where associations between PA and residualized bone mass at the whole body, hip and spine were observed. All White males who were in the highest quartile of activity showed residualized bone mass well above zero (the expected score for the weight and bone area of the child). It thus appears that they were the only group who had high enough levels of habitual physical activity, such that a positive and significant effect on bone mass at the whole body, hip and spine was seen. The lack of any effect of physical activity on radial bone mass adds support to the contention that it is a weight bearing effect of PA that induces the changes in bone mass. This study supports the hypothesis that mechanical loading during the growing years impacts on bone mass and structural indices such as bone area. Children with highest activity levels had residualized BAGAIN above zero, indicating that they were well above their weight and height matched bone area accumulation rates.

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There has been some work which suggests that the effect of interstitial pressure on BMC may cause accentuated bone gain. A study conducted by Dodd et al. (1999) demonstrated that after a few days of disuse, osteocytes present in long bone become hypoxic (68). A signal for osteoclastic resorption may occur in children not performing high mechanical loading activities due to osteocyte hypoxia.

These data do not suggest that calcium has a synergistic effect with physical activity on BMC in boys as has been previously suggested (234; 275). However, calcium and physical activity did show an interactive effect on bone area of White girls at the spine, radius and hip as has been reported in intervention studies (121). This may in part explain the increased residualized bone area gain observed in the fourth quartile of physical activity despite the fact that White girls were not as active as White boys. Calcium and exercise may play a synergistic role on bone area gain in girls when both factors are high. The current recommendation in the United States for calcium intake in Caucasian children is 1300mg/day (87). Based on this amount, none of the groups in this study met the current recommendation with the mean intake of White children being about 56% and that for Black children about 25% of the adequate intake for calcium. The possibility that calcium intakes were not high enough to induce a positive association with bone mass or a synergistic effect with physical activity in other groups must also be considered.

This study does raise an apparent paradox. Despite the low calcium intakes and low physical activity levels of South African Black children, they still have higher bone mass at the hip than White children and similar values to their White peers at other sites. The findings from the studies presented in this thesis, that Black South African children have greater bone mass at the hip than their White peers are similar to data reported for African American children. Our Black

South African children, however, are comparatively disadvantaged. These data suggest that racial differences are site specific and are likely to be the result of strong genetic influence in the face of adverse environmental factors.

In summary the findings of this study have demonstrated differences in habitual physical activity levels and calcium intakes between Black and White South African children. An interactive effect of calcium and physical activity was not shown in any groups expect for bone area gain in White girls. Additionally residualized bone mass gain, which is a good indicator of weight and bone area matched BMC gain, is highest at all weight bearing sites in the most physically active White children. The same trend was observed for weight and height matched BA gain, whereby BA gain was greatest at all weight bearing sites in the most active children. It is likely that the increase observed in BMC is due to a combination of both an increase in BA and BMD with increased activity as even after correcting for BA, analyses showed that BMC was still greatest in most active children. Studies making use of structural indices of bone (measured by using pQCT for example) will be able to elucidate this further in the future. These studies are currently underway.

6.7 Study Limitations

The Actical Study, while providing reliable and valid data, had some limitations. Separate analyses of the data for males, females, White and Black children were not appropriate because of the small sample sizes. Also, activity levels recorded on week days vs. weekend days were not different in this study, even though it has been documented that there are differences in activity patterns on these days (290). The non significance may well have been due to a small sample size and large variances. It is possible that the subjects' activities were not monitored for a long

enough time period. Moreover in the Actical Study all groups showed comparable levels of physical activity, while in studies conducted with larger sample sizes physical activity patterns have been shown to differ between gender and race groups (101; 221; 288). These findings are corroborated in later parts of the thesis (parts two to five), where gender and race differences in activity levels were observed. A further limitation is that the Actical is a uni-axial accelerometer, measuring acceleration in one plane only. Activities such as cycling and swimming may not have been accurately recorded.

It would have been preferable to measure actual oxygen consumption to assess VO_2 levels in the subjects used for the Fitness Study. However, due to budgetary and logistical constraints this was not possible. It is possible that subjects' personal motivational levels to perform well in the standardized fitness tests used to assess fitness may have differed on the day of testing. Some children may have been more motivated to do well, regardless of the fact that all subjects were give the same verbal encouragement on all tasks. A larger sample size would have been useful in this study in order to attempt to generate some South African norms with regards to general fitness levels in pre-pubertal children.

Other limitations to the studies conducted for this thesis include the smaller number of White children in comparison to the larger sample of Black children. This is largely a function of the racial distribution of the South African population and the way the cohort was developed, which was representative of the ethnicity of the SA population. Additionally, children were asked to recall their physical activity patterns over the previous year, the time period may have been too long for children to remember accurately. Quarterly assessments may have provided a more accurate representation of the subjects' PA patterns. The children enrolled in the Bone Health study are from urban areas and the results of this study may therefore not necessarily be

extrapolated to children from rural areas, where children may have higher levels of physical activity due to duties such as herding cattle, fetching water and firewood as well as having more space to play outdoors. The results reported in the present study of South African children may not be necessarily extrapolated to other populations. It will be important to follow these children longitudinally in order to examine whether the observations made here persist into adolescence. To date, only one study has reported on a maintained increased bone mass in more habitually physically active children after three years compared to their less active peers (126). Although a number of approaches to assessing children's PA have been described, no specific method has been identified as the best option for all studies (313). While there are limitations to using activity recall questionnaires in this large longitudinal cohort of children, recall questionnaires were the only practical way to assess PA in this cohort.

Additionally we are aware of the limitations of using DXA measurement in children, specifically that the measures reported on in this thesis provide no information on structural alterations of bone and overlook the periosteal and endosteal dimensions that influence bone strength.

6.8 Summary and Conclusions

Osteoporosis, a chronic musculoskeletal disease affecting a large proportion of the population over the age of 60 is likely to reach epidemic proportions over the next 20 years due to the ageing population. Low BMC in old age may be the result of low peak bone mass being attained during the first two decades of life, an excessive loss of bone during ageing, or both (260). Enhancing bone mass acquisition offers the best protection against later bone loss and is therefore the most

effective approach to preventing osteoporosis. Since peak bone mass is influenced by modifiable and non-modifiable factors, exercise may play a crucial role in the prevention of osteoporosis. There is convincing evidence showing that weight-bearing exercise during growth increases BMC accrual. Its effectiveness however, depends on the type, intensity and duration of exercise, as well as the age at which the exercise is started. Lack of physical activity is a major public health issue and intervention is necessary at the population level. Experts have declared consequences of low physical activity to be major factors influencing low bone mass, obesity, chronic diseases, seriously compromised health and well-being, and these are associated with high medical and social costs. A sustained campaign of physical activity awareness needs to be developed.

This thesis studied the assessment and determinants of physical activity for the purposes of understanding bone mass acquisition patterns and the factors influencing them in a racially diverse group of children living in a developing country. Additionally, the thesis aims to inform those involved in public health interventions and health promotion activities of the current South African situation. Methodological issues related to this research, such as issues of physical activity assessment and bone mass measurement were examined. Determinants of physical activity behaviours were explored and associations of lifestyle and environmental factors with bone mass acquisition were discussed. Five studies were conducted in series and parallel in order to establish a better understanding of factors influencing bone mass in children.

Few data exist on South African children's physical activity behaviour patterns and the influencers thereof. Furthermore, only limited data on South African children's bone mass status exists (49; 188; 202; 207; 208; 211; 304). The studies described in this thesis concern normal

habitual physical activity patterns in a racially diverse group of children living in post apartheid South Africa. The findings of the studies described, support the notion that habitual weight bearing exercise is positively associated with bone accrual in growing children provided it is above a mechanical threshold. The positive association of bone mass and physical activity is maintained when examined over a one year period. Black children were less fit, less physically active, had lower calcium intakes and came from less favourable socio-economic conditions than White children. Despite this, Black children remained with a size adjusted advantage of a higher hip bone mass than their age and maturity matched White peers at ages nine and 10 years. The rapidly changing way of life in South Africa could impact on the genetic advantage afforded to these children.

In conclusion, there are major disparities between the physical activity patterns of Black and White South African children. Moreover, there are racial differences in bone mass acquisition patterns in these children. South Africa is an emerging economy, characterised by high unemployment and low income per capita. While genetic protection against low bone density remains strong, it is assumed that South African Black adults will develop significant osteoporosis due to changes in lifestyle in the future. The only feasible way of confronting the possible epidemic of osteoporosis is to implement sustainable, cost effective strategies aimed at increasing bone mass acquisition during the pre and early pubertal years. Public health strategies directed towards improving bone health in children may be an effective means of pre-empting and reducing the future risk of osteoporosis. The data collected for this thesis will provide policy makers with information on general habitual physical activity and inactivity patterns of South African urban children. Specific prevention and intervention strategies taking all factors described in this thesis into account can be implemented based on these data. While major

influencing factors such as socio-economic status take many years to alter, healthy physical activity patterns and participation can be instilled in children at a young age. Studies reviewed in this thesis have shown that easily implemented programs aimed at enhancing bone mass can be easily incorporated into school regimes with no equipment needed at all.

This thesis has laid down foundation work in the field of physical activity and bone mass in South African children. In particular the data has shown that irrespective of race, there is a threshold of activity which needs to be reached in order for habitual physical activity to positively influence bone mass. Additionally irrespective of genetic predisposition, physical activity plays a role in the development of a leaner body composition. Physical activity patterns in children are highly influenced by socio-economic status and maternal characteristics. The next step will be to build on the work described here in order to develop and implement physical activity intervention programs within the frameworks described.

6.9 Future Research

The findings presented in this thesis raise a number of further questions which require probing. It will be useful for future work to expand on the findings of this thesis; in particular, the physical activity questionnaire should be conducted with a much larger sample of children from different geographical regions in South Africa. This would enable the questionnaire to be validated for use in hard-to-reach areas and in poor populations where it would not be feasible to use sophisticated physical activity measurement techniques. Alternately, it is hoped that there will be promising results from the Global Physical Activity Questionnaire (GPAQ) studies which would enable comparable data across countries to be generated. Since the doubly labelled water technique has not been used in a South African population, this would be a useful study to conduct too. Additionally with the advent of new tri-axial accelerometers, physical activity questionnaire data need to be compared to these readings.

A large scale fitness study needs to be conducted in South Africa. The tests described in this thesis are simple, cheap and easy to administer. If they are done in a large sample of children, the data will enable South African norms to be developed. Fitness testing could be incorporated into a physical education program at school, whereby children's fitness levels could then be compared annually or bi-annually across age, race and sex groups as is being done in other developed countries such as Australia and the United States.

It would be of interest to monitor whether the socio-economic status of South African Blacks changes as the country becomes a more developed democracy. Socio-economic data obtained could be used to design studies and programs which address the specific needs of high risk populations. The bone mass studies have raised questions regarding the type, intensity and best

frequency of physical activity for best enhancing bone acquisition. Intervention studies in South African children, which examine the timing of exercise and effects of calcium supplementation between race groups, should also be conducted to ascertain whether the response of bone would be same across race groups. Advanced statistical techniques using multi level modeling needs to be done on order to incorporate all factors identified in this thesis. Finally, the findings highlight the need for further research into changes in bone geometry using more advanced techniques such as pQCT in South African children.

References

Reference List

1. **Aaron D, Kriska A, Dearwater S, Cauley J, Metz K and LaPorte R**. Reproducibility and validity of an epidemiological questionnaire to assess past year physical activity in adolescents. *American Journal of Epidemiology* 142: 191-201, 1995.

2. **Abernathy TJ, Webster G and Vermeulen M**. Relationship between poverty and health among adolescents. *Adolescence* 37: 55-67, 2002.

3. **Ainsworth BE, Haskell WL, Leon AS, Jacobs DR, Montoye HJ, Sallis JF and Paffenbarger JR**. Compendium of physical activities: Classification of energy costs of human physical activities. *Medicine and Science in Sports and Exercise* 25: 71-80, 1993.

4. **Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz AM, Strath SJ, O'Brien WL, Basset DR, Schmitz KH, Emplaincourt PO, Jacobs DR and Leon DS**. Compendium of physical activities: an update of activity codes and MET intensities. *Medicine and Science in Sports and Exercise* 32: S498-S516, 2000.

5. **Ainsworth BE, Shaw JM and Hueglin S**. Methodology of activity surveys to estimate mechanical loading on bones in humans. *Bone* 30: 787-791, 2002.

6. **Allor KM and Pivarnik JM**. Stability and convergent validity of three physical activity assessments. *Medicine and Science in Sports and Exercise* 33: 671-676, 2001.

7. **Aloia JF, Vaswani JK, Yeh JK and Flaster E**. Risk for osteoporosis in Black women. *Calcified Tissue International* 59: 415-423, 1996.

8. **Andreacci JL, Robertson RJ, Dubé JJ, Aaron DJ, Balasekaran G and Arslanian SA**. Comparison of maximal oxygen consumption between Black and White prepubertal and pubertal children. *Pediatric Research* 56: 706-713, 2004.

9. **Andreacci JL, Robertson RJ, Dubé JJ, Aaron DJ, Dixon CB and Arslanian SA**. Comparison of maximal oxygen consumption between obese Black and White adolescents. *Pediatric Research* 58: 478-482, 2005.

10. **Armstrong D, Shakir K and Drake III A**. Dual X-Ray Absorptiometry total body bone mineral content and bone mineral density in 18-to 22 year-old Caucasian men. *Bone* 27: 835-839, 2000.

11. **Armstrong T and Bull F**. Development of the World Health Organization Global Physical Activity Questionnaire (GPAQ). *Journal of Public Health* 14: 70, 2006.

12. **Augut P, Reeb H and Claes LE**. Prediction of fracture load at different skeletal sites by geometric properties of the cortical shell. *Journal of Bone and Mineral Research* 11: 1356-1363, 1996.

13. **Bachrach LK**. Acquisition of optimal bone mass in childhood and adolescence. *Trends in Endocrinology and Metabolism* 12: 22-28, 2001.

14. **Bachrach LK, Hastie T, Wang MC, Narasimhan B and Marcus R**. Bone mineral acquisition in healthy Asian, Hispanic, Black, and Caucasian youth: A longitudinal study. *The Journal of Clinical Endocrinology and Metabolism* 84: 4702-4712, 1999.

15. **Bachrach LK, Marcus R, Ott SM, Rosenbloom AL, Vasconez O, Martinez V, Martinez AL, Rosenfeld RG and Guevara-Aguirre J**. Bone mineral, histomorphometry, and body composition in adults with growth hormone receptor deficiency. *Journal of Bone and Mineral Research* 13: 415-421, 1998.

16. **Bailey DA**. The Saskatchewan Pediatric Bone Mineral Accrual Study: Bone mineral acquisition during the growing years. *International Journal of Sports Medicine* 18: S191-S194, 1997.

17. **Bailey DA, Martin AD, McKay HA, Whiting S and Mirwald R**. Calcium accretion in girls and boys during puberty: a longitudinal analysis. *Journal of Bone and Mineral Research* 15: 2245-2250, 2000.

18. **Bailey DA, McKay HA, Mirwald RL, Crocker PRE and Faulkner RA**. A six-year longitudinal study of the relationship of physical activity to bone mineral accrual in growing children: The University of Saskatchewan Bone Mineral Accrual Study. *Journal of Bone and Mineral Research* 14: 1672-1679, 1999.

19. **Bamshad M and Olson S**. Does race exist? Scientific American Magazine . 11-10-2003.

20. **Baron R**. Anatomy and ultrastructure of bone. In: Primer on metabolic bone diseases and disorders of mineral metabolism, edited by Favus MJ. Philadelphia: Lippincott Williams & Williams, 1999, p. 3-10.

21. **Baroncelli GI, Bertelloni S, Ceccarelli C and Saggese G**. Measurement of volumetric bone mineral density accurately determines degree of lumbar undermineralization in children with growth hormone deficiency. *Journal of Clinical Endocrinology and Metabolism* 83: 3150-3154, 1998.

22. **Bass S, Delmas P, Pearce G, Hendrich E, Tabensky A and Seeman E**. The differing tempo of growth in bone size, mass, and density in girls is region-specific. *Journal of Clinical Investigation* 104: 795-804, 1999.

23. **Bass S, Pearce G, Bradney M, Hendrich E, Delmas PD, Harding A and Seeman E**. Exercise before puberty may confer residual benefits in bone density in adulthood: Studies in active prepubertal and retired female gymnasts. *Journal of Bone and Mineral Research* 13: 500-507, 1998.

24. **Bérard A, Bravo G and Gauthier P**. Meta-analysis of the effectiveness of physical activity for the prevention of bone loss in postmenopausal women. *Osteoporosis International* 7: 331-337, 1997.

25. **Bernstein M, Sloutskis D, Kumanyika S, Sparti A, Schutz Y and Morabia A**. Data based approach for developing a physical activity frequency questionnaire. *American Journal of Epidemiology* 147: 147-154, 1998.

26. **Bhopal R**. Glossary of terms relating to ethnicty and race: for reflection and debate. *Journal of Epidemiology and Community Health* 58: 441-445, 2004.

27. **Binkley T and Specker B**. Increased periosteal circumference remains present 12 months after an exercise intervention in preschool children. *Bone* 35: 1383-1388, 2004.

28. **Biro F, McMahon R, Striegel-Moore R, Crawford P, Obarzanek EMorrison J, Barton B and Falkner F.** Impact of timing of pubertal maturation on growth in Black and White female adolescents: The National Heart, Lung, and Blood Institute: Growth and Health Study. *Journal of Pediatrics* 138: 636-643, 2001.

29. **Bjornson KF**. Physical activity monitoring in children and youths. *Pediatric Physical Therapy* 17: 37-45, 2005.

30. **Blair S, Haskell W, Ho P, Paffenbarger R, Vranizan K, Farquhar J and Wood P**. Assessment of habitual physical activity by a seven-day recall in a community survey and controlled experiments. *American Journal of Epidemiology* 122: 794-804, 1985.

31. **Blank R**. Breaking down bone strength: A perspective on the future of skeletal genetics. *Journal of Bone and Mineral Research* 16: 1207-1211, 2001.

32. **Bohannon AD**. Osteoporosis and African American women. *Journal of Women's Health and Gender Based Medicine* 8: 609-615, 1999.

33. **Bonjour JP, Carrie AL, Ferrari S, Clavien H, Slosman D, Theintz G and Rizzoli R**. Calcium enriched foods and bone mass growth in prepubertal girls: a randomized, double-blind, placebo-controlled trial. *Journal of Clinical Investigation* 99: 1287-1294, 1997.

34. **Bonjour JP, Chevalley T, Ammann P and Rizzoli R**. Gain in bone mineral mass in prepubertal girls 3-5 years after discontinuation of calcium supplementation: a follow up study. *The Lancet* 358: 1208-1212, 2001.

35. **Boot AM, De Ridder MAJ, Pols HAP, Krenning EP and de Muinck Keizer-Schrama SMPF**. Bone mineral density in children and adolescents: relation to puberty, calcium intake, and physical activity. *Journal of Clinical Endocrinology and Metabolism* 82: 57-62, 1997.

36. **Booth M, Okely A, Chey T and Bauman A.** The reliability and validity of the physical activity questions in the WHO Health Behaviour in Schoolchildren (HBSC) Survey: A population study. *British Journal of Sports Medicine* 35: 263-267, 2001.

37. **Booth ML**. Assessment of physical activity: An international perspective. *Research Quarterly Exercise and Sport* 71: 114-120, 2000.

38. **Booth ML, Okely AD, Chey T and Bauman A**. The reliability and validity of the adolescent physical activity recall questionnaire. *Medicine and Science in Sports and Exercise* 34: 1986-1995, 2002.

39. **Boreham CA, Twisk J, Savage MJ, Cran GW and Strain J**. Physical activity, sports participation, and risk factors in adolescents. *Medicine and Science in Sports and Exercise* 29: 788-793, 1997.

40. **Bourchard C, Shepard R, Stephans T, Sutton J and McPherson B**. *Exercise, Fitness and Health*. Toronto: Human Kinetics Books, 1990.

41. **Bourchard C and Shepard RJ**. Physical activity, fitness and health: the model and key concepts. In: Physical activity, fitness and health. International Proceedings and Consensus Statement, edited by Bourchard C, Shepard RJ and Stephans T. Champaign, IL: Human Kinetics, 1994, p. 77-88.

42. **Bourne LT, Lambert EV and Steyn K**. Where does the Black population of South Africa stand on the nutrition transition? *Public Health Nutrition* 5: 157-162, 2006.

43. **Bradney M, Pearce G, Naughton G, Sullivan C, Bass S, Beck T, Carlson J and Seeman E**. Moderate exercise during growth in pubertal boys: Changes in bone mass, volumetric density, and bone strength: A controlled prospective study. *Journal of Bone and Mineral Research* 13: 1814-1821, 1998.

44. **Bradshaw D and Steyn K**. Poverty and Chronic Disease in South Africa. 2001. South Africa, Medical Research Council.

45. **Buchhelt M, Platat C, Oujaa M and Simon C**. Habitual physical activity, physical fitness and heart rate variability in preadolescents. *International Journal of Sport Medicine* 28: 204-210, 2007.

46. **Burr D**. Muscle strength, bone mass, and age-related bone loss. *Journal of Bone and Mineral Research* 12: 1547-1551, 1997.

47. **Cadogan J, Eastell R, Jones N and Barker ME.** Milk intake and bone mineral acquisition in adolescent girls: randomised, controlled intervention trial. *British Medical Journal* 315: 1255-1260, 1997.

48. **Cadogen J, Blumsohn A, Barker M and Eastell R**. A longitudinal study of bone gain in pubertal girls: Anthropometric and biochemical correlates. *Journal of Bone and Mineral Research* 13: 1602-1612, 1998.

49. **Cameron N, Pettifor JM, de Wet T and Norris SA**. The relationship of rapid weight gain in infancy to obesity and skeletal maturity in childhood. *Obesity Research* 11: 457-460, 2007.

50. **Canalis E, Pash J, Gabbitas B, Rydziel S and Varghese S**. Growth factors regulate the synthesis of insulin-like growth factor-I in bone cell cultures. *Endocrinology* 133: 33-38, 1993.

51. **Caspersen C, Pereira R and Curran K**. Changes in physical activity patterns in the United States, by sex and cross-sectional age. *Medicine and Science in Sports and Exercise* 32: 1601-1609, 2000.

52. **Caspersen C, Powell KE and Christensson GM**. Physical activity, exercise and physical fitness. Definitions and distinctions for health related research. *Public Health Reports* 100: 126-131, 1985.

53. **Chen KY and Bassett DR Jr**. The technology of acceleromoter-based activity monitors: Current and future. *Medicine and Science in Sports and Exercise* 37: S490-S500, 2005.

54. **Choi SC and Trotter M**. A statistical study of the mulitvariate structure and race-sex differences of American White and Negro fetal skeletons. *American Journal of Physical Anthropology* 33: 312, 1970.

55. **Coakley J and White A**. Making decisions: Gender and sport particpation among British adolescents. *Sociology of Sport Journal* 9: 20-35, 1992.

56. **Conway J, Seale J, Jacobs D, Irwin M and Ainsworth B**. Comparison of energy expenditure estimates from doubly labeled water, a physical activity questionnaire, and physical activity records. *American Journal of Clinical Nutrition* 75: 519-525, 2002.

57. **Cooper C, Cawley M, Bhalla A, Egger P, Ring F, Morton L and Barker D**. Childhood growth, physical activity, and Peak Bone Mass in women. *Journal of Bone and Mineral Research* 10: 940-947, 1995.

58. **Cooper C, Westlake S, Harbey N, Javaid MK, Dennison E and Hanson M**. Review: developmental origins of osteoporotic fracture. *Osteoporosis International* 17: 337-347, 2006.

59. **Council of Europe (Committee for the Development of Sport)**. The EUROFIT tests of Physical Fitness. Izmir, 26-30 June 1990. VIth European Research Seminar. 1992. Strasbourg.

60. **Courteix D, Lespessailles E, Peres SL, Obert P, Germain P and Benhamou CL**. Effect of physical training on bone mineral density in prepubertal girls:A comparative study between impact-loading and non-impact loading sports. *Osteoporosis International* 8: 152-158, 1998.

61. **Cowell CT and Tao C**. Nature or nurture: determinants of peak bone mass in females. *Journal of Peadiatric Endocrinology and Metabolism* 15 Suppl 5:1387-93.: 1387-1393, 2002.

62. **Craig CL, Marshall AL, Sjöström M, Bauman AE, Booth ML, Ainsworth BE, Pratt M, Ekelund U, Yngve A, Sallis JF and Oja P**. International physical activity questionnaire: 12- Country reliability and validity. *Medicine and Science in Sports and Exercise* 35: 1381-1395, 2003.

63. **Crouter SE, Churilla JR and Bassett Jr DR**. Estimating energy expenditure using accelerometers. *European Journal of Applied Physiology* 98: 601-612, 2006.

64. **Daniels ED, Pettifor JM, Schnitzler CM, Moodley GP and Zachen D**. Differences in mineral homeostasis, volumetric bone mass and femoral neck axis length in Black and White South African females. *Journal of Bone and Mineral Research* 13: 359-367, 1995.

65. **Davies JH, Evans BA and Gregory JW**. Bone mass acquisition in healthy children. *Archives of Disease in Childhood* 90: 373-378, 2005.

66. **De Courten M**. Developing a simple global physical activity questionnaire for population studies. *Australas Epidemiology* 9: 6-9, 2002.

67. **DeLany JP, Bray GA, Harsha DW and Volaufova J**. Energy Expenditure in Preadolescent African American and White Boys: the Baton Rouge Children's Study. *American Journal of Clinical Nutrition* 75: 705-713, 2002.

68. **Dodd JS, Raleigh JA and Gross TS**. Osteocyte hypoxia: a novel mechanotransducation pathway. *American Journal of Physiology* 277: C598-C602, 1999.

69. **Ducher G and Bass SL**. Exercise during growth: Compelling evidence for the primary prevention of osteoporosis? *BoneKEy* 4: 171-180, 2007.

70. **Düppe H, Gärdsell P, Johnell O, Nilsson BE and Ringsberg K**. Bone mineral density, muscle strength and physical activity. *Acta Orthopaedica Scandinavica* 68: 97-103, 1997.

71. **Elrick H, Samara TT and Demas A**. Missing links in the obesity epidemic. *Nutrition Research* 22: 1101-1123, 2002.

72. **Ernst E**. Exercise for female osteoporosis. In: Exercise for Health, edited by Shanahan J. Hong Kong: Adis International, 2000, p. 99-108.

73. **Eyberg C, Pettifor JM and Moodley G**. Dietary calcium intake in rural black South African children: the relationship between calcium intake and calcium nutritional status. *Human Nutrition Clinical Nutrition* 40C: 69-74, 1986.

74. **Faulkner RA, Bailey DA, Drinkwater DT, McKay HA, Arnold C and Wilkinson AA**. Bone densitometry in Canadian children 8-17 years of Age. *Calcif Tissue Int* 59: 344-351, 1996.

75. **Fehily A, Coles R, Evans W and Elwood P**. Factors affecting bone density in young adults. *American Journal of Clinical Nutrition* 56: 579-586, 1992.

76. **Ferretti JL, Capozza RF, Cointry GR, Garcia SL, Plotkin H, Alvarez Filgueira ML and Zanchetta JR**. Gender-related differences in the relationship between densitometric values of whole-body bone mineral content and lean body mass in humans between 2 and 87 years of age. *Bone* 22: 683-690, 1998.

77. **Florentino R, Villavieja G and Lana R**. Dietary and physical activity patterns of 8-10-year-old urban school children in Manila, Phillipines. *Food Nutrition Bulletin* 23: 267-273, 2003.

78. **Fogelhelm M, Hilloskorpi H, Laukkanen R, Oja P, Van Marken Lichtenbelt W and Westerterp KR**. Assessment of energy expenditure in overweight women. *Medicine and Science in Sports and Exercise* 30: 1191-1197, 1998.

79. **Fonn S, de Beer M and Kgamphe J**. Birth to ten: Pilot Studies to test the feasibility of a birth cohort study investigating effects of urbanisation in South Africa. *South African Medical Journal* 79: 449-454, 1991.

80. **Forwood M**. Physiology. In: Physical activity and bone health, edited by Robertson LD. Champaign, IL: Human Kinetics, 1999, p. 11-21.

81. **Forwood MR**. Mechanical effects on the skeleton: Are there clinical implications? *Osteoporosis International* -77, 2001.

82. **Forwood MR, Bailey DA, Beck TJ, Mirwald RL, Baxter-Jones AD and Uusi-Rasi K**. Sexual dimorphsim of the femoral neck during the adolescent growth spurt: a structural analysis. *Bone* 35: 973-981, 2004.

83. **Forwood MR, Baxter-Jones AD, Beck TJ, Mirwald RL, Howard A and Bailey DA**. Physical activity and strength of the femoral neck during the adolescent growth spurt: A longitudinal analysis. *Bone* 38: 576-583, 2006.

84. **Freedson P and Evenson S**. Familial aggregation in physical activity. *Research Quartely for Exercise and Sport* 62: 384-389, 1991.

85. **Freedson P, Pober D and Janz KF**. Calibration of acclerometer output for children. *Medicine and Science in Sports and Exercise* 37: S523-S530, 2005.

86. **Freedson PS, Cureton KJ and Heath GW**. Status of field-based fitness testing in children and youth. *Preventative Medicine* 31: S77-S85, 2000.

87. **French SA, Fulkerson JA and Story M**. Increasing weight-bearing physical activity and calcium intake for bone mass in children and adolescents: A review of intervention trials. *Preventative Medicine* 31: 722-731, 2000.

88. **Frost HM**. The mechanostat: A proposed pathogenic mechanism of osteoporosis and the bone mass effects of mechanical and nonmechanical agents. *Bone and Mineral* 2: 73-86, 1987.

89. **Frost HM**. Bone development during childhood: insights from a new paradigm. In: Pediatric Osteology, edited by Schoenau E. Amsterdam: Elsevier Science, 1996, p. 3-39.

90. **Fuchs R, Bauer J and Snow C**. Jumping improves hip and lumbar spine bone mass in prepubescent children: A randomixed controlled trial. *Journal of Bone and Mineral Research* 16: 148-156, 2001.

91. **Fuchs RK and Snow CM**. Gains in hip bone mass from high-impact training are maintained: a randomized controlled trial in children. *Journal of Pediatrics* 141: 357-362, 2002.

92. **Fujimara R, Ashizawa N, Watanabe M, Mukai N, Amagai H, Fukubayashi T, Hayashi K, Tokuyama K and Suzuki M**. Effect of resistance exercise training on bone formation and resorption in young male subjects assessed by biomarkers of bone metabolism. *Journal of Bone and Mineral Research* 12: 656-662, 1997.

93. **Fulkerson JA, Himes JHI, French SA, Jensen S, Petit MA, Stewart C, Story M, Ensrud K, Fillhouer S and Jacobsen K**. Bone outcomes and technical measurement issues of bone health among children and adolescents: Considerations for nutrition and physical activity intervention trials. *Osteoporosis International* 15: 929-941, 2004.

94. **Genant HK, Feurst T, Faulkner KG and Gluer CC**. In evaluating bone density for osteoporosis, are any of the available methods clearly superior? *AJR American Journal of Roentgenology* 167: 1589-1590, 1996.

95. **Gertner JM**. Childhood and adolescence. In: Primer on the metabolic bone diseases and disorders of mineral metabolism, edited by Favus MJ. Philadelphia: Lippincoot Williams & Williams, 1999, p. 45-49.

96. **Gibson J, Harries M, Mitchell A, Godfrey R, Lunt M and Reeve J**. Determinants of bone density and prevalance of osteopenia among female runners in their second to seventh decades of age. *Bone* 26: 591-598, 2000.

97. **Gilsanz V, Kovanlikaya A, Costin G, Roe T, Sayre J and Kaufman F**. Differential effect of gender on the sizes of the bones in the axial and appendicular skeletons. *Journal of Endocrinology and Metabolism* 82: 1603-1607, 1997.

98. **Gilsanz V, Roe TF, Mora S, Costin G and Goodman WG**. Changes in vertebral bone density in Black girls and White girls during childhood and puberty. *New England Journal of Medicine* 325: 1597-1600, 1991.

99. **Gilsanz V, Skaggs D, Kovanlikaya A, Sayre J, Luiza Loro M, Kaufman F and Korenman S**. Differential effect of race on the axial and appendicular skeletons of children. *Journal of Clinical Endocrinology and Metabolism* 83: 1420-1427, 1998.

100. **Ginty F, Rennie KL, Mills L, Stear S, Jones S and Prentice A**. Positive site-specific associations between bone mineral status, fitness and time spent at high-impact activites in 16-to 18-year-old boys. *Bone* 36: 101-110, 2005.

101. **Gorden-Larsen P, Adair L and Popkin B**. Ethnic differences in physical activity and inactivity patterns and overweight status. *Obesity Research* 10: 141-149, 2002.

102. **Gorden-Larsen P, McMurray RG and Popkin BM**. Adolescent physical activity and inactivity vary by ethnicity: The National Longitudinal Study of Adolescent Health. *Journal of Pediatrics* 135: 301-306, 1999.

103. **Groothausen J, Siemer H, Kemper H, Twisk J and Welten D**. Influence of peak strain on lumbar bone mineral density: An analysis of 15-Year physical activity in young males and females. *Pediatric Exercise Science* 9: 159-173, 1997.

104. **Gueguen R, Jouanny P, Guillemin F, Kuntz C, Pourel J and Siest G**. Segregation analysis and variance components analysis of bone mineral density in healthy families. *Journal of Bone and Mineral Research* 10: 2017-2022, 1995.

105. **Gunnes M**. Physical activity, dietary calcium and poly-unsaturated fat as predictors of forearm bone mineral density accumulation in healthy children and adolescents: A longitudinal study. *Bone* 18: 109, 1996.

106. **Haapasalo H, Kannus P, Sievänen H, Heinonen A, Oja P and Vuori I**. Long-term unilateral loading and bone mineral densiy and content in squash players. *Calcified Tissue International* 54: 249-255, 1994.

107. **Haapasalo H, Kannus P, Sievänen H, Pasanen M, Uusi-Rasi K, Heinonen A, Oja P and Vuori I**. Effect of long-term unilateral activity on bone mineral density of female junior tennis players. *Journal of Bone and Mineral Research* 13: 310-319, 1998.

108. **Haapasalo H, Kontulainen S, Sievänen H, Kannus P and Vuori I**. Exercise-induced bone gain is due to enlargement in bone size without a change in volumetric bone density: A peripheral Quantitative Computed Tomography study of the upper arms of male tennis players. *Bone* 27: 351-357, 2000.

109. **Hagberg JM, Hickson RC, Ehsani AA and Holloszy JO**. Faster adjustment to and recovery from submaximal exercise in the trained state. *Journal of Applied Physiology* 48: 218-224, 1980.

110. **Heaney RP**. The bone-remodeling transient: implications for the interpretation of clinical studies of bone mass change. *Journal of Bone and Mineral Research* 9: 1515-1523, 1994.

111. **Heaney RP**. The bone remodeling transient: interpreting interventions involving bone-related nutrients. *Nutrition Reviews* 59: 327-334, 2001.

112. **Heaney RP**. Design considerations for clinical investigations of osteoporosis. In: Osteoporosis, edited by Marcus R, Feldman D, Nelson D and Rosen C. San Diego: Elsevier Inc., 2007.

113. **Heaney RP, Abrams S, Dawson-Hughes B, Looker A, Marcus R, Matkovic V and Weaver C**. Peak Bone Mass. *Osteoporosis International* 11: 985-1009, 2000.

114. **Heath G, Pratt M, Warren C and Kann L**. Physical activity patterns in American high school students. *Archives of Pediatric and Adolescent Medicine* 148: 1131-1136, 1994.

115. **Heil DP**. Predicting activity energy expenditure using the Actical activity monitor. *Research Quartely Exercise and Sport* 77: 64-80, 2006.

116. **Heinonen A, Sievänen H, Kannus P, Oja P, Pasanen M and Vuori I**. High-impact exercise and bones of growing girls: A 9-month controlled trial. *Osteoporosis International* 11: 1010-1117, 2001.

117. **Hind K and Burrows M**. Weight-bearing exercise and bone mineral accrual in children and adolescents: A review of controlled trials. *Bone* 40: 14-27, 2007.

118. **Ho CP, Kim RW, Schaffler MB and Sartoris DJ**. Accuarcy of dual energy radiographic absorptiometry of the lumbar spine: Cadaver Study. *Radiology* 176: 173, 1990.

119. **HyakutakeS, Goto S, Yamagata M and Moriya H**. Relationship between bone mineral density of the proximal femur and lumbar spine and quadriceps and hamstrings torque in healthy Japanese subjects. *Calcified Tissue International* 55: 223-229, 1994.

120. **Illich-Ernst J, Brownbill RA, Ludemann MA and Fu R.** Critical factors for bone health in women Across the age span: How important is muscle mass? *Medscape Women's Health eJournal* 7: 1-15, 2002.

121. **Iuliano-Burns S, Saxon L, Naughton G, Gibbons K and Bass S**. Regional specificity of exercise and calcium during skeletal growth in girls: A randomized controlled trial. *Journal of Bone and Mineral Research* 18: 156-162, 2003.

122. **Iwamoto J, Shimamura C, Takeda T, Abe H, Ichimura S, Sato Y and Toyama Y**. Effects of treadmill exercise on bone mass, bone metabolism, and calciotropic hormones in young growing rats. *Journal of Bone and Mineral Metabolism* 22: 26-31, 2004.

123. **Jackman LA, Millane SS, Martin BR, Wood OB, McCabe GP, Peacock M and Weaver CM**. Calcium retention in relation to calcium intake and postmenarchal age in adolescent females. *American Journal of Clinical Nutrition* 66: 327-333, 2007.

124. **Jacobs DR, Ainsworth BE, Hartman TK and Leon AS**. A simultaneous evaluation of 10 commonly used physical activity questionnaires. *Medicine and Science in Sports and Exercise* 25: 81-91, 1993.

125. **Janz KF, Burns TC, Torner JC, Levy SM, Paulos R, Wiling MC and Warren JJ**. Physical activity and bone measures in young children: The Iowa Bone Development Study. *Pediatrics* 107: 1387-1393, 2001.

126. **Janz KF, Gilmore JM, Burns TL, Levy SM, Torner JC, Willing MC and Marshall TA**. Physical activity augments bone mineral accrual in young children: The IOWA bone development study. *Journal of Pediatrics* 148: 793-799, 2006.

127. **Johannsen N, Binkley T, Englert V, Neiderauer G and Specker B**. Bone response to jumping is site-specific in children: A randomized trial. *Bone* 33: 533-539, 2003.

128. **Jones G and Dwyer T**. Bone mass in prepubertal children: Gender differences and the role of physical activity and sunlight exposure. *The Journal of Clinical Endocrinology and Metabolism* 83: 4274-4279, 1998.

129. **Juul A, Bang P, Hertel NT, Main K, Dalgaard P, Jorgensen K, Muller J, Hall K and Skakkebaek NE**. Serum insulin-like growth factor-I in 1030 healthy children, adolescents, and adults: relation to age, sex, stage of puberty, testicular size, and body mass index. *Journal of Clinical Endocrinology and Metabolism* 78: 744-752, 1994.

130. **Kallman D, Plato C and Tobin J**. The role of muscle loss in the age-related decline of grip strength: Cross-sectional and longitudinal perspectives. *Journal of Gerentology* 45: M82-M88, 1990.

131. **Kalu D, Banu J and Wand L**. How cancellous and cortical bones adapt to loading and growth hormone. *Journal of Musculoskeletal and Neuron Interaction* 1: 19-23, 2000.

132. **Kannus P, Haapasalo H, Sankelo M, Sievänen H, Pasanen M, Heinonen A, Oja P. and Vuori I**. Effect of starting age of physical activity on bone mass in the dominant arm of tennis and squash players. *Annals of Internal Medicine* 123: 27-31, 1995.

133. **Katzman DK, Bachrach LK, Carter DR and Marcus R**. Clinical and anthropometric correlates of bone mineral aquisition in healthy adolescent girls. *Journal of Clinical Endocrinology and Metabolism* 73: 1332-1339, 1991.

134. **Kemper H, Bakker I, Twisk J and Van Mechelen W**. Validation of a physical activity questionnaire to measure the effect of mechanical strain on bone mass. *Bone* 30: 799-804, 2002.

135. **Kemper H, Twisk J, Van Mechelen W, Post G, Roos J and Lips P**. A fifteen-year longitudunal study in young adults on the relation of physical activity and fitness with the development of the bone mass: The Amsterdam Growth and Health Longitudinal Study. *Bone* 27: 847-853, 2000.

136. **Kemper HCG**. Skeletal development during childhood and adolescence and the effects of physical activity. *Pediatric Exercise Science* 12: 216, 2000.

137. **Khan K, McKay H, Kannus P, Bailey D, Wark J and Bennel K**. *Physical activity and bone health*. Champaign, IL: Human Kinetics, 2001.

138. **Khan K, McKay HA, Kannus P, Bailey D, Wark J, Bennel K and Heinonen A**. Biomechanics. In: Physical activity and bone health, United States of America: Human Kinetics, 2001, p. 23-34.

139. **Khan KM, Bennel KL, Hopper JL, Flicker L, Nowson CA, Sherwin AJ, Crichton KJ, Harcourt PR and Wark JD**. Self-Reported ballet classes undertaken at age 10-12 years and hip bone mineral density in later life. *Osteoporosis International* 8: 165-173, 1998.

140. **Kiratli B**. Skeletal changes with disuse. *American Journal of Physical Anthropology* 78: 253, 1988.

141. **Kontulainen SA, Kannus PA, Haapasalo H, Sievänen HT, Pasanen M, Heinonen A, Oja P and Vuori I**. Good maintenance of exercise-induced bone gain with decreased training of female tennis and squash players: A prospective 5-year follow-up study of young and old starters and controls. *Journal of Bone and Mineral Research* 16: 195-201, 2001.

142. **Kontulainen SA, Sievänen HT, Kannus PA, Pasanen ME and Vuori I**. Effect of long-term impact-loading on mass, size, and estimated strength of humerus and radius of female racquet-sports players: A peripheral Quantitative Computed Tomography study between young and old starters and controls. *Journal of Bone and Mineral Research* 18: 352-359, 2003.

143. **Krassas G, Tzotzas T, Tsametis C and Konstantinidis T**. Determinants of Body mass Index in Greek children and adolescents. *Journal of Pediatric Endocrinology and Metabolism* 14: 1327-1333, 2001.

144. **Kristjansdottir G and Vilhjamlmsson R.** Sociodemographic differences in patterns of sedentary and physically active behaviour in older children and adolescents. *Acta Paediatrica Scandinavia* 90: 429-435, 2001.

145. **Kroger H, Kotaniemi A, Kroger L and Alhava E**. Development of bone mass and bone density of the spine and femoral neck: a prospective study of 65 children and adolescents. *Bone and Mineral* 23: 171-182, 1993.

146. **Kroger H, Kotaniemi A, Vainio P and Alhava E**. Bone densitometry of the spine and femur in children by dual-energy x-ray absorptiometry. *Bone Miner* 17: 75-85, 1992.

147. **Kruger HS, Venter CS, Vorster HH and Margetts BM**. Physical inactivity is the major determinant of obesity in Black women in the North West Province, South Africa: The THUSA Study. Transition and Health during Urbanisation in South Africa. *Nutrition* 18: 422-427, 2002.

148. **Ku CY, Gower BA, Hunter GR and Goran MI**. Racial differences in Insulin secretion and sensitivity in prepubertal children: Role of physical fitness and physical activity. *Obesity Research* 8: 506-515, 2000.

149. **Kuh DJ and Cooper C**. Physical activity at 36 years: Patterns and childhood predictors in a longitudinal study. *Journal of Epidemiology and Community Health* 46: 114-119, 1992.

150. **Labadarios D, Steyn NP, Maunder E, MacIntrye U, Gericke G, Swart R, Huskisson J, Danhauser A, Vorster HH, Nesvuni AE and Nel JH**. The national food consumption survey (NFCS): South Africa, 1999. *Public Health Nutrition* 8: 533-543, 2005.

151. **Lamb K and Brodie D**. Leisure time physical activity as an estimate of physical fitness: A validation study. *Journal of Clinical Epidemiology* 44: 41-52, 1991.

152. **Lang TF, Kayak JH, Heitz MW, Augat P, Lu Y., Mathur A and Genant HK**. Volumetric quantitative computed tomography of the proximal femur: precision and relation to bone strength. *Bone* 21: 101-108, 1997.

153. **Lanou AJ**. Bone health in children. *British Medical Journal* 333: 764, 2006.

154. **Lanyon LE**. Control of bone architecture by functional load bearing. *Journal of Bone and Mineral Research* 7 Suppl 2:S369-75.: S369-S375, 1992.

155. **Lanyon LE**. Using functional loading to influence bone mass and architecture: objectives, mechanisms, and relationship with estrogen of the mechanically adaptive process in bone. *Bone* 18: 37S-43S, 1996.

156. **Lehtonen-Veromaa M, Möttönen T, Irjala K, Nuotio I, Leino A and Viikari J**. A 1-year prospective study on the relationship between physical activity, markers of bone metabolism, and bone acquisition in prepubertal girls. *The Journal of Clinical Endocrinology and Metabolism* 85: 3726-3732, 2000.

157. **Leyk D, Rohde U, Riddler D, Wunderlich M, Dinklage C, Sievert A, Rüther T and Essfeld D**. Physical performance, body weight and BMI of young adults in Germany 2000-2004; Results of the Physical-Fitness-Test Study. *International Journal of Sport Medicine* 27: 642-647, 2006.

158. **Lian JB, Stein GS, Canalis E, Robey PG and Boskey AL**. Bone formation: Osteoblast lineage cells, growth factors, matrix proteins, and the mineralization process. In: Primer on the metabolic bone diseases and disorders of mineral metabolism, edited by Favus MJ. Philadelphia: Lippincott Williams & Williams, 1999, p. 14-29.

159. **Lilley J, Walters BG, Heath DA and Drolc Z**. In vivo and in vitro precision of bone densitometry measured by dual-energy x-ray absorption. *Osteoporosis International* 1: 141-146, 2006.

160. **Lloyd T, Andon MB and Rollings N**. Calcium supplementation and bone mineral density in adolescent girls. *American Journal of Clinical Nutrition* 60: 750, 1994.

161. **Lloyd T, Petit MA, Lin HM and Beck TJ**. Lifestyle factors and the development of bone mass and bone strength in young women. *Journal of Pediatrics* 144: 776-782, 2004.

162. **Lohman T, Going S, Pameneter R, Hall M, Boyden T, Houtkooper L, Ritenbaugh C, Bare L, Hill A and Aickin M**. Effects of resistance training on regional and total bone mineral density in premenopausal women: A randomized prospective study. *Journal of Bone Mineral Reserve* 10: 1015-1024, 1995.

163. **Looker AC**. The skeleton, race and ethnicity. *Journal of Clinical Endocrinology and Metabolism* 87: 3047-3050, 2002.

164. **Luke A, Durazo-Arcizu RA, Rotimi CN, Iams H, Schoeller DA, Adeyemo AA, Forrester TE., Wilks R and Cooper RS**. Activity energy expenditure and adiposity among Black adults in Nigeria and United States. *American Journal of Clinical Nutrition* 75: 1045-1050, 2002.

165. **Mackelvie KJ, Khan KH and McKay HA**. Is there a critical period for bone response to weight bearing exercise in children and adolescents? A systematic review. *British Journal of Sports Medicine* 36: 357, 2002.

166. **Mackelvie KJ, Khan KM, Petit MA, Janssen PA and McKay HA**. A school-based exercise intervention elicits substantial bone health benefits: A 2-year randomized controlled trial in girls. *Pediatrics* 112: 447-452, 2003.

167. **Mackelvie KJ, McKay HA, Petit M, Moran O and Khan KM**. Bone mineral response to a 7-month randomized controlled, school-based jumping intervention in 121 prepubertal boys: Associations with ethnicity and Body Mass Index. *Journal of Bone and Mineral Research* 17: 834-844, 2002.

168. **Mackelvie KJ, Petit MA, Khan KM, Beck TJ and McKay HA**. Bone mass and structure are enhanced following a 2-year randomized controlled trial of exercise in prepubertal boys. *Bone* 34: 755-764, 2004.

169. **Mackeown JM, Cleaton-Jones PE, Edwards AW and Turgeon-O'Brien H**. Energy, macro- and micronutrient intake of 5-year-old urban black South African children in 1984 and 1995. *Peadiatric and Perinatal Epidemiology* 12: 297-312, 1998.

170. **Malina RM, Brown KH and Zalaveta AN**. Relative lower extremity length in Mexican Americans and in American Black and White youth. *American Journal of Physical Anthropology* 72: 89-94, 1987.

171. **Martinex-Gonzalez M, Martinez J, Hu F, Gibney M and Kearney J**. Physical Inactivity, Sedenatary Lifestyle and Obesity in the European Union. *International Journal of Obesity Related Metabolic Disorders* 23: 1192-1201, 1999.

172. **Matkovic V and Heaney RP**. Calcium balance during human growth: evidence for threshold behaviour. *American Journal of Clinical Nutrition* 84: 1319-1322, 1994.

173. **Matkovic V, Jelic T, Wardlaw G, Ilich J, Goel P, Wright J, Andon M, Smith K and Heaney R**. Timing of peak bone mass in Caucasian females and its implication for the prevention of osteoporosis. *Journal of Clinical Investigation* 93: 799-808, 1994.

174. **Maynard L, Guo S, Chumlea W, Roche A, Wisemandle W, Zeller C, Towne B and Siervogel R**. Total body and regional bone mineral content and areal bone mineral density in children aged 8-18 Years: The Fels Longitudinal Study. *American Journal of Clinical Nutrition* 68: 1111-1117, 1998.

175. **Mazess R, Chestnut III CH, McClung M and Genant H**. Enhanced precision with dual energy x-ray absortiometry. *Calcified Tissue International* 51: 14-17, 1992.

176. **McKay HA, MacDonald H, Reed K and Khan KH**. Exercise interventions for health: Time to focus on dimensions, delivery, and dollars. *British Journal of Sports Medicine* 37: 98-99, 2003.

177. **McKay HA, MacLean L, Petit M, MacKelvie-O'Brien K, Janssen P, Beck T and Khan KM**. "Bounce at the Bell": a novel program of short bouts of exercise improves proximal femur bone mass in early pubertal children. *British Journal of Sports Medicine* 39: 521-526, 2005.

178. **McKay HA, Petit MA, Khan KM and Schutz RW**. Lifestyle determinants of bone mineral: A comparison between prepubertal Asian and Caucasian Canadian Boys and Girls. *Calcified Tissue International* 66: 320-324, 2000.

179. **McMurray RG, Ring KB, Treuth MS, Welk GJ, Pate RR, Schmit KH, Pickrel JL, Gonzalez V, Almedia MJ, Young DR and Sallis JF**. Comparison of two approaches to structured physical activity surveys for adolescents. *Medicine and Science in Sports and Exercise* 36: 2135-2143, 2004.

180. **McNeill LH, Kreuter MW and Subramanian SV**. Social environment and physical activity: A review of concepts and evidence. *Social Science & Medicine* 63: 1011-1022, 2006.

181. **McVeigh JA, Norris S and Pettifor JM**. Bone mass accretion rates in pre- and early pubertal South African black and white children in relation to habitual physical activity and dietary calcium intakes. *Acta Paediatrica* 96: 874-880, 2007.

182. **McVeigh JA, Norris SA, Cameron N and Pettifor JM**. Associations between physical activity and bone mass in black and white South African children at age 9 yr. *Journal of Applied Physiology* 97: 1006-1012, 2004.

183. **McVeigh JA, Norris SA and de Wet T**. The relationship between socio-economic status and physical activity patterns in South African children. *Acta Paediatrica* 93: 982-988, 2004.

184. **Melton III L, Marquez M, Achenbach S, Tefferi A, O'Conner M, O'Fallon W and Riggs B.** Variations in bone density among persons of African heritage. *Osteoporosis International* 13: 551-559, 2002.

185. **Memon A, Pospula WM, Tantawy AY, Abdul-Ghafar S, Suresh A and Al-Rowith A**. Incidence of hip fracture in Kuwait. *International Journal of Epidemiology* 27: 860-865, 1998.

186. **Micklesfield L, Rosenberg L, Cooper D, Hoffman M, Kalla A and Lambert E**. Bone mineral density and lifetime physical activity in South African women. *Calcified Tissue International* 73: 463-469, 2003.

187. **Micklesfield LK, Norris SA, Nelson DA, Lambert EV, van der Merwe L, and Pettifor JM**. Comparisons of Body Size, Composition and Whole Body Bone Mass Between North American and South African Children. Journal of Bone and Mineral Research . 2007.

188. **Micklesfield LK, Zielonka EA, Charlton KE, Katzenellenbogen L, Harkins J and Lambert EV**. Ultrasound bone measurements in pre-adolescent girls: interaction between ethnicity and lifestyle factors. *Acta Paediatrica* 93: 752-758, 2004.

189. **Moore L, Lombardi D, White M, Campell J, Olshan A and Ellison R**. Influence of parents physical activity levels on activity levels of young children. *Pediatrics* 118: 215-219, 1991.

190. **Mora S, Pitukcheewanont P, Nelson JC and Gilsanz V**. Serum levels of insulin-like growth factor I and the density, volume, and cross-sectional area of cortical bone in children. *Journal of Clinical Endocrinology and Metabolism* 84: 2780-2783, 1999.

191. **Morris F, Naughton G, Gibbs J, Carlson J and Wark J**. Prospective ten-month intervention in premenarchal girls: Effects on bone and lean mass. *Journal of Bone and Mineral Research* 12: 1453-1462, 1997.

192. **Mosekilde L, Ebbesen E, Tornvig L and Thomsen J.** Trabecular bone structure and strength-remodelling and repair. *Journal of Musculoskeletal and Neuron Interaction* 1: 25-30, 2000.

193. **Mota J and Silva G**. Adolescents physical activity: Association with Socio-Economic Status and parental participation among a portuguese sample. *Sport, Education and Society* 4: 193-199, 1999.

194. **Nelson DA, Simpson PM, Johnson CC, Barondess DA and Kleerekoper M**. The accumulation of whole body skeletal mass in third- and fourth-grade children: effects of age, gender, ethnicity, and body composition. *Bone* 20: 73-78, 1997.

195. **Neu C, Manz F, Rauch F, Merkel A and Schoenau E**. Bone densities and bone size at the distal radius in healthy children and adolescents: A study using peripheral Quantitive Computed Tomography. *Bone* 28: 227-232, 2001.

196. **Neville CE, Murray L, Boreham C, Gallagher A, Twisk J, Robson P, Savage J, Kemper H, Ralston S and Davey Smith G**. Relationship between physical activiy and bone mineral status inyoung adults: The Northern Ireland young hearts project. *Bone* 30: 792-798, 2002.

197. **Nguyen T, Maynard L, Towne B, Roche A, Wisemandle W, Li J, Guo S, Chumlea C and Siervogel R**. Sex differences in bone mass acquisition during growth. *Journal of Clinical Densitometry* 4: 147-157, 2001.

198. **Niehoff A, Kersting UG, Zaucke F, Morlock MM and Bruggemann GP**. Adaptation of mechanical, morphological, and biochemical properties of the rat growth plate to dose-dependent voluntary exercise. *Bone* 35: 899-908, 2004.

199. **Nordström P, Nordström K, Thorsen K and Lorentzon R**. Local bone mineral density, muscle strength, and exercise in adolescent boys: A comparitive study of two groups with different muscle strength and exercise levels. *Calcified Tissue International* 58: 402-408, 1996.

200. **Norris SA and Pettifor JM**. Birth to ten: new research initiative investigating factors influencing bone health in black and white children in South Africa. *South African Journal of Epidemiology and Infection* 15: 113-117, 2000.

201. **Norris SA and Richter LM**. Usefulness and reliabilty of Tanner pubertal self-rating to urban black adolescents in South Africa. *Journal of Research on Adolesence* 15: 609-624, 2006.

202. **Nyathi LH, Norris SA, Cameron N and Pettifor JM**. Effect of ethnicity and sex on the growth of the axial and appendicular skeleton of children living in a developing country. *American Journal of Physical Anthropology* 131: 135-141, 2006.

203. **Padayachee V**. The South African economy. *Social Research* 72: 549-580, 2005.

204. **Paffenbarger RS, WIng AL and Hyde RT**. Physical activity as an index of heart attack risk in college alumni. *American Journal of Epidemiology* 108: 161-175, 1978.

205. **Parks S, Housemann R and Brownson R**. Differential correlates of physical activity in urban and rural adults of various socioeconomic backgrounds in the United States. *Journal of Epidemiology and Community Health* 57: 29-35, 2003.

206. **Pate RR, Heath GW, Dowda M and Trost SG**. Associations between physical activity and other health behaviours in a representative sample of US adolescents. *American Journal of Public Health* 86: 1577-1581, 1996.

207. **Patel DN, Pettifor JM and Becker PJ**. The effect of ethnicity on appendicular bone mass in White, Coloured and Indian schoolchildren. *South African Medical Journal* 83: 847-853, 1993.

208. **Patel DN, Pettifor JM, Becker PJ, Grieve C and Leschner K**. The effect of ethnic group on appendicular bone mass in children. *Journal of Bone and Mineral Research* 7: 262-272, 1992.

209. **Petit M, McKay H, MacKelvie K, Heinonen A, Khan K and Beck T**. A randomized school- based jumping intervention confers site and maturity-specific benefits on bone structural properties in girls: A hip structural analysis study. *Journal of Bone and Mineral Research* 17: 363-372, 2002.

210. **Pettifor JM**. Nutritional rickets: deficiency of Vitamin D, calcium, or both? *American Journal of Clinical Nutrition* 80: 172S-179S, 2004.

211. **Pettifor JM and Moodley GP**. Appendicular bone mass in children with a high prevalence of low calcium intakes. *Journal of Bone and Mineral Research* 12: 1824-1832, 1997.

212. **Pfeiffer KA, McIver KL, Dowda M, Almedia MJ and Pate RR**. Validation and calibration of the actical accelerometer in preschool children. *Medicine and Science in Sports and Exercise* 38: 152-157, 2006.

213. **Philippaerts RM, Matton L, Wijndaele K, Balduck AL, De Bourdeaudhuij I and Lefevre J**. Validity of a physical activity computer questionnaire in 12-to 18-year-old boys and girls. *International Journal of Sport Medicine* 2005.

214. **Pocock NA, Gwinn T, Sambrook PN, Kelly P, Freund J and Yeates MG**. Muscle strength, physical fitness and weight, but not age predict femoral bone mass. *Journal of Bone and Mineral Research* 4: 441-448, 1998.

215. **Popkin BM**. The Nutrition Transition and its Health Implications in Lower-Income Countries. *Public Health Nutrition* 1: 5-21, 1998.

216. **Prentice A, Ginty F, Stear SJ, Jones SC, Laskey MA and Cole TJ**. Calcium supplementation increases stature and bone mineral mass of 16-18 year old boys. *Journal of Clinical Endocrinology and Metabolism* 90: 3153-3161, 2005.

217. **Prentice A, Parsons T and Cole T**. Uncritical use of bone mineral density in absoptiometry may lead to size-related artifacts in the identification of bone mineral determinants. *American Journal of Clinical Nutrition* 60: 837-842, 1994.

218. **Proctor D, Meltin III L, Khosla S, Crowson C, O'Conner M and Riggs B**. Relative influence of physical activity, muscle mass and strength on bone density. *Osteoporosis International* 11: 944-952, 2000.

219. **Puyau MR, Adolph AL, Vohra FA and Butte NF**. Validation and calibration of physical activity monitors in children. *Obesity Research* 10: 150-157, 2002.

220. **Puyau MR, Adolph AL, Vohra FA, Zakeri I and Butte NF**. Prediction of activity energy expenditure using accelerometers in children. *Medicine and Science in Sports and Exercise* 36: 1625-1631, 2004.

221. **Ramírez-Marrero FA, Smith BA, Sherman WM and Kirby TE**. Comparison of methods to estimate physical activity and energy expenditure in African American children. *International Journal of Sport Nutrition* 26: 363-371, 2005.

222. **Rauch F**. Bone accrual in children: adding substance to surfaces. *Pediatrics* 119: S137-S140, 2007.

223. **Rauch F, Bailey D., Baxter-Jones AD, Mirwald R and Faulkner R**. The 'muscle-bone unit' during the pubertal growth spurt. *Bone* 34: 775, 2004.

224. **Rauch F and Schoenau E**. The developing bone: Slave or master of its cells and molecules. *Pediatric Research* 50: 309-314, 2001.

225. **Recker R, Davies M, Hinders S, Heaney R, Stegman R and Kimmel D**. Bone gain in young adult women. *Journal of the Amercian Medical Association* 268: 2403-2408, 1992.

226. **Recker RR and Heaney RP**. Peak bone mineral density in young women. *Journal of the Amercian Medical Association* 270: 2926-2927, 1993.

227. **Reddy SP, Panday S, Swart D, Jinabhai CC, Amasoun SL, James S, Monyeki KD, Stevens G, Morejele N, Kambaran NS, Omardien RS, and Van den Borne HW**. Umthenthe Uhlaba Usamila- The South African Youth Risk Behaviour Survey 2002. [Online]. 2003. Cape Town, South African Medical Research Council.

228. **Report of a Joint Food and Agriculture Organization of the United Nations/World Food Organiztion of the United Nations Expert Consultation**. Human vitamin and mineral requirements. fttp://ftp.fao.org/es/esn/nutrition/Vitrni/vitrni.html . 1998. Bangkok, Thailand.

229. **Richter LM, Norris SA and de Wet T**. Transition from Birth to Ten to Twenty: the South African cohort reaches 12 years of age. *Journal of Paediatric and Perinatal Epidemiology* 18: 290-301, 2004.

230. **Richter LM, Yach D, Cameron N, Greisel RD and de Wet T.** Enrollment into Birth to Ten (BTT): Population and sample characteristics. *Paediatric and Perinatal Epidemiology* 9: 109-120, 1995.

231. **Rideout CA, McKay HA and Barr SI**. Self-reported lifetime physical activity and areal bone mineral density in healthy postmenopausal women: The importance of teenage activity. *Calcified Tissue International* 79: 222, 2006.

232. **Rifas-Shiman SL, Gilman MW, Field AE, Frazier L, Berkey CS, Tomeo CA and Colditz GA**. Comparing physical activity questionnaires for youth. *American Journal of Preventative Medicine* 20: 282-285, 2001.

233. **Rowlands AV, Eston RG and Ingledew DK**. Relationship between activity levels, aerobic fitness, and body fat in 8- to 10-yr-old children. *Journal of Applied Physiology* 86: 1428-1435, 1999.

234. **Rowlands AV, Ingledew DK, Powell SM and Eston RG**. Interactive effects of habitual physical activity and calcium intake on bone density in boys and girls. *Journal of Applied Physiology* 97: 1203-1208, 2004.

235. **Rubin C and Lanyon L**. Regulation of bone formation by applied dynamic loads. *Journal of Bone and Joint Surgery* 66: 397-402, 1984.

236. **Rubin CT and Lanyon LE**. Regulation of bone mass by mechanical strain magnitude. *Calcified Tissue International* 37: 411-417, 1985.

237. **Ruff C, Holt B and Trinkaus E**. Who's afraid of the big bad Wolff?: "Wolff's law" and bone functional adaptation. *American Journal of Physical Anthropology* 129: 484-498, 2006.

238. **Ruiz JC, Mandel C and Garabedia M**. Influence of spontaneous calcium intake and physical exercise on vertebral and femoral BMD of children amd adolescents. *Journal of Bone and Mineral Research* 10: 675-682, 1995.

239. **Runyan SM, Stadler DD, Bainbridge CN, Miller SC and Moyer-Mileur LJ**. Familial resemblance of bone mineralization, calcium intake, and physical activity in early-adolescent daughters, their mothers, and maternal grandmothers. *Journal of the American Dietetic Association* 103: 1320-1325, 2003.

240. **Rush EC, Goedecke JH, Jennings C, Micklesfield L, Dugas L, Lambert EV and Plank LD**. BMI, fat and muscle differences in urban women of five ethnicities from two countires. *International Journal of Obesity* 1-8, 2007.

241. **Rütten A, Vuillemin A, Ooijendijk WT, Sjöström M, Stahl T, Vanden Auweele Y, Welshman J and Ziemainz H**. Physical activity monitoring in Europe- The European Physical Activity Surveillance System (EUPASS) approach and indicator testing. *Public Health Nutrition* 6: 377-384, 2003.

242. **Rzewnicki R, Vanden Auweele Y and De Bourdeudhuij I**. Adressing over reporting on the International Physical Activity Questionnaire (IPAQ) telephone surevy with a population sample. *Public Health Nutrition* 6: 377-384, 2003.

243. **Sabatier J, Guaydier-Souquières G, Laroche D, Benmalek A, Fournier L, Guillon-Metz F, Delavenne J and Denis A**. Bone mineral acquisition during adolescence and early adulthood: A study in 574 healthy females 10-24 years of age. *Osteoporosis International* 6: 141-148, 1996.

244. **Sallis J, Berry C, Shelia L, Broyles L, McKenzie T and Nader P**. Variability and tracking of physical activity over 2 yr in young children. *Medicine and Science in Sports and Exercise* 27: 1042-1049, 1995.

245. **Sallis J, Buono M, Roby J, Carlson J and Nelson J**. The Caltrac acclerometer as a physical activity monitor for school-age children. *Medicine and Science in Sports and Exercise* 22: 689-703, 1990.

246. **Sallis J, Condon S, Goggin K, Roby J, Kolody B and Alcarez J**. The development of self-administered physical activity surveys for 4th grade students. *Research Quartely Exercise and Sport* 64: 25-31, 1993.

247. **Sallis J, Haskell W, Wood P, Fortmann S, Rogers T, Blair S and Paffenbarger R**. Physical activity assessment methodology in the five-city project. *American Journal of Epidemiology* 121: 91-106, 1985.

248. **Sallis J, Zakarian J, Hovell M and Hofstetter C**. Ethnic, socioeconomic, and sex differences in physical activity among adolescents. *Journal of Clinical Epidemiology* 49: 125-134, 1996.

249. **Sallis JF, Strikmiller PK, Harsha DW, Feldman HA, Ehlinger S, Stone EJ, Williston J and Woods S**. Validation of interviewer-and self-administered physical activity cheklists for fifth grade students. *Medicine and Science in Sports and Exercise* 28: 840-851, 1996.

250. **Sambrook P and Cooper C**. Osteoporosis. *Lancet* 367: 2010-2018, 2006.

251. **Sargent DA**. The physical test of a man. *American Physical Education Review* 26: 188-194, 1921.

252. **Schiessl H, Frost HM and Jee WS**. Estrogen and bone-muscle strength relationships. *Bone* 22: 1-6, 1998.

253. **Schnitzler CM and Mesquita JM**. Bone marrow composition and bone microarchitecture and turnover in Blacks and Whites. *Journal of Bone and Mineral Research* 13: 1300-1307, 1998.

254. **Schnitzler CM and Mesquita JM**. Cortical bone histomorphometry of the iliac crest in normal black and white South African adults. *Calcified Tissue International* 79: 373-382, 2006.

255. **Schoenau E**. The development of the skeletal system in children and the influence of muscular strength. *Hormone Research* 49: 27-31, 1998.

256. **Schoenau E and Frost HM**. The "Muscle-Bone Unit" in children and adolescents. *Calcified Tissue International* 70: 405-407, 2002.

257. **Schoenau E, Neu C, Rauch F and Manz F**. The development of bone strength at the proximal radius during childhood and adolescence. *Journal of Clinical Endocrinology and Metabolism* 86: 613-618, 2001.

258. **Schoenau E, Neu CM, Beck B, Manz F and Rauch F**. Bone mineral content per muscle cross-sectional area as an index of the functional muscle-bone unit. *Journal of Bone and Mineral Research* 17: 1095-1101, 2002.

259. **Schoenau E, Neu CM, Mokov E, Wassmer G and Manz F**. Influence of puberty on muscle area and cortical bone area of the forearm in boys and girls. *Journal of Clinical Endocrinology and Metabolism* 85: 1095-1098, 2000.

260. **Seeman E**. From density to structure: growoing up and growing old on the surfaces of bone. *Journal of Bone and Mineral Research* 12: 509-521, 1997.

261. **Seeman E**. Editorial: Growth in bone mass and size-are racial and gender differences in bone mineral density more apparent than real? *Journal of Clinical Endocrinology and Metabolism* 83: 1414-1419, 1998.

262. **Seeman E, Duan Y, Fong C and Edmonds J**. Fracture site-specific deficits in bone size and volumetric density in men with spine or hip fractures. *Journal of Bone and Mineral Research* 16: 120-127, 2001.

263. **Seeman E, Hopper JL, Bach LA, Cooper ME, Parkinson E, McKay J and Jerums G**. Reduced bone mass in daughters of women with osteoporosis. *New England Journal of Medicine* 320: 554-558, 1989.

264. **Senekal M, Steyn NP and Nel JH**. Factors associated with overweight/obesity in economically active South African populations. *Ethnicity and Disease* 13: 109-116, 2003.

265. **Sequeira MM, Rickenback M, Wietlisback V, Tullen B and Schutz Y**. Physical activity assessment using a pedometer and its comparison with a questionnaire in a large population survey. *American Journal of Epidemiology* 142: 989-999, 1995.

266. **Shepard RJ**. Limits to the measurement of habitual physcial activity by questionnaires. *British Journal of Sports Medicine* 37: 197-206, 2003.

267. **Sirard JR and Pate RR**. Physical activity assessment in children and adolescents. *Sports Medicine* 31: 439-454, 2001.

268. **Skaggs DL, Loro ML, Pitukcheewanont P, Tolo V and Gilsanz V**. Increased body weight and decreased radial cross-sectional dimensions in girls with forearm fractures. *Journal of Bone and Mineral Research* 16: 1337-1342, 2001.

269. **Slemenda CW, Reister TK, Hui SL, Miller JZ, Christian JC and Johnston CC**. Influences on skeletal mineralization in children and adolescents of sexual maturation and physical activity. *Journal of Pediatrics* 125: 201-207, 1994.

270. **Smith AD**. *The ethnic origins of nations*. Blackwell publishers, 1987.

271. **Smith E and Gilligan C**. Physical activity effects on bone metabolism. *Calcified Tissue International* Suppl: S50-S54, 1991.

272. **Snow-Harter C and Marcus R**. Exercise, bone mineral and osteoporosis. *Exercise and Sport Science Review* 19: 418, 1991.

273. **Sobngwi E, Mbanya JCN, Unwin C, Aspray TJ and Alberti KGMM**. Development and validation of a questionnaire for the assessment of physical activity in epidemiological studies in Sub-Saharan Africa. *International Journal of Epidemiology* 30: 1361-1368, 2001.

274. **Solomon L**. Bone density in ageing Caucasian and African populations. *Lancet* 2: 1326-1330, 1979.

275. **Specker B and Binkley T**. Randomized trial of physical activity and calcium supplementation on bone mineral content in 3- to 5-Year-old children. *Journal of Bone and Mineral Research* 18: 885-892, 2003.

276. **Stafford M**. Television watching and fatness in children. *Journal of the Amercian Medical Association* 280: 1230-1231, 1998.

277. **Stager M, Harvey R, Secic M, Camlin-Shingler K and Cromer B**. Self-reported physical activity and bone mineral density in urban adolescent girls. *Journal of Pediatric and Adolescent Gynecology* 19: 17-22, 2006.

278. **Stear SJ, Prentice A, Jones SC and Cole TJ**. Effect of a calcium and exercise intervention on the bone mineral status of 16-18-y-old adolescent girls. *American Journal of Clinical Nutrition* 77: 985-992, 2003.

279. **Steinberger J and Daniels S**. Obesity, insulin resistance, diabetes, and cardiovascular risk in children. *Circulation* 107: 1448-1453, 2003.

280. **Suominen H**. Bone mineral density and long term exercise. An overview of cross-sectional athlete studies. *Sports Medicine* 16: 316-330, 1993.

281. **Tanner JM**. Normal growth and techniques of growth assessment. *Clinical Endocrinology and Metabolism* 15: 411-451, 1986.

282. **Teegarden D, Proulx WR, Martin BR, Zhao J, McCabe GP, Lyle RM, Peacock M, Slemenda C, Johnston CC and Weaver CM**. Peak bone mass in young women. *Journal of Bone and Mineral Research* 10: 711-715, 1995.

283. **Theintz G, Buchs B, Rizzoli R, Slosman D, Clavien H, Sizonenko PC and Bonjour JP**. Longitudinal monitoring of bone mass accumulation in healthy adolescents: evidence for a marked reduction after 16 years of age at the levels of lumbar spine and femoral

neck in female subjects. *Journal of Clinical Endocrinology and Metabolism* 75: 1060-1065, 1992.

284. **Tobias JH, Steer CD, Mattocks CG, Riddoch C and Ness AR**. Habitual levels of physical activity influence bone mass in 11-Year-Old children from the United Kingdon: Findings from a large population-based cohort. *Journal of Bone and Mineral Research* 22: 101-109, 2007.

285. **Treuth MS, Schmitz K, Catellier DJ, McMurray RG, Murray DM, Almedia MJ, Going S, Norman JE and Pate R**. Defining accelerometer thresholds for activty intensities in adolescent girls. *Medicine and Science in Sports and Exercise* 36: 1259-1266, 2004.

286. **Treuth MS, Sherwood NE, Butte NF, McClanahan B, Obarzanek E, Zhou A, Ayers C, Adolph AL, Jordan J, Jacobs DR and Rochon J**. Validity and reliability of activity measures in African-American Girls for GEMS. *Medicine and Science in Sports and Exercise* 35: 532-539, 2003.

287. **Trippe H**. Children and sport. *British Medical Journal* 312: 199, 1996.

288. **Trost S, Pate R, Sallis J, Freedson P, Taylor W, Dowda M and Sirard J**. Age and gender differences in objectively measured physical activity in youth. *Medicine and Science in Sports and Exercise* 34: 350-355, 2002.

289. **Trost SG, McIver KL and Pate RR**. Conducting accleremoter-based activity assessments in field-based research. *Medicine and Science in Sports and Exercise* 37: S531-S543, 2005.

290. **Trost SG, Pate RR, Freedson PS, Sallis JF and Taylor WC**. Using objective physical activity measures with youth: How many days of monitoring are needed? *Medicine and Science in Sports and Exercise* 32: 426-431, 2000.

291. **Trost SG, Ward DS, McGraw B and Pate RR**. Validity of the previous day physical activity recall (PDPAR) in fifth grade children. *Pediatric Exercise Science* 11: 341-348, 1999.

292. **Turner CH**. Toward a mathematical description of bone biology: the principle of cellular accommodation. *Calcified Tissue International* 65: 466-471, 1999.

293. **Turner RT, Hannon KS, Demers LM, Buchanan J and Bell NH**. Differential effects of gonadal function on bone histomorphometry in male and female rats. *Journal of Bone and Mineral Research* 4: 557-563, 1998.

294. **U.S.Department of Health and Human Services**. Healthy people 2010 fact sheet: Healthy people in healthy communities. 1999. Washington DC.

295. **Urist MR, DeLange RJ and Finerman GAM**. Bone cell differentiation and growth factors. *Science* 220: 680-686, 1983.

296. **US Census Bureau**. International Data Base. 2005.

297. **Van Mechelen W, Hlobol H and Kemper HCG**. Validation of two running tests as an estimate of maximal aerobic power in children. *European Journal of Applied Physiology* 55: 503-506, 1986.

298. **Vanhees L, Lefevre J, Philippaerts R, Martens M, Huygens W, Troosters T and Beunen G**. How to assess physical activity?How to assess physical fitness? *European Journal of Cardiovascular Preventative Rehabilitation* 12: 102-114, 2005.

299. **Vanreusel B, Renson R, Beunen G, Claessens A, Lefevre J, Lysens R and Eynde B.** A longitudinal study of youth sport participation and adherence to sport in adulthood. *International Review for the Sociology of Sport* 32: 373-387, 1997.

300. **Vicente-Rodriguez G, Ara I, Perez-Gomez J, Dorado C and Calbet JAL**. Muscular development and physical activity as major determinants of femoral bone mass acquisition during growth. *British Journal of Sports Medicine* 39: 611-616, 2005.

301. **Vicente-Rodriguez G, Dorado C, Perez-Gomez J, Gonzalez-Henriqez JJ and Calbet JAL**. Enhanced bone mass and physical fitness in young female handball players. *Bone* 35: 1208-1215, 2004.

302. **Vicente-Rodriguez G, Jimenez-Ramirez J, Ara I, Serrano-Sanchez JA, Dorado C and Calbet JAL**. Enhanced bone mass and physical fitness in prepubescent footballers. *Bone* 33: 853-859, 2003.

303. **Vico L, Lafage-Proust MH and Alexandre C**. Effects of gravitational changes on the bone system in vitro and in vivo. *Bone* 22: 95S-100S, 1998.

304. **Vidulich L, Norris SA, Cameron N and Pettifor JM**. Differences in bone size and bone mass between black and white 10-year-old South African children. *Osteoporosis International* 17: 433-440, 2006.

305. **Vidulich L, Norris SA, Cameron N and Pettifor JM**. Infant programming of bone size and bone mass in 10-year-old black and white South African children. *Paediatric and Perinatal Epidemiology* 21: 354-362, 2007.

306. **Wang MC**. Bone mass and hip axis length in healthy Asian, Black Hispanic and White American youths. *Journal of Bone and Mineral Research* 12: 1922-1935, 1997.

307. **Wang Q, Nicholson PH, Suuriniemi M, Lyytikainen A, Helkala E, Alen M, Suominen H and Cheng S**. Relationship of sex hormones to bone geometric properties and mineral density in early pubertal girls. *Journal of Clinical Endocrinology and Metabolism* 89: 1698-1703, 2004.

308. **Ward DS, Evenson KR, Vaughn A, Rodgers AB and Troiano RP**. Acclerometer use in physical activity: Best practices and research recommendations. *Medicine and Science in Sports and Exercise* 37: S582-S588, 2005.

309. **Wareham NJ**. Commentary: Measuring physical activity in Sub-Saharan Africa. *International Journal of Epidemiology* 30: 1369-1370, 2001.

310. **Wareham NJ, Jakes RW, Rennie KL, Mitchell J, Hennings S and Day NE**. Validity and repeatability of the EPIC-Norfolk Physical Activity Questionnaire. *International Journal of Epidemiology* 31: 168-174, 2002.

311. **Wareham NJ, Jakes RW, Rennie KL, Schulteis L., Mitchell J, Hennings S and Day NE**. Validity and repeatability of a simple index derived from the short physical activity questionnaire used in the European Prospective Investigation into Cancer and Nutrition (EPIC) study. *Public Health Nutrition* 6: 407-413, 2003.

312. **Welk GJ**. Principles of design and analyses for the calibration of accelerometry-based activity monitors. *Medicine and Science in Sports and Exercise* 37: S501-S511, 2005.

313. **Welk GJ, Corbin CB and Dale D**. Measurement issues in the assessment of physical activity in children. *Research Quarterly Exercise and Sport* 71: S59-73, 2000.

314. **Welk GJ, Schaben JA and Morrow JR**. Reliabilty of accelerometry-based activity monitors: A generalizability study. *Medicine and Science in Sports and Exercise* 36: 1637-1645, 2004.

315. **Wells JC**. Body composition in childhood: effects of normal growth and disease. *The Proceedings of the Nutrition Society* 62: 521-528, 2003.

316. **Welten D, Kemper H, Post G, Van Mechelen W, Twisk J, Lips P and Tuele G**. Weight-bearing physical activity during youth is a more important factor for peak bone mass than calcium intake. *Journal of Bone and Mineral Research* 9: 1089-1096, 1994.

317. **Whiting SJ, Vatanparast H, Baxter-Jones AD, Faulkner RA., Mirwald R and Bailey DA**. Factors that affect bone mineral accrual in the adolescent growth spurt. *Journal of Nutrition* 134: 696S-700S, 2004.

318. **WHO Regional Office for Europe**. Health21: The health for all policy framework for the WHO European region. 1999. Copehagen.

319. **Wilson ME and Tanner JM**. Long-term effects of recombinant human growth hormone treatment on skeletal maturation and growth in female rhesus monkeys with normal pituitary function. *Journal of Endocrinology* 130: 435-441, 1991.

320. **Wilson P, Paffenbarger R, Morris J and Havlik R.** Assessment methods for physical activity and physical fitness in population studies: Report of NHLBI workshop. *American Heart Journal* 111: 1177-1192, 1986.

321. **Winzenberg TM, Shaw K, Fryer J and Jones G**. Effects of calcium supplementation on bone density in healthy children: meta-analysis of randomised controlled trials. *British Medical Journal* 333: 775-778, 2006.

322. **Woodhead HJ, Kemp AF, Blimkie CJR, Briody JN, Duncan CS, Thompson M, Lam A, Howman-Giles R and Cowell CT**. Measurement of midfemoral shaft geometry: repeatability and accuracy using magnetic resonance imaging and dual-energy X-ray absorptiometry. *Journal of Bone and Mineral Research* 16: 2251-2259, 2001.

323. **World Health Organisation**. Interim report and recommendations of the WHO task force for osteoporosis. *Osteoporosis International* 10: 259-264, 1999.

324. **World Health Organisation**. Preliminary results of the World Health Survey, 2002-2003; International Physical Activity Data, South African Results. 2005. Geneva, WHO.

325. **Yach D, Cameron N, Padayachee G, Wagstaff L, Richter L and Fonn S**. Birth to Ten: Child health in South Africa in the 1990's. Rationale and methods of a birth cohort study. *Paediatric and Perinatal Epidemiology* 5: 211-233, 1991.

326. **Yarasheski KE, Campbell AJ and Kohrt WM**. Effect of resistance exercise and growth hormone on bone density in older men. *Clinical Endocrinology* 47: 223-229, 1997.

327. **Yilmaz D, Ersoy B, Bilgin E, Gumuser G, Onur E and Pinar ED**. Bone mineral density in girls and boys at different pubertal stages: relation with gonadal steroids, bone formation markers, and growth parameters. *Journal of Bone and Mineral Metabolism* 23: 476-482, 2005.

328. **Zanchetta JR, Plotkin H and Alvarez Filgueira ML**. Bone mass in children: normative values for the 2-20-year-old population. *Bone* 16: 393S-399S, 1995.

Appendices

Appendix 1- Sample Caregiver Information Sheet

Physical activity levels in South African children

Subject Information Sheet (primary caregivers)

Dear Parent,

Hello, my name is Joanne McVeigh and I am part of the Mineral Metabolism Research Unit at Wits University. We are researching the factors responsible for the development of good bone mass in children. The link between physical activity and a good bone mass has been established over the past few years. Frequent bouts of weight bearing activity during childhood are important in the attainment of a good bone mass and to offset normal age related bone loss. We are investigating the physical activity levels of South African children with the use of a questionnaire. This is to enable us to compare our children's levels to other children physical activity levels around the world. We need to validate our physical activity questionnaire against another measure of physical activity in order to see how reliable it is.

For this study we would like 30 children to wear accelerometers on their hip for a period of four school/week days. Accelerometers are non invasive devices that are simply clipped to a skirt or pair of pants on the hip bone of the child and serve to measure activity counts over a four day period. They are about the size of a R5 coin. The data collected from these accelerometers will be downloaded onto a computer and compared with data filled in on a physical activity questionnaire. The physical activity questionnaire will be filled in four times. We would like to see if our physical activity questionnaire is a good indicator of actual activity.

We ask that children behave as they normally would for the four days of the study. The accelerometers will be brought to your child's classroom and will be collected again four days later. Any sport participation should continue and the accelerometer should be worn at all times, except for when bathing, showering.

Please note that should you agree to participate in this research, you will be free to withdraw at anytime without prejudice. Additionally all results and information will remain confidential. A unique numerical identifier will be used for each child, such that names and identities will not be revealed.

If you would like to participate in this study, please fill out the informed consent sheet below. Or if you wish to ask me any questions about the study, please feel free to contact me on ******* **or email me on *****

Thank you so much for your participation and contribution to this important research.

Yours truly,

Joanne McVeigh

Wits Medical School

Informed Consent

I _____

(caregiver)   hereby agree to let _____participate is

this study conducted by the MRC Mineral Metabolism Research Unit to investigate physical

activity levels in South African Children. I acknowledge that I am fit and healthy and able to

partake in the two indirect measures of physical activity which have been explained to me. The

research has been explained to us and we understand what will be expected of us. We understand

that the Committee for Research on Human Subjects of the University of the Witwatersrand has

sanctioned all experimental procedures. We participate in this study on condition that our results

will be treated confidentially. We acknowledge that the results may be published in medical

journals; however our names and family names will not be mentioned. We understand that

participation is voluntary and we remain free to withdraw from the project at any time without

prejudice.

Caregiver_____Date_____

Appendix 2- Sample Subject Information Sheet (Child)

Physical activity levels in South African children

Subject Information Sheet (child)

Dear subject,

Hello, my name is Joanne McVeigh and I am part of a research unit at Wits University. We are very interested in finding out all about all the things that are good for our bones. Did you know that doing weight bearing exercises (like running and jumping) is very good for making our bones strong?

We need your help with some of our research! We need to find out how much exercise South African children are doing, so that we can see if it is enough to make strong and health bones.

What we need you to do is this:

Wear a little device (called an accelerometer), clipped onto your school uniform (or normal clothes) at the level of your hip bone for 4 days. The device is no bigger than a R5 coin. I will come to your classroom and show you how to attach it. You will need to wear this device all day, except while showering or bathing, and behave as you normally would. On the fourth day, I will come back to your classroom and collect the device. I will also ask you to fill out a physical activity questionnaire which asks questions all about the sport and exercise that you do. That's it!!

You guys should know that if you and your caregiver agree that you can participate in this study, you will able to withdraw or stop the research at anytime. Also your information will be kept very private because each child will be given their own number instead of their name.

If you would like to participate in this study, please fill out the informed consent sheet below. Or if you wish to ask me any questions about the study, please feel free to contact me on **** **or email me on ****

Thank you so much for your participation and contribution to this important research.

Yours truly,

Joanne McVeigh

PhD candidate

Wits Medical School

Appendix 3- Physical Activity Questionnaire (PAQ)

PHYSICAL ACTIVITY QUESTIONNAIRE

1.   ACTIVITIES AT SCHOOL

1.1   Do you attend physical education/P.E./games lessons at school?

Yes=1	No=0

What do you do in these classes? How often are classes held & how long are classes?

Activities	Times / week	Hours / time

2.   INFORMAL ACTIVITIES

Do you engage in any physical activity outside school but **NOT** in a sports club e.g. riding a bike, playing in the street or yard, etc? What activities do you engage in, how often & how long?

Activities	Times / week	Hours / time

3.   **SEDENTARY ACTIVITIES**

Do you engage in any of the following activities before or after school (**MON - FRI**)? If so, for how many hours per day?

Watching TV and videos

Yes=1	No=2	Hrs / day during the week_____

Reading, drawing, music lessons, homework during the week

Yes=1	No=2	Hrs / day during the week_____

Playing video games during the week

Yes=1	No=2	Hrs / day during the week_____

Do you engage in any of the following activities on the weekend (**SAT & SUN**)?
If so, for how many hours per day?

Watching TV and videos

Yes=1	No=2	Hrs / day during the week_____

Reading, drawing, music lessons, homework during the week

Yes=1	No=2	Hrs / day during the week_____

Playing video games during the week

Yes=1	No=2	Hrs / day during the week_____

TRANSPORT

How do you get to school and how long does it take to get there and back?
By car, bus, taxi, train etc.

Yes=1	No=2
There:_____minutes	
Back:_____minutes	

Walking

Yes=1	No=2
There:_____minutes	
Back:_____minutes	

When you walk, at what pace (how fast) do you usually walk?

At a vigorous pace, that makes me breath much harder than normal	1
At a medium pace that makes me breath somewhat harder than normal	2
At a slow pace when there is no change in my breathing	3

Bicycle

Yes=1	No=2
There:_____minutes	
Back:_____minutes	

When you cycle, at what pace (how fast) do you usually cycle?

At a vigorous pace, that makes me breath much harder than normal	1
At a medium pace that makes me breath somewhat harder than normal	2
At a slow pace when there is no change in my breathing	3

Combination: e.g. walking and taxi, bus and walking

Yes=1	No=2	
There:_____minutes		
Back:_____minutes		

Other

Yes=1	No=2
There:_____minutes	
Back:_____minutes	

EXTRA MURAL ACTIVITIES AT SCHOOL

	How many months of the yr?	Prac/Wk	Hrs/Prac	Comp/Wk
Athletics (running)				
Athletics (other)				
Cricket				
Swimming				
Tennis				
Hockey				
Netball				
Rugby				
Soccer				
Badminton				
Basketball				
Ballet				
Cycling				
Dancing				
Gymnastics				
Judo / karate				
Squash				
Volleyball				
Other				

PRIVATE EXTRA MURAL ACTIVITIES

	How many months of the yr?	**Prac/Wk**	**Hrs/Prac**	**Comp/Wk**
Athletics (running)				
Athletics (other)				
Cricket				
Swimming				
Tennis				
Hockey				
Netball				
Rugby				
Soccer				
Badminton				
Basketball				
Ballet				
Cycling				
Dancing				
Gymnastics				
Judo / karate				
Squash				
Volleyball				
Other				

Appendix 4- Socio-economic and Core Questionnaire

ADULT CORE QUESTIONNAIRE

BTT ID NUMBER

BONE STUDY ID NUMBER

CHILD'S FIRST NAME(S) & SURNAME

_____

PRIMARY CARETAKER'S NAME(S) & SURNAME

_____

PRIMARY CARETAKER'S RELATIONSHIP TO THE CHILD

Are you the biological mother of the child?

Yes=1	No=0

If you are not the biological mother: What is your relationship to the child?
(eg child's mother's sister or paternal grandmother)

_____

SCHOOL INFORMATION ON CHILD

What is the name of your child's school?_____

What the address of your child's school? _____

What grade is your child in?

Grade 1	1
Grade 2	2
Grade 3	3
Grade 4	4
Grade 5	5

Has your child repeated any grade(s) at school?

Yes=1	No=0

IF YES which grades?

Grade 1	1
Grade 2	2
Grade 3	3
Grade 4	4
Grade 5	5

HOUSEHOLD INFORMATION

Please list all the members of the household where the child lives (people generally sharing the same main meal).

Start with the **household head** and then complete from the oldest to the youngest person (including the child).

Name	Sex	Age	Relationship to child
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			
13.			

Please list all the people who have died in your household, since the child has been alive, and state their relationship to the child

Name	Sex	Age	Relationship to the child
1.			
2.			
3.			
4.			
5.			

In how many rooms do these above household members sleep (**including** kitchen, lounge, dining room, bedrooms or outside structures)?

_____

In your home, how many rooms are there just for sleeping?_____

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How would you describe your **home?**

Shack/Zozo	1	House	3	Shared House	5
Flat/cottage	2	Hostel	4	Room/Garage	6
Other, please state					

Household water: Do you have access to?

Indoor water	1	Only outside tap water	2	Other water source	3

What type of toilet do you have?

Flush inside	1	Only flush outside	2
Pit/bucket	3	Other, please state	

How do you dispose of your refuse?

Dump garbage away from home	Yes=1	No=0
Burn garbage	Yes=1	No=0
Bury garbage in yard	Yes=1	No=0
Garbage gets collected	Yes=1	No=0

Which of the following do you have in your household at the present time?

Electricity	Yes=1	No=0
Television	Yes=1	No=0
Radio	Yes=1	No=0
Motor vehicle	Yes=1	No=0
Fridge	Yes=1	No=0
Washing machine	Yes=1	No=0
Telephone	Yes=1	No=0
Video machine	Yes=1	No=0
Microwave	Yes=1	No=0
MNet	Yes=1	No=0
DSTV	Yes=1	No=0

Marital status of primary caretaker:

Single	1	Divorced / separated	2
Married	3	Widowed	4
Living with partner, not married	5		

Support for the child:

Is the child's biological father living with you (if you are the biological mother)?

Yes=1	No=0

Does the child's biological father give any financial assistance?

Yes=1	No=0

Do you get financial help **for the child** from your current partner (if you are the biological mother and if he is not the biological father of child)

Yes=1	No=0

Is the child currently covered by medical aid?

Yes=1	No=0

Education (last standard **passed**):

	Primary caretaker	Current Partner
No formal education	1	1
Grade 1-2	2	2
Std 1-3 (Grade 3-5)	3	3
Std 4-5 (Grade 6-7)	4	4
Std 6-7 (Grade 8-9)	5	5
Std 8 (Grade 10)	6	6
Std 9 (Grade 11)	7	7
Matric (Grade 12)	8	

If College or University education:
Please indicate highest degree/diploma

Primary caretaker _____   Partner _____

Primary caretaker's job /occupation (including work in the informal sector)

_____

If not formally employed, are you actively seeking a job?

Yes=1	No=0

Current partner's job/occupation (including work in the informal sector)

_____

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If not formally employed, is he actively seeking a job?

Yes=1	No=0

Income is a sensitive question to many people. However, it is very important that we have an idea of your monthly income. We would appreciate it if you could answer the following questions:

Primary caretaker's monthly income:

No cash income	0	Between R1 and R500	1
Between R501 and R1000	2	Between R1001 and R2000	3
Between R2001 and R3000	4	Between R3001 and R4000	5
Between R4001 and R5000	6	more than R5000	7

Current partner's monthly income:

No cash income	0	Between R1 and R500	1
Between R501 and R1000	2	Between R1001 and R2000	3
Between R2001 and R3000	4	Between R3001 and R4000	5
Between R4001 and R5000	6	More than R5000	7
Don't know	8		

FERTILITY OF THE CHILD'S BIOLOGICAL MOTHER (If applicable)

Does the child have any younger

    brothers or sisters?

Yes=1	No=0

IF YES specify dates of birth:

d d m m y y

Child 1 ____/____/__

Child 2 ____/____/__

Child 3 ____/____/__

Child 4 ____/____/__

Child 5 ____/____/__

Is the mother pregnant now?

Yes=1	No=0

GENERAL HEALTH OF THE CHILD

Compared to other children of this child's age, would you
say this child's health is:

Good=1	Fair=2	Poor=3

IF POOR please explain

_____

_____

_____

Does the child have Asthma?

Yes=1	No=0

IF YES has the child had any professional advice or treatment?

Yes=1	No=0

 IF YES please
explain_____

IF YES does he/she require inhalers, sprays or pumps?

Yes=1	No=0

IF YES how many severe attacks requiring treatment (at clinic/ hospital / GP)
has he/she had during the past year?

_____

Has the child ever had a fit?

Yes=1	No=0

 IF YES how old was the child?_____years_____months

IF YES is the child on any medication for the fits?

Yes=1	No=0

SERIOUS MEDICAL OR DEVELOPMENTAL PROBLEMS

Does the child have, or has the child had any serious medical or developmental problems (physical or mental)or any injuries during the past year?

Yes=1	No=0

IF YES please list the
a)   problem
b) type of treatment
        c)   the place where the child is or has been treated

Problem 1 (a)

treatment   (b)

place   (c)

Problem 2 (a)

treatment (b)

place   (c)

Problem 3 (a)

treatment (b)

place   (c)

MEDICAL HISTORY OF HOUSEHOLD MEMBERS

Biological mother:
Has a doctor or nurse told you that you had or have:

High blood pressure	No=0	Yes=1	Don't know=2
Diabetes or sugar in the blood	No=0	Yes=1	Don't know=2
Heart attack/angina	No=0	Yes=1	Don't know=2
Stroke: muscle paralysis or sensory loss	No=0	Yes=1	Don't know=2
High blood cholesterol (fats)	No=0	Yes=1	Don't know=2
Osteoporosis / Bone fractures	No=0	Yes=1	Don't know=2

Biological mother:
Do you take medication prescribed by a doctor (pills or injections) for:

High blood pressure	No=0	Yes=1	Don't know=2
Diabetes or sugar in the blood	No=0	Yes=1	Don't know=2
Heart disease	No=0	Yes=1	Don't know=2
Osteoporosis / Bone fractures	No=0	Yes=1	Don't know=2
Other (specify)	No=0	Yes=1	Don't know=2

Do you have a **close relative** (father, mother, brother, sister, grandparents or child) who has or had any of the following conditions?

High blood pressure	No=0	Yes=1	Don't know=2
Diabetes or sugar in the blood	No=0	Yes=1	Don't know=2
Heart attack/angina	No=0	Yes=1	Don't know=2
Stroke	No=0	Yes=1	Don't know=2
High blood cholesterol (fats)	No=0	Yes=1	Don't know=2
Osteoporosis / bone fracture	No=0	Yes=1	Don't know=2

IF YES please state who the person is (relationship to the child) and whether they are on the mother's or father's side of the family.

Condition	Relationship to the child	
	Maternal Family	**Paternal Family**
High blood pressure		
Diabetes or sugar in the blood		
Heart attack or angina		
Stroke		
High blood cholesterol (fats)		
Osteoporosis / bone fracture		

FOR GIRL CHILD'S MOTHER: MENSTRUATION

Has your daughter started to mature sexually in terms of?

a) breast development

Yes=1	No=2

b) growth of pubic hair

Yes=1	No=2

Has your daughter started menstruating?

Yes=1	No=0

      IF YES at what age did she start menstruating?_____mth / _____yr

Appendix 5- Human Ethics Approval Certificate

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
R14/49   McVeigh

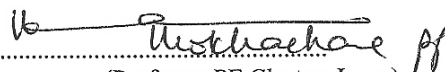|	
CLEARANCE CERTIFICATE	**PROTOCOL NUMBER M050226**
PROJECT	Association of Environmental & Lifestyle Factors with Bonse Mass Acquisitions in SA Children by Sex, Ethnicity & Age
INVESTIGATORS	Ms J McVeigh
DEPARTMENT	School of Physiology
DATE CONSIDERED	05.02.25
DECISION OF THE COMMITTEE*	Approved unconditionally

Unless otherwise specified this ethical clearance is valid for 5 years and may be renewed upon application.

DATE   05.03.18   **CHAIRPERSON** ....
(Professor PE Cleaton-Jones)

*Guidelines for written 'informed consent' attached where applicable

cc: Supervisor :   Dr S Norris

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10005, 10th Floor, Senate House, University.
I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to a completion of a yearly progress report.**

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix 6- Approval of Title Change to PhD

Faculty of Health Sciences
Medical School, 7 York Road, Parktown, 2193
Fax: (011) 717-2119
Tel: (011) 717-2075/6

Reference: Mrs Alison Mclean
E-mail: mcleanam@health.wits.ac.za
16 July 2007
Person No: 0002203A
TAA

Ms JA McVeigh
25 Via Avelland
Lingerett Str
Sunninghill Gardens
2191
South Africa

Dear Ms McVeigh

Doctor of Philosophy: Change of title of research

I am pleased to inform you that the following change in the title of your Thesis for the degree of has been approved:

From: **The association of environmental and lifestyle factors with bone mass acquisition in South African children by sex, ethnicity and age**

To   **The association of envronmental and lifestyle factors with bone mass acquisition in South African children by sex, race and age**

Yours sincerely

Mrs Sandra Benn
Faculty Registrar
Faculty of Health Sciences

Peer Reviewed Publications Emanating from Thesis

Associations between physical activity and bone mass in black and white South African children at age 9 yr

J. A. McVeigh,[1,2] S. A. Norris,[1] N. Cameron,[3] and J. M. Pettifor[1]

[1]*Medical Research Council Mineral Metabolism Research Unit, Department of Paediatrics, University of Witwatersrand, and* [2]*School of Physiology, University of Witwatersrand Medical School, Parktown, Gauteng 2193, South Africa; and* [3]*Department of Human Biology, University of Loughborough, Leicestershire LE11 3TU, United Kingdom*

McVeigh, J. A., S. A. Norris, N. Cameron, and J. M. Pettifor. Associations between physical activity and bone mass in black and white South African children at age 9 yr. *J Appl Physiol* 97: 1006 1012, 2004. First published May 7, 2004; 10.1152/japplphysiol.00068. 2004. We investigated differences in physical activity (PA) levels between black and white South African 9-yr-old children and their association with bone mineral content (BMC) and density (BMD) by using dual-energy X-ray absorptiometry. PA was analyzed in terms of a metabolic (METPA; weighted metabolic score of intensity, frequency, and duration) and a mechanical (MECHPA; sum of all ground reaction forces multiplied by duration) component. There were significant ethnic differences in patterns of activity. White children expended a significantly greater energy score (METPA of 21.7 ± 2.9) than black children (METPA of 9.5 ± 0.5) ($P < 0.001$). When children were divided into quartiles according to the amount and intensity of sport played, the most active white children (using METPA scores) had significantly higher whole body BMD and higher hip and spine BMC and BMD than less active children. White children in the highest MECHPA quartile also showed significantly higher whole body, hip, and spine BMC and BMD than those children in the lowest quartile. No association between exercise and bone mass of black children was found. In this population, PA has an osteogenic association with white children, but not black children, which may be explained by the lower levels of PA in the black children. Despite this, black children had significantly greater bone mass at the hip and spine (girls only) ($P < 0.001$) even after adjustment for body size. The role of exercise in increasing bone mass may become increasingly critical as a protective mechanism against osteoporosis in both ethnic groups, especially because the genetic benefit exhibited by black children to higher bone mass may be weakened with time, as environmental influences become stronger.

bone mass; South Africa; ethnicity

The need of exercise is a modern superstition, invented by people who ate too much and had nothing to think about.
George Santayana (1863 1952)

GIVEN THAT ADULT CHRONIC DISEASES often have their origins in childhood, there is a critical need to better understand how physical activity (PA) and fitness levels in childhood and adolescence may shape health status in adulthood. Many studies have addressed loading activities and bone loss in adults and in elite athletes, and, although a number of studies have addressed the issues of exercise in children and its association with bone mineral accretion (3, 19, 25), the research is particularly sparse for those living in developing countries such as

South Africa. We know very little about ethnic differences in these countries, particularly with regard to PA levels, bone mineral density (BMD), body composition, and obesity. Although the prevalence of obesity is higher in developed countries (24), it is nevertheless a serious emerging problem in developing countries (10) . Other chronic diseases of lifestyle, such as diabetes and hypertension, are also increasing, but little is known about the changing prevalence of osteoporosis and fragility fractures.

Evidence that PA is an effective strategy for the prevention of postmenopausal or age-related osteoporosis has been inferred from cross-sectional investigations of retired athletes, which showed increased bone mass in the athletes with a history of childhood weight-bearing PA (4). Studies have found a relationship between intensity of exercise and bone mass (16, 21). Further high levels of activity within the limits of normal lifestyle are also associated with increased BMD (9). This association has not been well explored or observed in prepubertal children and has not been observed in children living in developing countries such as South Africa. It is possible that the lower fracture rates reported in the elderly of developing countries may relate to higher PA levels during childhood and adulthood.

Bone adapts to loads applied to it; the crucial factors in optimizing this bone response are the age and degree of maturity of the subject during which the mechanical loading is initiated (6) and the magnitude of the load applied to the bone (13). Peak bone strain scores [mechanical PA (MECHPA)] have consequently been developed to "rate" the loading of different activities (13). It is during the growth period that mechanical loading is said to have the greatest influence on the skeleton (14, 15, 20).

There have been a number of studies that have confirmed that African Americans and South African blacks have greater BMD at the proximal femur and that African Americans have greater BMD at the lumbar spine as well as an increased cortical thickness than whites (2, 7). The age-adjusted hip fracture incidence is 50% lower in African American women than in Caucasian women (5), and what limited information there is suggests that South African blacks also have markedly lower hip fracture rates than South African white adults (32, 38). Very few of the factors influencing osteoporosis have been well studied between ethnic groups.

In this study, we assessed the association between PA [sedentary activity, sports participation, intensity of activity,

commuting (actively and passively) to and from school] and skeletal mass in 386 healthy 9-yr-old black and white, male and female South African children. We hypothesized that *1*) higher levels of PA [a greater metabolic equivalent PA (METPA) score] would be associated with higher bone mass; *2*) the type of sport played influences bone mass (sports with a higher MECHPA score would have a greater osteogenic effect); and *3*) ethnic groups would have different levels of PA, and, possibly, this could translate into different bone mass effects.

MATERIALS AND METHODS

Subjects. This is an observational study of a cohort of children recruited from the Birth to Twenty birth cohort, a longitudinal study of child health and development (11, 31, 41). All children born within a 6-wk period (April 23 to June 8, 1990) in the greater Johannesburg metropolitan area in South Africa were originally recruited. A random sample of children ($n = 682$), stratified by ethnic group (black and white), gender, and socioeconomic status, who were participating the Birth to Twenty cohort study were enrolled into a longitudinal study assessing factors influencing bone mass during childhood and adolescence (Bone Health Study) in 1999. Cross-checks were performed to ensure that there were no significant differences between the Birth to Twenty and Bone Health cohort for key demographic variables (residential area at birth, maternal age at birth, gravidity, gestational age, and birth weight). Complete data for this study were available for 386 children. Subjects were all healthy and aged 9 yr at the time of testing. Children who had asthma or were suffering from any disorder likely to affect bone metabolism were excluded from the study. The sample was composed of 44 white male, 158 black male, 38 white female, and 146 black female children. All subjects and their parents provided written, informed consent, and ethical approval was obtained from the University of the Witwatersrand Committee for Research on Human Subjects.

Questionnaire. All subjects completed an interview with the caregiver present. We examined past medication, known diseases,

and pubertal development [by Tanner hair development (39)]. Dietary calcium intakes were assessed by using a 24-h dietary recall questionnaire. Total PA was estimated by using a structured, detailed, retrospective interview taking into consideration all PA and inactivity over the previous 12 mo. The questionnaire was based on questionnaires validated in previous studies (12, 28) and modified appropriately for South African children. The intensity, frequency, and duration of all PA [at school, after school, at home, and commuting (actively and passively) to and from school] were taken into account. Intensities of activities were classified as multiples of one metabolic equivalent (the ratio of the associated metabolic rate for the specific activity to the resting metabolic rate). PA was scored in two ways as calculated from the questionnaire: *1*) metabolic PA (METPA) score by weighting the intensity [multiples of basal metabolic rate (metabolic equivalents) and duration (h/wk)] (1) and *2*) MECHPA score by weighting the peak bone strain [ground reaction forces as multiples of body mass and duration (h/wk)] (13). This score is based on the method developed by Groothausen et al. (13); however, we modified this by multiplying the ground reaction force by duration because the original measure did not include duration or frequency. Thus a sum score MECHPA was calculated as the sum of all MECHPA scores multiplied by duration (h/wk) per activity.

Bone measurements. We measured whole body and site-specific bone mineral content (BMC) and BMD by using a Hologic QDR 4500A dual-energy X-ray absorptiometer (DXA) according to standard procedures. A spine phantom was scanned daily to determine the intrinsic coefficient of variation of the machine. During the course of the study, coefficients of variation for BMC and BMD were 0.48 and 0.35%, respectively. A trained DXA technician performed all scans, and intra-observer variation for our study was found to be below 1% for all skeletal sites. DXA scans were performed on the nondominant radius, left hip, lumbar spine (L_1–L_4), and whole body. The whole body scan obtained from the DXA enabled the assessment of whole body lean and fat tissue (g) and percent body fat.

Table 1. *Unadjusted DXA, height, weight, age, BMI, and calcium data*

	Female Children		Male Children	
	White ($n = 38$)	Black ($n = 146$)	White ($n = 44$)	Black ($n = 158$)
Age, yr	9.6±0.05	9.5±0.02	9.5±0.05	9.5±0.02
Height, cm	136.3±1.2*	132.8±0.48*	137.4±0.95§	133.0±0.47§
Weight, kg	30.4±1.1	29.7±0.6	32.6±1.2†	29.1±0.4‡
BMI, kg/m²	16.2±0.04	16.7±0.02	16.6±0.04	16.7±0.02
Calcium intake, mg/day	719±44†	347±23§	778±42§	347±22§
WBBMC, g	887.0±183.2	889.2±146.3	966.5±145.8	927.6±121.3
Whole body total area, cm²	1,108.5±176.3	1,112.3±148.4	1,176.1±150.6	1,122.9±118.7
WBBMD, g/cm²	0.795±0.051	0.799±0.050	0.828±0.058	0.827±0.049
Radial bone BMC, g	3.0±0.5	3.0±0.559	3.3±0.499	3.3±0.5
Radial bone total area, cm²	7.7±1.0	8.0±1.1	8.3±1.1	8.4±1.1
Radial bone BMD, g/cm²	0.383±0.030	0.379±0.032	0.403±0.025	0.393±0.032
Hip BMC, g	12.7±2.8	13.0±2.3	14.3±2.6	14.4±2.4
Hip total area, cm²	21.5±4.6*	19.4±2.2*	20.5±2.41‡	19.0±3.3‡
Hip BMD, g/cm²	0.603±0.065†	0.671±0.079†	0.699±0.079‡	0.749±0.079‡
Spine BMC, g	20.8±4.4	22.0±3.9	23.5±4.3	21.9±3.5
Spine total area, cm²	39.4±4.1	39.2±5.0	42.7±4.3	40.7±4.1
Spine BMD, g/cm²	0.525±0.065*	0.557±0.069*	0.548±0.061	0.536±0.050
Lean tissue, g	19,916.2±3,183.3	19,720.7±2,746.5	22,791.8±2,966.1‡	20,718.6±2,700.2§
Fat tissue, g	9,473.9±4,224.4	9,010.0±4,564.6	8,385.1±5,189.6	6,974.4±3,301.7
Body fat, %	30.0±7.0	28.9±7.9	24.1±6.3	23.4±7.8

Values are means ± SD; *n*, no. of subjects. BMI, body mass index; WBBMC, whole body bone mineral content; WBBMD, whole body bone mineral density; BMC, bone mineral content; BMD, bone mineral density. Significant difference between white and black female children: *$P < 0.05$; †$P < 0.001$. Significant difference between white and black male children: ‡$P < 0.05$; §$P < 0.001$.

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Table 2. *Cohort bone mass characteristics after adjusting for differences in height and weight*

	Female Children		Male Children	
	White ($n = 38$)	Black ($n = 146$)	White ($n = 44$)	Black ($n = 158$)
BMC, g	864.2±16.0	894.0±8.2	919.5±15.3	943.1±8.2
BMD, g/cm²	0.793±0.009	0.800±0.005	0.824±0.008	0.828±0.005
Radial bone BMC, g	2.9±0.1	3.0±0.04	3.2±0.1	3.3±0.04
Radial bone BMD, g/cm²	0.382±0.005	0.38±0.003	0.4±0.005	0.394±0.003
Hip BMC, g	12.3±0.3	13.1±0.2	13.6±0.3‡	14.6±0.2‡
Hip BMD, g/cm²	0.598±0.013†	0.672±0.007†	0.688±0.012†	0.753±0.007§
Spine BMC, g	20.2±0.6*	22.1±0.3*	22.4±0.5	22.2±0.3
Spine BMD, g/cm²	0.521±0.01*	0.557±0.05§	0.540±0.01	0.539±0.005

Values are means ± SE; *n*, no. of subjects. Means are adjusted for height and weight. Significant difference between white and black female children: *$P <$ 0.05; †$P <$ 0.001. Significant difference between white and black male children: ‡$P <$ 0.05; §$P <$ 0.001.

Anthropometric measurements. The height of each child, recorded to the nearest millimeter, was measured by using a stadiometer (Holtain, Crosswell, UK), and weight, recorded to the nearest 100 g, was measured by using a digital scale (Dismed, Halfway House, South Africa). Both devices were routinely checked every 3 mo throughout the study, and no adjustments were necessary to the calibrations of the equipment. Subjects were measured with light clothing and no shoes.

Data analysis. Two kinds of relationships with bone mass, ethnicity, and PA were investigated. First, METPA and MECHPA scores were included as categorical variables (divided into quartiles) and analyzed separately for black and white children. Second, METPA and MECHPA scores were log transformed (data were negatively skewed) and correlated with bone mass variables separately for white and black children by using Pearson's correlation coefficients. All data are presented as means ± SD, unless otherwise noted. Data were analyzed by using SPSS version 11.0. An ANOVA was performed for all PA and bone and body composition measurements. An α-level of $P < 0.05$ was considered to be statistically significant. Bone mass differences within METPA and MECHPA quartiles and between the race groups were assessed by using a multivariate ANOVA. The Bonferroni multiple comparison test was used to assess group differences. χ² Tests were used for categorical variables. DXA data are reported both with and without adjustment for height and weight.

RESULTS

Anthropometric and bone characteristics. Included in the study were 82 white and 304 black 9-yr-old children, with approximately equal numbers of male and female children in each group. All children were prepubertal. Table 1 shows the results for unadjusted DXA and body composition data.

White children had significantly lower hip BMD ($P < 0.001$) and significantly greater hip area ($P = 0.002$) than black children, and white female children had lower spine BMD than black female children ($P = 0.005$). White female and male children were significantly taller ($P < 0.001$) and had higher calcium intakes ($P < 0.001$) than their black peers. White male children were also heavier then black male children ($P = 0.04$) and had significantly greater lean tissue mass ($P < 0.001$). There were no significant differences between black and white children for body mass index (BMI). Table 2 shows the results for bone mass data adjusted for height and weight. After adjustment for height and weight, black children still had a significantly higher hip BMD than white children ($P < 0.001$), black male children had higher hip BMC than white male children ($P = 0.038$), and black female children had higher spine BMC ($P = 0.005$) and spine BMD ($P = 0.004$) than white female children.

PA. PA data are presented in Table 3. Over 90% of white males and females participated in physical education classes at school compared with only ~30% of their black peers. White female children spent a significantly greater time sleeping ($P = 0.006$) and playing sports, with a higher METPA score ($P < 0.001$) and MECHPA score ($P = 0.034$) than black female children. Black female children spent a greater time actively commuting to and from school (i.e., walking or riding) each day than white female children ($P < 0.001$). White male children also spent a significantly greater time sleeping ($P = 0.019$), expending a significantly greater METPA score ($P < 0.001$), and playing sports,

Table 3. *Physical activity characteristics*

	Female Children		Male Children	
	White ($n = 38$)	Black ($n = 146$)	White ($n = 44$)	Black ($n = 158$)
Physical education, yes	34/38 (90%)†	50/146 (34%)†	41/44 (93%)§	43/158 (27%)§
Sedentary activity, h/day	8.61±0.54	9.03±0.34	10.48±0.79	10.63±0.33
Passive commuting, h/day	0.37±0.49	0.47±0.06	0.33±0.03	0.4±0.06
Active commuting, h/day	0.04±0.02†	0.27±0.03†	0.03±0.01§	0.35±0.03§
Sleep, h/night	10.11±0.14*	9.38±0.13*	10.02±0.09‡	9.24±0.78‡
METPA score	14.7±2.07	8.39±0.86	27.74±5.07§	10.65±0.63§
MECHPA score	2.97±0.56†	2.26±0.35†	5.7±1.05§	2.96±0.19§

Values are means ± SE; *n*, no. of subjects. Passive commuting, transport to and from school in a car, bus, taxi, or train; active commuting, transport to and from school via walking or riding a bicycle; METPA score, metabolic expenditure calculated from school sports and active commuting to and from school; MECHPA score, mechanical loading score; sedentary activity, television and video watching and reading. Significant difference between white and black female children: *$P <$ 0.05; †$P <$ 0.001. Significant difference between white and black male children: ‡$P <$ 0.05; §$P <$ 0.001.

which generated a higher MECHPA score ($P < 0.001$), than black male children. White and black children spent similar amounts of time participating in sedentary activities and commuting passively to and from school (i.e., via car, bus, taxi, or train).

Associations between bone characteristics and METPA. Subjects were divided into quartiles [from Q1 (least active) to Q4 (most active)] on the basis of their METPA scores. There were no significant differences in anthropometric values (height, weight, BMI, percent fat, and fat and lean tissue), between METPA quartiles for white or black children. There were no significant differences between bone mass values and METPA quartiles in black children except for whole body BMD ($P = 0.022$). There were, however, significant relationships between METPA quartiles and bone mass values in white children at the hip ($P = 0.013$; $P = 0.001$) and spine ($P = 0.019$; $P = 0.003$) (BMC and BMD) and for whole body BMD (Fig. 1).

Log METPA scores were significantly correlated with bone mass values at all sites except for the radius in white children (Table 4); however, in black children, the only significant relationship was between log METPA and WBBMD ($r = 0.18$, $P = 0.002$).

Associations between bone characteristics and MECHPA. Subjects were divided into quartiles [from Q1 (very low loading) to Q4 (high loading)] on the basis of their MECHPA scores. These MECHPA quartiles were then compared with BMC and BMD at various sites. There were no significant differences in anthropometric values (height, weight, BMI, and fat and lean tissue) between MECHPA quartiles for white or black children. However, body fat percent was significantly ($P = 0.025$) lower in black children with MECHPA scores in Q4 (highest loading) compared with Q2 (low loading). There were no significant differences between bone mass values and MECHPA quartiles in black children. There were, however, significant differences in bone mass measures between MECHPA quartiles for white children at all sites except for the radius. For white children, the most active group (Q4) had significantly higher whole body ($P = 0.016$), hip ($P = 0.001$), and spine ($P = 0.004$) BMD and hip ($P = 0.008$) and spine ($P = 0.024$) BMC than the two least active groups (Q1 and Q2) (Fig. 2).

Significant positive correlations between bone mass (BMC and BMD) and log MECHPA scores were found in white children at all sites except for the radius (Table 4). No correlations were found for any site in black children.

DISCUSSION

To our knowledge, this is the first study undertaken in a population of normal prepubertal children in a developing country to investigate ethnic differences in the bone mass response to PA. We have found that whole body BMD and
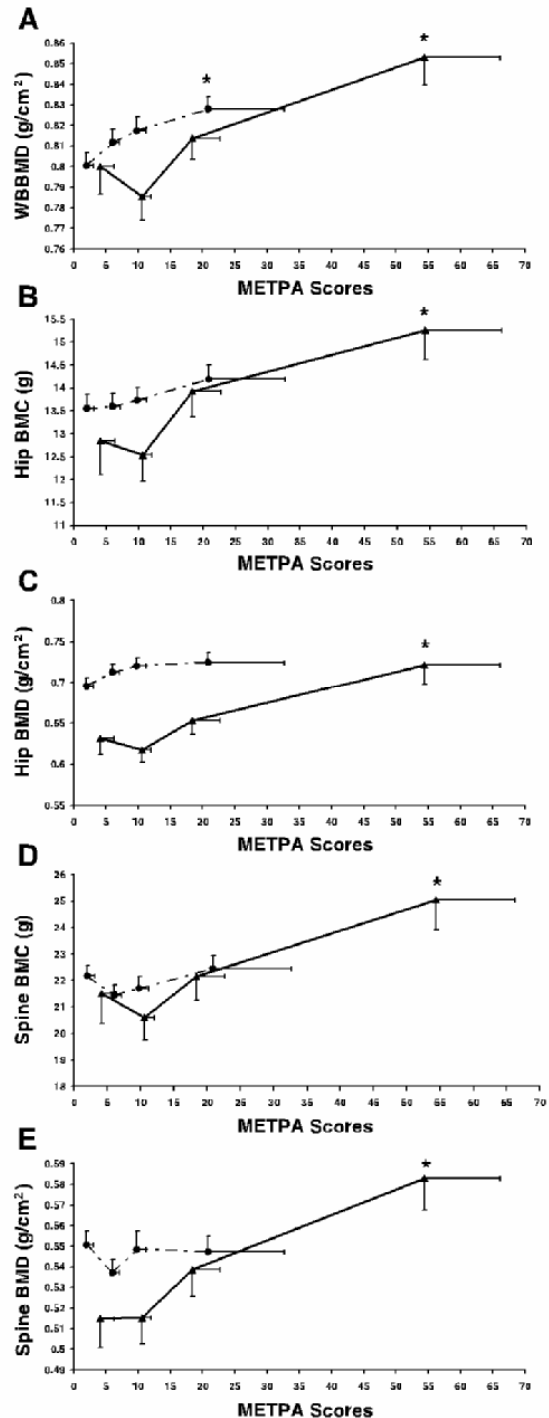

Fig. 1. Bone mass across metabolic equivalent physical activity (METPA) quartiles for black (●) and white (▲) children. *A:* whole body bone mineral density (WBBMD). *B:* hip bone mineral content (BMC). *C:* hip bone mineral density (BMD). *D:* spine BMC. *E:* spine BMD. Each symbol denotes a quartile, presented from *left* to *right* as lowest (Q1) to highest (Q4). Values are means ± SE. White children in Q4 had significantly higher bone mass than those in Q1 and Q2 (*$P < 0.05$).

Table 4. *Correlations between log METPA and MECHPA values and bone mass measurements in black and white children*

|	White Children (r)				Black Children (r)			
	Log METPA	P	Log MECHPA	P	Log METPA	P	Log MECHPA	P
WBBMC, g	0.26*	0.024	0.30*	0.011	0.03	0.590	0.03	0.628
WBBMD, g/cm²	0.34*	0.003	0.41**	<0.001	0.18*	0.002	0.1	0.101
Radial bone BMC, g	0.13	0.276	0.18	0.130	−0.02	0.785	−0.27	0.650
Radial bone BMD, g/cm²	0.07	0.574	0.18	0.116	−0.01	0.861	−0.77	0.197
Hip BMC, g	0.29*	0.014	0.36†	<0.001	0.06	0.289	0.02	0.736
Hip BMD, g/cm²	0.33*	0.004	0.51†	<0.001	0.07	0.229	−0.02	0.776
Spine BMC, g	0.26*	0.026	0.32†	<0.001	−0.01	0.887	−0.02	0.804
Spine BMD, g/cm²	0.34*	0.003	0.41†	<0.001	−0.05	0.424	−0.04	0.483

*$P < 0.05$. †$P < 0.001$

hip and spine BMC and BMD were significantly associated with increased levels of activity (i.e., a greater METPA score) and mechanical stress (MECHPA score) in white children. More active white children had a superior whole body BMD (up to 8% greater) and hip (up to 17% greater) mass and spine (up to 17%) mass than less active children, even before reaching adolescence and early adulthood, the period during which PA is assumed to be most influential on bone development (22, 37). These findings are in agreement with Janz et al. (18) and Slemenda et al. (36), who reported 4–7% greater bone mass in prepubertal children in the highest quartiles of weight-bearing PA. Significant positive correlations were found only for whole body BMD in black children. When BMC and BMD were plotted against activity quartiles for both METPA and MECHPA scores, an increase in both bone mass variables were seen for white children but not for black children. In this study, PA appeared to have an osteogenic association with bone mass in white children but not in black children. It appears that black children do not reach a high enough "threshold" of activity to induce an osteogenic association. This was evidenced by the black children's narrower range in activity scores. The highest activity and loading quartiles for black children had mean scores that were much lower than those of the white children's highest quartiles. Nevertheless, lower PA levels in this group of black children did not appear to negatively impact bone mass; black children as a whole still had a greater hip and spine (girls only) bone mass than the white children. The possibility of a genetic protection against low bone mass and fracture in blacks must be considered because calcium intakes and PA were lower in the black than in the white children. For blacks living in developing countries such as South Africa, as lifestyle and dietary patterns change with urbanization, fractures in the elderly may become more prevalent; thus PA may become increasingly more important as a means of protecting the skeleton in this population.

PA is an exogenous factor influencing bone health, and special attention should be given to its role in optimizing bone health. Studies performed in developed countries such as North America and Europe have shown that inactivity and activity patterns differ by ethnicity, with minority groups engaging in less PA (12). Hispanics and non-Hispanic blacks are less active than Caucasians, and African American children expend less energy than white children

(8). Obesity and higher body weight are strongly associated with a sedentary lifestyle and lack of PA in the adult population of the European Union (26), and the latter are key components in the growing overweight and obesity problem in Western populations. Of the few studies that have been recently published from developing countries, similar findings have been reported from South Africa (23, 35) and Nigeria (24). Despite differences in PA between black and white prepubertal children in the present study, no differences in BMI were noted between the ethnic groups.

The association between activity and bone mass is greatest in the weight-bearing regions of the skeleton. In our study, significant positive correlations were found at all weight-bearing sites in white children. Pocock et al. (29) have suggested that a possible reason for the hip being the site most receptive to differing levels of PA is because differences in skeletal load are most pronounced at the hip, as a result of the greater increment of load at this than at other sites. It is known that low-force activities, such as a long-distance running, swimming, and cycling, increase muscle endurance but not bone mass. Maximal force activities such as weight lifting and sports involving violent acceleration of the body put greater loads on bones than low-force exercises (33). Several studies have indicated that bone mass is a function of muscle strength (9, 27, 34). The positive influence of body weight and muscle mass on bone is well documented (17).

Studies investigating the association of past and present PA with bone mass and muscle mass and strength have led to inconsistent results. Although a few studies have examined the intensity, frequency, and duration of exercise needed to produce a significant effect on body composition and bone mass (3, 19, 25), no studies have observed children in developing countries. Additionally, most of these studies have been conducted in female subjects only and very few of these have examined ethnic differences. Schoenau and Frost (33) suggested that bone strength adapts to isometric muscle forces and peak momentary forces. Our data substantiate this observation. White children playing sports with a high bone strain such as rugby and gymnastics showed greater BMC and BMD at the whole body and at the hip, with the greatest difference again being observed at the hip (up to 17% greater in the "high-strain" group than in the "low-strain" groups). This suggests corresponding kinds of
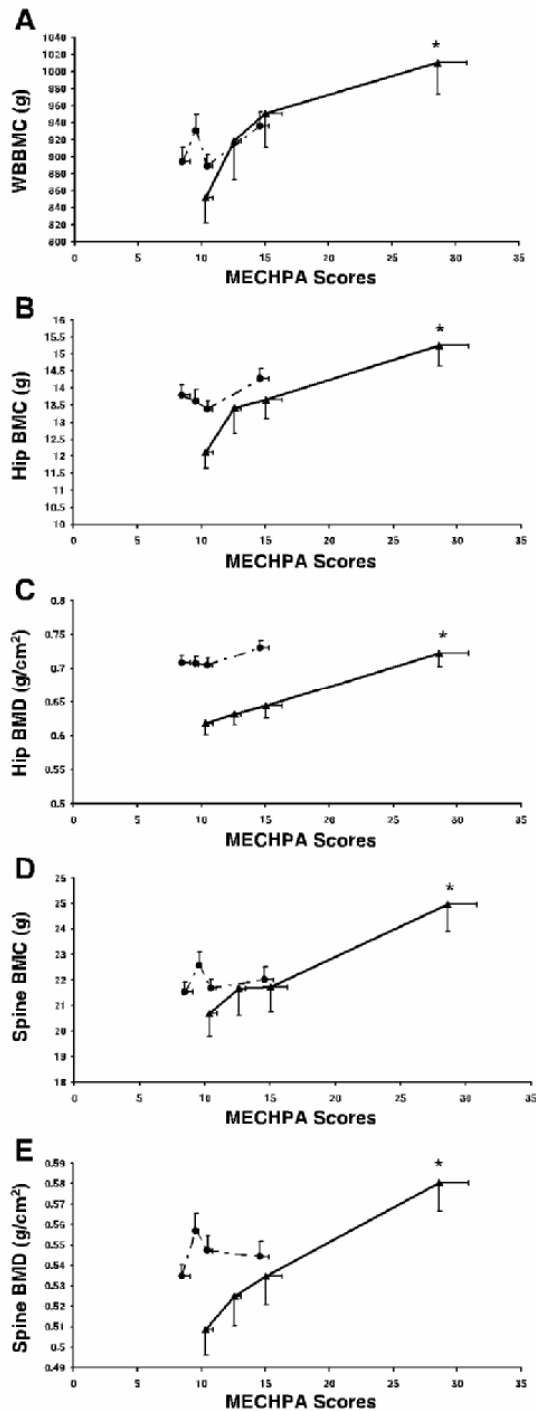
exercises during growth could help to achieve greater bone strength and subsequently minimize fractures in later life.

Studies have raised the possibility that the sooner children become active, the greater their bone accrual, lean muscle mass, and possible greater peak bone mass. On the basis of the present evidence, it is clear that bones of growing children benefit most from moderate to high levels of exercise and activity. What is unclear at present is the duration of the effect of exercise on bone once it is stopped and what effect this prepubertal exercise will have on bone mass after the pubertal growth spurt. Additionally, it is not clear whether we would see the same benefits of exercise with regard to bone mass in black children if they were participating at higher activity levels, similar to those of their white peers. One of the aims of the Birth to Twenty study is to attempt to answer these questions as these children move through puberty and into adulthood. Very few data exist on PA, bone mass, and body composition in developing countries. What is known, however, is that rapid changes in diet, activity, and the prevalence of obesity are occurring in residents of these countries (30). These changes are associated with an increase in chronic diseases, which will need to be addressed.

This study reports cross-sectional data from black and white 9-yr-old South African children involved in a longitudinal study. Therefore, these results may not necessarily be extrapolated to other populations. It will be important to follow up longitudinally to examine whether the observations made here persist into adolescence. Although a number of approaches to assessing children's PA have been described, no specific method has been identified as the best option for all studies (40). Although we acknowledge that there are limitations to using activity recall questionnaires, in this large longitudinal cohort of children, recall questionnaires are the only practical way to assess PA.

Understanding PA's impact on bone mass is central to developing primary prevention strategies for osteoporosis. Programs promoting physical education and PA are also desperately needed, specifically in the South African context. The lack of black children participating in physical education lessons at school is cause for concern, as it contributes to the lack of PA in the black children. Although fracture rates are relatively low at the present time in elderly black subjects, obesity and associated hypertension and diabetes are major concerns. Thus development of a culture of exercise is seen as being important in attempting to address these problems.

Fig. 2. Bone mass across mechanical physical activity (MECHPA) quartiles for black (●) and white (▲) children. A: WBBMC. B: hip BMC. C: hip bone BMD. D: spine BMC. E: spine BMD. Each symbol denotes a quartile, presented from *left* to *right* as lowest (Q1) to highest (Q4). Values are means ± SE. White children in Q4 had significantly higher bone mass than those in Q1 and Q2 (*P < 0.05).

REFERENCES

1. **Ainsworth BE, Haskell WL, Leon AS, Jacobs DR, Montoye HJ, Sallis JF, and Paffenbarger JR.** Compendium of physical activities: classification of energy costs of human physical activities. *Med Sci Sports Exerc* 25: 71–80, 1993.
2. **Aloia JF, Vaswani JK, Yeh JK, and Flaster E.** Risk for osteoporosis in black women. *Calcif Tissue Int* 59: 415–423, 1996.
3. **Bailey DA, McKay HA, Mirwald RL, Crocker PRE, and Faulkner RA.** A six-year longitudinal study of the relationship of physical activity to bone mineral accrual in growing children: the University of Saskatchewan Bone Mineral Accrual Study. *J Bone Miner Res* 14: 1672–1679, 1999.
4. **Bass S, Pearce G, Bradney M, Hendrich E, Delmas PD, Harding A, and Seeman E.** Exercise before puberty may confer residual benefits in bone density in adulthood: studies in active prepubertal and retired female gymnasts. *J Bone Miner Res* 13: 500–507, 1998.
5. **Bohannon AD.** Osteoporosis and African American women. *J Womens Health Gend Based Med* 8: 609–615, 1999.
6. **Courteix D, Lespessailles E, Peres SL, Obert P, Germain P, and Benhamou CL.** Effect of physical training on bone mineral density in prepubertal girls: a comparative study between impact-loading and non-impact loading sports. *Osteoporos Int* 8: 152–158, 1998.
7. **Daniels ED, Pettifor JM, Schnitzler CM, Moodley GP, and Zachen D.** Differences in mineral homeostasis, volumetric bone mass and femoral neck axis length in black and white South African females. *J Bone Miner Res* 13: 359–367, 1995.
8. **DeLany JP, Bray GA, Harsha DW, and Volaufova J.** Energy expenditure in preadolescent African American and white boys: the Baton Rouge Children's Study. *Am J Clin Nutr* 75: 705–713, 2002.
9. **Düppe H, Gärdsell P, Johnell O, Nilsson BE, and Ringsberg K.** Bone mineral density, muscle strength and physical activity. *Acta Orthop Scand* 68: 97–103, 1997.
10. **Elrick H, Samara TT, and Demas A.** Missing links in the obesity epidemic. *Nutr Res* 22: 1101–1123, 2002.
11. **Fonn S, de Beer M, and Kgamphe J.** Birth to ten: pilot studies to test the feasibility of a birth cohort study investigating effects of urbanisation in South Africa. *S Afr Med J* 79: 449–454, 1991.
12. **Gorden-Larsen P, McMurray RG, and Popkin BM.** Adolescent physical activity and inactivity vary by ethnicity: the National Longitudinal Study of Adolescent Health. *J Pediatr* 135: 301–306, 1999.
13. **Groothausen J, Siemer H, Kemper H, Twisk J, and Welten D.** Influence of peak strain on lumbar bone mineral density: an analysis of 15-year physical activity in young males and females. *Pediatr Exerc Sci* 9: 159–173, 1997.
14. **Haapasalo H, Kannus P, Sievänen H, Heinonen A, Oja P, and Vuori I.** Long-term unilateral loading and bone mineral density and content in squash players. *Calcif Tissue Int* 54: 249–255, 1994.
15. **Haapasalo H, Kannus P, Sievänen H, Pasanen M, Uusi-Rasi K, Heinonen A, Oja P, and Vuori I.** Effect of long-term unilateral activity on bone mineral density of female junior tennis players. *J Bone Miner Res* 13: 310–319, 1998.
16. **Heinonen A, Oja P, Kannus P, Sievänen H, Haapasalo H, Mänttäri A, and Vuori I.** Bone mineral density in female athletes representing sports with different loading characteristics of the skeleton. *Bone* 17: 197–203, 1995.
17. **Illich-Ernst J, Brownbill RA, Ludemann MA, and Fu R.** Critical factors for bone health in women across the age span: how important is muscle mass? *Medscape Women's Health eJ* 7: 1–15, 2002.
18. **Janz KF, Burns TC, Torner JC, Levy SM, Paulos R, Wiling MC, and Warren JJ.** Physical activity and bone measures in young children: the Iowa Bone Development Study. *Pediatrics* 107: 1387–1393, 2001.
19. **Johannsen N, Binkley T, Englert V, Neiderauer G, and Specker B.** Bone response to jumping is site-specific in children: a randomized trial. *Bone* 33: 533–539, 2003.
20. **Kannus P, Haapasalo H, Sankelo M, Sievänen H, Pasanen M, Heinonen A, Oja P, and Vuori I.** Effect of starting age of physical activity on bone mass in the dominant arm of tennis and squash players. *Ann Intern Med* 123: 27–31, 1995.
21. **Karlsson MK, Magnusson H, Karlsson C, and Seeman E.** The duration of exercise as a regulator of bone mass. *Bone* 28: 128–132, 2001.
22. **Kemper HCG.** Skeletal development during childhood and adolescence and the effects of physical activity (Abstract). *Pediatr Exerc Sci* 12: 216, 2000.
23. **Kruger HS, Venter CS, Vorster HH, and Margetts BM.** Physical inactivity is the major determinant of obesity in black women in the North West Province, South Africa: the THUSA Study. Transition and Health During Urbanisation in South Africa. *Nutrition* 18: 422–427, 2002.
24. **Luke A, Durazo-Arcizu RA, Rotimi CN, Iams H, Schoeller DA, Adeyemo AA, Forrester TE, Wilks R, and Cooper RS.** Activity energy expenditure and adiposity among black adults in Nigeria and United States. *Am J Clin Nutr* 75: 1045–1050, 2002.
25. **Mackelvie KJ, Khan KM, Petit MA, Janssen PA, and McKay HA.** A school-based exercise intervention elicits substantial bone health benefits: a 2-year randomized controlled trial in girls. *Pediatrics* 112: 447–452, 2003.
26. **Martinex-Gonzalez M, Martinez J, Hu F, Gibney M, and Kearney J.** Physical inactivity, sedentary lifestyle and obesity in the European Union. *Int J Obes Relat Metab Disord* 23: 1192–1201, 1999.
27. **Nordström P, Nordström K, Thorsen K, and Lorentzon R.** Local bone mineral density, muscle strength, and exercise in adolescent boys: a comparative study of two groups with different muscle strength and exercise levels. *Calcif Tissue Int* 58: 402–408, 1996.
28. **Pate RR, Heath GW, Dowda M, and Trost SG.** Associations between physical activity and other health behaviours in a representative sample of US adolescents. *Am J Public Health* 86: 1577–1581, 1996.
29. **Pocock NA, Gwinn T, Sambrook PN, Kelly P, Freund J, and Yeates MG.** Muscle strength, physical fitness and weight, but not age predict femoral bone mass. *J Bone Miner Res* 4: 441–448, 1998.
30. **Popkin BM.** The nutrition transition and its health implications in lower-income countries. *Public Health Nutr* 1: 5–21, 1998.
31. **Richter L, Yach D, Cameron N, Greisel D, de Wet T, and Anderson A.** Enrollment into birth to ten (BTT): sample and population characteristics. *Paediatr Perinat Epidemiol* 9: 109–120, 1995.
32. **Schnitzler CM and Mesquita JM.** Bone marrow composition and bone microarchitecture and turnover in blacks and whites. *J Bone Miner Res* 13: 1300–1307, 1998.
33. **Schoenau E and Frost HM.** The "muscle-bone unit" in children and adolescents. *Calcif Tissue Int* 70: 405–407, 2002.
34. **Schoenau E, Neu CM, Beck B, Manz F, and Rauch F.** Bone mineral content per muscle cross-sectional area as an index of the functional muscle-bone unit. *J Bone Miner Res* 17: 1095–1101, 2002.
35. **Senekal M, Steyn NP, and Nel JH.** Factors associated with overweight/obesity in economically active South African populations. *Ethn Dis* 13: 109–116, 2003.
36. **Slemenda CW, Reister TK, Hui SL, Miller JZ, Christian JC, and Johnston CC.** Influences on skeletal mineralization in children and adolescents of sexual maturation and physical activity. *J Pediatr* 125: 201–207, 1994.
37. **Snow-Harter C and Marcus R.** Exercise, bone mineral and osteoporosis. *Exerc Sport Sci Rev* 19: 418, 1991.
38. **Solomon L.** Bone density in ageing Caucasian and African populations. *Lancet* 2: 1326–1330, 1979.
39. **Tanner JM.** Normal growth and techniques of growth assessment. *Clin Endocrinol Metab* 15: 411–451, 1986.
40. **Welk GJ, Corbin CB, and Dale D.** Measurement issues in the assessment of physical activity in children. *Res Q Exerc Sport* 71: S59–S73, 2000.
41. **Yach D, Cameron N, Padayachee G, Wagstaff L, Richter L, and Fonn S.** Birth to ten: child health in South Africa in the 1990's. Rationale and methods of a birth cohort study. *Paediatr Perinat Epidemiol* 5: 211–233, 1991.

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The relationship between socio-economic status and physical activity patterns in South African children

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Aim: To examine: (1) the associations between socio-economic status, physical activity, anthropometric and body composition variables in South African children; (2) the influence maternal characteristics have on children's physical activity levels; and (3) associations between television watching, activity level and body composition. *Methods:* In 381 South African children, physical activity and socio-economic status were assessed via structured retrospective interview using validated questionnaires. An asset indicator score was calculated as a proxy measure of socio-economic status and used to divide children into quartiles. *Results:* Children falling into the highest socio-economic status quartile had mothers with the highest educational levels, generally came from dual parent homes, were highly physically active, watched less television, weighed more and had greater lean tissue than children in lower quartiles. A greater percentage of children living in dual parent homes and with mothers of a higher educational status were highly active compared with children living in single parent homes and with mothers of a lower educational status. We found greater levels of lean mass with increased activity level after controlling for television watching time and fat mass. There were high levels of low activity and high television watching time among lower socio-economic status groups. There were significant racial differences in patterns of activity. White children were found to be more active than black children, more likely to participate in physical education classes at school and watched less television than black children.

Conclusion: Physical activity levels and socio-economic variables are closely related in this population of South African children.

Key words: Children, physical activity, race, socio-economic status, South Africa

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I believe every human has a finite number of heartbeats. I don't intend to waste any of mine running around doing exercises. Neil Armstrong (1930–)

Promotion of physical activity (PA) minimizes the development of chronic diseases of lifestyle, aids in injury prevention by decreasing fall propensity, contributes to quality of life and improves psychological health (1). Adolescents with a healthy participation in PA are more likely to continue being active into adulthood (2). Thus, understanding the factors that may influence the adoption of good PA patterns in youth is crucial in aiming to establish life-long patterns of PA throughout adulthood.

In South Africa, much of the secular trend towards increased body size in adults has been attributed to the process of urbanization and associated socio-economic change. A shift from agriculturally-based economies to cash-based economies has minimized the need for physical labour and increased the demand on sedentary or less intensive physical work. Findings published by Kruger and colleagues in 2002 found a significant positive association between household income and obesity measures in South African black women. However, physical inactivity was found to have the strongest association with obesity in this study (3). This finding was recently substantiated in Senekal et al.'s (2003) paper, which identified physical inactivity as an important risk factor for overweight/obesity in South African adults (4). Although the literature regarding the relationship between PA and obesity in children and adolescents has been both scant and controversial, some authors have concluded that obesity in adolescents can only be altered by increasing PA and decreasing dietary intake at the same time (5, 6). Body composition is an important aspect to consider in the context of child and

adult health. It has recently been reported by Wells (2003) that lower PA levels may lead to reduced lean and increased fat mass, and that both of these occurrences may epitomize pathways of increased risk of adult disease (7). The link between low levels of PA and an associated increase in the risk of developing obesity emphasizes the need for these problems to be addressed in childhood.

Although we may commonly assume that PA is a normal part of childhood, a number of studies in developing countries have shown that children and adolescents are often very inactive (8, 9). In recent years, Western developed countries have positioned the promotion of PA in childhood and adolescence high on their agenda (10, 11). Developing countries, however, have not paid as much attention to this problem. In South Africa in particular, very little research has focused on PA patterns. Specifically, South African children's current social and economic situation and how this relates to children's PA patterns has not been examined. Socio-economic status (SES) has been identified as an important factor influencing PA participation (12). It is well known that children that come from low-income families often have limited access to resources supporting PA (13). The influence of demographic factors such as gender, race and SES provide us with information on variations in PA levels and allow for the design and implementation of appropriate programmes for different subgroups (13). It has been found that leisure time PA in childhood is related to maternal education levels (14). Studies have shown that families have an important role to play with regards to a child's quantity of exercise, creating access to facilities and encouragement of team and sport class participation (15). Many physical educators and scientists believe children of active parents tend to be more active themselves (16, 17).

The present study considers the prevalence of PA and inactivity in 9-y-old South African children, focusing on the prevalence of PA by gender, socio-economic status and maternal (primary caregiver) SES characteristics such as marital and employment status, as well as level of education. It is an additional aim of the study to examine body composition patterns in relation to SES and other sedentary behaviours such as television watching.

Subjects and methods

This is a population-based, cross-sectional study of children recruited from the Birth to Twenty birth cohort,

a longitudinal study of child health and development (18–20). All children born within a 6-wk period (23 April–8 June 1990) in the greater Johannesburg metropolitan area in South Africa were originally recruited. A random sample of children ($n = 682$) stratified by race group (black and white)*, gender and socio-economic status, participating in the Birth to Twenty birth cohort study, were enrolled into a longitudinal study assessing factors influencing bone mass during childhood and adolescence (Bone Health Study). Cross-checks were performed to ensure that there were no significant differences between the Birth to Twenty and Bone Health cohorts for key demographic variables (residential area at birth, maternal age at birth, gravidity, gestational age and birth weight). This study included data obtained from primary caregiver (defined as the mother for the purpose of this study) and child. Satisfying these requirements resulted in complete data for 381 children and mothers. Subsequent cross-checks were again performed between this study sample ($n = 381$) and the Bone Health cohort ($n = 682$) to ensure representation. Key demographic variables were similar and there were no differences in proportions of children in SES and race groups between this study sample and the original group. Subjects were all healthy and aged 9 at the time of testing. Children that were asthmatic or suffering from any disorder likely to affect bone metabolism were excluded from the study ($n = 10$). The sample comprised of 43 white males, 157 black males, 38 white females and 143 black females. All subjects and their parents provided written informed consent, and ethical approval was obtained from the University of the Witwatersrand Committee for Research on Human Subjects (protocol number: M980810).

All subjects completed an interview with the primary caregiver present. We examined past medication, known diseases, socio-economic and medical history, pubertal development and physical activity. Primary caregivers answered a number of questions regarding their social and economic status. This study utilized an asset indicator approach (22) by formulating a composite score from 11 bivariate factors (house type, electricity, indoor flushing toilet, indoor running water, television, motor vehicle, refrigerator, microwave, washing machine, video machine and telephone). From the asset indicator score we divided the sample into quartiles ranging from low to high SES. Mothers of the subjects also answered questions regarding their marital status and levels of education.

PA was estimated using a structured retrospective interview, taking into consideration all PA and inactivity over the previous 12 mo. The questionnaire is based on questionnaires validated in previous studies (23, 24). The questionnaire assessed the following parameters: whether or not the child partook in physical education classes at school; inactivity behaviours (TV and video watching, music, drawing and reading); passive (car/

taxi/bus) and active (walk/bicycle) commuting to and from school; number of hours of sleep per night; and intensity, frequency and type of organized sport played at school and after school. PA was then scored using a metabolic PA score (METPA) by weighting the intensity (multiples of basal metabolic rate (METs)) by the duration (h/wk) of each activity (25). These scores were divided into quartiles ranging from less active to highly active.

Anthropometric measures

The height of each child, recorded to the nearest millimetre, was measured using a stadiometer (Holtaine, UK), and weight, recorded to the nearest 100 g, was measured using a digital scale (Dismed, USA). Both devices were calibrated regularly throughout the study. Subjects were measured with light clothing and no shoes. Whole body scans were performed using a Hologic QDR 4500 dual-energy X-ray absorptiometer (DXA), according to standard procedures. The scan obtained from the DXA enabled the assessment of the whole body lean (LT) and fat tissue (FT) (g) and percent body fat (%).

Statistical analysis

Descriptive statistics were used to describe the physical features of the sample. Univariate analysis was used to determine ethnic and gender differences in physical activity. Factors contributing to the asset indicator score were identified as significant contributors through a factor analysis. The asset indicator score ranged from 1–11, and children were divided into four quartiles based on these scores. The analysis compared the prevalence of children falling into each of these quartiles in terms of percentages of PA and inactivity behaviour by socio-demographic background (maternal marital status, maternal education level and socio-economic score). Cross-tabulations with χ^2 tests were used to assess differences across ordinal variables such as education and support. Multivariate analysis, with confounding variables controlled for, was used to assess lean mass differences across activity and television quartiles.

Results

Socio-economic status results

These results describe the conditions under which the children in this study lived in Johannesburg, South Africa in 1999 (Fig 1.). Almost all of the children (99%) lived in homes with electricity. Approximately 88% of children lived in brick houses, whilst 12% lived in informal structures. Just over 60% had access to an indoor water source and almost 50% had toilets that flushed inside their houses. Television sets were owned in 95% of the houses; 94% of the families owned a

fridge; 76% had a land-line telephone; 54% had a video machine; 44% owned a washing machine; and 39% a microwave. Almost 60% of the sample did not own a motor vehicle.

In terms of partner support, 50% of mothers in this study were married and living with their husbands, 4% of mothers were living with their partners but not married, while 46% were single. Less than 50% of the children's mothers has completed a grade 12 (final year of school) education or higher. Diplomas were held by 17% of mothers, while only 6% of them held a university degree. At the time of the study 32% of mothers were not formally employed. Average maternal income ranged between R1000–2000 (Euro estimate: €100–200) per month. Almost all of the mothers described their children as being healthy; 9% of the mothers described their children's health as fair or poor. Private medical aid was held by 34% of the sample.

Profile of groups

Subjects were divided into quartiles according to their asset indicator score (lowest Q1–highest Q4). Table 1 indicates mean characteristic percentages of socio-economic, PA and anthropometric variables across each quartile.

There were approximately equal numbers of males and females within each quartile. No white children fell into the first three quartiles. Significantly fewer ($p < 0.001$) mothers in Q1 had completed high school (20%), whereas over 80% of mothers in Q4 had a high school education or higher. Significantly fewer mothers (40%) were married and living with their husbands in Q1 compared with over 70% in Q4 ($p < 0.001$). The majority of females in Q1–3 had no cash income, whereas the majority of females in Q4 earned a significantly greater income (>R4000/mo) ($p < 0.001$). There were no significant differences between maternal reports of their child's health across the quartiles.
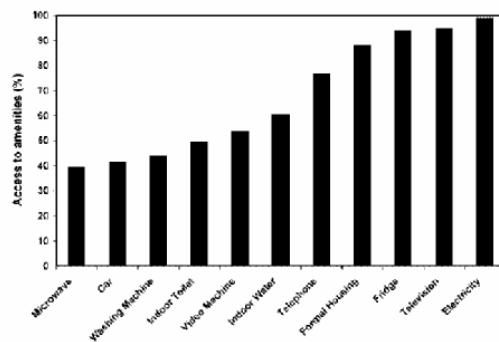

Fig. 1. Percentages of study sample (South African families) with access to amenities in 1999.

Table 1. Socio-economic, physical activity and anthropometric variables across SES quartiles.

	Q1 ($n=115$)	Q2 ($n=78$)	Q3 ($n=71$)	Q4 ($n=115$)
Asset indicator score (mean ± SE)	4.1 ± 0.1	6.4 ± 0.1	8.5 ± 0.1	10.7 ± 0.1[a]
Gender (% male)	53.9	52.6	49.3	52.2
Race (% white)	0	0	0	68.7[a]
Maternal education (% completed high school)	16.5	32.1	43.7	81.7[a]
Support (% mothers living with partner and married)	40	41	52.1	70.4[a]
Income (% with no cash income)	60	43.6	35.2	27.8[a]
Health of child (% good)	86.1	94.9	94.4	92.2
METPA score (mean ± SE)	10.5 ± 1.0	8.6 ± 1.3	8.5 ± 1.3	16.1 ± 1.0[d]
PE (% yes)	26.1	25.6	32.4	79.1[a]
TV (h) (mean ± SE)	21.99 ± 1.15[b]	26.91 ± 1.40[b]	26.53 ± 1.46	20.02 ± 1.15[c]
Weight (kg) (mean)	28.7 ± 0.6[f]	28.7 ± 0.7	31.1 ± 0.7	31.1 ± 0.6[d]
Height (mm) (mean)	1326 ± 5.6	1322 ± 6.8	1333 ± 7.2	1360 ± 5.8[a]
BMI (kg/m²) (mean)	16.3 ± 0.3	16.4 ± 0.4	17.5 ± 0.4	16.7 ± 0.3
TTF (g) (mean)	7255 ± 406	7575 ± 483	9000 ± 518	8824 ± 408[e]
TTL (g) (mean)	20123 ± 290	19839 ± 344[g]	20874 ± 367	21085 ± 391[g]

METPA: metabolic physical activity score calculated from school sport and active commuting to and from school; PE: physical education; TV: television; BMI: body mass index; TTF: tissue total fat; TTL: tissue total lean.
[a] Q4 > Q1, 2, 3; $p < 0.05$; [b] Q1 < Q2; $p < 0.05$; [c] Q4 < Q2, 3; $p < 0.05$; [d] Q4 > Q1, Q2; $p < 0.05$; [e] Q4 > Q1; $p < 0.05$; [f] Q1 < Q2, Q3; $p < 0.05$; [g] Q4 > Q2; $p < 0.05$.

Maternal health status perception of their child was not associated with PA participation.

Mean METPA scores were significantly greater in Q4 compared with all three other quartiles ($p < 0.001$). Percentages of children partaking in physical education (PE) at school rose significantly ($p < 0.001$) from 26% to 79% from Q1–4. Children in Q4 watched significantly less television than children in Q2 and 3 ($p < 0.05$) but not Q1. Children in Q1 watched significantly less television than children in Q2 ($p < 0.05$).

Significant differences were found across the groups for all anthropometric variables measured. Children in Q4 weighed significantly more than children in Q1 and Q2 ($p < 0.05$). They were also significantly taller ($p < 0.05$) than all three other quartiles. Children in Q1 weighed significantly less than those in Q2 and 3 ($p < 0.05$). There were no significant differences for BMI between groups, except that children in Q1 had a

significantly lower BMI ($p < 0.05$) than children in Q3. Children in Q4 had significantly greater fat tissue ($p < 0.05$) than children in Q1. Lean tissue was significantly greater ($p < 0.05$) in children in Q4 than Q2.

Socio-economic variables were correlated with physical activity variables. The variables with significant bivariate correlations were then examined further in terms of cross-tabulations and χ^2 likelihood ratios.

Maternal marital status ($r = 0.213$, $p < 0.001$), maternal education level ($r = 0.209$, $p < 0.001$) and asset indicator score ($r = 0.189$, $p < 0.001$) were significant correlates with physical activity level. Table 2 shows the results from bivariate cross-classifications of children partaking in the various levels of PA by socio-demographic variables. Inactive behaviour was more prevalent among children from households with single mothers than children who came from households with

Table 2. Analysis of physical activity levels by socio-demographic background.

	Inactive	Active	Moderately active	Highly active
Marital status			$p < 0.001$	
Single	32.4%	31.7%	21.4%	14.5%
Divorced/separated	24.0%	40.0%	16.0%	20.0%
Widowed	23.1%	7.7%	38.5%	30.8%
Married	18.9%	19.4%	28.6%	33.2%
Education			$p < 0.001$	
Incomplete schooling	23.0%	32.1%	25.4%	19.6%
Completed high school	30.2%	22.1%	24.4%	23.3%
Diploma	30.0%	11.7%	23.3%	35.0%
Degree	4.2%	8.3%	33.3%	54.2%
SES			$p = 0.001$	
Lower class	24.3%	25.2%	29.6%	20.9%
Working class	24.4%	37.2%	20.5%	17.9%
Middle class	28.2%	32.4%	19.7%	19.7%
Upper class	22.6%	12.2%	27.8%	37.4%

Reported p-levels are based on likelihood-ratio χ^2 tests.

Table 3. Lean mass (g) by television watching and activity level in South African 9-y-olds.

	n	Mean lean mass ± SE	*p* for trend
TV watching (h/wk)[a]			
<14	77	19939.9 ± 315.9	
14–22	81	20446.4 ± 303.4	
23–29	91	20477.2 ± 288.4	0.121
30–64	102	20950.1 ± 271.1	
Activity level[b]			
Less active	85	20170.3 ± 293.7	
Active	94	19874.5 ± 279.4	
Moderately active	87	20167.2 ± 290.0	<0.001
Highly active	85	21819.5 ± 294.3	

[a] Adjusted for fat mass and activity level.
[b] Adjusted for fat mass and TV watching time.

a married mother and father (32% vs. 19%). Highly active behaviour was more prevalent among children from married households than among children from single-parent households (33 % vs. 15%). Maternal education levels impacted on the type of activity children partook in. Children of mothers with degrees were more likely to be highly active (54%) than inactive (4%). Children whose mothers did not complete high school, or completed high school and had no further tertiary qualifications, were more likely to be inactive (23%) than highly active (20%). A greater percentage of children classified as coming from upper quartile (Q4) homes were highly active (38%) compared with 21% of children from lower quartile (Q1) homes that were highly active. On the whole, children that were from married households, had medical aid, had mothers with tertiary education and came from higher quartile homes were more highly active than children from lower socio-economic households.

Lean mass was explored by television watching (h/wk) and activity level (METPA score) (Table 3). After adjusting for fat mass and activity level, we found no significant differences in lean mass with increased hours spent watching television. However, after adjusting for fat mass and TV watching time, we found that

lean mass increased significantly ($p < 0.001$) with increased activity.

Physical activity results by race group

The data showed that 43% of the children participated in physical education (PE) classes at school (gym and swimming classes) at least once per week. METPA h/wk averaged 11 h/wk and television-watching time averaged 23 h/wk. Descriptive statistics for all physical characteristic variables are presented in Table 4.

Over 90% of white males and females participated in PE classes at school compared to only approximately 30% of their black peers. White children spent a significantly greater time ($p < 0.05$) sleeping and playing sports with a higher METPA ($p < 0.05$) than black children. Black children spent a greater amount of time watching TV and actively commuting to and from school ($p < 0.05$). After controlling for ethnic differences in PA, boys were significantly more ($p < 0.05$) active than girls (13.11 ± 0.77 MET h/wk vs 9.62 ± 0.81 MET h/wk). There was a significant positive correlation between participation in PE classes and METPA score ($r = 0.282, p < 0.001$) and a significantly negative correlation between METPA and hours of TV watched per week ($r = -0.145, p < 0.001$).

Discussion

This study analysed PA patterns and SES in South African children and the association between these variables. It is interesting to note that there were no white children in the first three quartiles of SES. A higher asset indicator score among the children was significantly associated with increased maternal education levels, better partner support and higher cash income. The number of children partaking in PE classes at school rose steadily with a higher asset indicator score. PA, as analysed by compiling a METPA score, showed an interesting trend. Children falling into Q1 (low SES) had a higher METPA score than Q2 and 3, but not 4. We would have expected the METPA score to

Table 4. Physical activity characteristics of 9-y-old South African children.

	White		Black	
	Female ($n-38$)	Male ($n-44$)	Female ($n-146$)	Male ($n-158$)
PE (% yes)	89.5§§	93.0**	34.3§§	27.4**
TV watching (h/wk)	14.87 ± 1.75§	17.28 ± 1.67**	23.52 ± 1.02§	26.54 ± 0.99**
Pass. comm. (h/d)	0.37 ± 0.05	0.33 ± 0.03	0.47 ± 0.06	0.4 ± 0.06
Act. comm. (h/d)	0.04 ± 0.02§	0.03 ± 0.01**	0.27 ± 0.03§	0.35 ± 0.03**
Sleep (h/night)	10.11 ± 0.14§	10.02 ± 0.09*	9.41 ± 0.13§	9.25 ± 0.77*
METPA score	14.7 ± 2.07§	22.25 ± 2.73**	8.28 ± 0.86§	10.71 ± 0.64**

PE: physical education; Pass. comm.: passive commuting (transport to and from school in a car/bus/taxi/train); Act. comm.: active commuting (transport to and from school via walking/riding a bicycle); METPA: metabolic physical activity score calculated from school sport and active commuting to and from school.
§ $p < 0.05$, white and black females differ; §§ $p < 0.001$, white and black females differ; * $p < 0.05$, white and black males differ; ** $p < 0.001$, white and black males differ.

have followed a "lowest-to-highest" trend. However, upon further analysis, it was found that almost 20% of the children who fell into Q1, did not own television sets. Consequently, these children spent the second lowest amount of time watching TV. Additionally, many of the children in this quartile did not have the same luxury items found in households of children from higher SES groups, suggesting that more of their time could be occupied with PA, both informal (on street, etc.) and formally (at school). These children had the lowest weight, BMI and fat tissue mass. This higher level of METPA and lower level of TV watching may be contributing to the healthier body composition patterns evident in the children in Q1. The highest METPA score was seen in Q4, which was significantly higher than all three other quartiles, and almost double the scores of Q2 and 3. There is some controversy in the literature regarding SES and PA. A study in the Philippines (26) showed that children from private schools were less physically active and more likely to prefer television to outdoor games. Our results in a South African population show the opposite and are in agreement with studies which have found higher PA levels to be associated with higher SES (27, 28). We found children in Q4 to have the highest PA scores, most likely to participate in PE at school and significantly higher lean mass.

In our whole sample, we found that weight increased significantly ($p = 0.002$) in the middle- and upper-class quartiles, compared with lower- and working-class quartiles. BMI increased up until the middle-class quartile and then decreased in the fourth upper-class quartile. Fat tissue increased and lean tissue increased with increasing SES. Children of mothers who were married or who had higher educational levels were found to be more active. Similar findings have been reported in adults, where inactivity has been found to be most common in those with a low educational level (29).

The sample was analysed by asset indicator score at first. However, these results showed that there were no white children in the first three lowest SES quartiles. The fact that all the white children fell into the highest SES quartiles is largely a function of South Africa's historical past. The physical activity data were then therefore analysed in terms of racial group. Results showed white children were more active than black children and that boys were more active than girls. These findings are consistent with studies performed in developed countries that have also found similar ethnic and gender differences in PA patterns (30). Less than half of the children in this study partook in PE classes at school. We found the PA score (METPA) to be significantly correlated with participation in PE classes; it may be that a lack of PE being offered at school level is translating into low levels of after-school or club sport and activity. This has serious implications for later health and social development.

We found no significant difference in lean mass between television quartiles after controlling for activity level and fat mass, but significant differences were shown for lean mass with increasing activity levels after controlling for television watching time and fat mass. Stafford's (1998) paper explored fat mass by TV and activity level. This study found a stronger relationship between fatness and activity level than between fatness and television watching (1). We found a similar relationship specifically when exploring lean mass.

To date, few studies have examined factors influencing PA in developing countries. Our data suggest important patterns of determinants of PA across groups of varying SES. It is clear that childhood PA is of a multi-dimensional nature, and socio-economic and cultural factors have a definite influence on these patterns. In spite of the well-documented negative associations between poverty or low SES and health (possibly due to low levels of PA) in adolescents and children, the mechanism by which this occurs is not well understood. In this group of children it appears that physical activity patterns could either be regulated by the primary caregiver or by the school that the child attends. If the school does not provide PE classes or after-school sport, parental or caregiver support may act as a buffer. If the parent or caregiver provides the support, their SES circumstances would be an influential factor.

Furthermore, few adjustable risk factors have been identified for intervention. PA is one of the most important modifiable causes of chronic disease. Abernathy et al. (2002) suggest that it may be possible to cushion the impact of poverty on health through policies that could increase PA levels among those living in poverty. In order to develop individual-level and policy-level interventions, it is imperative that we understand all aspects affecting PA in potentially disparate populations (29).

References

1. Stafford M. Television watching and fatness in children. JAMA 1998; 280: 1230–1
2. Vanreusel B, et al. A longitudinal study of youth sport participation and adherence to sport in adulthood. International Review for the Sociology of Sport 1997; 32: 373–87
3. Kruger H, Venter C, Vorster H, Margetts B. Physical inactivity is the major determinant of obesity in black women in the North West Province, South Africa: The THUSA Study. Transition and health during urbanisation in South Africa. Nutrition 2002; 18: 422–7
4. Senekal M, Steyn N, Nel J. Factors associated with overweight/obesity in economically active South African populations. Ethnic Dis 2003; 13: 109–16

5. Roberts SB. Abnormalities of energy expenditure and the development of obesity. Obes Res 1995; 3: 1555–635
6. Ballor DL, Keessey RE. A meta-analysis of the factors affecting exercise-induced changes in by body mass, fat mass and fat-free mass in males and females. Int J Obes Relat Metab Disord 1991; 15: 717–26
7. Wells JC. Body composition in childhood: effects of normal growth and disease. Proc Nutr Soc 2003; 62: 521–28
8. Heath G, Pratt M, Warren C, Kann L. Physical activity patterns in American high school students. Arch Pediat Adolesc Med 1994; 148: 1131–6
9. Trippe H. Children and sport. Br Med J 1996; 199: 199
10. U.S. Department of Health and Human Services. Healthy people 2010 fact sheet: healthy people in healthy communities; 1999
11. WHO Regional Office for Europe. Health21: the health for all policy framework for the WHO European region; 1999
12. Coakley J, White A. Making decisions: gender and sport participation among British adolescents. Sociology of Sport Journal 1992; 9: 20–35
13. Sallis J, Zakarian J, Hovell M, Hofstetter C. Ethnic, socio-economic, and sex differences in physical activity among adolescents. J Clin Epidemiol 1996; 49: 125–34
14. Kuh DJ, Cooper C. Physical activity at 36 years: patterns and childhood predictors in a longitudinal study. J Epidemiol Community Health 1992; 46: 114–9
15. Mota J, Silva G. Adolescents physical activity: association with socio-economic status and parental participation among a Portuguese sample. Sport, Education and Society 1999; 4: 193–9
16. Freedson P, Evenson S. Familial aggregation in physical activity. Res Q Exerc Sport 1991; 62: 384–9
17. Moore L, Lombardi D, White M, Campell J, Olshan A, Ellison R. Influence of parents physical activity levels on activity levels of young children. Pediatrics 1991; 118: 215–9
18. Yach D, Cameron N, Padayachee G, Wagstaff L, Richter L, Fonn S. Birth to ten: child health in South Africa in the 1990s. Rationale and methods of a birth cohort study. Paediatric and Perinatal Epidemiology 1991; 5: 211–33
19. Fonn S, de Beer M, Kgamphe J. Birth to ten: pilot studies to test the feasibility of a birth cohort study investigating effects of urbanisation in South Africa. S Afr Med J 1991; 79: 449–54

20. Richter L, Yach D, Cameron N, Greisel D, de Wet T. Enrolment into Birth to Ten (BTT): population and sample characteristics. Paediatric and Perinatal Epidemiology 1995; 9: 109–20
21. Zwarenstein M, Price M. The 1983 distribution of hospital and hospital beds in the RSA by area, race, ownership and type. S Afr Med J 1990; 77: 448–52
22. Bradshaw D, Steyn K. Poverty and chronic disease in South Africa. South Africa: Medical Research Council; 2001
23. Pate R, Heath G, Dowda M, Trost S. Associations between physical activity and other health behaviours in a representative sample of US adolescents. Am J Public Health 1996; 86: 1577–81
24. Sallis J, Condon S, Goggin K, Roby J, Kolody B, Alcarez J. The development of self-administered physical activity surveys for 4th grade students. Res Q Exerc Sport 1993; 64: 25–31
25. Ainsworth B, Haskell W, Leon A, Jacobs D, Paffenbarger R. Compendium of physical activities: classification of energy costs of human physical activities. Med Sci Sports Exerc 1993; 25: 71–80
26. Florentino R, Villavieja G, Lana R. Dietary and physical activity patterns of 8–10-year-old urban school children in Manila, Phillipines. Food Nutr Bull 2003; 23: 267–73
27. Kristjansdottir G, Vilhjamlmsson R. Sociodemographic differences in patterns of sedentary and physically active behaviour in older children and adolescents. Acta Paediatr 2001; 90: 429–35
28. Krassas G, Tzotzas T, Tsametis C, Konstantinidis T. Determinants of body mass index in Greek children and adolescents. JPEM 2001; 14: 1327–33
29. Parks S, Housemann R, Brownson R. Differential correlates of physical activity in urban and rural adults of various socio-economic backgrounds in the United States. J Epidemiol Community Health 2003; 57: 29–35
30. Gorden-Larsen P, Adair L, Popkin B. Ethnic differences in physical activity and inactivity patterns and overweight status. Obes Res 2002; 10: 141–9

REGULAR ARTICLE

Bone mass accretion rates in pre- and early-pubertal South African black and white children in relation to habitual physical activity and dietary calcium intakes

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Abstract

Aim: To examine bone mass changes in 321 black and white South African children in relation to habitual physical activity (PA) levels and calcium intakes.

Methods: Children underwent two bone mass scans at ages nine and 10 years using dual X-Ray absorptiometry. PA levels and calcium intakes were assessed using questionnaires. Data were analyzed by regressing change in bone mineral content (BMC) and bone area (BA) from age nine to 10, against BA (for BMC), height and body weight. The residuals were saved and called residualized BMCGAIN and BAGAIN. Residualized values provide good indication of weight, height and BA-matched accumulation rates.

Results: White children had significantly higher PA levels and calcium intakes than black children. Most active white males had significantly higher residualized BMCGAIN and BAGAIN at the whole body, hip and spine but not at the radius, than those who were less active. Most active white females had significantly higher residualized BAGAIN at all sites except the radius than less-active girls. No such effects were seen in black children. There was no interactive effect on residualized BMCGAIN for calcium intake and PA (except at the spine in white girls).

Conclusion: Bone mass and area gain is accentuated in pre- and early-pubertal children with highest levels of habitual physical activity. Limited evidence of an effect of dietary calcium intakes on BMC was found.

INTRODUCTION

The main determinants of peak bone mass are heredity, gender and race (1). Regardless of race or gender, nutrition and physical activity (PA) participation are considered to be the most modifiable environmental factors influencing peak bone mass. This is particularly so in the pre-pubertal years, which appear to be the most responsive to these influences (2,3).

A small number of studies have recently examined the effects of exercise and calcium interventions on bone mass (4–6). Iuliano-Burns et al. (2003) reported main and interactive effects for calcium and PA interventions at the hip in pre- and peri-pubertal females. Stear et al. (2003) also reported enhanced bone mass with a calcium and PA intervention in adolescent females, although the interactive effect (if any) of the two interventions was not reported. Specker et al.'s (2003) intervention showed that although PA stimulated growth in bone width, the actual amount of bone mineral accumulated is dependant on both PA level and calcium intake (5). In a 12-month follow-up to this trial, no consistent effect of calcium supplementation on leg bone mineral content (BMC) was noted (7).

None of these studies have reported on racial differences and all have been conducted in developed countries. There are little longitudinal observational data on the effects of habitual PA and calcium intakes on bone mass accretion in children, especially in racially diverse populations in developing countries such as in South Africa, where calcium intakes are generally lower than those in developed countries. Of the studies that have examined habitual PA and calcium intakes, data have only been reported for short time periods (1 week or less) (8). In addition, most studies have reported on the association between PA and BMC, and the issue of whether habitual exercise increases bone size as well has not yet been clarified. To date, only one elegantly performed study (9) has shown that a moderate level of PA within a school curriculum enhances BMC, bone mineral density (BMD) and bone area (BA).

With an exponentially increasing hip fracture rate in the ageing population in developed countries (10), scientists are advocating PA and calcium intake as important modifiers of bone mass. This research is particularly important in countries where a more sedentary lifestyle is becoming the norm and where physical education no longer forms part of the school curriculum. The situation in South Africa is of particular interest since South African blacks are reported to have among the lowest hip fracture rates in the world, but lifestyles are under rapid transition currently (11,12).

The aims of our study were to examine bone mass changes over a 12-month period in a group of black and white South African pre- and early-pubertal children and to explore these changes in relation to habitual PA levels and calcium intakes.

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MATERIALS AND METHODS

Subjects

This is an observational study of a cohort of children (Bone Health Study) recruited from the *Birth to Twenty* birth cohort, a longitudinal study of child health and development (13–16). The methods of enrolment into the Bone Health Study have been described in detail elsewhere (17,18). For this study, subjects were all healthy and aged 9 years [9.51 (0.27)] at visit one and 10 years (10.54 [(0.27)] at visit two. Children who were asthmatic or suffering from any disorder likely to affect bone metabolism were excluded from the study. Complete data for the two annual visits, spaced 1 year apart were available for 321 children. The sample was composed of 31 white males, 141 black males, 27 white females and 122 black females. The small number of white children was primarily due to the method of enrolment. Total births over the specified time period were enrolled, and there were fewer white than black children born during this time period. All subjects and their parents provided written informed consent and ethical approval was obtained from the University of the Witwatersrand Committee for Research on Human Subjects.

Measurements

At each visit, the height (Holtaine, UK) and weight (Dismed, USA) of each child were measured with subjects wearing light clothing and no shoes. Body and site-specific BMC, bone mineral BMD and BA were measured using a Hologic QDR 4500A dual energy X-Ray absorptiometer (DXA) according to standard procedures (software version 11.2 for adults, Hologic, USA). DXA scans were performed on the non-dominant midshaft radius, femoral neck of the left hip, lumbar spine (L1-L4) and whole body (WB). The analysis for the WB was done excluding the measurements of the head. The reader is referred to (17,18) for more detailed description of the methods used in the Bone Health and Birth to Twenty Studies.

Questionnaires

Each subject completed the same questionnaires on both visits, with the caregiver present. We examined past medication, known diseases and pubertal development (by Tanner hair development [(19)]. Girls were asked about their menstrual status. Dietary calcium intakes were assessed using a 24-h dietary recall questionnaire as well as by a Food Frequency Questionnaire. Total PA was estimated using a structured, detailed, retrospective interview taking into consideration all PA and inactivity over the previous 12 months. The questionnaire has previously been used by our group (17,18) and is based on questionnaires validated in other studies (20,21). The questionnaire has been modified appropriately for South African children. The intensity, frequency and duration of all physical activities (at school, after school, at home and commuting [actively and passively] to and from school) were taken into account. Intensities of activities were classified as multiples of one metabolic equivalent (MET) (the ratio of the associated metabolic rate for the specific activity to the resting metabolic rate). PA was scored

in two ways: (i) metabolic PA score (METPA) by weighting the intensity [multiples of basal metabolic rate (MET'S) and duration (h/wk)] (22); and (ii) mechanical PA score (MECHPA) by weighting the peak bone strain (ground reaction forces as multiples of body mass and duration [(h/wk)] (23).The latter score is based on the method of Groothausen and co-workers (23), which we modified by multiplying the ground reaction force (MECH) by duration, since the original measure did not include duration or frequency. Thus, a sum score MECHPA was calculated as the sum of all MECH scores multiplied by duration (h/wk) per activity. Since the PA questionnaire assessed all activity in the preceding 12 months, year 10 data was considered to be representative of activity in the 12-month assessment period.

Statistical analysis

Data were analyzed using SPSS v12.0, and a p level of <0.05 was considered to be statistically significant. Percentage gains in BMC and BA (BMCGAIN and BAGAIN) were calculated. An ANOVA was used to detect differences in BMCGAIN and BAGAIN between race and gender groups from age 9 to 10 years, and the Bonferroni multiple comparison test was used to assess group differences where appropriate. BMD is an areal density measurement (g/cm^2), and does not account effectively for diverse body sizes. To avoid size-related artefacts, BMC was adjusted for body weight and BA in multiple regression analyses (24,25). Our results indicated that height was not significantly related (p = 0.891) to BMC, thus it was excluded as a covariate. Height was, however, significantly related to BA (p < 0.001) at all sites and was therefore included as a covariate for BA analyses. We used a novel method based on the technique of Rowlands et al. to assess changes in bone-related variables (8). We regressed body weight and BA against BMCGAIN and saved the residuals to form a new variable called residualized BMCGAIN (BMCGAIN$_{res}$). The same procedure was followed for BAGAIN, whereby body weight and height were regressed against BAGAIN, and the residuals were saved to form a new variable called BAGAIN$_{res}$. Given the weight and height of a subject , BMCGAIN$_{res}$ and BAGAIN$_{res}$ provide a good indication of whether the subjects are above or below their expected value for their weight and height. To assess whether the non-bone–related components of weight (fat and lean mass) had different effects on BMCGAIN or BAGAIN, we ran a regression analysis including the additional covariates.

METPA and MECHPA scores were evaluated over the 1-year period preceding the second DXA scans and were assessed as categorical variables after subjects were divided into quartiles of activity within race and gender groups. To correct for the possible effects of differing PA on BMC and BA accumulation prior to the study period, METPA and MECHPA scores calculated at the first visit of the subject (age 9) were entered into the regression analysis as covariates. BMCGAIN$_{res}$ and BAGAIN$_{res}$ at the whole body, radius, hip and spine were assessed within METPA and MECHPA quartiles, between race and gender groups using a multivariate ANOVA. A stepwise linear multiple

regression analysis was conducted in order to assess the relationship between the PA of the past year (both METPA and MECHPA), calcium intake and BMCGAIN$_{res}$ at all sites measured. The independent variables were entered in the following order: calcium intake, METPA, MECHPA, product of calcium intake ∗ METPA and the product of calcium intake ∗ MECHPA. Independent variables were centred before being entered into the regression analysis, in order to avoid the problem of multi-collinearity (26). Centring involves subtracting the mean from each individual score thereby making the mean of the centred variable zero. The product terms were calculated from the centred variables. All data are presented as means (standard deviation), unless otherwise noted.

RESULTS

Included in the study were 58 white and 263 black children, with approximately equal numbers of males and females in each group. Pubertal scores were similar between black and white children of the same sex (Table 1 in Supplementary Material online). None of the girls had begun menstruating, and all subjects were considered to be either pre- or early pubertal. There were no significant differences between the skeletal ages of any of the groups.

Table 1 shows the results for percentage gain and actual change in height, weight and unadjusted BMC and BA from age 9 to 10 years, as well as calcium intakes and pubertal stage at age 10. Black males were significantly shorter at age 10 years and had significantly lower percentage BMCGAIN at the spine, BAGAIN at the whole body, calcium intake and PA scores than white males (p < 0.001). There were no significant differences in weight at 10 years, BMCGAIN at the radius or BAGAIN at the radius and hip between any of the groups.

We assessed whether the non-bone–related components of weight (fat and lean mass) had different effects on BMCGAIN or BAGAIN using a multiple regression analysis. The addition of fat mass, lean mass and calcium values to the regression had very little impact on the whole body content and area gain values. Each covariate did not contribute significantly more to the model than height alone. The same trend was evident at other sites and for other groups. We therefore did not control for these variables in the residual analysis.

Table 2 (in Supplementary Material online) shows the results for actual year 10 and percentage gain in BMC [adjusted for weight (kg) and BA (cm^2)] and BA [adjusted for weight (kg) and height (cm)] values. Black males had significantly greater adjusted hip BMC and radius BA at age 10 years (p = 0.001) and significantly lower percentage gains in spine BMC (p = 0.034) and WB BA (p = 0.027) than white males. Black females had significantly greater adjusted hip BMC (p = 0.001), WB BA (p = 0.03) and radius BA (p = 0.002) and significantly lower hip BA (p = 0.017) than white females at age 10.

We have reported previously descriptive data for the PA patterns of this population at age 9 (17,18). At age 10,

white males had significantly greater METPA and MECHPA scores than all other groups (p < 0.001) (Table 1 in Supplementary Material on-line). Subjects were divided into quartiles of activity within race and gender groups, and levels of activity were then related to BMCGAIN$_{res}$ and BAGAIN$_{res}$ at different sites. Residual values above 0 indicate that the BMC and BA of the subjects fall above their expected values for their weight, height and BA and vice versa.

Figures 1 and 2 show BMCGAIN$_{res}$ and BAGAIN$_{res}$ values at the whole body for different quartiles of METPA and MECHPA within race and gender groups. White children in quartile 4 (highest PA group for both METPA and MECHPA) showed significantly greater BMCGAIN$_{res}$ and BAGAIN$_{res}$ compared with the lowest quartiles. The same trend was observed at the weight bearing sites (hip and spine) for white males in quartile 4 showing significantly greater (p < 0.05) BMCGAIN$_{res}$ and BAGAIN$_{res}$ compared with groups in the lowest quartiles (see Figures S1–4). White females in quartile 4 had significantly higher (p < 0.05) BAGAIN$_{res}$ at the hip than children in lower quartiles. No differences were observed at the radius for any quartiles or groups. In addition, white males in the highest quartile of PA had BMCGAIN$_{res}$ and BAGAIN$_{res}$ values well above 0. White females had BAGAINres values above 0 at all sites. There were no other significant differences for any of the other groups between race and/or gender.

A multiple linear regression sought to examine the effects of calcium intake and PA (both METPA and MECHPA) on BMCGAIN$_{res}$ at the whole body, radius, hip and spine. There were no significant effects for any of the groups at the radius. No simple effects for calcium were found at any site for any of the groups except in white females at the hip (p = 0.012). There were significant effects of MECHPA in white boys on BMCGAIN$_{res}$ at the whole body (p = 0.03), hip (p = 0.002) and spine (p = 0.005) and of METPA at the hip (p = 0.03). A significant effect of METPA at the spine (p = 0.033) was observed for white girls. The only significant interaction between calcium and METPA was seen at the spine in white girls (p = 0.027).

DISCUSSION

The present study has shown that white females and males accumulate BMC, BA, height and weight at similar rates over a 12-month period between the ages of 9 and 10 years both before and after adjustment for body size. Black males, however, had lower height, weight, BMC (at all sites measured) and BA (whole body and spine) accumulation rates compared with that of the other groups. White males had the highest PA levels and white male children falling into the highest quartile of activity exhibited bone mass benefits at the whole body, total hip and lumbar spine sites. The same was true for white females at the whole body and hip. White children consumed approximately twice the amount of calcium as black children. Nevertheless, black children had higher hip BMC adjusted for body weight and BA than white children at age 9 (17) and 10 years, despite lower calcium intakes and PA levels.
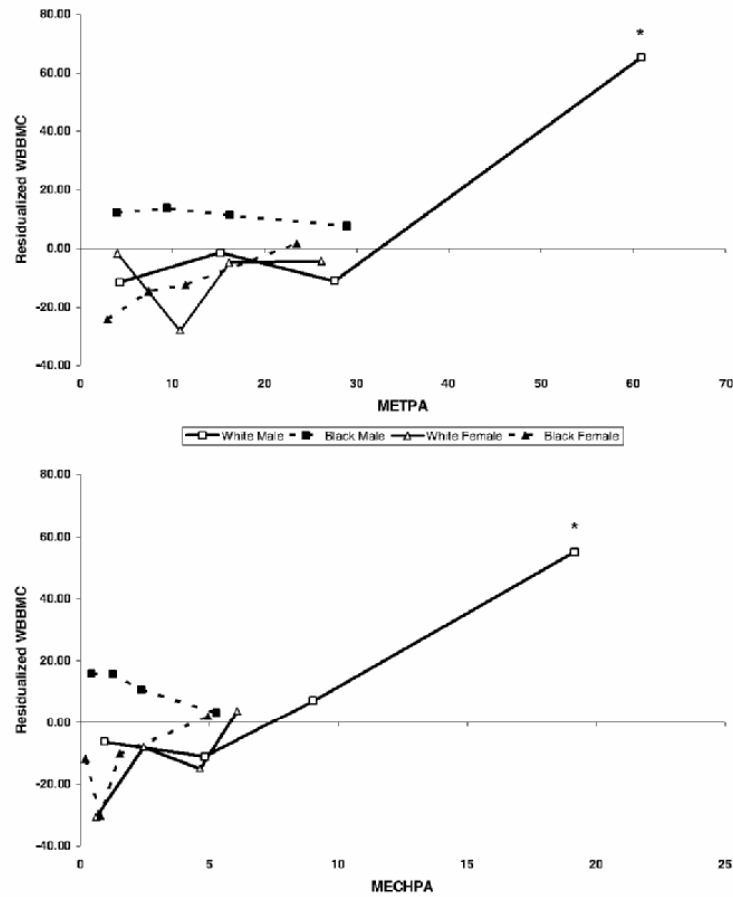
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Figure 1 Residualized whole body BMC gain (WBBMC) within quartiles of METPA (panel A) and MECHPA (panel B) for black and white male and female subjects. *p < 0.05, quartile 4 > quartile 1 and 2 for white males.

This study describes normal habitual PA patterns and calcium intakes in healthy children living in South Africa. We have comparatively small numbers of white children compared with that of black children. This is largely a function of the racial distribution of the South African population as well as the method of enrolment used in this study. It will be important to continue our longitudinal study in order to examine whether the observations made here persist through the pubertal growth spurt. Although a number of approaches to assessing PA of children have been described, no specific method has been identified as the best option for all studies (27). While we acknowledge that there are limitations to using activity recall questionnaires, in this large longitudinal cohort of children, recall questionnaires is the only practical way to assess PA. In addition, we are aware of the limitations of using DXA measurement in children, specifically in

that the measurements we report on in this paper provide no information on structural alterations of bone and overlook the periosteal and endosteal dimensions that influence bone strength. Measurements of bone structure such as those provided by pQCT would be invaluable in this group of subjects.

The relationship between PA and bone mass is governed by the degree of PA; in order for sizeable bone mass changes to occur, PA must be great enough to induce these positive effects (6). Our results agree with the notion that PA levels need to be above a certain threshold in order for bone mass benefits to be seen. White males showed both a wider and higher range of scores for METPA and MECHPA compared with that of all other groups, and the benefits of these higher levels of activity are reflected in the greater BMC and BA in highly active children (quartile 4). This 'threshold' of activity is important to consider when designing exercise programs
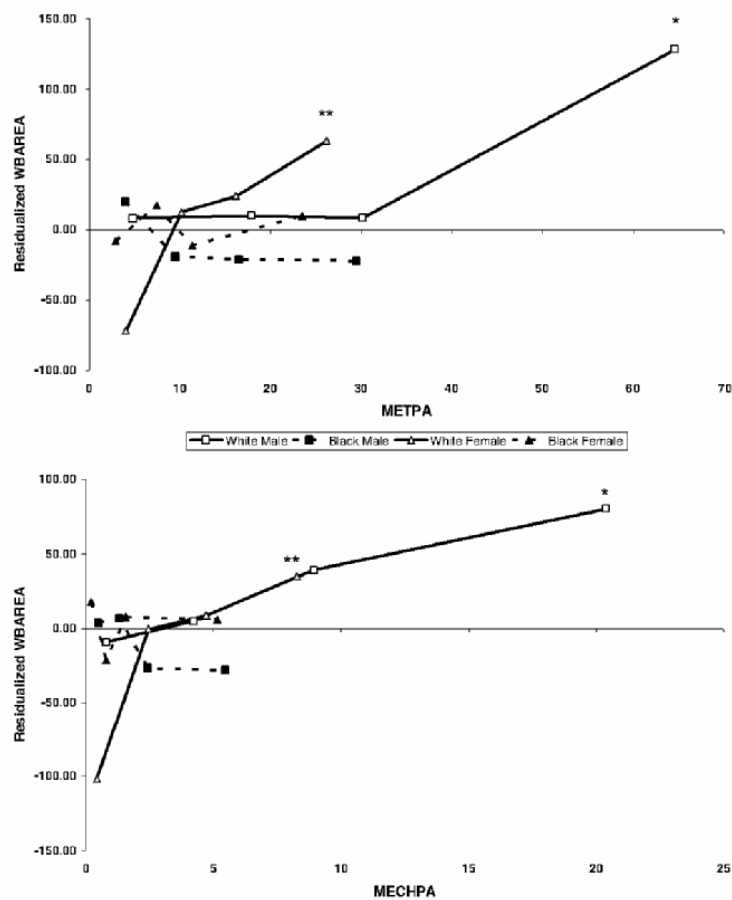
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Figure 2 Residualized whole body area gain within quartiles of METPA (panel A) and MECHPA (panel B) for black and white male and female subjects. *p < 0.05, quartile 4 > quartile 1, 2 and 3 (METPA) and quartile 4 > quartile 1 and 2 (MECHPA) for white males. **p < 0.05, quartile 4 > quartile 1 for white females.

aimed at increasing bone mass. Whether this threshold is reached by performing activities with a high enough strain on the bone for a short period of time or performing less strenuous activities for a longer period of time is unclear. The minimum effective dose of weight-bearing activity remains a controversy, as studies have shown bone mass increases from jumping for as little as 3 min per day (28). In our study, the most popular sports among white boys were soccer, cricket, tennis and swimming. White boys in the fourth quartile of activity were playing sport for approximately 1 1/2 h per day.

Our study confirms our previous findings of lower PA levels in black children. Similar findings have been reported in developed countries such as the United States, where African American children were found to have the lowest levels of activity when compared with non-Hispanic white, Hispanic and Asian children (3,29). We have shown that

when PA levels are high and possibly above a threshold or 'active' time period, significant bone mass effects are seen. This was evident for white males, where associations between PA and residualized bone mass at the whole body, hip and spine were observed. All white males that were in the highest quartile of activity showed residualized bone mass well above 0 (the expected score for the weight and BA of the child). White females had residualized bone mass above 0 at all sites for BA. It thus appears that these were the only group who had high enough levels of habitual PA, such that a positive and significant effect on bone mass at the whole body, hip and spine was seen. The lack of any effect of PA on radial bone mass adds support to the contention that it is a weight bearing effect of PA that induces the changes in bone mass. This study supports the hypothesis that mechanical loading during the growing year's impacts on bone mass and structural indices such as BA.

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Our data do not suggest that calcium has a synergistic effect with PA on bone as has been previously suggested (4,5,8). Calcium and METPA showed an interactive effect for white girls only. The current recommendation in the United States for calcium intake in Caucasian children is 1300 mg/day (30). According to this amount, none of our groups met the current recommendation with the mean intake of white children being about 56% and that for black children about 25% of the adequate intake for calcium. The possibility that calcium intakes were not high enough in any of the groups to induce a positive association with bone mass or a synergistic effect with PA must be considered. This study does raise an apparent paradox. Despite the low calcium intakes and low PA levels of South African black children, they still have higher bone mass at the hip than white children and similar values to their white peers at other sites.

In summary we have demonstrated differences in habitual PA levels and calcium intakes between black and white South African children. An interactive effect of calcium and PA was not shown in our study. In addition we have shown that residualized bone mass gain, which is a good indicator of weight and BA matched BMC gain, is highest at all weight bearing sites in the most physically active children. The same trend was observed for weight and height matched BA gain, whereby BA gain was greatest at all weight-bearing sites in the most active children. It thus appears that habitual PA above a certain level is related to both BMC and bone size (BA). Future research should examine whether the racial differences in BMC accumulation rates observed in our study would be exacerbated if PA levels in black children were increased to those of white males.

ACKNOWLEDGEMENTS

References

1. Gilsanz V, Roe TF, Mora S, Costin G, Goodman WG. Changes in vertebral bone density in black girls and white girls during childhood and puberty. *N Engl J Med* 1991; 325: 1597–600.
2. Haapasalo H, Kannus P, Sievänen H, Pasanen M, Uusi-Rasi K, Heinonen A, et al. Effect of long-term unilateral activity on bone mineral density of female junior tennis players. *J Bone Miner Res* 1998; 13: 310–9.
3. McKay HA, Petit MA, Khan KM, Schutz RW. Lifestyle determinants of bone mineral: a comparison between prepubertal Asian and Caucasian Canadian Boys and Girls. *Calcif Tissue Int* 2000; 66: 320–4.
4. Iuliano-Burns S, Saxon L, Naughton G, Gibbons K, Bass S. Regional specificity of exercise and calcium during skeletal growth in girls: a randomized controlled trial. *J Bone Miner Res* 2003; 18: 156–62.
5. Specker B, Binkley T. Randomized trial of physical activity and calcium supplementation on bone mineral content in 3- to 5-Year-old children. *J Bone Miner Res* 2003; 18: 885–92.

6. Stear SJ, Prentice A, Jones SC, Cole TJ. Effect of a calcium and exercise intervention on the bone mineral status of 16-18-y-old adolescent girls. *Am J Clin Nutr* 2003; 77: 985–92.
7. Binkley T, Specker B. Increased periosteal circumference remains present 12 months after an exercise intervention in preschool children. *Bone* 2004; 35: 1383–8.
8. Rowlands A, Ingledew DK, Powell SM, Eston RG. Interactive effects of habitual physical activity and calcium intake on bone density in boys and girls. *J Appl Physiol* 2004; 97: 1203–8.
9. Linden C, Ahlborg H, Besjakov J, Gardsell P, Karlsson M. A school curriculum-based exercise program increases bone mineral accrual and bone size in prepubertal girls: two-year data from the Pediatric Osteoporosis Prevention (POP) study. *J Bone Miner Res* 2006; 21: 829–35.
10. Memon A, Pospula WM, Tantawy AY, Abdul-Ghafar S, Suresh A, Al-Rowith A. Incidence of hip fracture in Kuwait. *Int J Epidemiol* 1998; 27: 860–5.
11. Schnitzler CM, Mesquita JM. Bone marrow composition and bone microarchitecture and turnover in blacks and whites. *J Bone Miner Res* 1998; 13: 1300–7.
12. Solomon L. Bone density in ageing Caucasian and African populations. *Lancet* 1979; 2: 1326–30.
13. Fonn S, de Beer M, Kgamphe J. Birth to ten: pilot studies to test the feasibility of a birth cohort study investigating effects of urbanisation in South Africa. *S Afr Med J* 1991; 79: 449–54.
14. Richter LM, Yach D, Cameron N, Greisel RD, de Wet T. Enrolment into Birth to Ten (BTT): population and sample characteristics. *Paediatr Perinat Epidemiol* 1995; 9: 109–20.
15. Richter LM, Norris SA, de Wet T. Transition from birth to ten to twenty: the South African cohort reaches 12 years of age. *Journal of Paediatric and Perinatal Epidemiology* 2004; 18: 290–301.
16. Yach D, Cameron N, Padayachee G, Wagstaff L, Richter L, Fonn S. Birth to ten: child health in South Africa in the 1990's. rationale and methods of a birth cohort study. *Paediatr Perinat Epidemiol* 1991; 5: 211–33.
17. McVeigh JA, Norris SA, Cameron N, Pettifor JM. Associations between physical activity and bone mass in black and white South African children at age 9 yr. *J Appl Physiol* 2004; 97: 1006–12.
18. McVeigh JA, Norris SA, de Wet T. The relationship between socio-economic status and physical activity patterns in South African children. *Acta Paediatr* 2004; 93: 982–8.
19. Tanner JM. Normal growth and techniques of growth assessment. *Clin Endocrinol Metab* 1986; 15: 411–51.
20. Pate RR, Heath GW, Dowda M, Trost SG. Associations between physical activity and other health behaviours in a representative sample of US adolescents. *Am J Pub Health* 1996; 86: 1577–81.
21. Gorden-Larsen P, McMurray RG, Popkin BM. Adolescent physical activity and inactivity vary by ethnicity: the National Longitudinal Study of Adolescent Health. *J Pediatr* 1999; 135: 301–6.
22. Ainsworth BE, Haskell WL, Leon AS, Jacobs DR, Montoye HJ, Sallis JF, et al. Compendium of physical activities: classification of energy costs of human physical activities. *Med Sci Sports Exerc* 1993; 25: 71–80.
23. Groothausen J, Siemer H, Kemper H, Twisk J, Welten D. Influence of peak strain on lumbar bone mineral density: an analysis of 15-Year physical activity in young males and females. *Pediatric Exercise Science* 1997; 9: 159–73.
24. Fulkerson JA, Himes JHI, French SA, Jensen S, Petit MA, Stewart C, et al. Bone outcomes and technical measurement issues of bone health among children and adolescents: considerations for nutrition and physical activity intervention trials. *Osteoporos Int* 2004; 15: 929–41.

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25. Prentice A, Parsons T, Cole T. Uncritical use of bone mineral density in absoptiometry may lead to size-related artifacts in the identification of bone mineral determinants. *Am J Clin Nutr* 1994; 60: 837–42.

26. Rowlands AV, Ingledew DK, Powell SM, Eston RG. Interactive effects of habitual physical activity and calcium intake on bone density in boys and girls. *J Appl Physiol* 2004; 97: 1203–8.

27. Welk GJ, Corbin CB, Dale D. Measurement issues in the assessment of physical activity in children. *Res Q Exerc Sport* 2000; 71: S59–73.

28. McKay HA, MacLean L, Petit M, MacKelvie-O'Brien K, Janssen P, Beck T, Khan KM. "Bounce at the Bell": a novel program of short bouts of exercise improves proximal femur bone mass in early pubertal children. *Br J Sports Med* 2005; 39: 521–6.

29. Gorden-Larsen P, Adair L, Popkin B. Ethnic differences in physical activity and inactivity patterns and overweight status. *Obes Res* 2002; 10: 141–9.

30. French SA, Fulkerson JA, Story M. Increasing weight-bearing physical activity and calcium intake for bone mass in children and adolescents: a review of intervention trials. *Prev Med* 2000; 31: 722–31.

Supplementary material

The following supplementary material is available for this article:

Fig S1. Residualized Hip BMC gain within quartiles of METPA (panel A) and MECHPA (panel B) for black, white, male and female subjects. *p < 0.05, quartile 4 > quartile 1 and 2 for white males.

Fig S2. Residualized Spine BMC gain within quartiles of METPA (panel A) and MECHPA (panel B) for black, white, male and female subjects. *p < 0.05, quartile 4 > quartile 1 and 2 for white males.

Fig S3. Residualized Hip area gain within quartiles of METPA (panel A) and MECHPA (panel B) for black, white, male and female subjects. *p < 0.05, quartile 4 > quartile 2 for white males. **p < 0.001, quartile 4 > quartile 1 for white females.

Fig S4. Residualized spine area gain within quartiles of METPA (panel A) and MECHPA (panel B) for black, male and female subjects.

Table S1. Anthropometric, calcium intakes (age 10), physical activity data and unadjusted DXA data, showing percentage gain in height, weight, BA (BAGAIN) and BMC (BMCGAIN) between ages 9 and 10. Data shown as Means (SD).

Table S2. Gain in bone mass measurements between years 9 and 10. Bone mineral content (BMC) at age 10 adjusted for BA (cm^2) and body weight (kg). BA adjusted for body weight (kg) and height (cm). Percentage gain in BMC (adjusted for body weight and BA cm^2) and percentage gain in BA [adjusted for body weight (kg) and BMC (g)] from age 9 to 10. Data shown as means (SE)

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