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# Bone Characteristics in Young Basketball Players and Middle-Aged Former Basketball Players

Georgino Al Chalouhi

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# PhD Thesis

Presented for **Doctoral school in social sciences and humanity (ED 481)**

**University of Pau and Adour Countries**

**Georgino Al Chalouhi**

*Bone Characteristics in Young Basketball Players and Middle-Aged Former Basketball Players*

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## **Abbreviations**

aBMD: areal bone mineral density  
BA: bone area  
BB: basketball  
BLHQ: bone loading history questionnaire  
BLU: bone loading unit  
BMC: bone mineral content  
BMD: bone mineral density  
BMI: body mass index  
BPAQ: bone-specific physical activity questionnaire  
BSI: bending strength index  
BTM: bone turnover marker  
CG: control group  
CQU: calcaneal quantitative ultrasound  
CSA: Cross sectional area  
CSI: compression strength index  
CSMI: cross-sectional moment of inertia  
CT: Cortical thickness  
DCI: daily calcium intake  
DPI: daily protein intake  
FB: football.  
FM: fat mass  
FN: femur neck  
FRAX: fracture risk assessment tool  
GRF: ground reaction force  
ISCD: International Society for Clinical Densitometry  
ISI: impact strength index  
LBM: lean body mass  
LE: lower extremity  
LM: lean mass

LR: left radius  
LS: lumbar spine  
MET: metabolic intensity  
MP: maximum power  
OP: osteoporosis  
PBM: peak bone mass  
R: Buckling ratio  
RF: right femur  
RL: right leg  
RR: right radius  
TBS: Trabecular bone score  
TH: total hip  
Tr: trochanter  
UE: upper extremity  
VB: volleyball  
WB: whole body  
WHO: world health organization  
Z: Section modulus

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## Introduction

### English:

Osteoporosis is a very common bone disease, especially in the process of aging. It is characterized by bone mineral density (BMD) weakness and deterioration of the bone microarchitecture inducing an increase in fracture risk (Cawthon, 2011). In 2001, a group of experts defined osteoporosis as a skeletal disorder characterized by low bone resistance which increases the risk of fracture (Gómez de Tejada Romero & Sosa Henríquez, 2014). Currently, the World Health Organization stated guidelines for the diagnosis of osteoporosis that is based on the BMD; a T-score  $\leq -2.5$  means the existence of osteoporosis. The BMD is subjective to several factors such as genetic factors, ethnicity, gender, nutrition, sleep and mechanical factors (like body weight and physical activity); these factors are best determinants of fracture risk (El Hage, 2013; Rudäng et al., 2012). However, in clinical practices, it is very common for subjects to sustain a fracture with low BMD scores, but greater than the densitometric osteoporosis threshold, or even normal scores (Briot, 2013; Vondracek et al., 2008). Because BMD alone cannot fully account for all instances of age and osteoporosis-related bone fragility, bone microstructure and chemical composition must also be considered (Osterhoff et al., 2016). On the other hand, peak bone mass, the amount of bone achieved when accrual reaches a plateau following the end of bone development and growth (Gordon et al., 2017), reached at a young age is crucial in defining bone characteristics in later stages; The higher the PBM reached, the better the bone quality becomes. This leads to a reduced likelihood of developing osteoporosis (OP) in later stages, or at the very least, it delays its onset (Boreham & McKay, 2011; Zhu and Zheng, 2021).

Exercise might reduce age-related bone resorption and skeletal diseases by regenerating bones both directly and indirectly (Santos et al., 2017). Exercise can protect bone modeling and remodeling (Qi et al., 2016) and it can positively affect the utilization of calcium and vitamin D, two key elements for bone health (Wanner et al., 2015). Moreover, Sport that puts stress on bones modifies bone geometry and strength in areas that are specifically stimulated by that activity (Lombardi et al., 2019).

Team sports consisting of high magnitude accelerations and decelerations in different planes of movements (non-habitual directions) produce load and loading rates for an effective osteogenic stimulus. Hence, the lifetime hours of training in team sports were found to be positively correlated with high bone mineral density (Kettunen et al., 2010).

The first objective of our thesis was to study the residual effect of basketball on bone variables for middle aged former professional basketball players compared with age matched control subjects.

The second objective was to compare the effect of playing basketball versus being physically active on bone variables for young adults.

Our thesis is essentially based on two hypotheses:

1. Basketball has a strong effect on bone variables whether for young or old adults
2. Athletic and strength tests have positive correlations with bone variables

This manuscript is structured in three parts. A first part includes a review of the literature that divides itself into eight sub-parts. A second part deals with the experimental contributions of this work and includes two main studies. A third part provides a synthesis of the work and is divided into two sub-parts, a general discussion of all the work carried out, followed by a general conclusion and outlook.

#### French:

L'ostéoporose est une maladie osseuse très courante, notamment au cours du processus de vieillissement. Elle se caractérise par une faiblesse de la densité minérale osseuse (DMO) et une détérioration de la microarchitecture osseuse induisant une augmentation du risque fracturaire (Cawthon, 2011). En 2001, un groupe d'experts a défini l'ostéoporose comme un trouble du squelette caractérisé par une faible résistance osseuse qui augmente le risque de fracture (Gómez de Tejada Romero & Sosa Henríquez, 2014). Actuellement, l'Organisation mondiale de la santé déclare que le diagnostic de l'ostéoporose repose sur la DMO ; un T-score  $\leq -2,5$  signifie l'existence d'une ostéoporose. La DMO, qui est influencée par plusieurs facteurs tels que des facteurs génétiques, l'origine ethnique, le sexe, la nutrition, le sommeil et des facteurs mécaniques (comme le poids corporel et l'activité physique), est l'un des meilleurs déterminants du risque de fracture (El Hage, 2013 ; Rudäng et al., 2012). Cependant, en pratique clinique, il est très fréquent de constater des fractures chez des sujets ayant une DMO normale ou une DMO faible mais supérieure au seuil densitométrique de l'ostéoporose (Briot, 2013 ; Vondracek et al., 2008). Par conséquent, et parce que la DMO ne peut à elle seule expliquer pleinement tous les cas de fragilité osseuse liée à l'âge et à l'ostéoporose, la microstructure osseuse et la composition chimique doivent également être prises en compte (Osterhoff et al., 2016). D'autre part, le pic de masse osseuse, la quantité d'os

obtenue lorsque l'accumulation atteint un plateau après la fin du développement et de la croissance osseuse (Gordon et al., 2017), atteint à un jeune âge est crucial pour définir les caractéristiques osseuses aux stades ultérieurs. ; où plus la pic masse osseuse atteinte est élevée, la meilleure est la qualité osseuse, ce qui réduit le risque d'avoir une OP à des stades ultérieurs ou du moins de la retarder (Boreham & McKay, 2011; Zhu and Zheng, 2021).

L'exercice pourrait réduire la résorption osseuse et les maladies du squelette liées à l'âge en régénérant les os directement et indirectement (Santos et al., 2017). L'exercice peut protéger le modelage et le remodelage osseux (Qi et al., 2016) et peut avoir un effet positif sur l'utilisation du calcium et de la vitamine D, deux éléments clés pour la santé des os (Wanner et al., 2015). De plus, le sport qui exerce une pression sur les os modifie la géométrie et la force des os dans les zones spécifiquement stimulées par cette activité (Lombardi et al., 2019).

Les sports d'équipe consistant en des accélérations et des décélérations de grandes amplitudes dans différents plans de mouvements (directions non habituelles) produisent des charges et des taux de chargement pour un stimulus ostéogénique efficace. Les sports d'équipe impliquent ces charges mécaniques, c'est pourquoi les heures d'entraînement à vie sont liées à une densité minérale osseuse élevée (Kettunen et al., 2010).

Le premier objectif de notre thèse était d'étudier l'effet résiduel du basketball sur les variables osseuses chez des anciens basketteurs professionnels d'âge moyen par rapport à un groupe témoin du même âge.

Le deuxième objectif était de comparer l'effet du basket-ball par rapport à l'activité physique sur les variables osseuses chez les jeunes adultes.

Notre thèse repose essentiellement sur deux hypothèses :

1. Le basket-ball a un effet important sur les variables osseuses, que ce soit chez les adultes jeunes ou âgés.
2. Les tests sportifs et de force ont des corrélations positives avec les variables osseuses

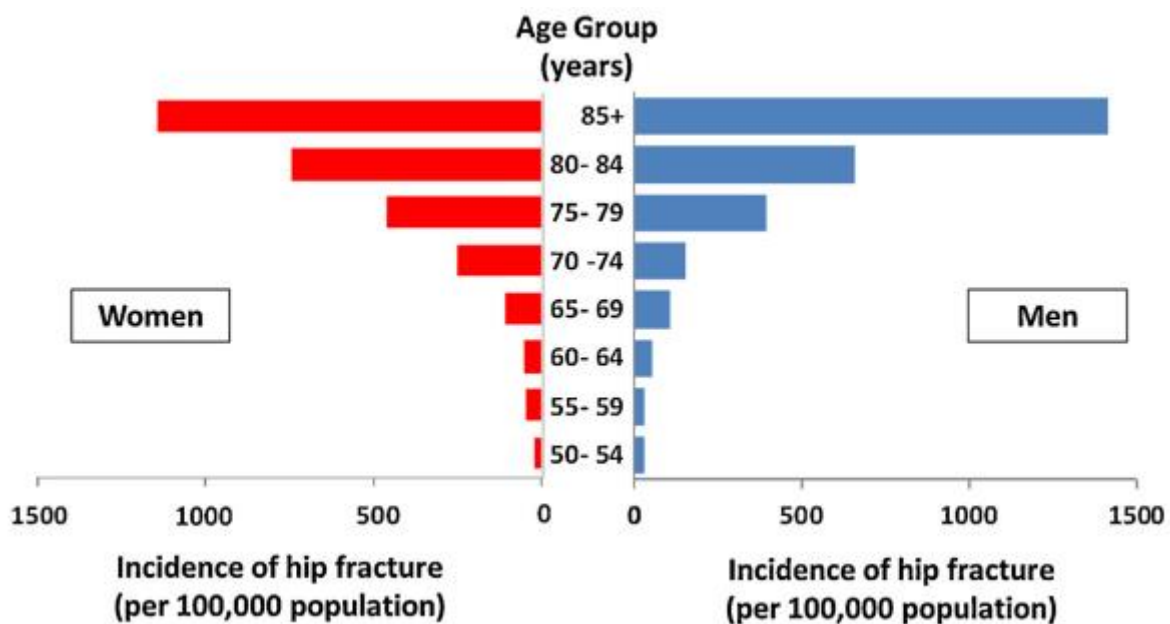
Ce manuscrit est structuré en trois parties. Une première qui comprend une revue de la littérature qui se divise en huit sous-parties. Une deuxième partie traite des apports expérimentaux de ce travail et comprend deux études principales. Une troisième partie propose une synthèse des travaux et est divisée en deux sous-parties portant respectivement sur une discussion générale de l'ensemble des travaux réalisés, suivie d'une conclusion générale et de perspectives.

## Part one: Literature review

### 1. Male osteoporosis

#### 1.1 Osteoporosis in men

Men have a better resistance to mechanical forces compared to women because of a larger periosteal deposition of bone (Bonjour et al., 2009). Because of this, men usually present with an osteoporotic fracture 10 years later than women do (Diab & Watts, 2021). Nevertheless, in industrialized countries, about 1 to 8% of men suffer from OP and 1 in 8 men (wade et al., 2014; Giusti & Bianchy, 2015) and 1 in 4 men (Willson et al., 2015) aged more than 50 years will suffer from osteoporotic fractures. Consequently, osteoporotic fractures can lead to death, as for men death rates are higher than women, reaching in some studies the double of the cases. (Cawthon, 2011).



**Figure 1: Age and gender specific incidence rates of hip fractures per 100,000 persons in Lebanon (Maalouf et al., 2013).**

As men predominantly experience trabecular thinning (Giusti et al., 2015), Osteoporotic fractures mainly occur at the metaphyseal sites clinically (Cheung et al., 2016); they can be found in many locations like distal radius, proximal extremity of the femur and vertebrae are predominant (Gómez de Tejada Romero & Sosa Henríquez, 2014).

## *1.2 Prevalence*

Male osteoporosis has always been underestimated or miss-studied (Aggarwal et al., 2021; Briot, et al., 2009). With the increase of population, aged people became more prevalent. This is why, osteoporosis increased not only for women, but also for men as well (Khosla et al., 2008 & Sato, et al., 2017). Assuring that, Osteoporosis reached 15.33% of males aged more than 50 in china (chen, et al., 2016). Moreover, 5.5 million men had osteoporosis in Europe in 2012 (Svedbom, et al., 2013). In Spain, the percentage of osteoporotic men aged more than 50 is 8.1% and 11.3 for more than 70 (Varsavsky et al., 2018). For Americans 2 million men had osteoporosis in 2010 (wright, et al., 2014), as for the present, it is estimated that 5% of men aged more than 50 are osteoporotic (Sarafrazi et al., 2021). Additionally, a systematic review and meta-analysis done by Salari et al. (2021) about the worldwide prevalence of osteoporosis concluded that 18.3% of the population is osteoporotic with 11.7% for men with the highest ratios for Africans. Eastern Mediterranean osteoporotic male (>50yrs) cases are significantly increasing reaching 20.4% in 2015 (Zamani, et al., 2018) with 22.7% (>65yrs) in Lebanon (Baddoura, et al., 2011). Furthermore, from the aging population, it has been estimated that bone disorders would increase 3 times in men until 2050 (Seem et al., 2019).

## *1.3 Screening*

OP is a silent disease until inflicting pain and robbing people of their mobility and potentially leading to long term disability and premature death. Consequently, every 3 seconds The International Osteoporosis Foundation reports an OP related fracture worldwide. Therefore, the importance of awareness and education in screening for primary care for people at risk is increasing (Cox & Hooper, 2021). According to the International Society for Clinical Densitometry (ISCD), men above the age of 70 should have their BMD measured; however, if there are numerous risk factors, the BMD should be measured at a younger age (Posman et al., 2015). By measuring the heel BMD, calcaneal quantitative ultrasound (QUS) can predict the BMD of the hip, spine, and peripheral tissues. In comparison to DXA, Guyen et al. (2021) looked at the usefulness of QUS as an osteoporosis screening technique. They found a modest correlation between QUS and DXA in bone parameters. Thus, they highlighted the importance of DXA as a standardized screening method for BMD and OP.

**WHO definitions of OP based on BMD**

<b>Classification</b>	<b>BMD</b>	<b>T Score</b>
Normal	Within 1 SD of the mean level for a young adult reference population	T score at –1.0 and above
Low bone mass (osteopenia)	Between 1 and 2.5 SD below that of the mean level for a young adult reference population	T score between –1.0 and –2.5
OP	2.5 or more below that of the mean level for a young adult reference population	T score at or below –2.5
Severe or established OP	2.5 or more below that of the mean level for a young adult reference population with fractures	T score at or below –2.5 with one or more fractures

**Figure 2: WHO screening osteoporosis based on bone mineral density (Pope et al., 2021).**

The international society for clinical densitometry has supported the use of Z-score, which describes sex-matched individuals’ BMD and standard deviations from healthy age, instead of T-score. Therefore, a Z-score  $\leq -2$  standard deviation is described as low bone mass (Crabtree et al., 2014).

*1.4 Causes*

Muñoz-Torres et al. (2010) stated that OP treatment and prevention depends not only on low BMD, but other factors must be taken into consideration such as sex, age, weight, family antecedence of fracture, consumption of glucocorticoid, intake of alcohol and previous fractures.

<i>Primary causes</i>
Aging
Idiopathic
<i>Secondary causes</i>
Smoking and alcohol abuse
Hypogonadism (primary and secondary)
Hypercortisolism
Hyperparathyroidism
Thyrotoxicosis
Diabetes mellitus (types 1 and 2)
Growth hormone deficiency
Renal failure
Inflammatory bowel disease and malabsorption

**Figure 3: Causes of male osteoporosis (Varsavsky, et al., 2018).**

Primary OP is caused by direct parameters; however, secondary OP is the result of diseases and habits that might lead to OP (Stein & Shane, 2003). Thus, when a diagnosis is made, a blood test, intact parathyroid hormone, chemical panel, and 24-hour urine calcium should all be evaluated, and other testing should be taken into consideration based on clinical suspicion (Vidal et al., 2019).

#### 1.4.1 Primary osteoporosis

With aging, contrary to women whose trabeculae lose their connectivity, men trabeculae become thinner (watts et al., 2012). Vidal et al. (2019) conducted a study about the causes of men OP and found that 57% had idiopathic osteoporosis and 43% developed secondary osteoporosis; moreover, primary OP was more frequent for men aged less than 60 and the secondary OP for men aged more than 60, while Idiopathic osteoporosis is mainly the result of a genetic predisposition or hypercalciuria which means excess calcium in the urine (Peris, et al., 2008).

#### 1.4.2 Secondary osteoporosis

Table 1: Secondary causes of osteoporosis (Diab & Watts, 2021)

Major causes of secondary osteoporosis				
Endocrine/Metabolic Diseases	Nutritional Conditions	Drugs	Genetic Disorders	Miscellaneous
Hypogonadism	Vitamin D deficiency	Glucocorticoids	Osteogenesis imperfecta	Rheumatoid arthritis
Hypercalciuria	Calcium deficiency	Anti-epilepsy drugs	Homocystinuria	Inflammatory bowel disease
Hyperthyroidism	Vitamin B12 deficiency	Excess thyroid hormone	Ehlers-Danlos syndrome	COPD
Hyperparathyroidism	Weight loss	Androgen deprivation therapy	Marfan syndrome	Organ transplantation
Cushing syndrome	Malabsorption	Heparin	Glycogen storage diseases	Immobilization
Diabetes mellitus	Gastric surgery	Thiazolidinediones	Gaucher disease	Muscular dystrophy
	Chronic liver disease	Selective serotonin reuptake inhibitors	Hypophosphatasia	Multiple sclerosis
	Alcoholism	Proton pump inhibitors	Porphyria	Multiple myeloma
	Malnutrition	Excess vitamin A	Hemochromatosis	Some cancers (leukemia and lymphomas)
	Prolonged TPN	Cyclosporine		ESRD
				Mastocytosis
				Thalassemia
				Sickle cell disease
				HIV

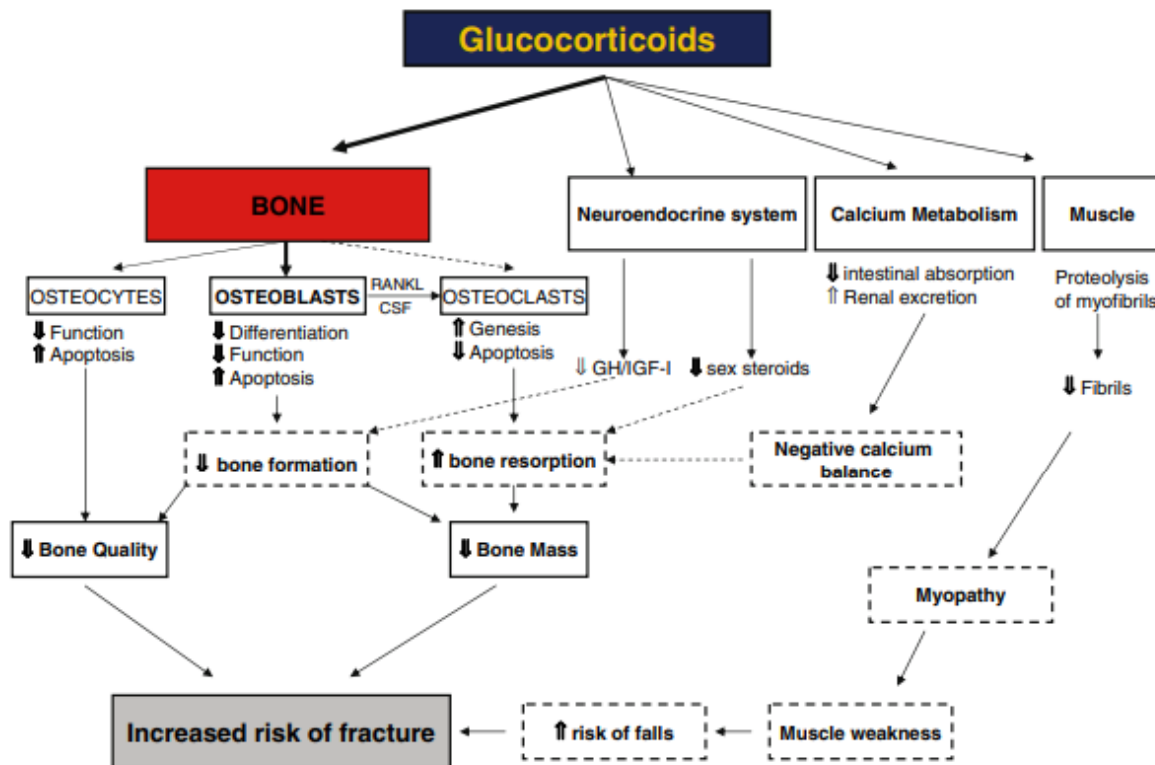
**Abbreviations:** COPD, chronic obstructive pulmonary disease; ESRD, end-stage renal disease; HIV, human immunodeficiency virus; TPN, total parenteral nutrition.

Men consuming more than 3 units/day of alcohol are highly exposed to experience low BMD hip fracture and moderately at risk to experience any fragility fracture (Kanis, et al., 2005 & Zhang et al., 2015). Additionally, a meta-analysis of 59232 subjects found that smoking increases the risk of OP fractures (kanis, et al., 2005).

Glucocorticoid medication has been proven to affect negatively bone health. Assuring that, low dosage of these medications (5mg/day) can affect BMD in the first few months due to high rates of trabecular bone loss (Rossini et al., 2017). This side effect of glucocorticoid on BMD is the result of an increase in apoptosis and decrease in the function of the osteoblasts as



well as prolonging the lifespan of osteoclasts; therefore, increasing bone resorption (Mitra, 2011). Furthermore, many indirect side effects of glucocorticoid on bone health are proven. It decreases the expression of sex steroids and insulin-like growth factor contributing in the increase of bone resorption and the suppression of bone formation. Additionally, by preventing the actions of vitamin D, it reduces intestinal calcium absorption and prevents renal tubular calcium reabsorption to promote bone resorption (Canalis et al., 2007).



**Figure 4: Direct and indirect effects of glucocorticoids on bone (Canalis et al., 2007).**

Altered absorption of vitamin D, inadequate sunlight exposure and medications are the etiologies of vitamin D deficiency. This deficiency will lead to hyperparathyroidism, altered bone turnover and osteomalacia and finally OP (Moreira & Paula, 2017). Furthermore, Chen et al. (2008) stated that oxidative stress can have a detrimental effect on bone health as well.

It is well known that sex steroid hormones are important for maintenance and acquisition of bone mass. Estrogen is one of these hormones and it is stated that deficiencies lead to rapid bone loss (Gosset et al., 2021). Assuring that, Gennari, et al. (2008) studied the relation between sex hormones and BMD and fracture risk. They concluded that estrogen is the dominant sex steroid defining OP in men, particularly for skeletal accrual.

### 1.5 Treatment

To treat OP general guidelines suggest assessing BMD with levels less than -2.5 for fracture risk combined with clinical risk calculations like fracture risk assessment tool (FRAX) (Compston et al., 2013). Additionally, the National Osteoporosis Foundation mentions monitoring BMD with DXA every two years or less in certain clinical conditions (Cosman et al., 2014). Furthermore, Cosman et al. (2014) and Watts et al. (2012) mentioned the current guidelines that treatment should be carried out for patients with:

- T-score  $\leq$  2.5 at the femoral neck, total hip, one-third distal radius, or lumbar spine (after doing a thorough analysis to rule out secondary factors)
- A vertebral or hip (clinical or morphometric) fracture
- Low bone mass (T-score between 1.0 and 2.5) and a 10-year probability of a major osteoporosis-related fracture  $\geq$  20% or a 10-year probability of a hip fracture  $\geq$  3% using the FRAX Web-based tool

Current common medicines for secondary OP are teriparatide, bisphosphonates, calcium prescription, selective estrogen receptor modulators, denosumab, calcilytics and estrogen replacement therapy (Burns et al., 2018; Zhao et al., 2021; Compston et al., 2017).

Table 2: FDA bone active agents for men with osteoporosis (Diab & Watts, 2021)

Drug	Oral			Intravenous Infusion	Subcutaneous Injection
	Daily	Weekly	Monthly		
Alendronate (Fosamax)	5 and 10 mg	35 and 70 mg			
Risedronate (Actonel)	5 mg	35 mg	150 mg		
Zoledronic acid (Reclast)				5 mg per year	
Denosumab (Prolia)					60 mg q6 months
Teriparatide (Forteo)					20 $\mu$ g daily

Bisphosphonates enter the osteoclast, accelerate the osteoclast apoptosis and cause a loss of resorptive function so they reduce osteoclastic bone resorption. Alendronate, the first approved Bisphosphonates by FDA, decreases bone turnover markers and increases BMD in the lumbar spine and the femoral neck (Xu, 2017; Orwoll et al., 2010). Similarly, in 2 longitudinal studies done by Ringe et al. (2009) and Ringe et al. (2006), they both studied the effect of Risedronate and concluded that the medicine reduces vertebral and non-vertebral

fractures for patients with OP and increases hip and spine BMD. Likewise, Denosumab is beneficial in increasing total hip, radius, lumbar spine and femoral neck BMD (Willson et al., 2015). However, in a placebo-controlled trial, zoledronic acid, the only intravenous bisphosphonate, demonstrated efficacy for reducing the fracture rate in males. A multicenter, double-blind trial comparing males with OP who took Zoledronic or a placebo every year for two years found a significant reduction in the risk of vertebral fracture (Boonen et al., 2012).

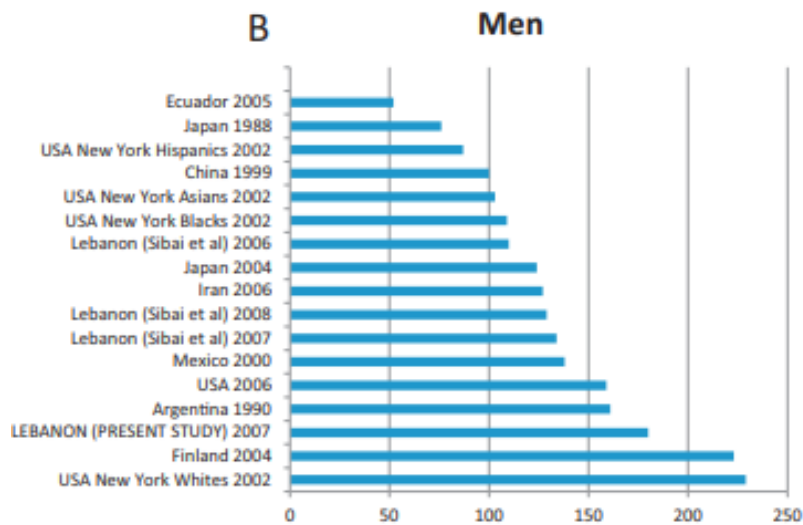
Nutrition can help treating OP. The main nutrients for healthy skeletons are calcium, zinc, phosphorus, magnesium, and copper (Tobeiha et al., 2020). Calcium ingestion is necessary for persons with OP or at risk; therefore, consuming 1000-1200mg/day coming from dietary sources with supplementation if consumption is not enough is required (watts et al., 2012; Compston et al., 2013). Stating that, Verbrugge et al. (2012) mentioned that for elderly OP cases aged more than 70 years, the recommended daily calcium consumption is 1200 mg/d preferable to come from dietary sources. Similarly, recommendation of vitamin D 25-hydroxy levels of at least 30 ng/ml in men with OP, so in case the levels are bellow, supplementation is required reaching 2000 IU daily (Holick et al., 2011; Ebeling, 2013).

Increase in BMD does not always mean reduce fracture risk. Assuring that, even if bisphosphonate do not elevate BMD or change significantly bone turnover marker (BTM), it reduces the risk of fracture (Carey, 2005). Three indicators that can help explain treatment failure were put to the test by the International Osteoporosis Foundation (IOF) Committee of Scientific Advisors: BMD, incidence fractures, and BTM (Diez-Perez et al., 2012).

### *1.6 Fracture risk*

Watts et al. (2012) stated that the Fracture Risk Assessment tool (FRAX) calculator and the Garvan nomogram are frequently used algorithms for calculating risk fracture. BTM may predict fracture risk over time. A 40% decrease in the risk of non-vertebral fracture was associated with a 70% decrease in BTMs in a meta-analysis by Hochberg et al. (2002) that included 18 clinical trials. However, an increase in BMD indicates a good treatment, but is not always in correlation with fracture risk (Vondracek et al., 2008). Macro- and microstructural alterations in trabecular bone influence bone mechanics, the progression of osteoporosis, and fracture risk (Chen et al., 2013; Chen & Kubo, 2014; Greenwood et al., 2015). Therefore, Bone microstructure and chemical composition must also be taken into account because BMD alone cannot explain all occurrences of age and osteoporosis-related

bone fragility (Osterhoff et al., 2016). Nevertheless, a 10% increase in PBM is believed to reduce fracture risk in adulthood by 50% (Zhu & Zheng, 2021).



**Figure 5: Rates (per100,000) in men over 50 in various countries standardized to the 2000 US population (Maalouf et al., 2013).**

It is widely known that osteoporotic fractures are not common between race, ethnicity and geography. Northern Europe and North America have the highest fracture rates. Asians and Black people have the lowest rates as well as some regions of South America (Watts et al., 2012).

## 2. Determinants of bone mass

### 2.1 Genetics and bone mass

Single nucleotide polymorphisms (SNPs), are the most prevalent genetic variations that affect bone mass heritability. Additionally, by targeting several genes in the same or separate signaling pathways, microRNAs (miRNAs, miRs) are important post-transcriptional regulators that influence the development and function of skeletal cells (Dole & Delany, 2016). Furthermore, genome wide association study identified 62 genome-wide significant loci associated with bone mineral density (Zhu & Xu, 2013; Iwai & Naraba, 2005). Moreover, Gordon et al. (2017) stated that the genetic factors of BMD are low-density lipoprotein receptor-related protein 5, vitamin D receptor and collagen 1 alpha 1

### 2.2 Hormones and bone mass

Hormones have a huge impact on bone mass (Zhang et al., 2021). Testosterone stimulates the periosteal apposition; whereas, Estrogen is responsible for the skeletal accrual (Gosset et al., 2021; Gennari et al., 2008). A combination of testosterone and Estrogen injection therapy had a positive significant effect on hip and spine BMD compared with testosterone injection or no injection for postmenopausal women (Frazzetta, 2023). Furthermore, GH, IGF-1 and IGFBP-3 hormones are believed to be positively correlated with BMD (Nebigh et al., 2009). However, a deficiency of any of these hormones will have a detrimental effect on the bone mass which will increase the risk of fracture (Gosset et al., 2021; Gennari et al., 2008).

### 2.3 Physical activity and bone mass

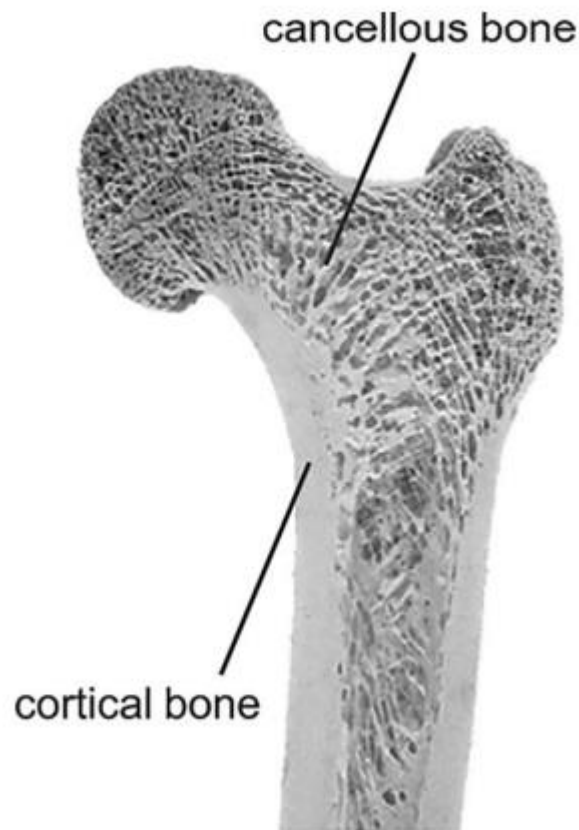
Environmental stressors stimulate the bones so their strength increases; therefore, a sport that stresses the bones changes bone shape and strength in regions that are especially stimulated by that activity (Lombardi et al., 2019). In addition, PA has positive effects in the protection of bone modeling and remodeling (Qi et al., 2016). Assuring that, Casey et al. (2023) studied the effect of moderate to vigorous physical activity on children aged 5 to 7 years old. As a result, the physical activity led to an increase in heel BMD for both boys and girls. For adults, physical activity and especially plyometric and high impact exercises are positively correlated with bone strength in increasing bone osteoprotegerin, a regulator of bone resorption (Kish et al., 2015). For women during their menopause and postmenopausal phase, leisure time physical activity can decrease the rate of BMD loss and even increase bone strength when the intensity of the exercises is increased (Greendale et al., 2023).

#### *2.4 Nutrition and bone mass*

Bone health post adolescence is generally dependent on bone density gained during young ages. These benefits depend on a variety of variables, including race, gender, genetics, and other environmental factors, such as endocrine status (growth hormone, vitamin D, sex hormones, and insulin-like growth factor 1), diet (protein and calcium intake), physical activity, and other factors such as smoking and alcohol intake (Rizzoli et al., 2010; Rudäng et al., 2012).

Containing the majority of calcium, skeletal stores play an essential role in calcium homeostasis and reserve in the face of any shortage. Vitamin D has a role in bone mineralization by optimizing intestinal calcium absorption (Kitchin & Morgan, 2007), where through calcium-permeable channels, the intestine luminal's epithelial cells interact with the calcium (Zhu & Zheng, 2021). Additionally, the vitamin D endocrine system's job is to maintain bone homeostasis and the extracellular fluid calcium concentration (Sahota, 2014).

Furthermore, in a systematic review by Nguyen (2021), he mentioned that milk supplementation for children increased daily consumption of calcium and vitamin D reaching the recommended levels. Consequently, the reviewed studies resulted in an increase in bone area ratio, BMC, BMD for total body and legs, BMD measures in periosteal diameter, medullary diameter and thickness in the cortex, as well as enhanced bone metabolism measures and significant decrease in parathyroid hormone at 1 and 2 years and in bone alkaline phosphatase at 1 year. Assuring that, Kadilkar et al. (2012) asserted that during critical years of skeletal growth, below recommended vitamin D and calcium intake result in low PBM. Furthermore, daily protein consumption is positively associated with microstructure-estimated bone strength, BMD and cortical and trabecular microstructure (Rizzoli et al., 2021).



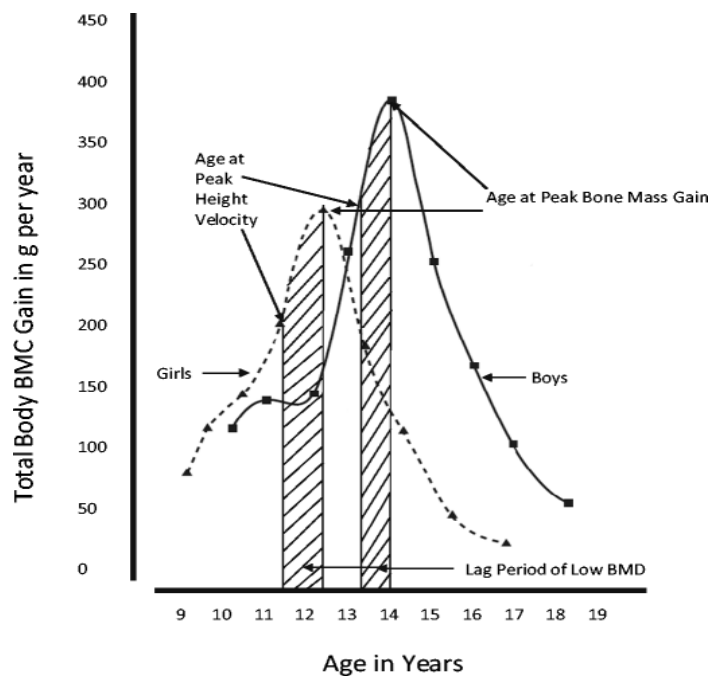
**Figure 6: A sample of the proximal femur demonstrates how bone tissue is made up of an internal compartment of trabecular or cancellous bone and an outside, denser shell of cortical bone (Willems et al., 2014).**

### *2.5 Other factors*

Soininen et al. (2018) studied the determinants of BMD for children aged 6 to 8 years old, they found that LM had the best correlation with bones, also FM had a significant effect as well as Plasma irisin. For teenagers, LM is a better determinant of TB BMD for boys whereas, for girls both LM and FM are significant determinants (Sanchez, et al. 2010). Moreover, body mass is believed to be highly correlated with BMD for adolescents. In a cross-sectional study conducted by Moro et al. (1996), the findings suggested that an increase in mid-femoral bone mass and cross-sectional characteristics during adolescence are predominantly correlated with increases in mechanical loads as indicated by body mass.

### 3. Peak bone mass

After completion of development and growth of bones, PBM is the amount of bone attained when accrual plateau (Gordon et al., 2017). On the other hand, Golden et al. (2014) stated that most of bone mass is gained during early childhood and adolescence. The greatest gains in bone mass comes shortly after peak growth spurt in height, reaching 94% of PBM at the age of 16 (Berger et al., 2010). However, gains in bone density and mass continue for years thereafter (Gordon et al., 2017).

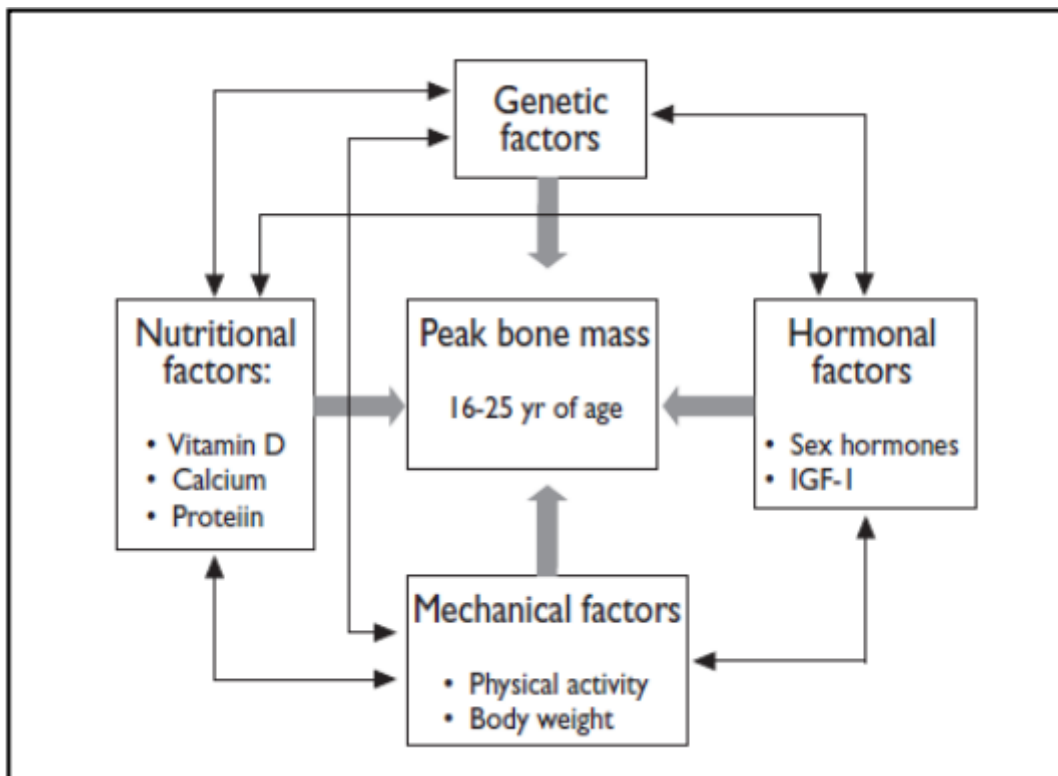


**Figure 7: Age of Peak bone mass (Weaver et al., 2016).**

Additionally, a steady skeletal state is reached during early adulthood; thus, the amount of bone gained during this period of age is largely thought as PBM. The idea captures the maximum bone strength, which is determined by bone mass, density, micro-repair processes, microarchitecture, and geometrical characteristics that offer structural strength (Weaver et al., 2016). Furthermore, Lu et al. (2016) stated that PBM is greater in African Americans than in non-Hispanic whites and in men than in women. Additionally, in Lu's study they studied the age of PBM and concluded that total body mineral content and total body mineral density's median ages were approximately 23 and 26 years respectively for men and approximately 22 years for the two variables for women.



### 3.1 Factors correlated with peak bone mass



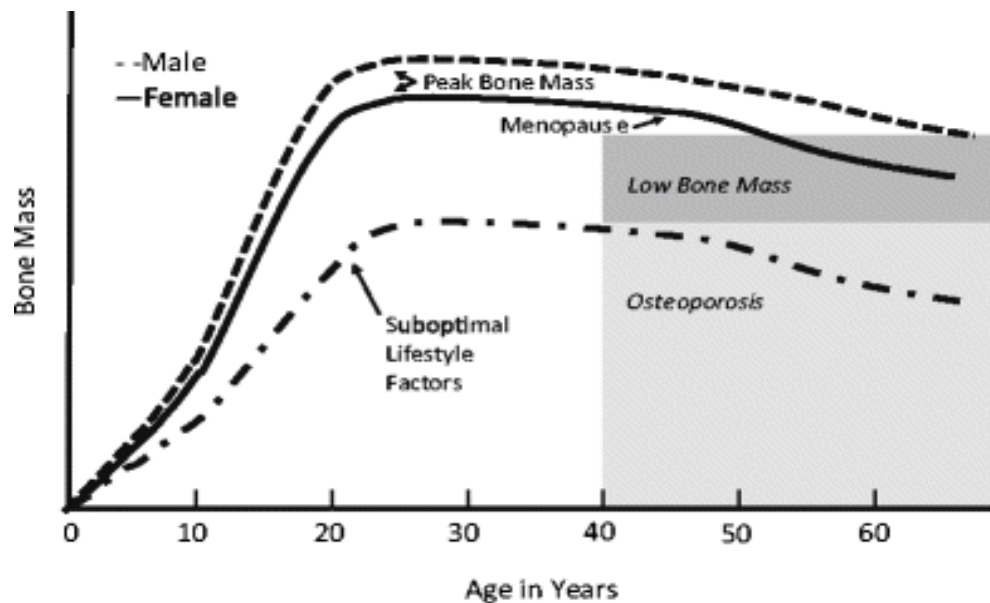
**Figure 8: Determinants of peak bone mass (bonjour et al., 2009).**

Multiple factors determine peak bone mass, genetics, race, nutrition, lifestyle and physical activity. PBM is strongly believed to be highly predisposed genetically as Nguyen et al. (2020) stated that variance in PBM is ~90% accounted to genetic factors, and Weaver et al. (2016) asserted that ~80% of PBM is affected by heritability factors. Additionally, Gordon et al. (2017) stated that the genetic factors of BMD are low-density lipoprotein receptor-related protein 5, vitamin D receptor and collagen 1 alpha 1.

Hormonal factors have a role in PBM, testosterone's main effect on bone is to stimulate the periosteal apposition that is responsible for the thicker cortices. Additionally, estrogen is believed to have a more important role in maintaining PBM as studied in the cross-sectional study done by Napoli et al. (2007), that correlation between estrogen and BMD are higher compared to that between testosterone and BMD. Moreover, Nebigh et al. (2009) stated that, BMD is correlated with GH, IGF-1 and IGFBP-3 hormones.

Adequate nutrition is as important as hormonal factors in PBM. Chevalley and Rizzoli (2022) asserted that optimizing protein and calcium intake during growth is a significant strategy for optimal acquisition of bone strength and PBM. Furthermore, Physical activity and its consequences like increased lean mass is positively associated with BMD therefore, assuring

its importance to achieve PBM for young individuals (Soininen et al., 2018; Nguyen et al., 2020). Therefore, WHO stated that schoolchildren aged between 5 to 17 years exercise medium to high intensity physical activity for 60 minutes on a daily basis for health and bone promotion (Okayama et al., 2021). On the other hand, socioeconomic status has an important role in reaching PBM. Crandall et al. (2012) stated that negative socioeconomic status can prevent children from reaching their potential PBM and vice versa.



**Figure 9: Suboptimal factors of peak bone mass (Weaver et al., 2016).**

All of these factors are hugely important to increase PBM and therefore prevent or at least delay OP, as mentioned by Zhu and Zheng (2021) that an increase of 10% in PBM can delay OP for 13 years later in life. And on the other hand, a decrease of 6.4% of bone mass in early childhood might double the risk of fracture in adulthood (Boreham & McKay, 2011).

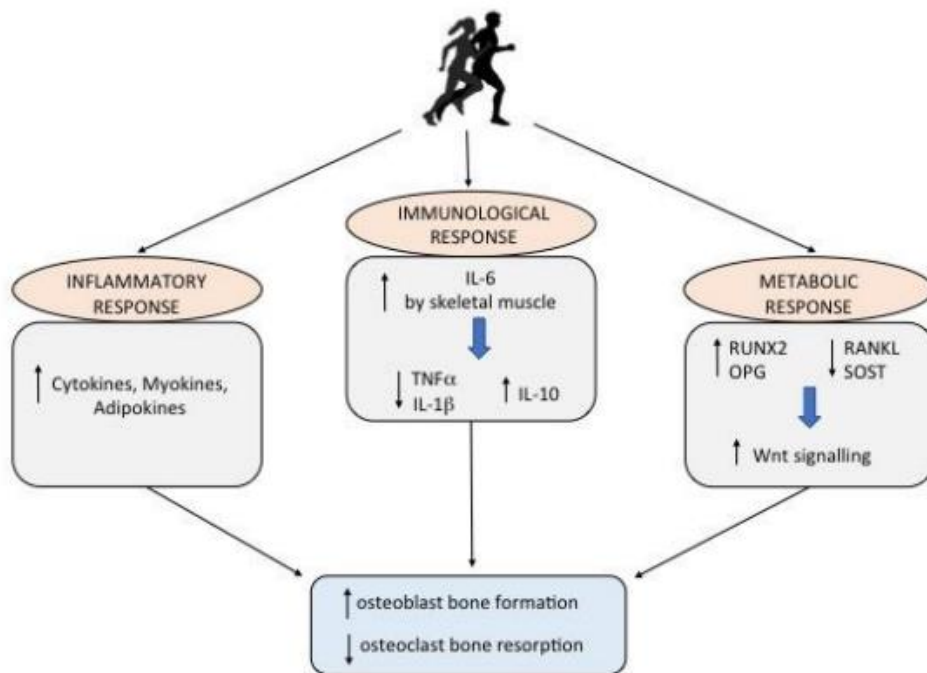
### 3.2 Mechanisms

Dual coordinated actions of bone deposition, occurs at four surfaces; the endo-cortical, periosteal, intra-cortical, and trabecular (Morseth et al., 2011), and resorption are the mechanisms of skeletal growth: periosteal apposition of the cortical bone (growth in width), and cancellous endochondral ossification (growth in length). It takes place in the “basic multicellular units” containing cluster of osteoblasts, cells that build up bone, and osteoclasts, cells that break down bone, which work sequentially (Raggat & Partridge, 2010). It begins during fetal growth and continues until the closure of the epiphyseal plate, usually by the end

of second decade of life (Chevalley & Rizzoli, 2022; West, 2006). In addition, 39% of the body's total bone mineral is acquired in the four years prior to the peak in bone accretion, and 95 % of adult bone mass has been achieved by 4 years following the peak (Baxter-jones et al., 2011).

#### 4. Effect of physical activity on bone variables

Exercise could have a rejuvenating direct and indirect effect on bones and possibly prevent age related bone resorption and skeleton disorders (Santos et al., 2017). It has several positive effects in protecting bone modeling and remodeling (Qi et al., 2016). Physical activity has an important role in the absorption of some major nutrients for the bone health like calcium and vitamin D (Wanner et al., 2015). Therefore, during growth physical activity leads to greater PBM, for the period of adulthood weight-bearing exercises should be executed to increase bone strength and maintain bone mass (Ertec & Cicero, 2012).



**Figure 10: The effects of exercise on bone health (Faienza et al., 2020).**

Through a variety of processes, physical activity significantly impacts bone metabolism: 1. activation of an inflammatory cascade comprising innate and adaptive immune cells as well as inflammatory mediators; 2. immune activation brought on by a rise in IL-6 produced by skeletal muscle; 3. stimulation of the Wnt signaling pathway.

Furthermore, bone strength increases as a result to environmental stressors. Thus, a sport that puts stress on bones modifies bone geometry and strength in areas that are specifically stimulated by that activity. A number of signals, including calcium, mitogen-activated protein kinase, Wnt, and the RhoA/ROCK pathways, are activated as a result of the deformation of bone tissue during exercise. These signals are caused by mechanosensors within the cells, such as integrin and ion channels, which change their original conformation (Lombardi et al.,

2019). Moreover, because muscles place the most mechanical strain and stress on bones, the muscle-bone unit in children and adolescents shows that muscles are primarily responsible for the development of optimum bone strength. Sports that demand submaximal muscle forces, like long-distance running, will not result in as strong of bones as those that need maximum muscle forces, like soccer, which involves quick acceleration (Tenforde & Fredericson 2011). Beside muscle to bone connection, it has been indicated that weight bearing regular PA with moderate intensity and long duration would reduce bone resorption and increase BM during growth, therefore promoting bone health while aging (Gil-Díaz et al., 2019; Qi et al., 2016).

Exercise is categorized into 6 classes: great impact weight-bearing drills like hopping and running, static weight bearing drills such as single leg standing, little impact weight bearing physical activity such as walking and Tai Chi, low impact non-weight bearing exercises like swimming, great impact non-weight bearing drills like RT and combination PA (Howe et al., 2011; Hong & Kim, 2018).

Table 3: The kind of exercise performed at each anatomical location and the amount of mechanical stress put on bone tissue (Ainsworth et al., 2002)

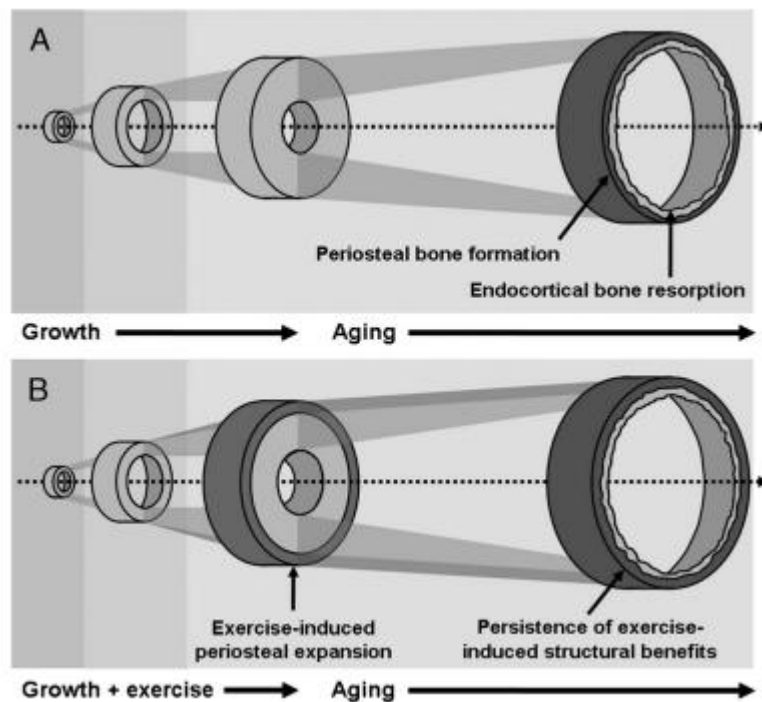
Loading impact	Spine	Wrist	Hip
Low	Canoeing	Stair climber	Canoeing
	Archery	Hiking	Archery
	Bowling	Bowling	Bowling
	Stair climber	Archery	Golf
	Golf	Golf	Stair climber
	Hiking	Canoeing	Hiking
	Weight lifting	Tennis	Weight lifting
High	Tennis	Weight lifting	Tennis

#### 4.1 Pre-adulthood

Entering adulthood with greater bone mass may decrease the risk of fractures later in life (Gunter et al., 2012), even if physical activity is reduced in adulthood (Karlsson & Rosengren, 2012). Assuring that, Owen and Reilly (2018) noted that while the first two decades of life account for 60% of the risk of OP, the remaining 40% are determined by events that occur after that. The 60% risk mentioned previously includes the age at which the child starts to walk (Ireland et al., 2017). Accordingly, Bonjour et al. (2009) stated that an increase in 1sd in

PBM would reduce fracture risk by as much as 50%. Therefore, Because of the high rates of modeling and remodeling and the quickly expanding periosteal surfaces, growth periods are regarded as the ideal time to strengthen the bones. Additionally, Physical activity during growth spurt enhances bone mass of periosteal surfaces that increase bone strength. These changes are most often observed before puberty (prepubertal and peripubertal ages) because it indicates a time period when the skeleton is most susceptible to mechanical loads (Going & Farr, 2012; Tan et al., 2010; Janz et al., 2010).

In a longitudinal study done by Baxter-jones et al. (2008), they have shown that kids aged between 8 and 15 years whom are physically active have 8-10% greater hip BMC compared with less active kids at the age of 23-30 years. Similarly, Warden et al. (2014), have shown in a controlled cross-sectional study that after three years of physical activity intervention for adolescent, bone parameters' benefits persisted, asserting that the effect of exercise for youth on bone variables is kept throughout life. Moreover, Löfgren et al. (2012) studied in a longitudinal study the difference between the intensities of 4 years exercise program on children regarding bone health; they concluded that a program consisting of various intensities (40 min/day and 5 days/week) have significantly gained higher femoral neck width and higher lumbar spine BMC compared with a program having a normal intensity and duration physical activities. Correspondingly, Janz et al. (2014) studied in a 10-year prospective study the effect of different exercise intensities on bone variables starting from 5 years and taking 5 measurements till 17 years. They determined that subjects who have trained with the highest intensities resulted a better bone geometry and mass at the age of 17.



**Figure 11: Physical activity and periosteal surfaces (Gunter et al., 2012).**

However, not all physical activity is beneficial for bone. Exercises that target the complete circumferences of the bone and are moderate to high magnitude, targeted, quick, and odd-impact (achieved by multidirectional movement) have produced positive and substantial improvements in bone size (Gordon et al., 2017) and stress fracture for adolescent athletes (Lynch et al., 2017). Similarly, Fuchs et al. (2001) stated that in the pre-pubertal age, jumping exercises increase PBM at the lumbar spine and hip. On the other hand, the amount of bone mass accrued by early adulthood explains 60% of the risk of developing osteoporosis (Baxter-jones et al., 2011). Therefore, the importance of physical exercises for adolescents in enhancing bone variables and preventing osteoporosis is confirmed.

To significantly affect bone variables, physical activity is recommended for more than 7 months for adolescents (Gunter et al., 2008; Hind and Burrows, 2007). After nine months of karate training for adolescent, Ito et al. (2017) showed significant bone related changes, with higher effects on lower limb BMD. They believed that the results are found by the fact that karate generates multidimensional loads and intense stimuli on skeleton. Similarly, Varley et al. (2016) stated that because of the mix of mechanical stress and reaction ground stress caused in soccer, it promotes adaptations on cortical bones for adolescent generating healthy bones. Smock et al., (2009) studied the effect of distance running in young male and females

and stated that the experimental group resulted in a better bone geometry in male runners than in the control group, with no significant effect on volumetric bone density. On the other hand, hypo-gravity environment such as swimming has no correlation with BMD therefore, swimming is not considered beneficial in enhancing bone variables for adolescents (Agostinete et al., 2017).

#### *4.2 Adult*

For adults, impact activities as jogging and hopping have greater osteogenic potential than habitual walking (Savikangas et al., 2021). Assuring that, Kish et al. (2015) studied the effect of plyometric exercises on adults and found a significant increase in bone osteoprotegerin. Considering walking exercises, 10 weeks of moderate intensity walking stabilized the levels of bone osteoprotegerin compared to a decrease for control group, assuring Savikangas' findings that high intensity impact exercises are better regarding bone variables than low intensity impact drills. In the other hand, Mezil et al. (2015) concluded that high intensity low impact exercises have a significant positive impact on bone turnover markers and cytokines, and that this type of exercise may be beneficial for whom high impact exercise might be contraindicated.

Resistance exercises (RE) affect significantly bone variables for adults. These effects are due to the muscular loads that are applied on the bones during RE, which create stimuli and stimulate an osteogenic response of the bone (Hong & kim 2018). Notomi et al. (2014) studied the effect of RE on adults and found that this type of exercises may contribute to a better bone health by exerting anabolic effects on bone by modifying gene expression related to bone remodeling. Furthermore, Hong and Kim (2018) stated that progressive RE has greater results on bone variables over time reaching up to 85% of 1RM, and they mentioned that the spine was more responsive than the hip. Similarly, in a recent meta-analysis by Martyn-St James and Carroll (2009), they stated that for pre- and post-menopausal women, resistance training alone increased BMD in the lumbar spine only, and that impact exercises increased femoral neck BMD; whereas, combining RE and impact drills leads to an increase both sites (James & Carroll, 2010). Likewise, a combination of weight bearing exercise and RE have a significant result on bone variables as weight bearing provides mechanical loading and RE provides muscular loading. Precisely, this combination improves multiple musculoskeletal outcomes including muscle strength and mass as well as aBMD (Martyn & Carroll 2019; Kukuljan et al., 2009).



Racket sports like tennis, demonstrated a significant increase in muscle mass and bone thickness in the playing arm (Hervás et al., 2019). Similarly, for the other racket sports, the athletes showed a better bone strength and mass in playing arm compared with the other one (Boreham & McKay, 2011). Assuring that, Bass et al. (2002) studied the effect of tennis on the arms and found a significant difference in the playing arm with thicker cortices and greater BMD by 22% compared with the non-playing arm.

The current literature shows that both gravitational and muscle joint forces are able to result in bone adaptation independently; Although they act together in most situations. Ground impact exercises of a certain rate and magnitude seem to have a significant effect for BMD at the hip but not the spine, whereas RE seems to have great effect on spine BMD. Suggesting that the two forces have act differently on body sites. To induce significant results, the exercises should be dynamic with high rate and magnitude of the stimuli, preferentially involving high ground reaction activities and RE training. On the other hand, endurance exercises are less beneficial and low-impact activities have no significant effect. Finally, points to be taken into consideration while programming a physical activity are the variation and increase of the intensity and frequency beyond the habitual level, with no direct effect of the duration of the workout (Morseth et al., 2011).

#### *4.3 Mechanism*

During growth, bones are more adaptable to mechanical loading compared to after maturity. This is the mechanostat process, which describes how mechanical loading affects bone structure by altering mass (the amount of bone) and architecture (the way it is arranged) to provide a structure that resists habitual loads with a minimal amount of material, allowing physiological adaptation to maintain a bone's species-specific property, as well as the evolutionary adaptation in population (Parfitt, 1994). Furthermore, the osteogenic effect of a particular sport is conditioned upon the rate at which the load is applied, the magnitude of the applied load, and the period of the loading bout. In fact, physical activities with a moderate to high loading magnitude at a rapid rate have the greater osteogenic effect on growing skeleton (Gunter et al., 2012). Consequently, supporting the mechanostat theory (Frost, 2003), bone strength and mass normally adapt to the largest voluntary loads on bones. Theoretically, the magnitude of muscle loading on bone is greater than the gravitational loading, because of differences in lever arm length during a given static movement (Beck, 2009; Judex & Carlson, 2009). Assuring that an experimental research done by Kohrt et al. (1997) compared the peak ground reaction with peak muscle forces during walking and jogging; with 1.5 and 2.8 to 4.8

times body weight respectively for walking and 2 to 3 and 5 to 6 times body weight respectively for jogging. However, in non-static movement like impact movements, muscle contractions are less substantial, but still effective, and the amplitude of ground-reaction forces is crucial for site-specific BMD. According to Tobeiha et al. (2020), bones have an inbuilt biological system that stimulates bone growth in response to mechanical pressures. Physical activity might elevate anti-inflammatory cytokines, regulate collagen synthesis during bone formation (Mezil et al., 2015) and induce a muscle tension which is transmitted to the bones to encourage osteoblast proliferation (Kaspar et al., 2002). In contrast, sedentary and bedridden enhance osteoclasts activity and decrease osteoblasts activity, misbalancing the regulation of skeleton homeostasis (Klein-Nulend et al., 2013; Hong & Kim, 2018)

In addition to mechanical stimulation, impact exercises on land aim to strengthen bone tissue by increasing the physical burden load on the bone tissues and creating the required stress in every cellular process (osteoblast, osteoclast, and osteocyte), leading to significant changes in BMD (Maillane-Vanegas et al., 2020). In contrast, no-impact exercises affect bone mostly through muscle loading (Morseth et al., 2011) that is believed to provoke osteoblasts proliferation and therefore boosts their activities (Tobeiha et al., 2020).

Finally, the mechanostat theory designates that there is an upper and lower strain threshold, creating a “physiological loading zone”, which is a range where stimuli sustain homeostasis of the bone mass and bone remodeling. Above the upper strain threshold (2000 microstrains), “the minimum effective strain for modeling”, bone formation is dominant, inducing bone gains. Below the lower strain threshold (200 microstrains), “the minimum effective strain for remodeling”, here the resorption will be overriding process because the stimuli are insufficient to sustain formation, inducing bone loss. Furthermore, the 2 thresholds might be relative to individualized habitual loads (Skerry, 2008; Lindén, 2006; Frost, 2003).

## 5. Effect of team sports on bone variables

As mentioned previously, high impact loading consisting of high magnitude accelerations and decelerations in different planes of movements (non-habitual directions), produces load and loading rates which exceed the upper strain threshold (mechanostat theory) for an effective osteogenic stimulus. Team sports involve those mechanical loadings; hence lifetime hours of training were linked to high bone mineral density (Kettunen et al., 2010).

### *5.1 Team sports in the pre-puberty age*

For the prepubertal phase, basketball practice enhanced bone mineral content and bone area in whole body, upper and lower extremities, total hip, trochanter, and whole right and left radius compared with control (Zribi et al., 2014). Additionally, and for the same age, volleyball practice significantly increased BMC in WB and most weight bearing and non-weight bearing sites, and BA in WB, LS, limbs, and femoral region all compared with CG (Zouch et al., 2016). Furthermore, Lozano-Berges et al. (2018) stated that football practice induces positive effects on bone variables for the weight bearing sites including LS, hip, FN, trochanter, intertrochanteric region and both legs.

### *5.2 Team sports for the adolescents*

Football practice increased BMD as well for adolescent compared with control group in a longitudinal study done by Agostinete et al. 2016. Maillane-Vanegas et al. (2020), studied the effects of various PA on adolescents. They stated that soccer and basketball had significantly greater upper and lower body BMD compared to other sports and control groups. Furthermore, Jallai et al. (2017) concluded that for adolescent and on a youth league level, basketball and soccer had significant effects on BMD and basketball had significantly greater results specifically for the upper limbs.

Considering the type of football turf, Lozano-Berges et al. (2015) studied the effect of different playing surfaces on BMD in pubertal football players; compared with natural, second generation, and non-grass turf surfaces, third generation turf had the greatest results on lower limbs BMD highlighting the importance of playing surface on bone variables for adolescents.

### *5.3 Team sports for adults*

For adults, in a cross-sectional study done by Sanfilippo et al. (2019), they stated that first division basketball athletes had significantly increased BMD compared with baseline.

Moreover, Carbuhn et al. (2010) studied the effect of college level sports on bone variables and concluded a greater increase in BMD for basketball and volleyball athletes compared with track runners, swimmers and control groups. Additionally, in a systematic review done by Taylor et al. (2017), they mentioned that team sport like basketball, volleyball, football, handball, futsal, and field hockey all have significant effect on BMD. However, compared to football and volleyball, basketball requires a higher-intensity of running and sprinting, as well as more abrupt cutting and stops, which causes greater stimulus to the musculoskeletal system compared to volleyball and soccer. On the other hand, Scerpella et al. (2018) compared bone variables for college league team sports athletes (basketball, ice hockey, and football) between sophomore senior years; at first, the athletes experienced a significant increase in bone variables compared with high school year; however, a light non-significant increase in BMD values and even decrease in the case of soccer was seen between sophomore and senior year. This highlights the theory that bones have an adaptable response to stimuli and that training at the same intensities over years will no longer affect the bones.

#### 5.4 Basketball

Table 4: Cross sectional studies on Basketball and bone variables

Study	Population	Age	Results	Conclusion
Stojanović et al. (2020)	N=15 First division	Young adults	↑ WB, spine, LS, UE, LE, pelvis, trunk, FN BMD	BB → ↑ BMD % non-athletes, swimming, volleyball, football
Maillane-Vanegas et al. (2020)	N=429 Academy level	Adolescents	↑ WB, LS, UE, LE BMD	BB → ↑ UE BMD % judo, Kung Fu, karate, football, swimming
Sanfilippo et al. (2019)	N=337 First division	Young adults	↑ WB BMD	BB → ↑ BMD % CG
Scerpella et al. (2018)	N=85 College league	Young adults	↑ LE BMD ↑ WB, LE BMC	↑ BMD and BMC was greater during 1 <sup>st</sup> year of college BB because of bone adaptation to training intensity
Tenforde et al. (2018)	N=239 College league	Young adults	↑ WB, LS BMD	Athletes in low impact sports, ↓ BMI → ↓BMD
Agostinete et	N=53	Adolescents	↑ LE BMC	BB ↑ bone variables compared to swimmers and CG

al. (2017)	Academy level		↑ LE BA ↑ LE BMD	
Jallai et al. (2017)	N=27 National youth league	Adolescents	↑ WB, LR, RR, LS, RL, RL, RF, RFN BMD	BB ↑ BMD in weight bearing and non-bearing sites + Correlation between BMD and LBM
Stanforth et al. (2016)	N=170 College league	Young adults	↑ WB, LS BMD ↑ WB BMC	BB > BMC and BMD compared with VB, FB, swimmers, track athletes and CG for except WB and LS
Zouch et al. (2016)	N=170 Academy level	Pre-puberty	↑ LE BMC ↑ WB, LE, UP, LS, femur, BA	+ effects on BMC and BA in loaded sites
Agostinete et al. (2016)	N=82 Academy level	Adolescents	↑ WB, UE, LE, LS BMD	BB ↑ BMD % FB, karate, judo, swimming, CG
Zribi et al. (2014)	N=98 Academy level	Pre-puberty	↑ BMC, BA in WB, UE, LE, Tr, TH, RR, LR	BB ↑ LBM and bone mass % CG + correlation between LBM and BMD
Quiterio et al. (2011)	N=80 Academy	Adolescents	↑ WB, LE, UE BMD	This study confirms the beneficial relationships between high-impact physical activity and teenage boys' bone health.

	level			
Sone et al. (2006)	N=94 College level	Young adults	<p>↑non-dominant leg BMC</p> <p>↑non dominant leg cortical width</p> <p>↑non dominant leg CSMI</p> <p>↑non dominant leg cortical BMD</p>	The non-dominant leg supports the movements of the dominant leg while the dominant leg is employed for mobility or manipulation → resulting in loading variations in the bilateral legs of young athletes, which may have an impact on the remodeling pace and cause side-to-side variations in cortical BMD.
McClanahan et al. (2002)	N=184 College league	Young adults	↑dominant arm BMD	↑ mechanical stress for dominant arm in dribbling passing and shooting
Morel et al. (2001)	N=704 Amateur level	Young adults	↑WB, LE BMD	Site-specific increases in bone mineral density are linked to the allegedly high and atypical strains produced at particular places during sport-specific training by muscle tension and gravity forces.
Lee et al. (1995)	N=62 College level	Young adults	<p>↑dominant arm BMD</p> <p>↑WB LS BMD</p>	BB ↑ bone variables in loading sites with greater results on site specific loads
Nichols et al.	N=58	Young	↑ FN, LS, WB	> correlation BMD and LBM than with fat mass

(1995)	College level	adults	BMD	
Risser et al. (1990)	N=44 College level	Young adults	↑ calcaneal BMD	Vertical weight bearing exercises → ↑ BMD values

BMD: bone mineral density; FN: femur neck; LS: lumbar spine; BA: bone area; TH: total hip; WB: whole body; Tr: trochanter; UE: upper extremity; LE: lower extremity; RR: right radius; LR: left radius; BMC: bone mineral content; RL: right leg; RF: right femur; CSMI: cross-sectional moment of inertia; CG: control group; LBM: lean body mass; VB: volleyball; BB: basketball; FB: football.

Table 5: Effect of Basketball on bone variables

Study	Population	Age	Results	Conclusion
Randers et al. (2018)	N=35	Young adults	↑ WB BMD ↑ LE BMC	Street BB ↑ bone variables, with ↑ effects for full court than half court

BMD: bone mineral density; WB: whole body; LE: lower extremity; BMC: bone mineral content; BB: basketball.

Basketball is a highly stimulating sport for bone variables. Targeting the whole body and site specific loaded body parts, including the lower extremity sites like femoral neck, calcaneus, hip, total hip, trochanter, pelvis, the upper extremity sites like arm, radius and the trunk like spine and lumbar spine. Besides, significant differences were seen in side to side extremities. For the lower extremities the non-dominant leg, having the role of support for the other leg, resulted in significant higher bone values compared w the dominant leg. In the contralateral comparison of the upper extremities, basketball induced better effects on the dominant arm resulting from the higher mechanical stress while dribbling, passing, and shooting.



## 5.5 Volleyball

Table 6: Cross sectional studies on Volleyball and bone variables

<b>Study</b>	<b>Population</b>	<b>Age</b>	<b>Results</b>	<b>Conclusion</b>
Sanfilippo et al. (2019)	N=337 First division	Young adults	↑ WB BMD	VB → ↑ BMD % CG
Tenforde et al. (2018)	N=239 College league	Young adults	↑ WB, LS BMD	Athletes in low impact sports, ↓ BMI → ↓BMD
Zouch et al. (2016)	N=170 Academy level	Pre-puberty	↑ ultra-distal radius, LE BMC ↑ WB, LE, UE, LS, femur, radius, BA	↑ mechanical stress on loaded sites % BB + effects on BMC and BA in loaded sites
Stanforth et al. (2016)	N=170 College league	Young adults	↑ arm, leg, pelvis, LS, WB BMD	↑ BMD and BMC % CG No significant difference between BMD and BMC % FB and track athletes
Sone et al. (2006)	N=94 College level	Young adults	↑ non-dominant leg BMC ↑ non dominant leg cortical	The non-dominant leg supports the movements of the dominant leg while the dominant leg is employed for mobility or manipulation, hence loading disparities in the bilateral legs of young athletes may alter the remodeling pace, resulting in side-to-side variances in cortical BMD.

			width ↑ non dominant leg CSMI ↑ non dominant leg cortical BMD	
McClanahan et al. (2002)	N=184 College league	Young adults	↑ dominant arm BMD	↑ mechanical stress for dominant arm in shooting
Morel et al. (2001)	N=704 Amateur level	Young adults	↑ WB, LE BMD	The increase in BMD is location-specific and associated with the allegedly high and atypical strains produced at certain locations during sport-specific training by muscle stress and gravity forces.
Lee et al. (1995)	N=62 College level	Young adults	↑ FN, LS, WB, Tr BMD ↑ dominant arm BMD ↑ non-dominant foot BMD	VB ↑ bone variables in loading sites with greater results on site specific loads
Nichols et al. (1995)	N=58 College level	Young adults	↑ FN, LS, WB BMD	> correlation BMD and LBM than with fat mass

Calbet et al. (1999)	N=30 First division	Young adults	↑ WB, limb, dominant arm, non-dominant leg BMC ↑ LS, FN, dominant arm BMD	↑ BMD and BMC for correlated with LBM for UE and mechanical load for LE
Risser et al. (1990)	N=44 College level	Young adults	↑ calcaneal BMD	Vertical weight bearing exercises → ↑ BMD values

BMD: bone mineral density; FN: femur neck; WB: whole body; LS: lumbar spine; Tr: trochanter; CSMI: cross-sectional moment of inertia; VB: volleyball; BB: basketball; FB: football; LE: lower extremities; UE: upper extremities; LBM: lean body mass; BA: bone area.

Volleyball is a highly stimulating sports for bone variables. Targeting the whole body and site specific loaded body parts, including the lower extremity sites like femoral neck, calcaneus, hip, total hip, trochanter, pelvis, the upper extremity sites like arm, radius, ultra-distal radius and the trunk like spine and lumbar spine. Besides, significant differences were seen in side to side extremities. For the lower extremities the non-dominant leg, having the role of support for the other leg, resulted in significant higher bone values compared with the dominant leg. In the contralateral comparison of the upper extremities, volleyball induced better effects on the dominant arm resulting from the higher mechanical stress smashing the ball.

## 5.6 Football

Table 7: Cross sectional studies on Football and bone variables

Study	Population	Age	Results	Conclusion
Finianos et al. (2021)	N=35 Former division 1	Middle aged adults	↑ CSI, BSI, ISI	Residual effect on FB → higher composite indices of FN strength in middle-aged men % CG
Maillane-Vanegas et al. (2020)	N=429 Academy level	Adolescents	↑ WB, LS, UE, LE BMD	Football → ↑ BMD % judo, karate, basketball, swimming, kung Fu
Sanfilippo et al. (2019)	N=337 First division	Young adults	↑ WB BMD	FB → ↑ BMD % CG
Hagman et al. (2018)	N=140 Division 1	Young adults	↑ LE, WB, FN, femur BMD	Football → ↑ BMD % CG
Hagman et al. (2018)	N=140 Former division 1	Old adults	↑ FN, ward, shaft, femur, Tr BMD	Football → ↑ residual effect BMD % same age CG, young CG LE BMD
Scerpella et al. (2018)	N=85 College league	Young adults	↑ LE BMD ↑ LE BMC	↑ BMD and BMC was greater during 1 <sup>st</sup> year of college because of bone adaptation to training intensity
Lozano-	N=27	Pre-puberty	↑ WB, LS, FN,	FB ↑ BMD and BMC in puberty % pre-puberty ages.

Berges et al. (2018)	Academy level	& puberty	Tr BMD	Weight bearing sites: LS, hip, FN, Tr, intertrochanteric region and both legs are sensitive to FB
Tenforde et al. (2018)	N=239 College league	Young adults	↑ WB, LS BMD	Athletes in low impact sports, ↓ BMI → ↓BMD
Jallai et al. (2017)	N=27 National youth league	Adolescents	↑ supporting foot BMD	Football ↑ BMD in weight bearing sites + correlation between BMD and LBM
Stanforth et al. (2016)	N=170 College league	Young adults	↑ WB BMC Leg BMD	↑ BMD and BMC % CG No significant difference between BMD and BMC % FB and track athletes
Agostinete et al. (2016)	N=82 Academy level	Adolescents	↑ WB BMD	FB ↑ BMD % CG
Hage (2014)	N=53 Division 1	Young adults	↑ LS, TH, FN BMD	↑ LS, hip BMD % CG
Anliker et al. (2013)	N=66 Academy level	Adolescents	↑ non dominant leg bone mass and geometry	Non-dominant support the action of the dominant leg, meaning that the mechanical load experienced by the tibia might be more pronounced for the non-dominant leg leading to the observed higher bone strength values
Seabra et al.	N=150	Adolescents	↑ WB, LE BMD	Muscle strength of knee extensors is associated with BMD and BMC at all

(2012)	Amateur national level			body sites.
Marmara and Kosmas (2012)	N=81 National level	Middle-aged adults	↑ WB, LS, femur BMD	FB has a positive residual effect on BMD values after termination of the career
Nebigh et al. (2009)	N=152 Academy level	Adolescents	↑ WB, LS, FN, LE, pelvis BMD ↑ WB, LS, FN, LE, pelvis BMC	FB ↑ BMD early and late puberty stages
Fredericson et al. (2007)	N=45 National level	Young adults	↑ calcaneus, hip, tibia, LS, WB BMD	FB ↑ BMD values % long distance runners and CG
Sone et al. (2006)	N=94 College level	Young adults	↑ non-dominant leg BMC ↑ non dominant leg cortical width ↑ non dominant leg CSMI ↑ non dominant	The non-dominant leg supports the movements of the dominant leg while the dominant leg is employed for mobility or manipulation, hence loading disparities in the bilateral legs of young athletes may alter the remodeling pace, resulting in side-to-side variances in cortical BMD.

			leg cortical BMD	
Vicente-Rodriguez et al. (2003)	N=104 Academy level	Pre-puberty	↑ femur, LS BMD ↑ Tr BMC	FB ↑ BMC and BMD in load specific sites The combination of anthropometric and fitness variables may be useful to detect children with potentially reduced bone mass.
McClanahan et al. (2002)	N=184 College league	Young adults	↑ non-dominant leg BMD	↑ mechanical stress in the non-dominant leg while supporting the movement of the dominant leg
Calbet et al. (2001)	N=52 Recreation	Young adults	↑ leg, FN, LS, WT, WB BMD ↑ WB BMC	Long-term football activity is linked to significantly higher BMC and BMD at the femoral neck and lumbar spine regions compared to the control group beginning at pre-pubertal age.
Morel et al. (2001)	N=704 Amateur level	Young adults	↑ WB, LE BMD	The increase in BMD is location-specific and associated with the allegedly high and atypical strains produced at certain locations during sport-specific training by muscle stress and gravity forces.
McCulloch et al. (1992)	N=68 Academy level	Adolescents	↑ calcaneus BMD	FB develops the largest loads on LE % swimmers and CG; therefore the ↑ BMD

BMD: bone mineral density; LS: lumbar spine; WB: whole body; UE: upper extremity; LE: lower extremity; BMC: bone mineral content; Tr: trochanter; WT: ward triangle; CSI: compression strength index; ISI: impact strength index; BSI: bending strength index; CSMI: cross-sectional moment of inertia; CG: control group; LBM: lean body mass; VB: volleyball; BB: basketball; FB: football; FN: femoral neck;

Football is a highly stimulating sport for bone variables. Targeting the whole body and site specific loaded body parts, including the lower extremity sites like femoral neck, calcaneus, hip, ward triangle, ward, shaft, total hip, trochanter, pelvis and the trunk like spine and lumbar

spine, with no significant effect on the upper extremity. Besides, significant differences were seen in side to side lower extremity where the non-dominant leg, having the role of support for the other leg, resulted in significant higher bone values compared with the dominant leg.



## 5.7 Ice hockey

Table 8: Cross sectional studies on Ice Hockey and bone variables

Study	Population	Age	Results	Conclusion
Dengel et al. (2021)	N=83 College level	Young adults	BMD = throughout the season	No difference between positions in BMD values
Scerpella et al. (2018)	N=85 Division 1 college	Young adults	↑ LE BMD ↑ LE BMC	↑ BMD and BMC was greater during 1 <sup>st</sup> year of college IH because of bone adaptation to training intensity
Tervo et al. (2010)	N=92 National level	Young adults	↑ legs, LS, FN, WB, humerus BMD	IH induced ↑ BMD values than CG
Gustavsson et al. (2003)	N=68 Academy level	Adolescents	↑ FN, WB, LS BMD ↑ FN volumetric BMD	Active IH players increased BMD % CG Fast BMD loss at the FN after ↓ PA in young men → If the activity is not continued, playing ice hockey during childhood and adolescence may not be able to stop the onset of femoral neck osteoporosis later in life.
Nordström & Lorentzon (1996)	N=44 Academy level	Adolescents	↑ WB, Tr, FN, pelvis BMD	No correlations between muscle strength and BMD Difference in BMD with CG related to site specific loads Compressive forces acting on tibia and femur diaphysis are not enough to induce enhancements in BMD

BMD: bone mineral density; LS: lumbar spine; WB: whole body; UE: upper extremity; LE: lower extremity; BMC: bone mineral content; Tr: trochanter; WT: ward triangle; CSI: compression strength index; ISI: impact strength index; BSI: bending strength index; CSMI: cross-sectional moment of inertia; CG: control group; LBM: lean body mass; IH: ice hockey; FN: femoral neck; PA: physical activity.

Ice hockey is a stimulating sport for bone variables. Targeting the whole body and site specific loaded body parts, including the lower extremity sites like humerus, femoral neck, trochanter, pelvis and the trunk like lumbar spine. No studies conducted the contralateral differences for ice hockey players.

## 5.8 Rugby

Table 9: Cross sectional studies on Rugby and bone variables

Study	Population	Age	Results	Conclusion
Varley et al. (2022)	N=46 National level	Young adults	↑ WB BMD ↑ Le, WB BMC ↑ tibia bone mass and area	As a result of the modeling data on anticipated changes in bone properties, practitioners now have a way to identify players who have atypical bone responses to rugby training and match play.
Entwistle et al. (2021)	N=138 National level	Middle aged	↑ hip, LS BMD	Rugby has a residual effect on hip and LS % CG
Jones et al. (2018)	N=12 Division 1	Young adults	↑ total trunk, UE, LE BMC	6 years of rugby ↑ significantly bone values in loaded sites
Till et al. (2016)	N=97 Academy level & division 1	Young adults & adolescents	↑ WB BMC	Senior rugby players had greater BMC values than academy players, highlighting the importance of rugby for adults.
Hind et al. (2015)	N=84 Division 1	Young adults	↑ total hip, FN BMD ↑ hip bone geometry	BMD ↓ in proportion to BW and LBM. The improvement in bone geometry indicates that overall bone strength might be sufficient to meet loading requirements.

Higham et al. (2014)	N=65 Division 1	Young adults	↑ bone values in forwards vs backs	Bone mineral mass is associated with player's position
Georgeson et al. (2012)	N=37 Division 1	Young adults	↑ WB BMD until mid-season	Over the course of a professional rugby league season, significant anthropometric changes were seen in players, including a general loss of muscle and an initial gain but subsequent drop in bone mass.
Elloumi et al. (2009)	N=36 Division 1	Young adults	↑ BMD and BMC in WB, spine, pelvis, UE, LE	In adult athletes, rugby boosted bone turnover, increased axial and appendicular bone mass, and improved physical fitness. These players' improved bone health may be caused by an increase in the rate of bone remodeling in favor of bone creation, notably in the forwards.
Elloumi et al. (2006)	N=49 National level	Young adults	↑ spine BMD ↑ UE, LE, pelvis, spine BMC ↑ bone values in forwards vs backs	Long-term rugby starting at pubertal age → All skeletal sites, with the exception of the head, had increased BMC, BMD, and bone size. The bone features that are localized in particular stressed regions can be explained by the musculoskeletal adaptations, which are more pronounced in forwards than in backs and could resemble training responses.
Bell et al. (2005)	N=51 Division 1	Young adults	↑ absolute amount of bone mineral mass	Forwards had the greatest ↑ in bone mass % backs and CG

Morel et al. (2001)	N=704 Amateur level	Young adults	↑ WB, LE, UE, spine BMD	The increase in BMD is location-specific and associated with the allegedly high and atypical strains produced at certain locations during sport-specific training by muscle stress and gravity forces.
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BMD: bone mineral density; LS: lumbar spine; WB: whole body; UE: upper extremity; LE: lower extremity; BMC: bone mineral content; Tr: trochanter; WT: ward triangle; CSI: compression strength index; ISI: impact strength index; BSI: bending strength index; CSMI: cross-sectional moment of inertia; CG: control group; LBM: lean body mass; IH: ice hockey; FN: femoral neck; PA: physical activity; BW: body weight.

Rugby is a highly stimulating sport for bone variables. Targeting the whole body and site specific loaded body parts, including the lower extremity sites like femoral neck, hip, total hip, tibia, pelvis, the upper extremity sites like arm, radius and the trunk like total trunk, spine and lumbar spine. No studies conducted the contralateral differences for rugby players.

## 5.9 Handball

Table 10: Cross sectional studies on Handball and bone variables

Study	Population	Age	Results	Conclusion
Hagman et al. (2021)	N=130 Former division 1	Old adults	↑ WB, LS, femoral WT, Tr, left leg BMD	In older people, ongoing exercise is linked to improved bone mineralization and altered bone turnover.
Missawi et al. (2016)	N=100 Academy level	Pre-puberty	↑ right, left FN, total hip, ↑ legs, total hip BMC ↑ BMD in non-dominant leg ↑ BMC total hip, right radius in dominant sides	Training in handball significantly stimulates some bone locations in prepubescent boys.
Selmi et al. (2013)	N=17 Academy level	Adolescents	↑ LS, femur BMD	Playing handball frequently appears to be an osteogenic factor. Adolescents' bone health should be optimized during the growth phase.

Quiterio et al. (2011)	N=80 Academy level	Adolescents	↑ WB, LE, UE BMD	This study confirms the beneficial relationships between high-impact physical activity and teenage males' bone health.
Morel et al. (2001)	N=704 Amateur level	Young adults	↑ WB, LE BMD	The increase in BMD is location-specific and associated with the allegedly high and atypical strains produced at certain locations during sport-specific training by muscle stress and gravity forces.

BMD: bone mineral density; LS: lumbar spine; WB: whole body; UE: upper extremity; LE: lower extremity; BMC: bone mineral content; Tr: trochanter; WT: ward triangle; CSI: compression strength index; ISI: impact strength index; BSI: bending strength index; CSMI: cross-sectional moment of inertia; CG: control group; LBM: lean body mass; IH: ice hockey; FN: femoral neck; PA: physical activity; BW: body weight.

Table 11: Effect of Handball on bone variables

Study	Population	Age	Results	Conclusion
Fristrup et al. (2020)	N=54 Recreation	Young adults	↑ WB, LE BMC ↑ total hip BMD	In previously untrained young adults, recreational small-sided team handball training appears to successfully enhance quick force capability, postural balance, lean and fat body mass, and bone health.
Hornstrup et al. (2019)	N=26 Recreation	Young adults	↑ proximal femur BMD ↑ WB BMC	Recreational handball training results in beneficial cardiovascular, skeletal, and muscular adaptations, such as increased muscular enzymatic activity, increased maximum oxygen uptake, better bone mineralization, and decreased body fat percentage. For young guys, recreational team handball practice may be a beneficial exercise for promoting their health.

BMD: bone mineral density; WB: whole body; LE: lower extremity; BMC: bone mineral content.



Handball is a highly stimulating sport for bone variables. Targeting the whole body and site specific loaded body parts, including the lower extremity sites like proximal femur, femoral neck, ward, trochanter, hip, total hip, trochanter, the upper extremity sites like arm, radius and the trunk like spine and lumbar spine. Besides, significant differences were seen in side to side extremities. For the lower extremities the non-dominant leg, having the role of support for the other leg, resulted in significant higher bone values compared with the dominant leg. In the contralateral comparison of the upper extremities, handball induced better effects on the dominant arm resulting from the higher mechanical stress smashing the ball.

#### *5.10 Basketball vs football*

Basketball activity requires more jumping than football activity, endorsing greater strain and ground reaction forces imposed on the skeletal system. Comparing basketball with football, in contrast to general mild, repetitive stress, such as continuous jogging, which is frequently practiced in football, Scofield and Hecht (2012) noted that intermittent, varied loading patterns offer a stronger osteogenic stimulation. Furthermore, basketball requires more jumps than football, and high strain loads are applied repeatedly when jumping, resulting in more rigid and fracture-resistant bones. The greater total BMD for basketball players compared to football players was increased in participants aged > 18 years compared to individuals aged 18 years, according to Stojanovi et al. (2020), who took age into account.

#### *5.11 Basketball vs volleyball*

Stojanović et al. (2020) stated in his study that Basketball players showed significantly greater pelvis measurements and total body BMD than volleyball players. While repetitive vertical jumps and landings are a crucial part of both basketball and volleyball, basketball produces more osteogenic stimuli than volleyball. In particular, a thorough examination of the game's action indicated that volleyball rallies typically last 6 s and are followed by 14 s of rest with mobility restrictions (Mroczek et al., 2014), Basketball players, on the other hand, are free to move anywhere on the field and can alter their movement intensities every 1-3 seconds (Stojanovi et al., 2018) demonstrating that players exert more high-intensity, multi-directional movements, such as cutting, sprinting, shuffling, accelerating, and decelerating, more frequently than volleyball athletes, putting more strain on the skeletal system.

## 6. Residual effect of physical activity on bone variables

When compared to matched control subjects, individuals who began high-impact physical activity at a younger age typically had higher trochanter and femoral neck aBMD and sustained hip fractures at longer ages; hence, this form of exercise appears to have positive long-term benefits on bone values, which may help to prevent falls in the future (Kettunen et al., 2010).

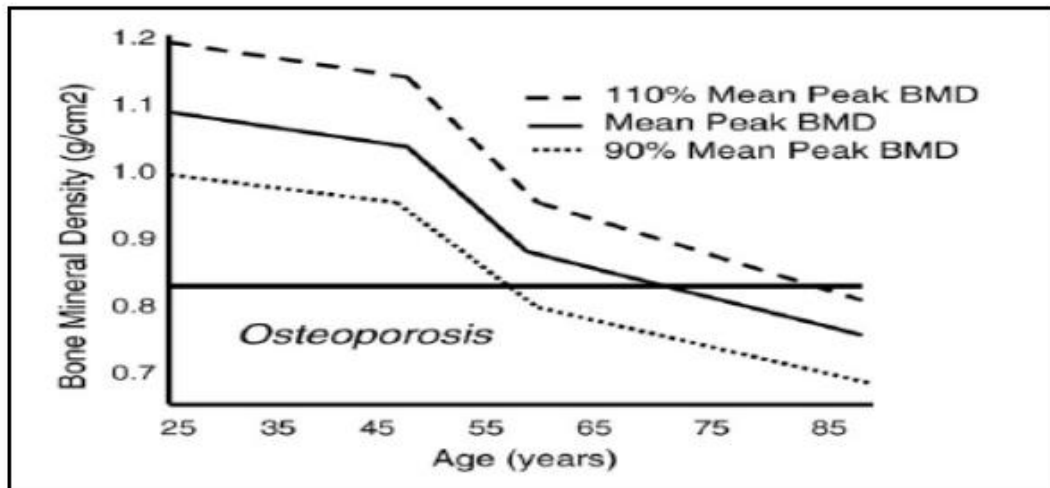
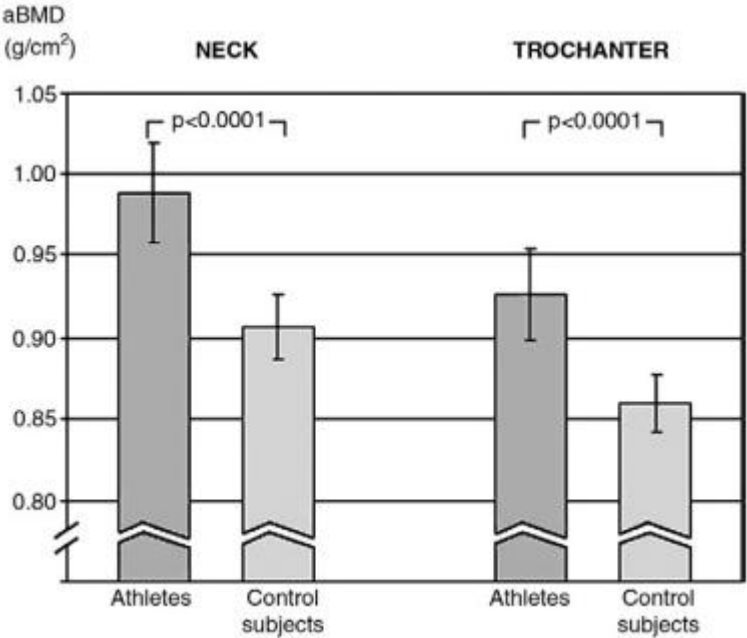


Figure 12: Evolution of peak BMD with age (Rizzoli et al., 2010).

### 6.1 Team sports

Team sports are considered high impact physical activity and believed to induce a residual effect on bone variables. Assuring that, a cross sectional study done by Hagman et al. (2021), They came to the conclusion that compared to an age-matched control group, older handball players had greater bone mineralization and altered bone turnover. For rugby, Entwistle et al. (2021) stated that it has a residual effect on hip and lumbar spine compared with age matched control group. Similarly, football has a positive residual effect on BMD values after termination of the career (Marmara and Kosmas, 2012). Hagman et al. (2018) have done a cross sectional study on the residual effect of football on bone variables for elderly compared with age matched and young control groups; all the BMD values were significantly higher for former footballers compared with the same age's control, and they interestingly had higher lower extremity BMD compared with the young control. Beside the bone variables, football's residual effect on composite indices is adequate. Finianos et al. (2021) stated that former footballers had higher composite indices of femoral neck strength compared with age matched control group. On the other hand, Gustavsson et al. (2003) mentioned that former ice hockey

players experienced a rapid loss in BMD values, mainly FN, after stopping training, highlighting the hypothesis that ice hockey may not prevent the development of OP in the femoral neck after ending their careers.



**Figure 13 : In the population-based control group and former high impact athletes, the femoral neck and trochanter aBMD were adapted for age and BMI (Kettunen et al., 2010)**

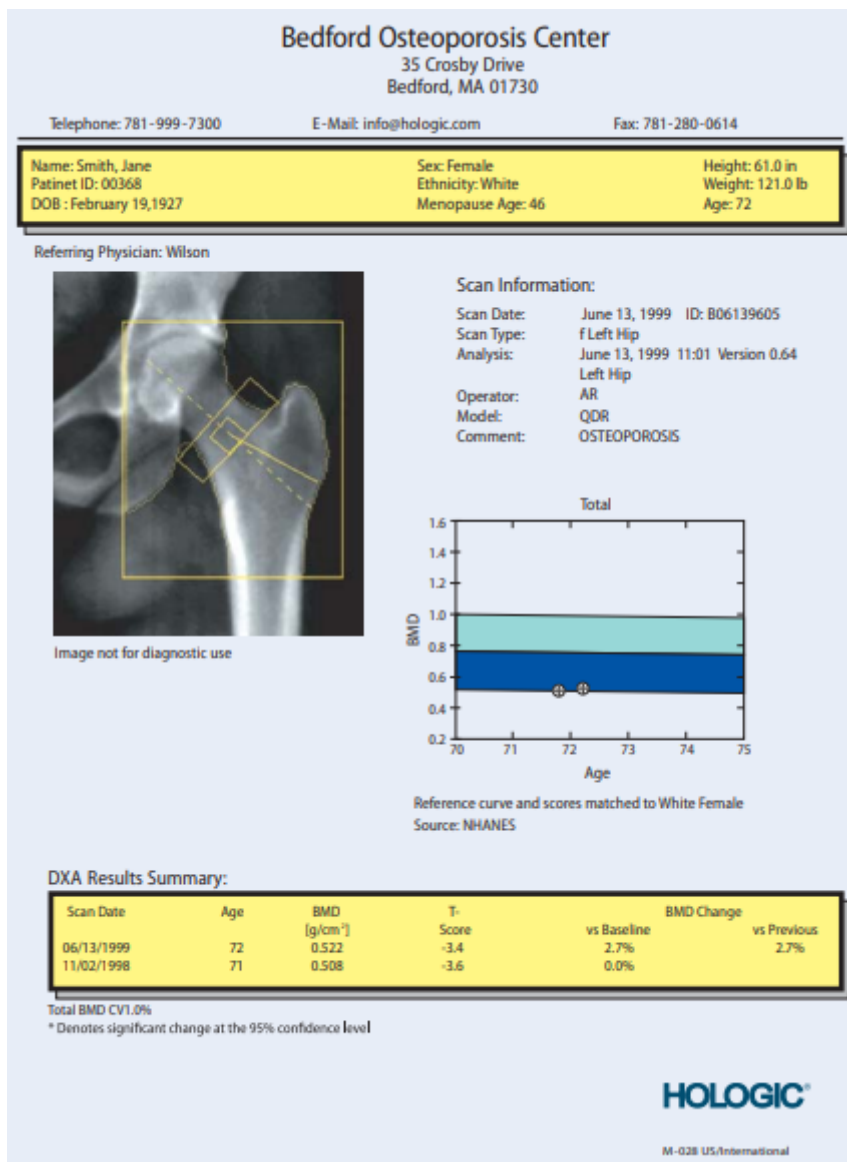
## 7. Methods of assessment of bone variables

### 7.1 Dual-energy X-ray absorptiometry

**Table 12: Bone variables measured and calculated by DXA**

<b>Bone variables</b>	<b>Abbreviation</b>	<b>Clinical importance</b>
Bone mineral content	BMC	Associated with the bones' mechanical resistance (Ammann & Rizzoli, 2003).
Bone mineral density	BMD	ideal factor to determine bone mechanical resistance (Ammann & Rizzoli, 2003).
Areal bone mineral density	aBMD	Estimation of the volumetric bone mineral density (Katzman et al., 1991). Advised for kids and adolescents (Carter et al., 1992).
ratio of height to bone mineral density	BMD/height	Index of the volumetric bone mineral density in g/cm <sup>3</sup> (Reid et al., 1992).
Ratio of body mass index to bone mineral density	BMD/BMI	Value the rise of BMD compared with the weight (De Laet et al., 2005).
Ration of height to bone mineral content	BMC/height	To offer children and teenagers a general understanding of the bone mineralization for a given height (Leonard et al., 2004).
Ration of fat mass to bone mineral content	BMC/FM	This ratio is used to know whether the bone mineralization is adequate to the fat mass (Schoenau et al., 2001).
Trabecular bone score	TBS	Bone texture index that gives information about the trabecular bone microarchitecture (bousson et al., 2005).
<b>Geometrical indices of Beck (Beck et al., 1990)</b>		
Cross sectional area	CSA	It reflects the total surface area of bone in the section across the region studied. It measures how well a bone can endure axial compression.

Cross sectional moment of inertia	CSMI	It measures the bone's structural rigidity.
Cortical thickness	CT	it determines the risk of osteoporotic fracture and bone strength
Section modulus	Z	It reflects bending resistance.
Buckling ratio	BR	it reflects cortical stability to deformation.
<b>Bone strength indices of Karlamangla (Karlamangla et al., 2004)</b>		
Compression strength index	CSI	It displays the femoral neck's capacity to tolerate an axial compression force.
Bending strength index	BSI	It illustrates the femoral neck's capacity to tolerate bending forces.
Impact strength index	ISI	It reflects the capacity of the femoral neck to absorb energy during an impact.



**Figure 14: Left hip DXA scan (Pevrhal, 2006).**

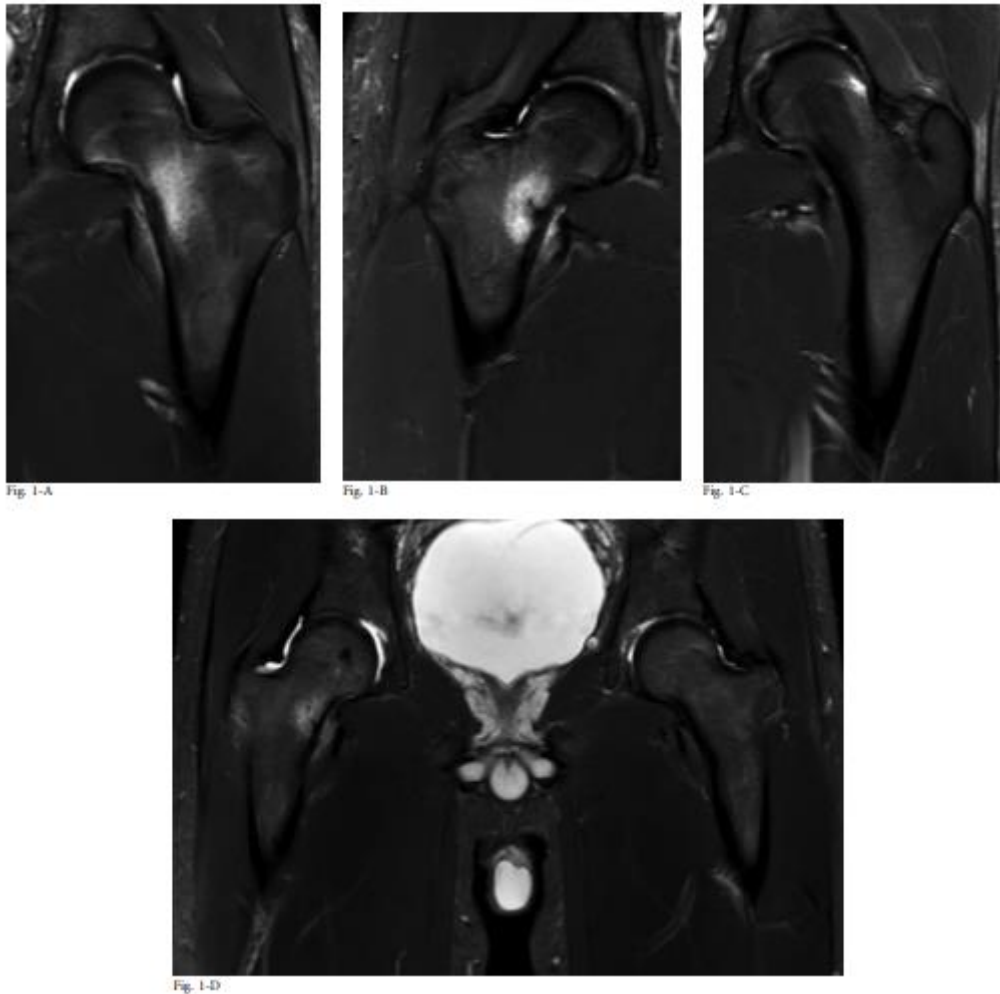
- The microarchitecture is measured indirectly by DXA. Although TBS is correlated with some micro-architectural variables, DXA cannot measure it directly (Ackerman et al., 2011).
- DXA cannot distinguish the cortical bone from the trabecular.
- This method does not make it possible to quantify and thus measure the different types of body fat and its distribution, this influence bone status differently. It uses indices and ratios for indirect measurement of the distribution of body fat (Ackerman et al., 2011).
- The type of device, the operator and the way the patient is positioned influence the BMD value (HAS, 2006).

- Depending on the brand of the device, different samples were examined and used for the reference measurements (the reference bases are used for the calculation of the T score) (HAS, 2006).
- Small differences in BMD values may appear depending on the site measured in the same subject (HAS, 2006).
- The weight of the subject is limited to 150 kg for certain machines. Massively obese persons are not suited for current technology (Barbe & Ritz, 2005). Additionally, the subject's abdominal diameter shouldn't be greater than 60 to 65 cm. As a result, participants with a BMI more than 35 kg/m<sup>2</sup> should not be used to test the TBS. Studies have proved that DXA overestimates BMD values in obese subjects (Kremer & Gilsanz, 2016).
- The potential infiltration of water or fat into the muscle is not taken into consideration by this method, and its ability to assess how well the muscle is functioning is also not provided.
- Patients who have mobility issues should not use the current technology (intensive care situation...).

## 7.2 Magnetic resonance imaging

The parameters of bone microarchitecture measured by MRI (Lespessailles et al., 2006) and defined by Parfitt et al. (1983) can be summarized by the following:

- The ratio of bone volume to tissue volume is known as the bone volume fraction. (bone volume/tissue volume). This fraction is measured by the MIL method (Mean Intercept Length) (Whitehouse, 1974).
- The trabecular number (TbN) using the MIL method.
- The thickness of the spans.
- Intra-trabecular spacing.
- The trabecular surface.
- The ratio bone surface/bone volume (BS/BV).
- Texture analysis (Lespessailles et coll. 2006).
- The Porosity Index, a biomarker of cortical bone porosity that can be used to forecast the mechanical stiffness of bones (Hong et al., 2019).
- BMD (Russell et al., 2010).
- BMC (Pollock et al., 2010).



**Figure 15: Hips MRI scan (Steele et al., 2018).**

T2-weighted coronal MRI scans are shown the Figures. Fig. 1-A isolated bone edema without a clear fracture line on the compression side of the femoral neck. Fig. 1-B Compression-sided cortical fracture with high signal intensity and surrounding bone edema involving about 50% of the femoral neck. Fig. 1-C High signal intensity bone edema at the anterolateral head-neck junction on the tension side of the femoral neck. Fig. 1-D a right-sided femoral neck stress fracture with an accompanying right hip effusion and a fracture line affecting the compression side of the femoral neck (Steele et al., 2018).

From the Parfitt parameters, we can calculate the number of anastomoses between the bone spans and also the number of free ends that correspond to disconnected segments (Mellish et al., 1991). It is also possible to obtain the interconnectivity index which reflects the skeleton of bone marrow (Le et al., 1992). The Trabecular Bone Pattern Factor is an index that reflects the connectivity (Hahn et al. 1992). The "star volume" of the marrow and the Euler technique would reflect connectivity (Vesterby et al., 1989; Feldkamp et al., 1989). The "ridge number



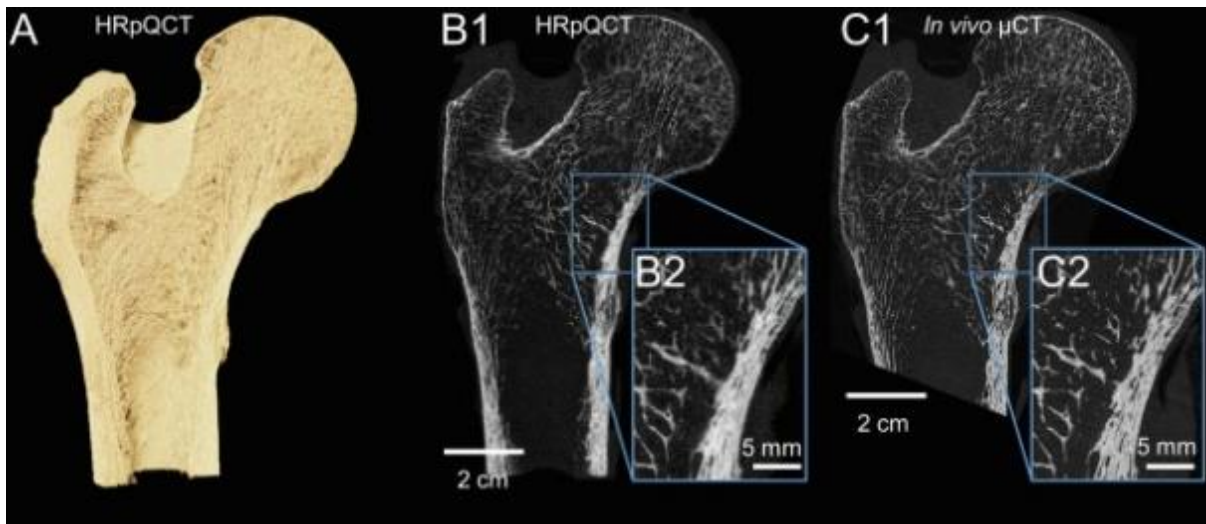
density” introduced by Laib et al. (1997), would reflect the density of the spans. Finally, the "structure model index” quantifies the characteristic shape of a three-dimensional structure in terms of quantity of plates and beams making up the structure (Hildebrand et al., 1997).

### 7.3 Tomography

Microcomputed tomography stands out among X-ray imaging methods because it has a better spatial resolution than traditional computed tomography (Porrelli et al., 2022).

Tomography bone related variables:

- Volumetric BMD (Haffer et al., 2022).
- Bone geometry (Gilsanz et al., 2009).
- BMD (Choi et al., 2010).
- Connectivity density.
- Spans number.
- Spans separation.
- Mechanical vertebral behavior (Silva et al., 2014).
- Fraction of bone volume.
- Microarchitecture.
- Morphological parameters of trabecular bone including bone architecture, loss/remodeling (Barou et al., 2002) and osteoporotic fracture risk in small animals (Jin et al., 2016).
- Porosity [%]: the proportion of empty space to total volume, calculated as  $1 - BV/TV$  (BV: bone volume; TV: Total Volume).
- TBS.
- Trabecular Thickness.
- Trabecular microstructure.
- Trabecular Spacing, the average diameter of pores.
- TbN, or the average number of trabeculae per unit length, is sometimes taken as an indicator of the complexity of an architectural design.
- Connectedness Density (ConnD), a parameter that relates the intricacy of the trabeculae structure to the degree of connectivity of the trabeculae (Porrelli et al., 2022).
- Geometrical aspect of trabeculae (Salmon et al. 2015).
- BMC (Pritchard et al., 2020).



**Figure 16: Hierarchical structure of a human proximal femur (Wittig et al., 2022).**

Using high resolution peripheral quantitative computed tomography (HRpQCT), human bone structure is examined over a range of decreasing length scales, in vivo microscopic computed tomography  $\mu$ CT. (A) A full proximal femur scanned by HRpQCT is depicted in 3D. For scale, the proximal femur's length from the trochanter to the cut off is 11 cm. (B-C) Virtual 2D slice of the proximal femur as measured by (B1-2) HRpQCT and (C1-2) in vivo  $\mu$ CT. Scale bars are 20 mm in B1 and C1 and 5 mm in B2 and C2 (Wittig et al., 2022).

Quantitative tomography makes it possible to evaluate bone variables but it is expensive and irradiating and therefore cannot be used routinely in clinical practice (Ducher & Blimkie, 2006). Additionally, the fact that high-resolution radiographic imaging techniques, including micro-CT, may only be used on tiny animals in vivo (Burghardt et al., 2011), and that the outcomes of these approaches may depend on the computational methods used for picture interpretation (Alsayednoor et al., 2018; Hara et al., 2002) is one of their key drawbacks. It has been demonstrated that, in some circumstances, even the micro-CT data is insufficient to fully characterize the bone structure and the harm brought on by mechanical loading (Mirzaali et al., 2020).

#### *7.4 Peripheral tomography*

Fracture risk is influenced by characteristics that DXA-derived BMD cannot measure or by physical restrictions on DXA-derived BMD, such as dependence on soft tissue composition. To try to close this diagnostic gap, a variety of technologies have been created. Peripheral quantitative computed tomography is one such innovation (pQCT) (Anderson et al., 2021). When compared to standard clinical CT, pQCT is only used at peripheral regions,

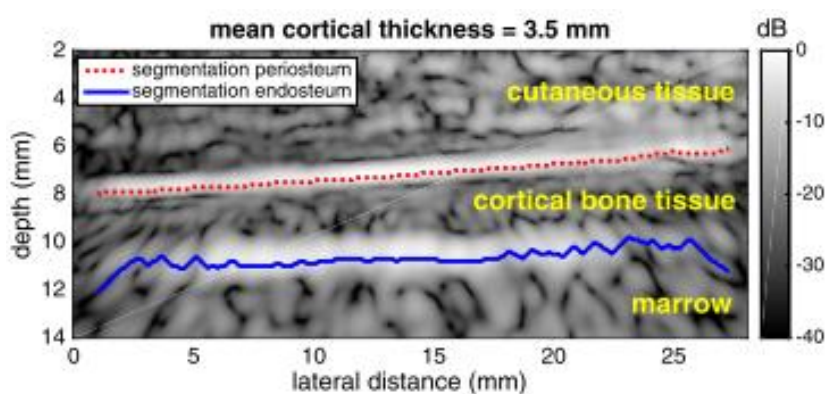
specifically the radius and tibia, providing greater resolution imaging of peripheral bones in human subjects (Wittig et al., 2022; Anderson et al., 2021).

Peripheral tomography bone related variables:

- BMC (Jankowska et al., 2001).
- Trabecular microarchitecture (Khosla et al., 2006)
- Bone microarchitecture (Lespessailles et coll. 2006).
- Total bone density.
- Cortical density.
- Radial and tibial bone mass.
- Total area at the 66% tibial area (Holloway-Kew et al., 2022).
- Radius bone mass, total area, total density, trabecular density, cortical area, cortical density, cortical thickness, radius and ulna total area and cortical density, and polar stress strain index.
- Tibia bone mass, total area, total density, trabecular density, cortical area, cortical density, cortical thickness, tibia and fibula total area and cortical density, and polar stress strain index (Anderson et al., 2021).

While HRpQCT provides a good representation of the femur, *in vivo* micro-CT offers better information on the trabecular fine structure and the porosity of the cortex, which is crucial for assessing changes in cortical porosity associated with aging (Wittig et al., 2022).

### 7.5 Ultrasound



**Figure 17: Ultrasound image of the cortical layer of a radius *in vivo* (Grimal & Laugier, 2019).**

Researchers have created quantitative ultrasound methods to assess trabecular and cortical bone over the past three decades in an effort to get around the drawbacks of DXA and give a non-ionizing, portable, easily usable, and reasonably priced diagnostic tool for osteoporosis.

Furthermore, because ultrasound uses mechanical waves, which are intrinsically sensitive to mechanical factors influencing bone total resistance, it is believed to be a particularly useful modality for assessing bone health. (Grimal & Laugier, 2019). Additionally, Glüer et al. (2004) have shown that quantitative ultrasound techniques can identify subjects at high risk for developing osteoporotic vertebral fractures.

Periosteum and endosteum are represented by red and blue lines, respectively. The mean distance between these lines, which is a metric of cortical thickness, is found to be 3.5 mm for this acquisition, which is consistent with the thickness determined by high-resolution peripheral computed tomography. (HR-pQCT) (Grimal & Laugier, 2019).

Ultrasound bone related variables:

- Bone transmission time and ultrasound bone profile index Speed of sound on the Achilles.
- UBIS 5000, DTU-one.
- Broad-band ultrasound attenuation.
- Stiffness index.
- Amplitude dependent SOS (Glüer et al., 2004).
- Bone strength and toughness.
- Cortical bone thickness (Grimal & Laugier, 2019).

## 8. Bone loading questionnaires

### *8.1 The physical activity questionnaire*

The Amsterdam Growth and Health Longitudinal Study (AGAHLS) physical activity questionnaire (PAQ) was developed to investigate the long-term impacts of adolescent physical activity habits on fitness and health in later adulthood. The PAQ estimates both the mechanical components of physical activity (MECHPA) and the metabolic components of physical activity (METPA). In a young population of boys and females aged 13 to 32 years, longitudinal measures of METPA and MECHPA were taken. This made it possible to compare the effects of physical activity on BMD of the lumbar spine during adolescence (13–16 years), young adulthood (2–28 years), and the entire period of 15 years (age 13–28 years), as determined by DXA in males ( $n = 139$ ) and females ( $n = 163$ ) at a mean age of 32 years. The PAQ used in the AGAHLS during adolescence (13–16 years) and young adulthood (21–28 years) is possible due to the ability to measure the physical activity patterns of both sexes, which are essential for the development of bone mass at adult age.

Table 13: Important questions and interview topics related to physical activity utilized in the Amsterdam growth and health longitudinal study (Kemper et al., 2002).

- I. Activities in relation to school or work
  - A. All transportation
    - Means: first and second possible choice (walking, cycling, or public transport) and average number of times used
    - Active time per means (both ways)
    - Score* = mean active transportation time in minutes per week
  - B. Physical education and extracurricular sport activity
    - Average active time per lesson
    - Obligatory number of lessons per week
    - Real number of lessons participated in
    - Real extracurricular activity
    - Score* = mean active physical education or sport time in minutes per week
  - C. Work-related activities like walking, cycling, lifting and stair climbing
    - Average active time per working day above minimum intensity
    - Score* = mean activity plus active transportation time in minutes per week
- II. Organized activities
  - A. Activities in sport clubs
    - Kind of sport club membership
    - 1. Training (club 1; repeat in case of more memberships)
      - Average active time per training
      - Number of training sessions per week
      - Real number of training sessions participated in
      - Score* = mean active training time in minutes per week
    - Matches (club 1; repeat in case of more memberships)
      - Average active playing time per match
      - Number of matches per week
      - Real number of matches participated in
      - Score* = mean active playing time in minutes per week
    - 2. Transportation
      - Score* = mean active transportation time in minutes per week of all organized sports activities
  - B. Activities in other clubs
    - Kind of membership
    - Average active time per meeting above minimum intensity (club 1)
    - Real number of meetings participated in
    - Score* = mean activity plus active transportation time in minutes per week
- III. Unorganized activities
  - A. General leisure time activities (unorganized sports, etc.)
    - Monday through Sunday: average active time in minutes per week
    - Score* = mean active leisure time in minutes per week
  - B. Activities in jobs (housekeeping, shopping, volunteer work)
    - Kind of job
    - Average active time per working day above minimum intensity
    - Score* = mean activity plus active transportation time in minutes per week

The AGAHLs questionnaire (Kemper et al., 1997) can quantify male and female habitual physical activity habits, which are essential for the growth of bone density in adults. The mechanical components are more significant than the metabolic components, as shown by ground reaction forces. However, the metabolic components of physical activities' score is also an important predictor of BMD if only the moderate and heavy metabolic activities (7 MET) and not the light metabolic activities (4–7 MET) are taken into account (Kemper et al., 2002).

Table 14: Comparison between physical activities measured in terms of their estimated metabolic intensity (met) and their estimated mechanical strain from ground reaction force (GRF) (Kemper et al., 2002).

Physical activities	Metabolic intensity		Mechanic strain	
	(MET)	Score	(GRF)	Score
Yoga	<4	0	0.5–1	0
Volleyball	4–7	1	5–10	3
Bicycling	4–7	1	0.5–1	0
Soccer, field hockey	7–10	2	3–5	2
Skating	7–10	2	1–3	1
Running	>10	3	1–3	1
Swimming	>10	3	0.5–1	0
Basketball	>10	3	5–10	3

The amount of mechanical exercise during adolescence (13–16 years) and early adulthood (21–18 years) ought to have a better osteogenic impact on the lumbar BMD attained at the adult age of 32 years, according to the hypothesis, based on a longitudinal data for both males and females from age 13 over a period of 20 years of physical activity (Kemper et al., 2002).

### *8.2 Bone loading history questionnaire*

The BLHQ was created to quantify past physical activity by only scoring exercises in bone loading units. The benefits of measuring the amount and rate of mechanical force acting on the skeleton have been established, making this form of questionnaire crucial (Turner & Robling, 2003). The bone loading units were calculated using both of these force components. The questionnaire also determines how premenopausal women, who are susceptible to bone mineral losses, but who are not frequently examined for low BMD, have been exposed to physical activity throughout their lifetimes as well as more recently (Dolan et al., 2006).

Table 15: Measurement of bone loading history using BLHQ (Dolan et al., 2006).

**Step 1: Calculate bone loading unit (BLU) for each individual activity.**

Example: gymnastics  
 Gymnastics load score for hip or spine = 3  
 Gymnastics loading rate score for hip or spine = 3

Calculation: load score + (loading rate score × 3) = BLU  
 Example: (3) + (3 × 3) = 12

**Step 2: Calculate the bone loading value for each activity listed in a reference period.**

Bone Loading Unit	Seasons	Years	Frequency	Loading Value
Specific to activity and skeletal site	*	0.25 for each season (3 months)	1-3 × month <sup>-1</sup> = 1 1-2 × wk <sup>-1</sup> = 2 3-5 × wk <sup>-1</sup> = 3 > 5 × wk <sup>-1</sup> = 4	=
Example:	*	2 seasons	1-2 × wk <sup>-1</sup>	
12	0.50	4 yr	2	= 48

**Step 3: Calculate the total bone loading in each reference period.**

Loading value gymnastics	Loading value dodgeball	Loading value four-square	Loading value monkey bars	Loading value biking	Total loading for elementary school
48	+42	+34	+32	+28	= 184

**Step 4: Calculate total bone loading across all reference periods.**

Elementary	Junior high	High school	Young adult	Adult	Total
184+	150+	95+	150+	200	779

**Step 5: Calculate total bone loading exposure.**

Total bone loading exposure in a 40-yr-old woman  
 Total bone loading/total years assessed by RI HQ  
 [779/(40 - 5)] = 22.3

**Step 6: Calculate recent bone loading exposure.**

Recent bone loading exposure in a 40-yr-old woman  
 Adult reference period/years in recent reference period  
 [200/(40 - 30)] = 20.0

The BLHQ demonstrates that a self-report questionnaire can provide accurate and valuable information about associations between lifetime physical activity and premenopausal bone health. Additionally, the current data emphasize the significance of continuing bone-loading physical activity throughout one's lifetime in order to achieve and maintain good bone health.

Table 16: Hip and spine bone loading unit in reference with some activities (Groothausen et al., 1997).

Activity	Ground Reaction Force* (× Body Weight)	Bone Loading Unit: Hip	Bone Loading Unit: Spine
Yoga	0.5-1.0	4.0	5.0
Biking—road	0.5-1.0	4.1	4.6
Biking—mountain		7.3	11.1
Swimming	0.5-1.0	4.0	4.0
Walking	1.6-2.0	7.0	4.0
Softball	2.0	8.0	11.1
Skating	1.0-3.0	7.4	4.4
Running	1.0-3.0	8.1	8.1
Aerobics	2.8-3.0	8.0	5.0
Soccer	3.0-5.0	8.4	8.3
Sprinting	2.0-6.0	11.7	11.1
Plyometrics	4.0-7.0	12.0	11.0
Volleyball	4.8-10.0	11.9	11.3
Basketball	4.1-10.0	11.7	8.4
Gymnastics	11.0	12.0	12.0

*8.3 Bone-specific physical activity questionnaire*

A bone-specific physical activity questionnaire (BPAQ) to predict fracture risk and the characteristics of bone density in young, healthy adults. The BPAQ predicted indicators of bone strength at clinically important sites in both men and women.



**BPAQ**  
Bone-Specific Physical Activity Questionnaire and Calculator

Griffith UNIVERSITY  
Queensland, Australia

Age:   Export Data  Hide Instructions

**Current Activities (last 12 months)**

Activity:  Times per week:  + Add

Subcategory:

**Past Childhood Activities (0 to 15 yrs)**

Activity:  Number of years:  + Add

Subcategory:

**Past Adult Activities (>15 yrs)**

Activity:  Number of years:  + Add

Subcategory:

**Griffith UNIVERSITY**  
B. K. Weeks, B. R. Beck  
School of rehabilitation sciences  
Australia 2013  
Program by  
G. Inoué & G. Wooda

**Instructions:**

1. Click on age box to select subject's age
2. Select "Current Activities" by choosing the activity type and the average number of bouts per week.
3. Select "past" childhood (0-15 years) activities and the approximate number of years of participation.
4. Select "past" adult (16 years to present age) activities and the approximate number of years of participation.
5. Click on the "Done" button to see the scores
6. (Optional) The first time you click "Export" the program will ask you for a file name (.csv) and will record the data in that file. After that, every time you click on "Export" the data will be added to the file already created until you close the program. When the BPAQ is reopened and new data is exported, a new export file must be created. It will be necessary to cut and paste from each new file to a master file if not completing all analyses for one study in one sitting.
7. To reset the program for a new subject: Click "Reset All", then repeat steps 1 to 5

**Note:** If an activity is not available on the list, select "Other" at the end of the activity list indicating if the activity is of low impact (e.g. swimming, walking, cycling, rollersports), moderate impact (e.g. tennis, basketball, football) or high impact (e.g. cheerleading, gymnastics).

Score	Current BPAQ score	Past BPAQ score	Total BPAQ score
	0.00	0.00	0.00

**Figure 18: Bone specific physical activity questionnaire and calculator (Weeks & Beck, 2008).**

Men's femoral neck BMD, lumbar spine BMD, and whole BMD were all significantly predicted by the current activity component of the BPAQ ( $R^2 = 0.36-0.68$ ,  $p < 0.01$ ), whereas women's calcaneal BMD was predicted by the past activity component of the BPAQ ( $R^2 = 0.48$ ,  $p < 0.001$ ). As a conclusion, compared to the BPAQ, other PA evaluation methods did not accurately predict bone strength indices at skeletal regions at risk of osteoporotic fracture.

#### 8.4 Physical activity bone loading questionnaire

This questionnaire and score system may be employed if a researcher wanted to determine historical leisure-time physical activity habits among women and the risk of osteoporosis in a retrospective study. A historical, quantitative history design is used in this questionnaire, which asks respondents to recall the types of activities they engaged in, how frequently they engaged in each activity on average each year since they were 10 years old, and how long they typically engaged in each activity per event. The years might then be multiplied by the amount of time (in hours) that the activity was practiced, yielding a frequency duration score that is reported as hour-years of exposure. The hour-years of exposure can represent various lifetime activity periods because it's crucial to consider the developmental stage during which the activity was undertaken.

Table 17: Template for a fictitious physical activity bone loading questionnaire that measures the frequency and duration of different kinds of physical activity over the course of a given age range (Ainsworth et al., 2002).

	Have you done this activity since age 10?		If yes, between what ages?	Events/year	Hours: minutes/event	Hour-years of exposure
	Yes	No				
Soccer	x		12 to 16	140	1:30	2100
			30 to 32	48	1:00	144
Tai Chi	x		50 to 60	52	1:00	520
			to			
Tennis	x		35 to 50	4	1:00	60
			to			

Hour-years of exposure are produced by multiplying the number of incidents each year by the length of each event in hours or minutes.

Table 18: Example of a BLU weighting scheme (Ainsworth et al., 2002).

Activity	Site		
	Spine	Hip	Wrist
Soccer	4	2	4
Tai Chi	3	2	2
Tennis	3	2	3
Total	10	6	9

**Scale: 1: normal weight bearing; 2: small load; 3: moderate load; 4: high load**

Table 18 exemplifies how BLU can be applied to the load that three physical activities place on critical fracture risk locations. By altering the BLU to reflect the load exerted by various physical activities on bones, the osteogenic stimulus imparted to anatomic sites by a single activity or a mix of activities can be estimated.

Table 19: Scoring system expressing the bone loading score of a respondent's physical activity as the sum of BLU \* hour-years of exposure for each anatomical bone site (Ainsworth et al., 2002).

Activity	Spine (BLU × hour-years)	+	Wrist (BLU × hour-years)	+	Hip (BLU × hour-years)	=	Bone loading score
Soccer	(4 × 2240)	+	(2 × 2240)	+	(4 × 2240)	=	22,400
Tai Chi	(3 × 520)	+	(2 × 520)	+	(2 × 520)	=	3640
Tennis	(3 × 60)	+	(4 × 60)	+	(3 × 60)	=	600
<b>Total</b>							<b>26,640</b>

A physical activity bone loading score is produced by multiplying the hour-years of exposure by a BLU that represents the mechanical load applied to a bone anatomic location.

## **Second Part: General contribution**

### **Methodology**

Subjects and study design of study 1:

The participants who volunteered to be in the study are middle-aged men between the ages of 38 and 52; they were 43 volunteers. None of the participants were smokers, and all of them had a clean record free from any major orthopedic problem or other disorders known to affect bone metabolism including diabetes. The researchers excluded any subject with any medical condition likely to affect bone metabolism including history of chronic disease with vital organ involvement or intake of medications that may affect bone metabolism. The goal of the study was to divide the subjects into 2 different groups: one group of inactive men included 25 subjects, and the other group was made up of 18 former basketball players. Participants were assigned to each group based on their former practice of basketball. Participants of the inactive group were middle-aged inactive men. Being inactive was defined as “performing less than 150 minutes of moderate intensity PA or less than 75 minutes of vigorous-intensity PA or less than an equivalent combination of moderate- and vigorous-intensity activity a week accumulated across work, home, transport or discretionary domains”. Moreover, the subjects in the inactive group had never regularly practiced any impact sport in their adolescence and young adulthood ages. In contrast, the subjects included in the former basketball group were middle-aged men who had practiced basketball for at least 10 consecutive years; this practice started when the subjects were adolescents. They had regularly participated in national competitions while training, and their training took place in their clubs 4 to 6 times per week, for 6-9 h/week for at least 10 years. They all had very clear knowledge about the objective of the study including the risks and benefits of participation. Prior to their participation in the study, all the participants signed a written informed consent. The work described has been carried out in accordance with the declaration of Helsinki (regarding human experimentation developed for the medical community by the World Medical Association).

Subjects and study design of the second study:

The participants who volunteered to be in the study are young-aged men between the ages of 20 and 28; they were 47 volunteers. None of the participants were smokers, and all of them had a clean record free from any major orthopedic problem or other disorders known to affect

bone metabolism including diabetes. The researchers excluded any subject with any medical condition likely to affect bone metabolism including history of chronic disease with vital organ involvement or intake of medications that may affect bone metabolism. The goal of the study was to divide the subjects into 3 different groups: one group of inactive men included 15 subjects, the second group was made up of 17 active subjects, and the third group was made up of 15 semi-professional basketball players. Participants of the inactive group were young-age inactive men. Being inactive was defined as “performing less than 150 minutes of moderate intensity PA or less than 75 minutes of vigorous-intensity PA or less than an equivalent combination of moderate- and vigorous-intensity activity a week accumulated across work, home, transport or discretionary domains”. Moreover, the subjects in the inactive group had never regularly practiced any impact sport in their adolescence. In contrast, for the subjects included in the active group, being active was defined as “performing more than 150 minutes of moderate intensity PA or more than 75 minutes of vigorous-intensity PA or more than an equivalent combination of moderate- and vigorous-intensity activity a week accumulated across work, home, transport or discretionary domains”. Moreover, the subjects included in the basketball group were young-aged men who are practicing basketball; this practice started when the subjects were adolescents. They are regularly participating in national competitions while training, and their training is taking place in their clubs 4 to 6 times per week, for 6-9 h/week. They all had very clear knowledge about the objective of the study including the risks and benefits of participation. Prior to their participation in the study, all the participants signed a written informed consent. The work described has been carried out in accordance with the declaration of Helsinki (regarding human experimentation developed for the medical community by the World Medical Association).

Anthropometric measures for both studies:

A standard mechanical scale (precision of 100g) was used to measure the body weight of the subjects, and a standard stadiometer (vertical position to the nearest 0.5 cm) was used to measure their height. While they were being measured, the subjects were asked to wear very light clothes and to remove their shoes. BMI was calculated as body weight divided by height squared (in kilogram per square meter). Body composition including lean mass (LM; Kg) and FM (% , Kg) was also assessed by DXA (GE-Lunar iDXA, Madison, WI).

Bone measures for both studies:

DXA (GE-Lunar iDXA, Madison, WI) was used to evaluate BMC (in grams) and BMD (in grams per square centimeter) for each individual. DXA was used to complete the measurements of BMD for the whole body (WB), the lumbar spine (L1-L4), the total hip (TH), the FN and total radius BMD of the right side. Also, DXA calculated the geometric indices of FN strength (CSA, CSMI, Z, BR and SI). Composite indices of FN strength (CSI, BSI and ISI) were calculated as previously described by Karlamangla et al. (2004). These indices can predict hip fracture risk in the elderly [10-12]. CSI ( $CSI = [FN\ BMD * FN\ width/weight]$ ) and BSI ( $BSI = [FN\ BMD * FN\ width\ 2] / [hip\ axis\ length * weight]$ ) express the forces that the FN has to withstand in axial compressive and bending forces, whereas ISI ( $ISI = [FN\ BMD * FN\ width * hip\ axis\ length] / [height * weight]$ ) expresses the energy that the FN has to absorb in an impact from standing height. All of the previously mentioned measurements done by DXA scans were performed by the same certified technician (holder of a Bachelor of Science in medical imaging sciences) who used the same technique for all measurements. The same DXA machine was used for all participants. In our laboratory, the coefficients of variation were <1% for BMC and BMD. The coefficients of variation for CSA and Z evaluated by duplicate measurements in 10 subjects were <3%

Procedures of physical tests for both studies:

An explanatory session was given to the participants of the study in order for them to understand and be familiar with the procedures and the equipment needed to perform the physical tests; this was done prior to the evaluation procedures. Testing was done on 3 non-consecutive days. On the first day, the tests determined the time of the 10-meter sprint and the performances of both VJ, horizontal jump (HJ) and triple jump (TJ). On the second day, the test determined the maximal oxygen consumption. On the third day, the tests determined the one-repetition maximum (1-RM) of squat, bench press on a Smith machine, leg extension, barbell curl and triceps extension. Since the total Radius BMD was measured at the right side, the right side was chosen.

Sprint performance for both studies:

The measurement of time of the 10-m sprint took place with the use of 2 pairs of photoelectric cells that were connected to an electronic timer (BROWER Timing Systems). For proper measurement, the first pair was placed at the starting line (0 m), and the second pair was placed at the 10-meter finish line. A specific warm-up was performed by the subjects of the study before beginning the evaluation process. The assessment was made up of a 10-meter maximal sprint to be done four times; after every maximal sprint, the subjects passively rested

for 3 consecutive minutes, and then they went for another sprint. Every sprint's time was recorded, and out of the four times, the best one was chosen to be evaluated. Moreover, the 10-meter average velocity (m/sec) of the best sprint was calculated. Finianos et al. (2020) has previously described the followed protocol.

Jumping performance for both studies:

The jump and reach Sargent tests were used to measure VJ height. A specific warm-up was performed by the participants before beginning the process of evaluation. All participants performed a counter movement jump with free movements of the upper limbs. The number of times that the participants jumped was 3; they rested for 2 consecutive minutes between each jump, and the highest jump was chosen. The highest value of the VJ was used to calculate the peak power of the lower limb by using the Lewis Formula. HJ and TJ were also calculated. The HJ was performed by all subjects starting from a standing position. The start of the jump was done by performing a swing movement of their arms. A take-off line was drawn on the ground. Their feet, which were in a shoulder-width position, were directly positioned before the line. All subjects also performed a TJ. They made an HJ for distance incorporating three distinct, continuous movements; a hop, in which the athlete takes off and lands on the same foot; a step, landing on the other foot; and a jump, landing with both feet together. A jump is dismissed only if the jumper touches the ground with the wrong leg while doing it. A metric tape was used to measure the length of the jump; it was done by measuring from the take-off line to the closest point of landing contact (back of the heels). Three attempts were performed by every participant, and the attempt with the longest distance achieved was the one chosen.

Maximal oxygen consumption for both studies:

VO<sub>2</sub> max was calculated by using the STEP tool protocol. Because the participants of this study were middle-aged, the researchers chose this indirect test instead of the triangular maximal test since it is well-known that this test is more suitable for this population; moreover, it is valid and reliable in this kind of population. VO<sub>2</sub> max was expressed either as an absolute rate (L/min) or as a relative rate (ml/min/Kg).

Maximal strength measurements for both studies:

Each participant performed the squat, the bench press, the leg extension, the barbell curl and the triceps extension techniques following the protocol established by the National Strength and Conditioning Association (NSCA). The method utilized to predict 1- RM from a 4 to 6 RM submaximal strength test follows the same protocol. Moreover, there is a large chance of

injury or an accident for an individual who is not familiar with lifting heavy weights while training. A specific standardized warm-up was done before starting the test. If the participant was not able to perform the exercise in its full range of motion, then the test was stopped. Furthermore, if a participant was able to perform more than 6 repetitions of an exercise, he was stopped and was asked to repeat the test after increasing the load. The test was successful when the subject reached his RM between 4 and 6-RM. Squat on a Smith machine was used as an exercise to identify lower limb maximal strength. Because the participants were afraid to perform squats with heavy weights, direct measure of 1-RM was not used. While performing the squats, the participants had to squat to a depth where a 90- degree knee angle was achieved; this had to be done in all the attempts. The evaluation to the upper limb maximal strength was done through the bench press on a Smith machine. As for the evaluation of the lower limb maximal strength, the leg extension exercise was used. Barbell curl and triceps extension were used to identify arms maximal strength.

Questionnaires for both studies:

#### Sleep quality

The quality of sleep and the disturbances of sleep were assessed by the Pittsburgh Sleep Quality Index (PSQI); this took place over a 1-month time interval. Scores were given for 7 "components" which are related to subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction. The result of the sum of scores for the 7 components resulted in one global score. The higher the PSQI score was, the worse the sleep quality. Because a significant correlation has been shown between parameters of bone health and sleep quality in several preceding studies, sleep quality was evaluated.

#### Daily Calcium and Protein Intakes

Validated semi-quantitative food frequency questionnaires evaluated the DCI, which is daily calcium intake and DPI, which is daily protein intake. The assessment of the consumption of milk and dairy products such as yoghurt, cheese and chocolate, and other products such as eggs, meat, fish, cereals, bread, vegetables and fruits was done through the DCI questionnaire. As for the DPI questionnaire, it gives the participants the opportunity to appreciate the intake of food that provides the majority of proteins. The participants did not require any help in filling in the DCI and DPI questionnaires. The participants in the study were not taking any supplements.



## Physical Activity

The global PA questionnaire was used to evaluate the PA duration for every week; it checks for the number of hours of PA per week. 16 questions are included in the questionnaire; it provides information about intensity, duration and frequency of PAs in 3 domains (activity at work, during travel and when performing recreational activities).

Statistical analysis for both studies:

Calculations were done to measure the means and standard deviations for all clinical, physical performance and bone parameters. The Shapiro-Wilk test was used to evaluate for normality of all variables. Comparisons between the 2 groups (inactive group and basketball group) were made after checking for Gaussian distribution. The use of unpaired t-tests was required in case Gaussian distribution was found. If not, Mann-Whitney U-tests were used. Pearson's Test was used to compute univariate correlations. Moreover, to determine the differences in bone parameters between the two groups, we calculated Cohen's d (which is the difference between the means of the two groups divided by a pooled standard deviation) for bone parameters. Cohens' d is a standardized measure of the effect of a factor (which is former basketball practice in our study) independent of the scale of the parameter under consideration. It has been reported that a Cohen's d of 0.2 corresponds to a small effect size, 0.5 to a medium effect size and 0.8 to a large effect size. Bone variables were compared between the 2 groups after adjustment for height using a one-way analysis of covariance. Data were analyzed with Number Cruncher Statistical System (NCSS, 2001; NCSS, Kaysville, UT). A level of significance of  $p < 0.05$  was used.

## Study 1: Bone health parameters in middle-aged former basketball players vs. middle-aged inactive men

**Objective.** – The purpose of this study was to compare bone health parameters (bone mineral content [BMC], bone mineral density [BMD], geometric indices of femoral neck [FN] strength (cross-sectional area [CSA], cross-sectional moment of inertia [CSMI], section modulus [Z], buckling ratio [BR] and strength index [SI]) and composite indices of FN strength (compression strength index [CSI], bending strength index [BSI], and impact strength index [ISI])) in middle-aged inactive men (n = 25) and middle-aged former basketball players (n = 18).

**Methods.** – The participants of the study were 43 middle-aged men; their ages ranged from 38 to 52 years. Dual-energy X-ray absorptiometry was used to evaluate body composition, BMD and geometric indices of FN strength. Composite indices of FN strength (CSI, BSI, and ISI) were calculated. Physical performance tests were used to evaluate the vertical jump (VJ), horizontal jump (HJ), triple jump (TJ), maximum power (MP) of the lower limbs (watts), maximal squat strength, maximal bench press strength, maximal leg extension strength, maximal barbell curl strength, maximal triceps extension strength, sprint performance (10 meters), and maximum oxygen consumption (VO<sub>2</sub> max, L/min).

**Results.** – WB BMC, WB BMD, L1-L4 BMD, CSA, CSMI and Z were significantly higher in former basketball players compared to inactive men. MP, TJ, VJ, maximal squat strength and maximal bench press strength were significantly higher in former basketball players compared to inactive men.

**Conclusion.** – The present study suggests that former basketball practice is associated with greater bone health parameters in middle-aged men.



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ORIGINAL ARTICLE

## Bone health parameters in middle-aged former basketball players vs. middle-aged inactive men



*Paramètres de santé osseuse chez des anciens joueurs de basket-ball et des hommes inactifs*

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### KEYWORDS

Bone health parameters;  
Basketball;  
Middle-aged men;  
DXA;  
Osteoporosis

### Summary

**Objective.** – The purpose of this study was to compare bone health parameters (bone mineral content [BMC], bone mineral density [BMD], geometric indices of femoral neck [FN] strength (cross-sectional area [CSA], cross-sectional moment of inertia [CSMI], section modulus [Z], buckling ratio [BR] and strength index [SI]) and composite indices of FN strength (compression strength index [CSI], bending strength index [BSI], and impact strength index [ISI]) in middle-aged inactive men ( $n = 25$ ) and middle-aged former basketball players ( $n = 18$ ).

**Methods.** – The participants of the study were 43 middle-aged men; their ages ranged from 38 to 52 years. Dual-energy X-ray absorptiometry was used to evaluate body composition, BMD and geometric indices of FN strength. Composite indices of FN strength (CSI, BSI, and ISI) were calculated. Physical performance tests were used to evaluate the vertical jump (VJ), horizontal jump (HJ), triple jump (TJ), maximum power (MP) of the lower limbs (watts), maximal squat strength, maximal bench press strength, maximal leg extension strength, maximal barbell curl strength, maximal triceps extension strength, sprint performance (10 meters), and maximum oxygen consumption ( $\text{VO}_2 \text{ max}$ , L/min).

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**Results.** – WB BMC, WB BMD, L1-L4 BMD, CSA, CSMI and Z were significantly higher in former basketball players compared to inactive men. MP, TJ, VJ, maximal squat strength and maximal bench press strength were significantly higher in former basketball players compared to inactive men.

**Conclusion.** – The present study suggests that former basketball practice is associated with greater bone health parameters in middle-aged men.

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## MOTS CLÉS

Paramètres de santé osseuse ;  
Basket-ball ;  
Hommes ;  
DXA ;  
Ostéoporose

## Résumé

**Objectif.** – Le but de cette étude était de comparer les paramètres de santé osseuse (contenu minéral osseux [CMO], densité minérale osseuse [DMO], indices géométriques du col fémoral [CF] (surface de section transversale [CSA], moment d'inertie de la surface transversale [CSMI], module de section [Z], buckling ratio [BR] et indice de résistance [SI]) et indices de résistance osseuse du CF (indice de résistance en compression [CSI], indice de résistance en flexion [BSI] et indice de résistance aux contraintes [ISI])) chez des hommes inactifs ( $n=25$ ) et d'anciens joueurs de basket ( $n=18$ ).

**Méthodes.** – Les participants à l'étude étaient 43 hommes ; leur âge variait de 38 à 52 ans. L'absorptiométrie biphotonique à rayons-X (DXA) a été utilisée pour évaluer la composition corporelle, la DMO et les indices géométriques du CF. Les indices de résistance osseuse du CF (CSI, BSI et ISI) ont été calculés. Des tests de performance physique ont été utilisés pour évaluer la détente verticale (DV), la détente horizontale (DH), le triple saut (TS), la puissance maximale (PM) des membres inférieurs, la force maximale en squat, la force maximale au développé couché, la force maximale en extension des jambes, la force maximale en leg curl, la force maximale en extension des triceps, la performance au sprint (10 mètres) et la consommation maximale d'oxygène ( $VO_2$  max, L/min).

**Résultats.** – Le CMO CE, la DMO CE, la DMO L1-L4, la CSA, le CSMI et le Z étaient significativement plus élevés chez les anciens basketteurs que chez les hommes inactifs. La PM des membres inférieurs, le TS, la DV, la force maximale en squat et la force maximale au développé couché étaient significativement plus élevés chez les anciens basketteurs que chez les hommes inactifs.

**Conclusion.** – La présente étude suggère qu'un passé de basketteur est associé à de meilleurs paramètres osseux.

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## 1. Introduction

Physical activity (PA) has been considered an important factor in the prevention of osteoporosis [1]. PA practice is considered the best preventive measurement against the decrease in bone mineral density (BMD) with age [1]. However, the mechanisms by which PA affects bone density are complex [1]. It is recommended to practice regular PA throughout life [1]. Vigorous muscle exercise appears to be the most effective type of PA with a positive effect on BMD [1].

The best diagnosis known for osteoporosis is done by the dual-energy X-ray absorptiometry (DXA), which measures BMD [2]. BMD is considered to be the reference standard of diagnosis as well as the best determinant of bone strength [3]. However, only 50–70% of bone strength can be explained by BMD [4]. DXA can also measure geometric indices of bone resistance that can be evaluated at the level of the femoral neck (FN); these indices include cross-sectional area [CSA], cross-sectional moment of inertia [CSMI], section modulus [Z], buckling ratio [BR] and strength index [SI] [5]. These indices are correlated with the mechanical strength of the bone and are predictive of osteoporotic fracture in elderly women and men [6–8]. FN width and bending strength are

factors, which also influence hipbone strength [9,10]. The prediction of incident hip fracture risk by composite indices of FN strength (compression strength index [CSI], bending strength index [BSI], and impact strength index [ISI]) constructed from DXA scans of the hip has been studied by Karlamangla et al. [10]. These indices integrate FN size and body size with bone density [11]. CSI, BSI, and ISI reflect the ability of the FN to withstand axial compressive and bending forces and to absorb energy from an impact [11]. Moreover, the risk of hip fracture in the elderly as well as assessments of bone strength are improved by these indices [10–12].

Currently, the prevention of osteoporosis later in life is directly linked to the increase of peak BMD; therefore, it is essential to implement strategies, which would increase peak BMD [13]. Significant correlations have been shown by many studies between bone health parameters and the performances obtained in some physical tests used in current sports practice [14–20]. Stojanovic et al. [21] conducted a systematic review and meta-analysis which aimed to assess the differences in total and regional BMD among basketball athletes, non-athletes, and athletes competing in swimming, soccer, and volleyball, considering age and sex. They demonstrated that the BMD of basketball athletes was greater than the BMD of matched non-athletes and swimming, soccer, and volleyball athletes [21]. When the athletes

continue to train and to compete after the adolescence years [21], the differences in the BMD are intensified even more. The result of the higher BMD shown in the basketball athletes as opposed to the other non-athletes and swimming, and soccer athletes is much clearer in males than females [21]. Many authors have shown that male basketball athletes aged < 18 years exhibited greater lower limb BMD compared to male non-athlete controls aged < 18 years [22–24]. Based on our information, no studies have explored the effect of former practice of basketball (before the occurrence of peak bone mass) on bone health parameters in middle-aged men. The purpose of this current study was to compare bone health parameters (bone mineral content [BMC], BMD, geometric indices of FN strength [CSA, CSMI, Z, BR, SI] and composite indices of FN strength [CSI, BSI and ISI]) in middle-aged inactive men and middle-aged former basketball players. Our hypothesis is that middle-aged men who formerly practiced basketball have greater bone health parameters compared to inactive men.

## 2. Materials and methods

### 2.1. Subjects and study design

The participants who volunteered to be in the study are middle-aged men between the ages of 38 and 52; they were 43 volunteers. None of the participants were smokers, and all of them had a clean record free from any major orthopedic problem or other disorders known to affect bone metabolism including diabetes. The researchers excluded any subject with any medical condition likely to affect bone metabolism including history of chronic disease with vital organ involvement or intake of medications that may affect bone metabolism. The goal of the study was to divide the subjects into 2 different groups: one group of inactive men included 25 subjects, and the other group was made up of 18 former basketball players. Participants were assigned to each group based on their former practice of basketball. Participants of the inactive group were middle-aged inactive men. Being inactive was defined as "performing less than 150 minutes of moderate intensity PA or less than 75 minutes of vigorous-intensity PA or less than an equivalent combination of moderate- and vigorous-intensity activity a week accumulated across work, home, transport or discretionary domains" [25]. Moreover, the subjects in the inactive group had never regularly practiced any impact sport in their adolescence and young adulthood ages. In contrast, the subjects included in the former basketball group were middle-aged men who had practiced basketball for at least 10 consecutive years; this practice started when the subjects were adolescents. They had regularly participated in national competitions while training, and their training took place in their clubs 4 to 6 times per week, for 6–9 h/week for at least 10 years. They all had very clear knowledge about the objective of the study including the risks and benefits of participation. Prior to their participation in the study, all the participants signed a written informed consent. The work described has been carried out in accordance with the declaration of Helsinki (regarding human experimentation developed for the medical community by the World Medical Association).

### 2.2. Anthropometrics

A standard mechanical scale (precision of 100 g) was used to measure the body weight of the subjects, and a standard stadiometer (vertical position to the nearest 0.5 cm) was used to measure their height. While they were being measured, the subjects were asked to wear very light clothes and to remove their shoes. BMI was calculated as body weight divided by height squared (in kilogram per square meter) [26]. Body composition including lean mass (LM; kg) and FM (% kg) was also assessed by DXA (GE-Lunar iDXA, Madison, WI).

### 2.3. Bone measurements

DXA (GE-Lunar iDXA, Madison, WI) was used to evaluate BMC (in grams) and BMD (in grams per square centimeter) for each individual. DXA was used to complete the measurements of BMD for the whole body (WB), the lumbar spine (L1–L4), the total hip (TH), the FN and total radius BMD of the right side. Also, DXA calculated the geometric indices of FN strength (CSA, CSMI, Z, BR and SI). Composite indices of FN strength (CSI, BSI and ISI) were calculated as previously described by Karlamangla et al. [10]. These indices can predict hip fracture risk in the elderly [10–12]. CSI ( $CSI = [FN \text{ BMD} \times FN \text{ width}/weight]$ ) and BSI ( $BSI = [FN \text{ BMD} \times FN \text{ width}^2]/[hip \text{ axis length} \times weight]$ ) express the forces that the FN has to withstand in axial compressive and bending forces, whereas ISI ( $ISI = [FN \text{ BMD} \times FN \text{ width} \times hip \text{ axis length}]/[height \times weight]$ ) expresses the energy that the FN has to absorb in an impact from standing height [10–12]. All of the previously mentioned measurements done by DXA scans were performed by the same certified technician (holder of a Bachelor of Science in medical imaging sciences) who used the same technique for all measurements. The same DXA machine was used for all participants. In our laboratory, the coefficients of variation were < 1% for BMC and BMD. The coefficients of variation for CSA and Z evaluated by duplicate measurements in 10 subjects were < 3%.

### 2.4. Procedures of physical performance tests

An explanatory session was given to the participants of the study in order for them to understand and be familiar with the procedures and the equipment needed to perform the physical tests; this was done prior to the evaluation procedures. Testing was done on 3 non-consecutive days. On the first day, the tests determined the time of the 10-meter sprint and the performances of both VJ, horizontal jump (HJ) and triple jump (TJ). On the second day, the test determined the maximal oxygen consumption. On the third day, the tests determined the one-repetition maximum (1-RM) of squat, bench press on a Smith machine, leg extension, barbell curl and triceps extension. Since the total Radius BMD was measured at the right side, the right side was chosen.

## 2.5. Sprint performance

The measurement of time of the 10-m sprint took place with the use of 2 pairs of photoelectric cells that were connected to an electronic timer (BROWER Timing Systems). For proper measurement, the first pair was placed at the starting line (0 m), and the second pair was placed at the 10-meter finish line. A specific warm-up was performed by the subjects of the study before beginning the evaluation process. The assessment was made up of a 10-meter maximal sprint to be done four times; after every maximal sprint, the subjects passively rested for 3 consecutive minutes, and then they went for another sprint. Every sprint's time was recorded, and out of the four times, the best one was chosen to be evaluated. Moreover, the 10-meter average velocity (m/s) of the best sprint was calculated. Finianos et al. [27] has previously described the followed protocol.

## 2.6. Jumping performance

The jump and reach Sargent test [27] was used to measure VJ height. A specific warm-up was performed by the participants before beginning the process of evaluation. All participants performed a counter movement jump with free movements of the upper limbs. The number of times that the participants jumped was 3; they rested for 2 consecutive minutes between each jump, and the highest jump was taken. The highest value of the VJ was used to calculate the peak power of the lower limb by using the Lewis Formula [28]. HJ and TJ were also calculated. The HJ was performed by all subjects starting from a standing position. The start of the jump was done by performing a swing movement of their arms. A take-off line was drawn on the ground. Their feet, which were in a shoulder-width position, were directly positioned before the line. All subjects also performed a TJ. They make an HJ for distance incorporating three distinct, continuous movements; a hop, in which the athlete takes off and lands on the same foot; a step, landing on the other foot; and a jump, landing with both feet together. A jump is dismissed if while doing it, the jumper touches the ground with the wrong leg. A metric tape was used to measure the length of the jump; it was done by measuring from the take-off line to the closest point of landing contact (back of the heels). Three attempts were performed by every participant, and the attempt with the longest distance achieved was the one chosen.

## 2.7. Maximum oxygen consumption

VO<sub>2</sub> max was calculated by using the STEP tool protocol [26]. Because the participants of this study were middle-aged, the researchers chose this indirect test instead of the triangular maximal test since it is well-known that this test is more suitable for this population; moreover, it is valid and reliable in this kind of population [26]. VO<sub>2</sub> max was expressed either as an absolute rate (L/min) or as a relative rate (mL/min/kg).

## 2.8. Maximal strength measurements

Each participant performed the squat, the bench press, the leg extension, the barbell curl and the triceps extension techniques following the protocol established by the National Strength and Conditioning Association (NSCA) [29]. The method utilized to predict 1-RM from a 4- to 6-RM submaximal strength test [30] follows the same protocol. Moreover, there is a large chance of injury or an accident for an individual who is not familiar with lifting heavy weights while training. A specific standardized warm-up was done before starting the test. If the participant was not able to perform the exercise in its full range of motion, then the test was stopped. Furthermore, if a participant was able to perform more than 6 repetitions of an exercise, he was stopped and was asked to repeat the test after increasing the load. The test was successful when the subject reached his RM between 4- and 6-RM.

Squat on a Smith machine was used as an exercise to identify lower limb maximal strength. Because the participants were afraid to perform squats with heavy weights, direct measure of 1-RM was not used. While performing the squats, the participants had to squat to a depth where a 90-degree knee angle was achieved; this had to be done in all the attempts. The evaluation to the upper limb maximal strength was done through the bench press on a Smith machine. As for the evaluation of the lower limb maximal strength, the leg extension exercise was used. Barbell curl and triceps extension were used to identify arms maximal strength.

## 2.9. Questionnaires

### 2.9.1. Sleep Quality

The quality of sleep and the disturbances of sleep were assessed by the Pittsburgh Sleep Quality Index (PSQI); this took place over a 1-month time interval. Scores were given for 7 "components" which are related to subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction. The result of the sum of scores for the 7 components resulted in one global score [31]. The higher the PSQI score was, the worse the sleep quality. Because a significant correlation has been shown between parameters [32–34] of bone health and sleep quality in several preceding studies, sleep quality was evaluated.

### 2.9.2. Daily calcium and protein intakes

Validated semi-quantitative food frequency questionnaires [35–37] evaluated the DCI, which is daily calcium intake and DPI, which is daily protein intake. The assessment of the consumption of milk and dairy products such as yoghurt, cheese and chocolate, and other products such as eggs, meat, fish, cereals, bread, vegetables and fruits [35] was done through the DCI questionnaire. As for the DPI questionnaire, it gives the participants the opportunity to appreciate the intake of food that provides the majority of proteins [37]. The participants did not require any help in filling in the DCI and DPI questionnaires. The participants in the study were not taking any supplements.

### 2.9.3. Physical activity

The global PA questionnaire [38] was used to evaluate the PA duration for every week; it checks for the number of hours of PA per week. Sixteen questions are included in the questionnaire; it provides information about intensity, duration and frequency of PAs in 3 domains (activity at work, during travel and when performing recreational activities).

## 2.10. Statistical analysis

Calculations were done to measure the means and standard deviations for all clinical, physical performance and bone parameters. The Shapiro–Wilk test was used to evaluate for normality of all variables. Comparisons between the 2 groups (inactive group and basketball group) were made after checking for Gaussian distribution. The use of unpaired *t*-tests was required in case Gaussian distribution was found. If not, Mann–Whitney U-tests were used. Pearson's Test was used to compute univariate correlations. Moreover, to determine the differences in bone parameters between the two groups, we calculated Cohen's *d* (which is the difference between the means of the two groups divided by a pooled standard deviation) for bone parameters. Cohens' *d* is a standardized measure of the effect of a factor (which is former basketball practice in our study) independent of the scale of the parameter under consideration. It has been reported that a Cohen's *d* of 0.2 corresponds to a small effect size, 0.5 to a medium effect size and 0.8 to a large effect size. Bone variables were compared between the 2 groups after adjustment for height using a one-way analysis of covariance. Data were analyzed with Number Cruncher Statistical System (NCSS, 2001; NCSS, Kaysville, UT). A level of significance of  $P < 0.05$  was used.

## 3. Results

### 3.1. Clinical characteristics and bone variables of the study population

Age, weight, LM, FM, DCI, DPI, PSQI, TH BMD, FN BMD, total Radius BMD, BR, SI, CSI, BSI and ISI were not significantly different between the 2 groups. BMI and FM percentage were significantly higher in inactive men compared to former basketball players. Height and PA were significantly higher in former basketball players compared to inactive men. WB BMC (Cohen's  $d = 0.88$ ), WB BMD (Cohen's  $d = 0.97$ ), L1-L4 BMD (Cohen's  $d = 0.80$ ), CSA (Cohen's  $d = 0.65$ ), CSMI (Cohen's  $d = 0.74$ ) and Z (Cohen's  $d = 0.81$ ) values were significantly higher in former basketball players compared to inactive men (Table 1).

### 3.2. Physical performance variables of the study population

HJ, 1-RM leg extension, 1-RM barbell curl and 1-RM triceps extension were not significantly different between the 2 groups. Ten meters sprint performance was significantly higher in inactive men compared to former basketball players. MP, TJ, VJ, 1-RM squat and 1-RM bench press were

significantly higher in former basketball players compared to inactive men (Table 1).

### 3.3. Correlations between clinical variables and bone characteristics of the study population

Age was negatively correlated to FN BMD and SI. Weight was positively correlated to WB BMC, CSA, and CSMI. Weight was negatively correlated to CSI, BSI and ISI. Height was positively correlated to WB BMC, WB BMD, CSA, CSMI, and Z. BMI was negatively correlated to CSI, BSI and ISI. LM was positively correlated to WB BMC, WB BMD, FN BMD, total radius BMD, CSA, CSMI, and Z. LM was negatively correlated to CSI and ISI. FM was negatively correlated to CSI, BSI and ISI. FM percentage was negatively correlated to CSI. PA was positively correlated to WB BMD, L1-L4 BMD, TH BMD and FN BMD (Table 2).

### 3.4. Correlations between physical performance variables and bone characteristics of the study population

MP was positively correlated to WB BMC, WB BMD, FN BMD, CSA, CSMI, and Z. VJ was positively correlated to WB BMD. 1-RM squat was positively correlated to WB BMC and WB BMD. 1-RM leg extension was negatively correlated to SI. Ten meters sprint performance was negatively correlated to WB BMD, L1-L4 BMD and CSI.  $VO_2$  max (L/min) was positively correlated to WB BMC, WB BMD, TH BMD, FN BMD, total radius BMD, CSA, CSMI, and Z.  $VO_2$  max (mL/min/kg) was positively correlated to SI, CSI and ISI (Table 2).

### 3.5. Bone variables adjusted for height in the 2 groups

After adjusting for height, WB BMD and L1-L4 BMD remained significantly higher in former basketball players compared to inactive men. CSI values were also higher in former basketball players compared to inactive subjects after adjusting for height (Table 3).

## 4. Discussion

Throughout the current study, two groups of middle-aged men were compared; the first group was made up of former basketball players, and the second one was made up of inactive men. There was a clear difference in the results in that several bone health parameters (WB BMC, WB BMD, L1-L4 BMD, CSA, CSMI and Z) were significantly higher in the first group.

Age, weight, LM, FM, DCI, DPI, PSQI, TH BMD, FN BMD, total Radius BMD, BR, SI, CSI, BSI and ISI were not significantly different between the 2 groups. The former basketball players' BMI and FM percentage were significantly lower. However, height and PA were significantly higher in former basketball players compared to inactive men. As for bone health parameters, WB BMC, WB BMD, L1-L4 BMD, CSA, CSMI and Z were significantly higher in former basketball players compared to inactive men. Due to the fact that basketball athletes have significantly greater bone health parameters

**Table 1** Clinical characteristics and bone health parameters of the study population.

	Former basketball players (n = 18)	Inactive men (n = 25)	P-value
	Mean ± SD	Mean ± SD	
Age (years)	45.2 ± 4.1	44.4 ± 3.8	0.521
Weight (kg)	88.2 ± 10.6	89.4 ± 16.7	0.793
Height (cm)	<b>183.1 ± 6.2</b>	<b>176.1 ± 6.0</b>	< 0.001
BMI (kg/m <sup>2</sup> )	<b>26.2 ± 2.3</b>	<b>28.6 ± 4.2</b>	0.033
Lean mass (kg)	60.155 ± 6.658	57.775 ± 8.053	0.311
Fat mass (kg)	24.619 ± 5.971	28.656 ± 9.481	0.119
Fat mass percentage	<b>27.7 ± 4.4</b>	<b>31.4 ± 4.2</b>	<b>0.007</b>
Physical activity (h/week)	<b>1.6 ± 0.6</b>	<b>1.0 ± 0.7</b>	<b>0.007</b>
Daily calcium intake (mg/d)	995 ± 338	1002 ± 440	0.952
Daily protein intake (g/d)	70.9 ± 21.4	65.5 ± 20.4	0.408
PSQI	5.3 ± 3.0	5.0 ± 2.0	0.620
WB BMC (g)	<b>3312 ± 436</b>	<b>2985 ± 311</b>	<b>0.006</b>
WB BMD (g/cm <sup>2</sup> )	<b>1.374 ± 0.139</b>	<b>1.259 ± 0.101</b>	<b>0.003</b>
L1–L4 BMD (g/cm <sup>2</sup> )	<b>1.329 ± 0.186</b>	<b>1.197 ± 0.148</b>	<b>0.013</b>
TH BMD (g/cm <sup>2</sup> )	1.131 ± 0.131	1.053 ± 0.141	0.077
FN BMD (g/cm <sup>2</sup> )	1.092 ± 0.141	1.013 ± 0.160	0.101
Total Radius BMD (g/cm <sup>2</sup> )	0.805 ± 0.060	0.809 ± 0.054	0.838
CSA (mm <sup>2</sup> )	<b>192 ± 31</b>	<b>174 ± 25</b>	<b>0.039</b>
CSMI (mm <sup>4</sup> )	<b>19,634 ± 6078</b>	<b>16,231 ± 3163</b>	<b>0.021</b>
Z (mm <sup>3</sup> )	<b>1001 ± 233</b>	<b>843 ± 159</b>	<b>0.012</b>
BR	3.55 ± 1.57	3.38 ± 1.14	0.680
SI	1.60 ± 0.39	1.44 ± 0.25	0.101
CSI (g/kg-m)	4.58 ± 0.93	4.19 ± 0.82	0.147
BSI (g/kg-m)	1.41 ± 0.39	1.23 ± 0.40	0.146
ISI (g/kg-m)	0.304 ± 0.069	0.273 ± 0.082	0.202
Maximum power (watts)	<b>1069 ± 163</b>	<b>886 ± 147</b>	< 0.001
Horizontal jump (m)	1.861 ± 0.281	1.712 ± 0.296	0.104
Triple jump (m)	<b>5.55 ± 0.70</b>	<b>4.62 ± 0.66</b>	< 0.001
Vertical jump (m)	<b>31.389 ± 5.271</b>	<b>21.360 ± 4.434</b>	< 0.001
1-RM squat (kg)	<b>95 ± 11</b>	<b>80 ± 8</b>	< 0.001
1-RM bench press (kg)	<b>68 ± 19</b>	<b>54 ± 16</b>	<b>0.015</b>
1-RM leg extension (kg)	111 ± 21	113 ± 18	0.776
1-RM barbell curl (kg)	37 ± 8	36 ± 5	0.595
1-RM triceps extension (kg)	65 ± 10	61 ± 9	0.177
10 m sprint performance (s)	<b>2.03 ± 0.11</b>	<b>2.33 ± 0.25</b>	< 0.001
VO <sub>2</sub> max (L/min)	3.71 ± 0.45	3.58 ± 0.31	0.276
VO <sub>2</sub> max (ml/min/kg)	42.5 ± 6.1	40.9 ± 5.2	0.36

SD: standard deviation; BMI: body mass index; WB: whole body; BMC: bone mineral content; BMD: bone mineral density; L1–L4: lumbar spine; TH: total hip; FN: femoral neck; CSA: cross-sectional area; CSMI: cross-sectional moment of inertia; Z: section modulus; BR: buckling ratio; SI: strength index; CSI: compression strength index; BSI: bending strength index; ISI: impact strength index; RM: repetition maximum; VO<sub>2</sub> max: maximum oxygen consumption. In bold, significant differences between the 2 groups.

compared to non-athlete controls [21], the received results are logical and expected. The BMD for total-body, lumbar spine, upper limbs, lower limbs, pelvis, trunk, and FN in basketball athletes showed significantly higher measurements compared to non-athlete controls [21]. The age subgroups exhibited significant differences [21]. Basketball athletes' aged > 18 years exhibited moderate to very large differences in BMD compared to non-athlete controls aged > 18 years for total-body, upper limbs, and lower limbs [21]. However, basketball athletes aged < 18 years exhibited small differences in BMD compared to non-athlete controls aged < 18 years in these same measurements [21]. These results are in line

with several other studies, which showed that male basketball athletes aged < 18 years exhibited greater (small-large) lower limb BMD compared to male non-athlete controls aged < 18 years [22–24].

There was no significant difference when the 2 groups were compared for the physical performance variables, HJ, 1-RM leg extension, 1-RM barbell curl and 1-RM triceps extension. Sprinting time (seconds) was significantly higher in inactive men compared to former basketball players. A logical result was also received when MP, TJ, VJ, 1-RM squat and 1-RM bench press were significantly higher in former basketball players compared to inactive men. It



**Table 2** Correlations between clinical characteristics and bone health parameters.

	WB BMC (g)	WB BMD (g/cm <sup>3</sup> )	L1-L4 BMD (g/cm <sup>3</sup> )	TH BMD (g/cm <sup>3</sup> )	FN BMD (g/cm <sup>3</sup> )	Total Radius BMD (kg/m <sup>2</sup> )	CSA (mm <sup>2</sup> )	CSMI (mm <sup>4</sup> )	Z (mm <sup>3</sup> )	BR	SI	CSI (g/kg-m)	BSI (g/kg-m)	ISI (g/kg-m)
Age (years)	0.06	0.02	0.11	-0.09	-0.34*	-0.12	-0.25	-0.07	-0.21	-0.08	-0.33*	-0.09	-0.02	-0.03
Weight (kg)	0.43**	0.19	-0.00	0.24	0.29	0.23	0.41**	0.30*	0.25	-0.04	-0.13	-0.42**	-0.30*	-0.40**
Height (cm)	0.59***	0.34*	0.15	0.10	0.09	-0.00	0.38*	0.54***	0.42**	-0.02	0.02	-0.10	0.06	-0.05
BMI (kg/m <sup>2</sup> )	0.18	0.06	-0.04	0.23	0.29	0.29	0.28	0.06	0.08	-0.02	-0.17	-0.39**	-0.35*	-0.40**
Lean mass (kg)	0.56***	0.33*	0.06	0.27	0.31*	0.30*	0.49***	0.41**	0.33*	-0.01	-0.04	-0.33*	-0.25	-0.37*
Fat mass (kg)	0.17	-0.02	-0.11	0.13	0.19	0.11	0.22	0.10	0.08	-0.05	-0.21	-0.45**	-0.31*	-0.37*
Fat mass %	-0.08	-0.20	-0.15	0.00	0.05	0.01	0.02	-0.08	-0.05	-0.06	-0.25	-0.38*	-0.26	-0.27
Physical activity (h/week)	0.21	0.41**	0.43**	0.42**	0.38*	0.17	0.26	0.13	0.26	-0.07	0.14	0.29	0.18	0.15
Daily calcium intake (mg/d)	-0.08	0.01	-0.13	0.13	0.07	0.24	-0.08	-0.20	-0.14	-0.05	-0.24	-0.19	-0.22	-0.16
Daily protein intake (g/d)	-0.00	0.00	-0.14	0.10	0.08	0.12	-0.01	-0.14	-0.04	-0.08	0.20	-0.13	-0.11	-0.14
PSQI	0.24	0.17	-0.03	0.22	0.17	0.06	0.25	0.29	0.27	-0.04	0.03	0.03	0.10	0.02
Maximum power (watts)	0.51***	0.41**	0.11	0.30	0.34*	0.25	0.46**	0.37*	0.36*	-0.10	-0.00	-0.21	-0.09	-0.19
Horizontal jump (m)	-0.13	0.02	-0.04	-0.03	0.01	0.15	-0.08	-0.13	-0.05	-0.08	0.01	0.10	0.09	0.13
Triple jump (m)	0.07	0.22	0.13	0.07	0.07	0.03	0.09	0.09	0.12	-0.10	0.19	0.23	0.24	0.22
Vertical jump (m)	0.17	0.31*	0.16	0.14	0.15	0.04	0.13	0.11	0.16	-0.09	0.10	0.13	0.16	0.15
1-RM squat (kg)	0.40**	0.41**	0.25	0.21	0.20	0.03	0.29	0.27	0.27	-0.06	0.00	0.01	0.03	-0.02
1-RM bench press (kg)	0.18	0.21	0.16	0.17	0.19	0.09	0.11	-0.02	0.02	-0.06	-0.14	-0.06	-0.13	-0.10
1-RM leg extension (kg)	0.02	0.06	-0.15	0.04	0.02	0.06	0.00	-0.09	-0.10	-0.02	-0.32*	-0.27	-0.25	-0.23
1-RM barbell curl (kg)	0.02	-0.00	-0.14	0.05	0.06	-0.00	0.04	-0.11	-0.09	-0.20	-0.11	-0.10	-0.14	-0.22
1-RM triceps extension (kg)	0.28	0.28	0.07	0.15	0.15	0.22	0.20	0.12	0.09	0.07	-0.13	-0.09	-0.13	-0.14
10 m sprint performance (s)	-0.18	-0.33*	-0.30*	-0.19	-0.19	-0.05	-0.18	-0.18	-0.26	-0.03	-0.23	-0.35*	-0.20	-0.25
VO <sub>2</sub> max (L/min)	0.36*	0.41**	0.19	0.43**	0.55***	0.47**	0.52***	0.30*	0.37*	-0.00	0.21	-0.09	-0.18	-0.16
VO <sub>2</sub> max (mL/min/kg)	-0.26	0.05	0.12	0.06	0.08	0.07	-0.10	-0.15	-0.04	0.03	0.31*	0.38*	0.18	0.34*

BMI: body mass index; WB: whole body; BMC: bone mineral content; BMD: bone mineral density; L1-L4: lumbar spine; TH: total hip; FN: femoral neck; CSA: cross-sectional area; CSMI: cross-sectional moment of inertia; Z: section modulus; BR: bucking ratio; SI: strength index; CSI: compression strength index; BSI: bending strength index; ISI: impact strength index; RM repetition maximum; VO<sub>2</sub> max: maximum oxygen consumption.

\*  $P < 0.05$ .

\*\*  $P < 0.01$ .

\*\*\*  $P < 0.001$ .

**Table 3** Bone variables adjusted for height in both groups.

	Former basketball players (n = 18)	Inactive men (n = 25)	P-value
	Mean ± SE	Mean ± SE	
WB BMC (g)	3192 ± 76	3072 ± 64	0.30
WB BMD (g/cm <sup>2</sup> )	<b>1.360 ± 0.027</b>	<b>1.268 ± 0.023</b>	<b>0.03</b>
L1–L4 BMD (g/cm <sup>2</sup> )	<b>1.333 ± 0.039</b>	<b>1.193 ± 0.032</b>	<b>0.02</b>
TH BMD (g/cm <sup>2</sup> )	1.137 ± 0.032	1.047 ± 0.028	0.09
FN BMD (g/cm <sup>2</sup> )	1.095 ± 0.036	1.010 ± 0.030	0.12
Total Radius BMD (g/cm <sup>2</sup> )	0.804 ± 0.013	0.809 ± 0.015	0.82
CSA (mm <sup>2</sup> )	187 ± 6	178 ± 5	0.32
CSMI (mm <sup>4</sup> )	18,232 ± 975	17,241 ± 827	0.50
Z (mm <sup>3</sup> )	964 ± 44	869 ± 37	0.16
BR	3.61 ± 0.31	3.34 ± 0.27	0.58
SI	1.63 ± 0.07	1.42 ± 0.06	0.07
CSI (g/kg-m)	<b>4.73 ± 0.20</b>	<b>4.08 ± 0.17</b>	<b>0.03</b>
BSI (g/kg-m)	1.43 ± 0.09	1.22 ± 0.08	0.15
ISI (g/kg-m)	0.313 ± 0.018	0.265 ± 0.015	0.39

WB: whole body; BMC: bone mineral content; BMD: bone mineral density; L1–L4: lumbar spine; TH: total hip; FN: femoral neck; CSA: cross-sectional area; CSMI: cross-sectional moment of inertia; Z: section modulus; BR: buckling ratio; SI: strength index; CSI: compression strength index; BSI: bending strength index; ISI: impact strength index. In bold, significant differences between the 2 groups.

was deemed logical since practicing basketball ameliorates jumping and sprinting performances, lower limb strength and upper limb strength.

Regarding the correlations, weight was positively correlated to WB BMC, CSA and CSMI. On the other hand, weight, BMI and FM were negatively correlated to CSI, BSI and ISI. FM percentage was negatively correlated to CSI. These findings align with many preceding studies whose subjects were young adults that have found that body weight, BMI and FM were negatively correlated to composite indices of FN strength [16–20]. FN strength's composite indices are seemingly negatively affected by the excess of FM. Therefore, in order to prevent later on in life incidents of fractures related to osteoporosis in middle-aged men, work should be done on the implementation of strategies that reduce FM excess. Moreover, the results we received are a confirmation of the positive importance of LM on bone health in middle-aged men. LM was positively correlated to WB BMC, WB BMD, FN BMD, total radius BMD, CSA, CSMI, and Z. On the other hand, LM was negatively correlated to CSI and ISI. However, PA was positively correlated to WB BMD, L1–L4 BMD, TH BMD and FN BMD. These findings confirm those of previous studies conducted on young adults that have shown significant associations between LM, PA and bone health parameters [18,20]. Thus, implementing strategies to increase LM is important for middle-aged men to avoid the occurrence of osteoporotic fractures later in life.

The current study showed that MP calculated by the Sargent test was positively correlated to WB BMC, WB BMD, FN BMD, CSA, CSMI, and Z. These results highlight the positive influence of MP of the lower limbs on WB BMC, WB BMD, FN BMD, CSA, CSMI and Z in middle-aged men. Interestingly, the results we have received stress the positive significance of increasing lower limb MP, so this would lead to the prevention of osteoporosis in later life. Moreover, these results are

consistent with those of many previous studies conducted on young adults [14,15,20,39,40]. Our results showed that VJ was positively correlated to WB BMC and WB BMD. Several studies conducted by our laboratory on young adults have demonstrated a positive correlation between VJ and bone health parameters [14,15,40]. Therefore, the results we received call attention to the significance of expanding or augmenting VJ performance of the lower limbs to prevent osteoporosis later in life. The VJ test highlights the relative power. The weight status of the studied population may have influenced the relationships between bone health parameters and VJ performance. The current study demonstrated that 1-RM squat was positively correlated to WB BMC and WB BMD. Many previous recent studies found that 1-RM half-squat was positively correlated with bone health parameters in overweight and obese adult women [14], in overweight men [41] and in middle-aged men [20]. In the study we conducted, 1-RM leg extension was negatively correlated to SI. This study is the pioneer in finding those significant correlations, which exist between 1-RM leg extension and SI. SI is the ratio of estimated compressive yield strength of the FN to the expected compressive stress of a fall on the greater trochanter adjusted for the patient's age, height and weight. We also found that sprinting performance (seconds) was negatively correlated to WB BMD, L1–L4 BMD and CSI. This result is consistent with a preceding recent study conducted on middle-aged men that have shown a negative correlation between sprinting performance and bone health parameters [20]. They found that the performance of sprinting best determined the composite indices in middle-aged men [20]. Sprint training increases mechanical stimuli on the hip and the lumbar spine regions [42]. In addition, a recent study has shown that sprint training decreases subcutaneous adipose tissue sclerostin levels [43]. Interestingly, inhibiting sclerostin has been used as a therapeutic target for treating low bone mass [44]. Studies that are longitudinal and to

be done in the future ought to verify the impact of sprint training on bone health parameters.

VO<sub>2</sub> max (L/min) was positively correlated to WB BMC, WB BMD, TH BMD, FN BMD, total radius BMD, CSA, CSMI, and Z. VO<sub>2</sub> max (mL/min/kg) was positively correlated to SI, CSI and ISI. The results we received are consistent with the results of a previous recent study conducted on middle-aged men suggested that absolute VO<sub>2</sub> max (L/min) was a positive determinant of BMC, BMD and geometric indices of hipbone strength (CSA, CSMI, and Z) [20]. This study also suggested that relative VO<sub>2</sub> max (mL/min/kg) was a positive determinant of CSI and ISI [20]. The received results cannot be taken immediately but should be dealt with and explained with caution because the results received for performance of the step test, which is an indirect test, may be affected by several factors such as strength of the lower limb, balance and leg length. In contrast, two current studies have shown that one of the strongest determinants of BMC and BMD in young adults [20,27] is VO<sub>2</sub> max (L/min). High values of VO<sub>2</sub> max (L/min) may be the cause of higher habitual physical activity levels that led to an increase in bone mass through several mechanisms which include an increased lean mass, a better vascularisation of bone tissue and higher mechanical impact loading on bones [27]. Therefore, it is very crucial for the future prevention of fractures related to osteoporosis in men to implement strategies which will increase jumping performance, maximal strength of the lower limbs, sprinting performance and VO<sub>2</sub> max. The results showed that practicing basketball for a long time during the periods of adolescence and young adulthood seems to enhance bone health parameters. These long periods of practicing might confer residual benefits in bone health parameters in middle-aged men.

This current study has many limitations although it is an original study. The first limitation is that the study's nature is cross-sectional and therefore a causal relationship between former basketball practice and bone health parameters cannot be confirmed. The second limitation is that the number of subjects is low in every group; however, power values were sufficient to run the analyses and to test the differences between the 2 groups regarding bone health parameters. The third limitation is that in the study, several bone health correlates (hormones and vitamin D levels) were not evaluated. The fourth limitation of the study is that visceral FM was not evaluated; however, visceral fat has a well-known deleterious effect on bone health parameters [45,46]. As has been said before, the last limitation was the lack of use of a specific PA questionnaire [47,48] to measure the effect of mechanical strain on BMD. But, based on our information, comparing bone health parameters (BMC, BMD, geometric indices of FN strength [CSA, CSMI, Z, BR, SI] and composite indices of FN strength [CSI, BSI, and ISI]) in inactive middle-aged men and middle-aged former basketball players has been done for the first time in this study.

Bone variables were compared between the 2 groups after adjusting for height. The results showed that WB BMD and L1–L4 BMD remained significantly higher in former basketball players compared to inactive subjects. CSI values were also higher in former basketball players compared to inactive subjects after adjusting for height. This result suggests that the differences between the 2 groups regarding

BMD are not related to the differences in their height but are most probably due to the former basketball practice.

## 5. Conclusion

Our study indicated that bone health parameters in men who are middle-aged is increased due to previous basketball training in those men's years of adolescence and young adulthood. Also, the results received are the only ones so far to show that regular basketball practice before the young adulthood period may confer residual benefits in bone health parameters in middle-aged men. Therefore, it is our belief that practicing basketball while a male is still in his adolescence and young adulthood years could have a preventive effect against fractures resulting from osteoporosis later in life. The designation of exercise programs during adolescence and young adulthood should be adapted accordingly.

## Disclosure of interest

The authors declare that they have no competing interest.

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Study 2: Bone health parameters in young adult basketball players vs. young adult active men.

**Objective.** – The purpose of this study was to compare bone health parameters (bone mineral content [BMC], bone mineral density [BMD], geometric indices of femoral neck [FN] strength, cross-sectional area [CSA], cross-sectional moment of inertia [CSMI], section modulus [Z], buckling ratio [BR] and strength index [SI]) and composite indices of FN strength (compression strength index [CSI], bending strength index [BSI], and impact strength index [ISI]) in young-aged inactive men (n = 15), young aged active men (n=17), and young-aged basketball players (n = 15).

**Methods.** – The participants of the study were 47 young-aged men; their ages ranged from 20 to 28 years. Dual-energy X-ray absorptiometry was used to evaluate body composition, BMD and geometric indices of FN strength. Composite indices of FN strength (CSI, BSI, and ISI) were calculated. Physical performance tests were used to evaluate the vertical jump (VJ), horizontal jump (HJ), triple jump (TJ), maximum power (MP) of the lower limbs (watts), maximal squat strength, maximal bench press strength, maximal leg extension strength, maximal barbell curl strength, maximal triceps extension strength, sprint performance (10 meters), and maximum oxygen consumption (VO<sub>2</sub> max, L/min).

**Results.** – No significant differences were seen between the active group and the basketball players. MP, HJ, TJ, VJ, maximal squat strength, maximal barbell curls strength, maximal bench press strength, 10m sprint performance were significantly higher in basketball players compared to inactive men, but not with active group. Body mass index (BMI), total weight (TW), lean mass (LM), 1-RM Bench press, 1-RM leg press, 1-RM barbell curl, relative and absolute VO<sub>2</sub> max, daily protein intake DPI and daily calcium intake DCI are all positively correlated to WB BMC and BMD. 1-RM half squat, 1-RM barbell curl, maximum power (MP), 1-RM triceps extension were positively correlated with WB BMD, WB BMC, L1-L4, TH, FN, and total radius BMD, CSA, CSMI, Z, and BR.

**Conclusion.** – The present study suggests physical and athletic parameters are positively correlated with bone health in young adults.

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## Bone health parameters in young adult basketball players vs. young adult active men

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### Abstract

**Objective:** The purpose of this study was to compare bone health parameters (bone mineral content (BMC), bone mineral density (BMD), geometric indices of femoral neck (FN) strength, cross-sectional area (CSA), cross-sectional moment of inertia (CSMI), section modulus (Z), buckling ratio (BR) and strength index (SI)) and composite indices of FN strength (compression strength index (CSI), bending strength index (BSI), and impact strength index (ISI)) among three groups: young inactive men (n = 15), young active men (n=17), and young basketball players (n = 15).

**Methods:** The participants of the study were 47 young-aged men; their ages ranged from 20 to 28 years. Dual-energy X-ray absorptiometry was used to evaluate body composition, BMD and geometric indices of FN strength. Composite indices of FN strength (CSI, BSI, and ISI) were calculated. Physical performance tests were used to evaluate vertical jump (VJ), horizontal jump (HJ), triple jump (TJ), maximum power (MP) of the lower limbs (watts), maximal squat strength, maximal bench press strength, maximal leg extension strength, maximal barbell curl strength, maximal triceps extension strength, sprint performance (10 meters), and maximum oxygen consumption (VO2 max, L/min).

**Results:** No significant differences were observed between the active group and the basketball group regarding bone health parameters. MP, HJ, TJ, VJ, maximal squat strength, maximal barbell curls strength, maximal bench press strength, 10m sprint performance were significantly higher in basketball players compared to inactive men. In the whole population (n = 47), body mass index (BMI), total weight (TW), lean mass (LM), 1-RM Bench press, 1-RM leg press, 1-RM barbell curl, relative and absolute VO2 max, daily protein intake (DPI) and daily calcium intake (DCI) were positively correlated to WB BMC and WB BMD. In addition, 1-RM half squat, 1-RM barbell curl, maximum power (MP), 1-RM triceps extension were positively correlated to WB BMD, WB BMC, L1-L4 BMD, TH BMD, FN BMD, total radius BMD, CSA, CSMI and Z in the whole population.

**Conclusion:** The present study suggests physical and athletic parameters are positively correlated with bone health parameters in young adults.

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\*Speaker

**Table 1: Clinical characteristics and bone variables of the study population**

	YACG (n=15)	YAAG (n=17)	YAEG (n=15)	p-value
	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	
Age (years)	23.2 $\pm$ 1.8	23.4 $\pm$ 1.6	24.2 $\pm$ 2.6	0.383
Weight (kg)	77.4 $\pm$ 11.7	84.7 $\pm$ 11.2	83.6 $\pm$ 14.2	0.223
Height (cm)	<b>180.4 <math>\pm</math> 4.7</b>	<b>182.7 <math>\pm</math> 6.0</b>	<b>187.1 <math>\pm</math> 7.8<sup>b</sup></b>	<b>0.019</b>
BMI (kg/m <sup>2</sup> )	24.0 $\pm$ 3.7	25.6 $\pm$ 2.7	24.1 $\pm$ 3.6	0.343
Lean mass (Kg)	53.854 $\pm$ 5.300	60.094 $\pm$ 17.844	51.841 $\pm$ 19.768	0.309
Fat mass (Kg)	20.464 $\pm$ 7.164	16.640 $\pm$ 6.751	19.541 $\pm$ 9.493	0.359
Fat mass (%)	<b>25.8 <math>\pm</math> 5.2<sup>a</sup></b>	<b>20.0 <math>\pm</math> 5.3</b>	<b>23.5 <math>\pm</math> 6.2</b>	<b>0.021</b>
WB BMC (g)	<b>3010 <math>\pm</math> 384<sup>a</sup></b>	<b>3431 <math>\pm</math> 403</b>	<b>3328 <math>\pm</math> 511</b>	<b>0.026</b>
WB BMD (g/cm <sup>2</sup> )	<b>1.293 <math>\pm</math> 0.127<sup>a</sup></b>	<b>1.399 <math>\pm</math> 0.104</b>	<b>1.366 <math>\pm</math> 0.127</b>	<b>0.049</b>
L1-L4 BMD (g/cm <sup>2</sup> )	<b>1.237 <math>\pm</math> 0.147<sup>a</sup></b>	<b>1.378 <math>\pm</math> 0.139</b>	<b>1.322 <math>\pm</math> 0.117</b>	<b>0.019</b>
TH BMD (g/cm <sup>2</sup> )	1.114 $\pm$ 0.118	1.214 $\pm$ 0.151	1.181 $\pm$ 0.112	0.099
FN BMD (g/cm <sup>2</sup> )	1.124 $\pm$ 0.103	1.228 $\pm$ 0.158	1.218 $\pm$ 0.131	0.070
Total Radius BMD (g/cm <sup>2</sup> )	0.788 $\pm$ 0.087	0.816 $\pm$ 0.062	0.803 $\pm$ 0.062	0.546
CSA (mm <sup>2</sup> )	<b>189 <math>\pm</math> 24<sup>a</sup></b>	<b>219 <math>\pm</math> 33</b>	<b>210 <math>\pm</math> 27</b>	<b>0.019</b>
CSMI (mm <sup>4</sup> )	17.8 $\pm$ 4.3	21.8 $\pm$ 5.2	20.8 $\pm$ 4.8	0.062
Z (mm <sup>3</sup> )	1003 $\pm$ 179	1159 $\pm$ 253	1093 $\pm$ 170	0.114
BR	4.23 $\pm$ 1.33	3.15 $\pm$ 2.28	3.42 $\pm$ 0.96	0.179
SI	1.63 $\pm$ 0.30	1.71 $\pm$ 0.34	1.48 $\pm$ 0.28	0.136
CSI (g/kg-m)	5.142 $\pm$ 0.807	5.081 $\pm$ 0.775	5.016 $\pm$ 1.124	0.931
BSI (g/kg-m)	1.381 $\pm$ 0.493	1.467 $\pm$ 0.365	1.436 $\pm$ 0.510	0.869
ISI (g/kg-m)	0.304 $\pm$ 0.113	0.342 $\pm$ 0.054	0.330 $\pm$ 0.078	0.445
Maximum power (watts)	<b>876 <math>\pm</math> 136<sup>a</sup></b>	<b>1067 <math>\pm</math> 182</b>	<b>1091 <math>\pm</math> 198<sup>b</sup></b>	<b>0.002</b>
Horizontal jump (m)	<b>1.533 <math>\pm</math> 0.184<sup>a</sup></b>	<b>1.924 <math>\pm</math> 0.195</b>	<b>1.900 <math>\pm</math> 0.273<sup>b</sup></b>	<b>&lt;0.001</b>
Triple jump (m)	<b>5.04 <math>\pm</math> 0.40<sup>a</sup></b>	<b>5.59 <math>\pm</math> 0.56</b>	<b>5.69 <math>\pm</math> 0.68<sup>b</sup></b>	<b>0.005</b>
Vertical jump (m)	<b>27.267 <math>\pm</math> 2.939<sup>a</sup></b>	<b>33.588 <math>\pm</math> 4.651</b>	<b>36.333 <math>\pm</math> 5.851<sup>b</sup></b>	<b>&lt;0.001</b>
1-RM bench press (kg)	<b>54.461 <math>\pm</math> 8.196<sup>a</sup></b>	<b>110.351 <math>\pm</math> 33.646</b>	<b>72.844 <math>\pm</math> 18.521<sup>b</sup></b>	<b>&lt;0.001</b>
1-RM leg extension (kg)	<b>103.074 <math>\pm</math> 10.904<sup>a</sup></b>	<b>134.405 <math>\pm</math> 24.577<sup>c</sup></b>	<b>119.417 <math>\pm</math> 23.938</b>	<b>&lt;0.001</b>
1-RM squat (kg)	<b>74.941 <math>\pm</math> 9.538<sup>a</sup></b>	<b>135.277 <math>\pm</math> 41.593<sup>c</sup></b>	<b>107.048 <math>\pm</math> 21.222<sup>b</sup></b>	<b>&lt;0.001</b>

1-RM barbell curl (kg)	<b>33.534 ± 5.500<sup>a</sup></b>	<b>51.892 ± 13.129<sup>c</sup></b>	<b>41.219 ± 7.291<sup>b</sup></b>	<b>&lt;0.001</b>
1-RM triceps extension (kg)	<b>57.957 ± 12.063<sup>a</sup></b>	<b>91.625 ± 31.672<sup>c</sup></b>	<b>69.857 ± 11.615</b>	<b>&lt;0.001</b>
10 m sprint performance (s)	<b>2.219 ± 0.096<sup>a</sup></b>	<b>1.942 ± 0.111<sup>c</sup></b>	<b>2.015 ± 0.087<sup>b</sup></b>	<b>&lt;0.001</b>
VO <sub>2</sub> max (L/min)	<b>4.06 ± 0.31<sup>a</sup></b>	<b>4.54 ± 0.41</b>	<b>4.54 ± 0.32<sup>b</sup></b>	<b>&lt;0.001</b>
VO <sub>2</sub> max (ml/min/kg)	53.144 ± 4.611	53.999 ± 4.726	55.171 ± 6.693	0.590
DPI (g/day)	<b>57.0 ± 19.1<sup>a</sup></b>	<b>80.4 ± 24.6</b>	<b>69.7 ± 26.1</b>	<b>0.028</b>
DCI (mg/day)	<b>634.6 ± 155.4</b>	<b>999.4 ± 516.3</b>	<b>1034.4 ± 551.8</b>	<b>0.033</b>
PSQI (h/day)	<b>5.7 ± 2.5<sup>a</sup></b>	<b>3.8 ± 1.9</b>	<b>3.4 ± 1.3<sup>b</sup></b>	<b>0.007</b>

SD, standard deviation; BMI, body mass index; WB, whole body; BMC, bone mineral content; BMD, bone mineral density; L1-L4, Lumbar spine; TH, total hip; FN, femoral neck; CSA, cross-sectional area; CSMI, cross-sectional moment of inertia; Z, section modulus; BR, buckling ratio; SI, strength index; CSI, compression strength index; BSI, bending strength index; ISI, impact strength index; RM, repetition maximum; VO<sub>2</sub> max, maximum oxygen consumption; DPI, daily protein intake; DCI, daily calcium intake; PSQI, Pittsburgh sleep quality index.

<sup>a</sup>Significant differences between YACG and YAAG  $p < 0.05$ .

<sup>b</sup>Significant differences between YACG and YAEG  $p < 0.05$ .

<sup>c</sup>Significant differences between YAEG and YAAG  $p < 0.05$ .



Table 2: Correlations between clinical characteristics and bone variables in the whole population

	WB BMC (g)	WB BMD (g/cm <sup>2</sup> )	L1-L4 BMD (g/cm <sup>2</sup> )	TH BMD (g/cm <sup>2</sup> )	FN BMD (g/cm <sup>2</sup> )	Total Radius BMD (g/cm <sup>2</sup> )	CSA (mm <sup>2</sup> )	CSMI (mm <sup>4</sup> )	Z (mm <sup>3</sup> )	BR	SI	CSI (g/kg- m)	BSI (g/kg- m)	ISI (g/kg- m)
Age (years)	0.29 *	0.33 *	0.25	0.12	0.10	0.24	-0.00	-0.00	0.11	-0.38 **	-0.28	-0.12	-0.18	0.12
Weight (kg)	0.76 ***	0.69 ***	0.44 **	0.37 **	0.49 ***	0.42 **	0.63 ***	0.64 ***	0.61 ***	-0.28	-0.30 *	-0.53 ***	-0.35 *	-0.22
Height (cm)	0.61 ***	0.47 ***	0.43 **	0.19	0.33 *	0.22	0.46 ***	0.47 ***	0.41 **	-0.16	-0.30 *	-0.23	-0.20	-0.32 *
BMI (kg/m <sup>2</sup> )	0.53 ***	0.53 ***	0.29 *	0.32 *	0.37 **	0.36 *	0.44 **	0.43 **	0.43 **	-0.22	-0.20	-0.46 **	-0.29 *	-0.07
Lean mass (Kg)	0.29 *	0.20	0.20	0.37 *	0.33 *	0.15	0.43 **	0.33 *	0.36 *	-0.30 *	0.04	0.01	-0.03	0.08
Fat mass (Kg)	0.20	0.23	-0.09	0.02	0.14	0.07	0.16	0.19	0.17	0.00	-0.21	-0.39 **	-0.21	-0.25
Fat mass (%)	0.04	0.10	-0.20	-0.09	-0.01	-0.00	-0.02	0.02	0.00	0.06	-0.21	-0.26	-0.10	-0.22
Maximum power (watts)	0.79	0.70	0.48	0.46	0.57	0.39	0.68	0.63	0.58	-0.30	-0.29	-0.45	-0.34	-0.20

	***	***	***	**	***	**	***	***	***	*	*	**	*	
Horizontal jump (m)	0.27	0.20	0.28 *	0.26	0.23	0.00	0.35 *	0.25	0.19	-0.16	0.25	0.16	0.18	0.37 **
Triple jump (m)	0.18	0.10	0.14	0.19	0.19	0.11	0.28 *	0.21	0.14	-0.03	0.21	0.23	0.24	0.28
Vertical jump (m)	0.33 *	0.27	0.25	0.31 *	0.35 *	0.14	0.40 **	0.31 *	0.25	-0.06	0.21	-0.04	-0.09	0.24
1-RM bench press (kg)	0.57 ***	0.49 ***	0.49 ***	0.26	0.25	0.37 **	0.45 **	0.46 ***	0.45 **	-0.39 **	0.00	-0.29 *	-0.21	-0.06
1-RM leg extension (kg)	0.51 ***	0.41 **	0.43 **	0.37 **	0.44 **	0.35 *	0.52 ***	0.46 ***	0.47 ***	-0.15	0.00	-0.36 *	-0.34 *	-0.20
1-RM squat (kg)	0.70 ***	0.59 ***	0.61 ***	0.44 **	0.46 **	0.40 **	0.60 ***	0.54 ***	0.55 ***	-0.46 ***	-0.10	-0.29 *	-0.25	-0.03
1-RM barbell curl (kg)	0.63 ***	0.50 ***	0.52 ***	0.30 *	0.35 *	0.40 **	0.59 ***	0.63 ***	0.60 ***	-0.26	-0.02	-0.36 *	-0.29 *	-0.13
1-RM triceps extension (kg)	0.52 ***	0.46 ***	0.50 ***	0.35 *	0.33 *	0.34 *	0.49 ***	0.47 ***	0.48 ***	-0.39 **	0.16	-0.13	-0.17	-0.04
10 m sprint duration (s)	-0.27	-0.29 *	-0.38 **	-0.36 *	-0.31 *	-0.12	-0.28	-0.19	-0.20	0.21	-0.15	-0.13	-0.04	-0.40 **
VO <sub>2</sub> max (L/min)	0.69	0.62	0.47	0.51	0.58	0.36	0.67	0.59	0.60	-0.45	-0.18	-0.40	-0.32	-0.07

	***	***	***	***	***	*	***	***	***	**		**	*	
VO <sub>2</sub> max (ml/min/kg)	-0.58 ***	-0.54 ***	-0.30 *	-0.13	-0.23	-0.31 *	-0.37 **	-0.45 **	-0.40 **	0.01	0.29 *	0.44 **	0.26	0.27
DPI (g/day)	0.53 ***	0.45 **	0.38 **	0.25	0.34 *	0.43 **	0.41 **	0.35 *	0.36 *	-0.21	-0.41 **	-0.52 ***	-0.49 ***	-0.48 ***
DCI (mg/day)	0.59 ***	0.46 **	0.37 **	0.36 *	0.47 **	0.32 *	0.49 ***	0.40 **	0.41 **	-0.26	-0.43 **	-0.48 ***	-0.48 ***	-0.29 *
PSQI (h/day)	-0.11	-0.14	-0.21	-0.29 *	-0.33 *	-0.05	-0.16	-0.02	-0.01	0.08	0.20	0.04	0.11	-0.12

SD, standard deviation; BMI, body mass index; WB, whole body; BMC, bone mineral content; BMD, bone mineral density; L1-L4, Lumbar spine; TH, total hip; FN, femoral neck; CSA, cross-sectional area; CSMI, cross-sectional moment of inertia; Z, section modulus; BR, buckling ratio; SI, strength index; CSI, compression strength index; BSI, bending strength index; ISI, impact strength index; RM, repetition maximum; VO<sub>2</sub> max, maximum oxygen consumption; DPI, daily protein intake; DCI, daily calcium intake; PSQI, Pittsburgh sleep quality index. \* $p < 0.05$ . \*\* $p < 0.01$ . \*\*\* $p < 0.001$ .

## General discussion

This thesis's objective is to identify the effects of basketball on the determinants of bone health for middle-aged and young-aged men.

For the middle-aged, playing Basketball for at least 10 years on a high level, has proven to induce a positive residual effect on bone parameters compared to an age matched control group. In this study, WB BMC, WB BMD, L1-L4 BMD, CSA, CSMI and Z were significantly higher in the EG compared to the CG.

Regarding the correlations, weight was positively correlated to WB BMC, CSA, CSMI, and Z. On the other hand, weight, BMI and FM were negatively correlated to CSI, BSI and ISI. FM percentage was negatively correlated to CSI. These findings align with many preceding studies whose subjects were young adults that have found that body weight, BMI and FM were negatively correlated to composite indices of FN strength (El Hage, 2014; Finianos et al., 2021; El Hage, 2014; Kim, et al., 2017).

FN strength's composite indices are seemingly negatively affected by the excess of FM. Therefore, in order to prevent later on in life incidents of fractures related to osteoporosis in middle-aged men, work should be done on the implementation of strategies that reduce FM excess. Increased FM is associated with several endocrine factors such as reduced testosterone and growth hormone levels, and these could be the cause of a negative effect on bone health parameters in men (Kelly & Jones, 2015; Grossman, 2018). Moreover, the results we received are a confirmation of the positive importance of LM on bone health in middle-aged men. LM was positively correlated to WB BMC, WB BMD, FN BMD, total radius BMD, CSA, CSMI, and Z. On the other hand, LM was negatively correlated to CSI and ISI. However, PA was positively correlated to WB BMD, L1-L4 BMD, TH BMD and FN BMD. These findings confirm those of previous studies conducted on young adults that have shown significant associations between LM, PA and bone health parameters (Finianos et al., 2021; Zakhem et al., 2020; El Hage et al., 2014; El Hage et al., 2014; El Hage et al., 2014). Bone formation (El Khoury et al., 2018) is stimulated by mechanical factors, and this process is well-known. For this reason, implementing strategies to increase LM is important for middle-aged men to avoid the occurrence of osteoporotic fractures later in life. A recent study has demonstrated that LM is a positive determinant of BMD, CSA, CSMI, Z and ISI in young overweight men (Zakhem et al., 2020). The result received from our study is the same as the

results received by various preceding studies in that LM is an important determinant of WB BMC, FN CSA and FN Z (El Khoury et al., 2018; El Hage et al., 2009).

A cross-sectional study which included 70 women who were osteoporotic and menopausal, has shown a significant correlation between LM and bone health parameters such as BMC and BMD (Genaro et al., 2010). It has demonstrated that FN BMD and femur BMD were correlated to LM (Genaro et al., 2010). Another study (Zakhem et al., 2016) conducted on a group of young adults has shown that LM was positively correlated to WB BMC and WB BMD in both young men and women.

The current study showed that MP calculated by the Sargent test was positively correlated to WB BMC, WB BMD, FN BMD, CSA, CSMI, and Z. These results highlight the positive influence of MP of the lower limbs on WB BMC, WB BMD, FN BMD, CSA, CSMI and Z in middle-aged men. Interestingly, the results we have received stress the positive significance of increasing lower limb MP, so this would lead to the prevention of osteoporosis in later life. Moreover, these results are consistent with those of many previous studies conducted on young adults (Khawaja et al., 2021; Finianos et al., 2020; Berro et al., 2019; Khawaja et al., 2019; Finianos et al., 2021; El Hage et al., 2014). Our results showed that VJ was positively correlated to WB BMD. Several studies conducted by our laboratory on young adults have demonstrated a positive correlation between VJ and bone health parameters (Berro et al., 2019; Khawaja et al., 2019; Khawaja et al., 2021). Therefore, the results we received call attention to the significance of expanding or augmenting VJ performance of the lower limbs to prevent osteoporosis later in life. The VJ test highlights the relative power. The weight status of the studied population may have influenced the relationships between bone health parameters and VJ performance. The current study demonstrated that 1-RM squat was positively correlated to WB BMC and WB BMD. Many previous recent studies found that 1-RM half-squat was positively correlated with bone health parameters in overweight and obese adult women (Berro et al., 2019), in overweight men (Khawaja et al., 2019), in middle-aged men (Finianos et al., 2021), in elderly men (Nasr et al., 2019) and in elderly women (Nasr et al., 2018). In the study we conducted, 1-RM leg extension was negatively correlated to SI. This study is the pioneer in finding those significant correlations which exist between 1-RM leg extension and SI. SI is the ratio of estimated compressive yield strength of the FN to the expected compressive stress of a fall on the greater trochanter adjusted for the patient's age, height and weight. We also found that sprinting performance (seconds) was positively correlated to WB BMD, L1-L4 BMD and CSI. This result is consistent with a preceding

recent study conducted on middle-aged men that have shown a positive correlation between sprinting performance and bone health parameters (Finianos et al., 2021). They found that the performance of sprinting best determined the composite indices in middle-aged men (Finianos et al., 2021). Studies that are longitudinal and to be done in the future ought to verify the impact of sprint training on bone health parameters. Interestingly,  $VO_2$  max (L/min) was positively correlated to WB BMC, WB BMD, TH BMD, FN BMD, total radius BMD, CSA, CSMI, and Z.  $VO_2$  max (mL/min/kg) was positively correlated to SI, CSI and ISI. The results we received are consistent with the results of two recent studies conducted on young adults (El Khoury et al., 2018; Sabbagh et al., 2020). Similarly, a recent study (Finianos et al., 2021) conducted on middle-aged men suggested that absolute  $VO_2$  max (L/min) was a positive determinant of BMC, BMD and geometric indices of hip bone strength (CSA, CSMI, and Z). This study also suggested that relative  $VO_2$  max (ml/min/kg) was a positive determinant of CSI and ISI (Finianos et al., 2021). The received results cannot be taken immediately but should be dealt with and explained with caution because the results received for performance of the step test, which is an indirect test, may be affected by several factors such as strength of the lower limb, balance and leg length. In contrast, various current studies have shown that one of the strongest determinants of BMC and BMD in young adults (Finianos et al., 2021; Finianos et al., 2020; Sabbagh et al., 2020; El Hage et al., 2011) is  $VO_2$  max (L/min). Therefore, it is very crucial for the future prevention of fractures related to osteoporosis in men to implement strategies which will increase jumping performance, maximal strength of the lower limbs, sprinting performance and  $VO_2$  max. The results showed that practicing basketball for a long time during the periods of adolescence and young adulthood seems to enhance bone health parameters. These long periods of practicing might confer residual benefits in bone health parameters in middle-aged men.

The objective of the second study was to compare the effect of playing basketball versus being physically active on bone variables for young adults. It showed that although most of the studies showed a positive effect of basketball on bone variables (Stojanović et al., 2020; Maillane-Vanegas et al., 2020; Sanfilippo et al., 2019; Scerpella et al., 2018; Tenforde et al., 2018; Agostinete et al., 2017; Jallai et al., 2017; Stanforth et al. 2016), but this was not the case in the conducted study. However, several positive correlations were found between anthropometric and physical tests from one side and bone health parameters on the other side.

Lean mass was correlated with WB BMC, TH and FN BMD, these results were similar to a study conducted on young Australian adults (Liberato et al., 2015). Strength tests were

positively correlated with both whole-body BMD and BMC, as well as BMD in the L1-L4 region. Similarly, in a longitudinal study, done by Borba-Pinheiro et al. (2012), they stated that strength tests are positively correlated with bone variables for female adults. Moreover, Zakhem et al. (2013) found that 1 RM half squat is positively correlated with bone health parameters for young aged women. Furthermore, upper limb strength training had a positive significant result on bone parameters for middle-aged men (Harding et al., 2020), and for elderly (Wagner et al., 2018). Likewise, upper limb strength was positively correlated with bone health parameters for young adults in Okamoto et al. (2009).

Absolute  $VO_2$  max was positively correlated with WB BMC and BMD, L1-L4, TH, FN, total radius BMD, CSA, CSMI, and Z scores. Similarly, numerous studies (Finianos et al., 2021; Finianos et al., 2020; Sabbagh et al., 2020; El Hage et al., 2011) have demonstrated that  $VO_2$  max (L/min) is one of the most influential factors determining BMC and BMD in young adults.

Sprinting performance was positively correlated with WB, L1-L4, TH, and FN BMD. Thus the importance of sprint training to increase the bone health parameters, and as proven by Kamlé et al. (2023). Therefore, it is very crucial for young adults to implement strategies which will increase maximal strength of the lower limbs, sprinting performance, and  $VO_2$  max. The results showed that training the lower body strength, the  $VO_2$  max, and sprinting abilities during the periods of young adulthood seems to enhance bone health parameters.

Daily protein intake and daily calcium intake were positively correlated with WB BMC, WB, FN, L1-L4, and total radius BMD in addition to the geometric indices of FN strength. This comes in Accordance to Nguyen's (2021) comprehensive study, children who receive milk supplements have higher daily consumption of calcium and vitamin D, meeting recommended levels. As a result, the evaluated research produced increased bone area ratios, BMC, BMD for the legs and entire body, BMD measurements in the cortex's medullary diameter and thickness, and improved bone metabolism metrics. Additionally, Kadilkar et al. (2012) claimed that inadequate consumption of calcium throughout the crucial years of skeletal growth leads to poor PBM. Moreover, BMD, cortical and trabecular microstructure, and microstructure-estimated bone strength are all favorably correlated with daily protein consumption (Rizzoli et al., 2021).

The current study showed that MP calculated by the Sargent test was positively correlated to WB BMC, WB, L1-L4, TH, FN, total radius BMD, CSA, CSMI, and Z. These findings

demonstrate the beneficial effects of MP of the lower limb on WB BMC, WB, L1-L4, TH, FN, total radius BMD, CSA, CSMI, and Z in young men. Interestingly, the results we have received stress the positive significance of increasing lower limb MP, so this would lead to a better BMD profile. Moreover, these results are consistent with those of many previous studies conducted on young adults (Khawaja et al., 2021; Finianos et al., 2020; Berro et al., 2019; Khawaja et al., 2019; Finianos et al., 2021; El Hage et al., 2014). Additionally, the jumping performances were positively correlated to bone parameters, horizontal jump was positively correlated to L1-L4 BMD, CSA, and ISI, triple jump was positively correlated to CSA, and vertical jump was positively correlated to CSA, CSMI, FN and total hip BMD, and WB BMC. These results come with the findings of our laboratory on young adults that demonstrated a positive correlation between VJ and bone health parameters (Berro et al., 2019; Khawaja et al., 2019; Khawaja et al., 2021) and between HJ and bone health parameters (Hage et al., (2015). Similarly, Zakhem et al. (2013) studied the effect of horizontal jump performances on BMD for young adult women; as a result, there was a positive correlation between the two variables. On the other hand, maximum power was positively correlated to WB BMC, WB, L1-L4, TH, FN, total radius BMD, CSA, CSMI, and Z.

This current thesis has many limitations although it is an original study. The first limitation is that the study's nature is cross-sectional and therefore a causal relationship between former basketball practice and bone health parameters cannot be confirmed. The second limitation is that the number of subjects is low in every group; however, power values were sufficient to run the analysis and to test the differences between the 2 groups regarding bone health parameters. The third limitation is that in the study, several bone health correlates (hormones and vitamin D levels) were not evaluated. The fourth limitation of the study is that visceral FM was not evaluated; however, visceral fat has a well-known deleterious effect on bone health parameters (El Hage et al., 2011; El Hage et al, 2013). As has been said before, the lack of use of a specific PA questionnaire was another limitation (Dolan et al., 2006; Kemper et al., 2002) to measure the effect of mechanical strain on BMD. However, based on our information, comparing bone health parameters (BMC, BMD, geometric indices of FN strength [CSA, CSMI, Z, BR, SI] and composite indices of FN strength [CSI, BSI, and ISI]) in inactive middle-aged men and middle-aged former basketball players have been done for the first time in this study. The last limitation goes for the second study, that the basketball



group were second division players in Lebanon (semi-pro) which might have led to the actual results.

## **Conclusions and Perspectives**

This thesis, carried out on middle-aged and young-aged adult men, mainly shows that:

- Basketball practice has a residual effect on bone variables after cessation.
- The residual effect is on: whole body bone mineral content and density, L1-L4 bone mineral density, cross-sectional area, cross-sectional moment of inertia and section modulus.
- Sprinting performance (seconds) is positively correlated to whole body bone mineral density, L1-L4 bone mineral density and cross-sectional area.
- Lean mass, maximum power, vertical jump, and 1-RM half squat are all positively correlated to whole body bone mineral density and bone mineral density in middle aged-men.
- Lean mass is positively correlated to cross-sectional area, bending strength index, and impact strength index; whereas, fat mass, total weight and body mass index are negatively correlated in middle-aged men.
- Body mass index, total weight, lean mass, maximum power, 1-RM Bench press, 1-RM leg press, 1-RM half squat, 1-RM barbell curl, relative and absolute VO<sub>2</sub> max, daily protein intake and daily calcium intake are all positively correlated to whole body bone mineral density and bone mineral content in young adults.

Our study defined many determinants of bone mass for middle aged men and for young adults. Moreover, it showed that although basketball might not have direct positive effect on bones, but eventually, it will have a positive residual effect later with aging compared with control group.

Looking into our results, it will be interesting to conduct a longitudinal study on the effect of a one-year basketball practice for middle-aged men. Additionally, a cross-sectional study on former basketball players in their 7<sup>th</sup> decade would be interesting and unique as well. Finally, writing a meta-analysis resuming the effects of basketball on bone health parameters is definitely needed.



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## **Annex**

Al Chalouhy, G., Khawaja, A., Pinti, A., Khalil, N., Zunquin, G., & El Hage, R. (2023). Bone health parameters in middle-aged former basketball players vs. Middle-aged inactive men. *Science & Sports*, 38(5-6), 551-560. <https://doi.org/10.1016/j.scispo.2023.03.002>

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Al Chalouhy, G., Zunquin, G., & El Hage, R. (2023). Bone health parameters in young adult basketball players vs. young adult active men. [sciencesconf.org:acaps2023:490357](https://www.sciencesconf.org/acaps2023:490357)



## **Abstract**

### English:

The aim of this thesis was to study the effects of basketball on bone health parameters in adult men. Two studies were conducted. The first study revealed that even after cessation, professional basketball practice for at least 10 years will induce residual effects on bone variables when compared to the control group. Additionally, it demonstrated a positive correlation between absolute VO<sub>2</sub> max values and whole-body bone mineral content (BMC) and bone mineral density (BMD). The second study found that for young adults, half squat, bench press, triceps extension, leg extension, and biceps barbell curl strength, and maximum power are positively correlated with both whole-body BMD and BMC, as well as BMD of the L1-L4 region.

Keywords: maximal oxygen consumption, bone mineral density, bone mineral content, basketball, strength.

### French :

L'objectif de cette thèse était d'étudier les effets du basketball sur les paramètres de santé osseuse chez les hommes adultes. Deux études ont été menées. La première étude a révélé que même après l'arrêt, la pratique professionnelle du basket-ball pendant au moins 10 ans induirait des effets résiduels sur les variables osseuses par rapport au groupe témoin. De plus, il a démontré une corrélation positive entre les valeurs absolues de VO<sub>2</sub> max et le contenu minéral osseux (BMC) et la densité minérale osseuse (DMO) du corps entier. La deuxième étude a montré que chez les jeunes adultes, la force du demi squat, développé couché, extension de triceps, extension des jambes, et de la flexion des biceps avec barre, et la puissance maximale sont positivement corrélés à la DMO et à la CMO du corps entier, ainsi qu'à la DMO au niveau de la région L1-L4.

Mots clés : consommation maximale d'oxygène, densité minérale osseuse, contenu minéral osseux, basketball, force.