The effects of a 1-year recreational football protocol on bone mineral density and physical performance parameters in a group of healthy inactive 50 years old men

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The Effects of a 1-year Recreational Football Protocol on Bone Mineral Density and Physical Performance Parameters in a Group of Healthy Inactive 50-year-Old Men

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ABBREVIATIONS

ADT	Androgen deprivation therapy
BMAD	Bone mineral apparent density
BMC	Bone mineral content
BMD	Bone mineral density
BMI	Body mass index
BR	Buckling Ratio
BSI	Bending strength index
CMJ	Counter movement jump
CSA	Cross-sectional area
CSI	Compression Strength Index
CSMI	Cross-sectional moment of inertia
CT	Cortical thickness
DXA	Dual energy X-ray absorptiometry
FM	Fat mass
FN	Femoral neck
GH	Growth hormone
HG	Hand grip
IGF-1	Insulin-like growth factor 1
IOF	International Osteoporosis Foundation
ISCD	International Society for Clinical Densitometry
ISI	Impact strength index
L1-L4	Lumbar spine
LM	Lean mass
PBM	Peak bone mass
RF30	Recreational football 30 minutes
RF60	Recreational football 60 minutes
RM	Maximum repetition
T2DM	Type 2 diabetes mellitus
TBS	Trabecular bone score

TH	Total hip
TR	Total radius
VO_2	Oxygen consumption
VO_2 max	Maximal oxygen consumption
WB	Whole body
WHO	World heath organisation
Z	Section modulus

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INTRODUCTION

Osteoporosis is "the most common bone disease in humans and it is characterized by low bone mineral density (BMD) and deterioration of bone microarchitecture leading to increased risk of fracture" (WHO, 1994). It is a major public health problem which not only affects women as it is traditionally believed but affects men as well. Hip and vertebral fractures are the most common fractures associated with osteoporosis (Warriner et al., 2011). Hip fractures are considered to be the most serious of these fractures because they are correlated to a high rate of morbidity and mortality (Zaheer and LeBoff, 2000). An increased risk of death during the first year after hip fracture is found in both sexes but at a higher rate in men compared to women (Chrischilles et al., 1991; Magaziner et al.,1997; Melton et al, 1997). Currently, the diagnosis of osteoporosis is based on measuring BMD by Dual-energy X-ray absorptiometry (DXA) (a T-score $\leq$ - 2.5 means the existence of osteoporosis).

In 2001, a group of experts defined osteoporosis as "a skeletal disorder characterized by low bone strength which increases the risk of fractures" (NIH, 2001). According to these experts, bone strength is influenced by three major factors which are the total bone mass, the geometric distribution of the mass, and the material properties (NIH, 2001). BMD measurements by DXA reflect some of the components of bone strength, including bone mass. BMD, which is influenced by several factors such as genetic factors, ethnicity, gender, nutrition and mechanical factors (such as body weight and physical activity), is one of the best determinants of fracture risk (Bonjour et al. 2009; Compston, 2002; El Hage, 2009; Eisman et al. 1999; Pouresmaeili et al., 2018). BMD values of Lebanese people are generally lower than US and European values (Maalouf et al., 2000; El Hage et al., 2011). This may be due to the deficiency in vitamin D levels and low calcium consumption that is commonly found in this population (El Hage et al., 2009; Chakhtoura et al., 2018; Salamoun et al., 2005; Alwan et al., 2018). Moreover, the majority of Lebanese children and youth are inactive and do not follow the physical activity guideline recommendations (Abi Nader et al., 2019; Fazah et al., 2010).

However, in clinical practice, it is very common to notice fractures in subjects with normal BMD or low BMD values but above the threshold for densitometric osteoporosis (Roux et al., 2013; Briot et al., 2013; Kanis, 1994). Poor bone geometry and deteriorated bone quality are the reason of these fractures (Bouxsein, 2005). Subjects with same BMD can present different levels of bending and compression mechanical resistance depending on their bone dimensions and geometry (Bouxsein, 2005). In addition, subjects with normal BMD but

deteriorated microarchitecture (bad material properties) may be prone to fractures (Dalle Carbonare and Giannini, 2004). In addition to BMD, other densitometric variables also predict osteoporotic fracture such as Beck's geometric indices and femoral neck bone resistance indices established by Karlamangla (Bousson et al., 2015; Beck et al., 1990; Karlamangla et al., 2004; Ayoub et al., 2014). In order to reduce the risk of fractures, it is important to increase peak bone mass (normally established around the age of 25) and to reduce the risk factors for osteoporosis (smoking, sedentary lifestyle, absence of physical activity, alcoholism, weight loss, intake of certain drugs) throughout life (Bonjour et al., 2009; El Hage, 2013). Increasing physical activity levels through any period over lifespan could help to decrease the risk of bone loss and osteoporotic fractures (Carter and Hinton, 2014). There are types of physical activity that are superior to others in affecting bone health. It has been shown that individuals who participated in high impact sport (for example: volleyball and gymnastics) had significantly higher BMD compared to those who participated in low-impact sports (such as cycling and swimming). Furthermore, there is compelling data that shows that a consistent physical activity practice, especially weight bearing and impact activities, helps to prevent bone loss that is associated with aging. Previous reports have shown that exercise before puberty may confer residual benefits in BMD in adulthood (Eser et al., 2009; Bass et al., 1998).

Soccer is considered a high impact weight-bearing sport (Kohrt et al., 2004). Practicing soccer during adolescence and young adulthood has a positive osteogenic effect on bone health parameters. However, longitudinal studies that aim to investigate the effects of football practice on bone health parameters in middle-aged men are rare. Moreover, the best frequency of training to stimulate osteogenic adaptation needs to be defined in this age group.

The first objective of this PhD thesis was to explore the relationships between several physical performance variables and bone parameters in a group of middle-aged men.

The second objective was to compare composite indices of femoral neck strength ((compression strength index (CSI), bending strength index (BSI) and impact strength index (ISI)) in inactive middle-aged men and aged matched former football players.

Finally, the third objective was to compare the effects of two recreational football protocols (RF30: 2x30min vs RF60: 2x60min for 1 year) on bone health and physical performance parameters in a group of healthy middle-aged men.

This thesis is based on three hypotheses. First maximal oxygen consumption and lower body maximal strength are positively correlated to BMD in middle-aged men.

Second, long term former football practice is associated with higher composite indices of femoral neck strength in healthy middle-aged men.
Third, both recreational football protocols (2x30min and 2x60min per week) improve bone health and physical performance variables in healthy middle-aged men.

FIRST PART: LITERATURE REVIEW

1. Osteoporosis

1.1 Definition of osteoporosis

According to the world health organization in 1994, "Osteoporosis is a worldwide disease characterized by reduction of bone mass and alteration of bone architecture resulting in increased bone fragility and increased fracture risk" (Kanis,1994). The definition of osteoporosis is thus based on the quantity reduction of bone mass and the quality deterioration of bone tissue. Osteoporosis increases the risk of bone fracture that mainly occurs with minor shock like falling from a vertical position (Akkawi and Zmerly, 2018).

In 2001, this definition was simplified to become as "a skeletal disorder characterized by compromised bone strength leading to an increased risk of fracture" (NIH, 2001).

In most cases, patients do not know if they are vulnerable to bone fractures since their deterioration happens quietly, gradually and without any signs or symptoms until the fracture occurs (Van Oostwaard, 2018). Therefore, it is very essential to have an early diagnosis for osteoporosis. This can be done by performing a dual energy X-ray absorptiometry (DXA) examination (Kuo and Chen, 2017).

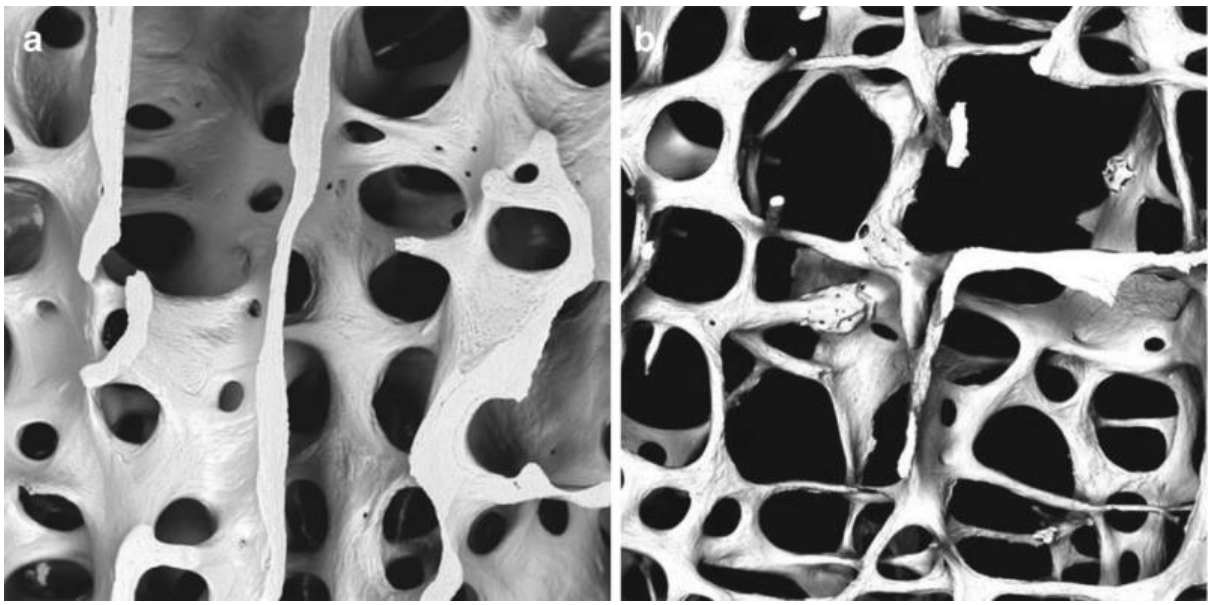

Figure 1: Microscopic view of normal (a) and osteoporotic bone (b) (van Oostwaard, 2018).

1.1.1 Diagnostics of osteoporosis: T-score and Z-score

The world health organisation has proposed a quantitative definition of osteoporosis based on the measurements of bone mineral density (BMD) by DXA. The values of BMD are compared to reference data for each site of measurement thus resulting in two scores: The T and the Z-scores (Kanis, 1994). By knowing the value of the T-score of each site, osteoporosis could be diagnosed when the T-value is lower than -2.5 SD of the mean value of a population that is young and healthy (Cosman et al, 2014). Moreover, the WHO (1994) categorised the diagnostics of osteoporosis as follows:

Table 1: Osteoporosis' diagnostic criteria according to the World health organization.

Normal	T-score > -1
Osteopenia	T-score is between -1 and -2.5
Osteoporosis	T-score is strictly less than -2.5
Severe osteoporosis	T-score <-2.5 with the presence of one or more fractures

According to International Society for Clinical Densitometry (ISCD), the diagnostic standards of the WHO mentioned above should be applied only to postmenopausal women and to men over the age of 50 (Shuhart et al., 2019). On the other hand, children and adults that are under the age of 50 must use the Z-scores rather than the T-scores. A Z-score of -2.0 or lower is defined as "below the expected range for age," and a Z-score above -2.0 is "within the expected range for age" (Shuhart et al., 2019).

The T-score is defined as "the difference between a patient's BMD and that of a young normal population divided by the standard deviation of the young normal population" as follows (Cummings et al., 2002):

$$\text{T-score} = \frac{Patient\ BMD - Young\ normal\ mean\ BMD}{Standard\ deviation\ of\ young\ normal\ population}$$

In addition to the T-score, the Z-score is calculated similarly to the T-score but instead of using a young BMD as a reference, similar age, race, and sex of the patient must be used (Zhou et al., 2010).

1.1.2 Reference data

On most densitometers to this day, reference data for males were young males, and for females were young females; for example, T-scores in men are the result of the comparison with a normal young male population (Binkley et al., 2014). Since the average BMD of the normal young population is greater in males than in females, using the male reference database will produce a lower T-score compared to when female database is used. However, we know that the risk of bone fracture in men is similar to women at the same BMD, so using sex-specific database (for males) is inappropriate and affects the diagnosis of osteoporosis (Binkley et al., 2002). As a result, normal young female data was used for both sexes for the femoral neck T-score as recommended by the IOF (Kanis et al., 2011). The ISCD was previously endorsing this position. White females, aged between 20 and 29 years were the standard reference database (NHANES III database) to calculate the T-score in many studies (Watts et al., 2013).

1.2 Dual energy X-ray absorptiometry (DXA)

DXA scanners have been available since 1987. According to the WHO, DXA is considered as the gold standard to assess bone density (Garg and Kharb, 2013). It is the most commonly used method to determine BMD and therefore to diagnose osteoporosis. Before introducing DXA, many devices were mainly used for osteoporosis diagnostics (for example: Dual and single photon Absorptiometry) (Pisani et al., 2013). DXA has many advantages compared to its antecedents, including a decrease in radiation exposure, an energy source that is more stabilised, a faster pace and a more precise data acquisition. The investment in a DXA device is small compared to 3D imaging devices. In addition, DXA tests are mainly inexpensive. DXA measurements are validated in adults, adolescents and children (Weaver et al., 2016).

A DXA machine involves an examination table for the patient, a mobile part below the patient that produces X-ray (X-ray source) and a system above the examination table that detects the produced radiation. The X-ray source and the X-ray detector move together and are located precisely in an opposite way (figure 2)

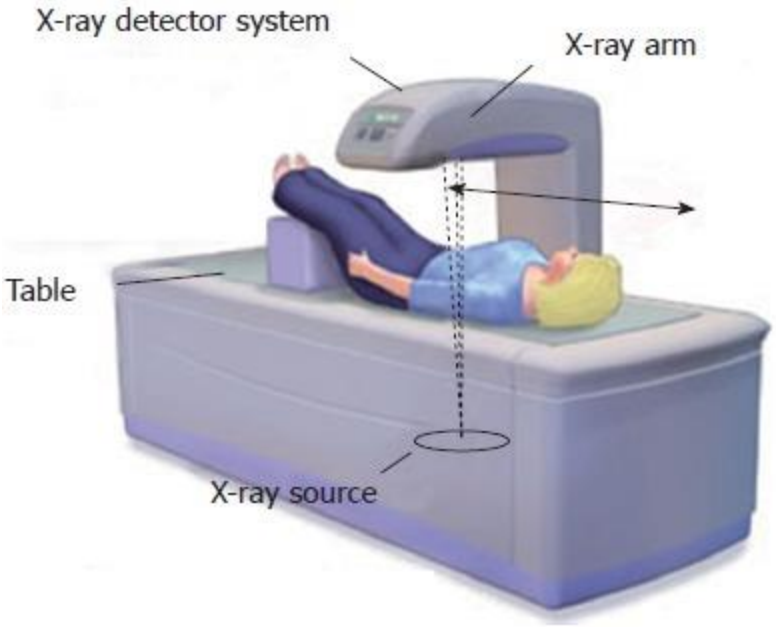

Figure 2: Schematic representation of DXA scan's X-rays source and detector system (Pisani et al., 2013).

Dual energy X-ray absorptiometry as its name shows, uses X-ray that is composed of dual photon energy (high and low; constant and pulsed energy) (Pisani et al., 2013). It is a technology that measures the attenuation of X-rays (of high-energy and low-energy) passing through tissues of varying densities. In addition to bone mineral content, DXA can calculate many bone variables (table 2).

1.2.1 Variables tested by DXA

Table 2 : Variables measured by DXA and their clinical importance.

Variables measured by DXA	Abbreviation	Clinical importance
Bone mineral content	BMC	It is correlated to the mechanical strength of bone (Ammann and Rizzoli, 2003).
Bone mineral density	BMD	BMD is the best determinant of the mechanical strength

		of bone (Ammann and Rizzoli, 2003).
Bone mineral apparent density	BMAD	BMAD is an estimate of volumetric BMD (Katzman et al., 1991). Its use in children and adolescents is recommended (Carter et al., 1992).
The ratio of bone mineral density to height	BMD/HEIGHT	It is used as an index of the volumetric BMD expressed in g/cm^3 (Reid et al., 1992).
The ratio of bone mineral density to body mass index	BMD/BMI	It is used to evaluate the increase in BMD relative to mass (De Laet et al., 2005).
The ratio of bone mineral content to height	BMC/HEIGHT	It is used in children and adolescents to get an idea about the level of bone mineralization for a given height (Leonard et al., 2004).
The ratio of bone mineral content to lean mass	BMC/LM	This ratio is used to find out if bone mineralization is adequate for lean mass (Schoenau et al., 2001).
Trabecular bone score	TBS	The TBS is an index which provides some information on the trabecular bone microarchitecture (Bousson et al., 2015).

Table 3: Geometric indices of Beck (Beck et al, 1990) and their clinical importance.

Geometric indices of Beck (Beck et al., 1990)	Abbreviation	Clinical importance
Cross-sectional area	CSA	It is an index of the bone's ability to withstand axial compression.
Cross-sectional moment of inertia	CSMI	It is an index of structural rigidity of the bone.
Cortical thickness	CT	It is a determinant of bone strength and the risk of osteoporotic fracture.
Section modulus	Z	It reflects the flexural strength.
Buckling Ratio	BR	It reflects cortical stability to deformation.

Table 4: Karlamangla's (2004) bone resistance indices and their clinical importance.

Karlamangla's bone resistance indices (2004)	Abbreviation	Calculation formulas	Clinical importance
Compression Strength Index	CSI	CSI = BMD x FNW/ Weight	It reflects the ability of the femoral neck to withstand axial compressive force.
Impact Strength Index	ISI	(BMD x FNW x HAL)/(Height x Weight)	It reflects the ability of the femoral neck to absorb energy upon impact.
Bending Strength Index	BSI	BSI = (BMD x FNW^2)/(HAL x Weight)	It reflects the ability of the femoral neck to resist bending force.

FNW: femoral neck width; HAL: hip axis length.

1.2.2 Limits of DXA

The nature of DXA scans is two-dimensional (2D), but the true nature of bone is three-dimensional (3D) (Carter et al., 1992; Katzman et al., 1991). Thus, bone size is not taken into account by DXA. The strength of a bone depends on its volume; a larger volume vertebra will have a higher resistance than a smaller volume vertebra (Beck, 2003). DXA measures the area of the projection of a volume (Beck, 2003). Therefore, it may underestimate the value of BMD depending on the area of the measured volume. To solve this problem, mathematical formulas have been used to estimate volumetric BMD taking into account areal BMD and bone dimensions (Katzman et al., 1991). These formulas calculate bone mineral apparent density (BMAD) which is an estimate of volumetric BMD.

Bone microarchitecture cannot be directly measured by DXA (Cortet and Bousson, 2016). The trabecular bone score (TBS) is correlated to some micro-architectural parameters, but it is not considered a direct measure of it.

DXA scans do not distinguish between cortical bone and trabecular bone.

DXA does not distinguish between visceral fat mass and subcutaneous fat mass. These two types of fat have different effects on bone structure. In addition, DXA does not distinguish between brown fat and white fat which also have different effects on bone health. (Ackerman et al., 2011).

Theoretically, the subject's abdominal diameter should not exceed 60 to 65 cm. Thus, TBS should not be measured in subjects with a BMI greater than 35 kg /m^2.

The type of the DXA machine, the operator, and the positioning of the patient can change the BMD value (HAS, June 2006).

DXA does not take into account the possible infiltration of water or fat into the muscle; thus in an obese subject, the measurements may be falsified (Horber et al., 1992).

The estimate of muscle mass is not suitable for obese subjects who, in addition to having a large body fat, have an increased muscle mass. However, in proportion to their total body weight, their muscle mass (%) is actually low while in lean individuals, the muscle mass is proportionately higher.

The sample studied on which the reference measurements were made differ according to the brand of the device (the reference bases are used for the calculation of the T score) (HAS, June 2006).

DXA does not assess muscle functionality. Current devices are not suitable for patients who cannot move easily (resuscitation situation, etc).

In obese subjects, the measurements have technical limitations given the thickness of the soft tissue around the measurement areas (lumbar spine and hip), which can modify the precision of the measurements (Bolotin et al., 2001).

In old machines, the subject's weight is limited to 150 kg. These devices were not suitable for subjects with massive obesity (Barbe and Ritz, 2005). However, new DXA devices are more adapted to extreme obese subjects.

1.3 Physiopathology of osteoporosis

Osteoporosis could be classified into primary and secondary osteoporosis. There are two types of primary osteoporosis: type 1 and type 2 (Dobbs et al., 1999).

Type 1 osteoporosis is named postmenopausal osteoporosis since it is generally shown in females at an early age not long after menopause. Type 2 osteoporosis or senile osteoporosis is related to aging.

Secondary osteoporosis is related to factors like medical disorders or the use of some type medication (Dobbs et al., 1999).

1.3.1 Primary osteoporosis

Type 1 osteoporosis is found mostly in post-menopausal women because these women present low levels of oestrogens leading to the increase in bone resorption compared to bone formation thus accelerating bone loss (Gallagher and Tella, 2014). Also, type 1 osteoporosis can be found in men. Type 1 osteoporosis in males might be caused by genetic factors involving genes for IGF-I (Rosen et al., 1998) or estrogen metabolism (Van Pottelbergh et al., 2004). Also at this age, secondary osteoporosis might show.

Bone remodelling is a continuous self-regeneration process; it consists of removing old bones and replacing them with newer ones. Bone formation and resorption respectively by

osteoblasts and osteoclasts help to maintain a balance in bone mass and strength to resist deformity. With aging, the balance between the formation and the resorption of bone is shifted favouring greater bone resorption and a lesser bone formation. This results in a decrease in bone mass and strength that results in type 2 osteoporosis (Demontiero et al., 2012).

Bone deterioration related to ageing is accelerated by the presence of several factors (Pouresmaeili et al., 2018). These risk factors for osteoporosis can be divided into 2 categories: modifiable and non-modifiable factors shown in table 5 (Pouresmaeili et al., 2018).

Table 5: The major modifiable and non-modifiable risk factors of osteoporosis.

Major modifiable risk factors:	**Major non-modifiable risk factors:**
Inadequate nutritional absorption (vitamin D deficiency, low calcium intake)	History of falls (Prior fracture)
Absence of physical activity (immobilization)	Genetics
Low body mass index	Older age (increasing age)
Cigarette smoking	Gender (female sex and postmenopausal status)
Air pollution	Ethnicity
Alcohol abuse	Reproductive factors (family history of osteoporosis)
Stress	

Type 1 and 2 osteoporosis have to some extent different effect on bone loss. Type 1 appears to affect mostly trabecular bone, while type 2 affects both cortical and trabecular bone (Riggs and Melton, 1983). A decrease in trabecular bone mass is present in both sexes but to a higher rate in females. Before reaching 50 years, trabecular bone is reduced by 42% (Riggs et al., 2008). Therefore, type 1 osteoporosis affects trabecular bone more than cortical bone.

Middle-aged men who are affected by type 1 osteoporosis mainly show low BMD by DXA and vertebral fractures. On the other hand, cortical bone mass does not show any significant loss before midlife in both males and females. The loss is found in both sexes after the age of 50 (Riggs et al., 2008). Hence, cortical and trabecular bone loss are found in males and females affected by primary type 2 osteoporosis after the age of 50 causing fractures in numerous bone sites (vertebra, femur and radii). Men and women have different bone changes with aging. Khosla et al. (2006) showed that with aging, men's trabeculae became thinner. Meanwhile, a loss and an increase in spacing of the trabeculae were only found in females. Christiansen et al. (2011) showed that while aging, the loss of cortical bone is superior in women than in men. At peak bone mass, men present larger bones compared to women. Therefore, less periosteal bone is found in long bones in women compared to men while aging (Seeman, 2002).

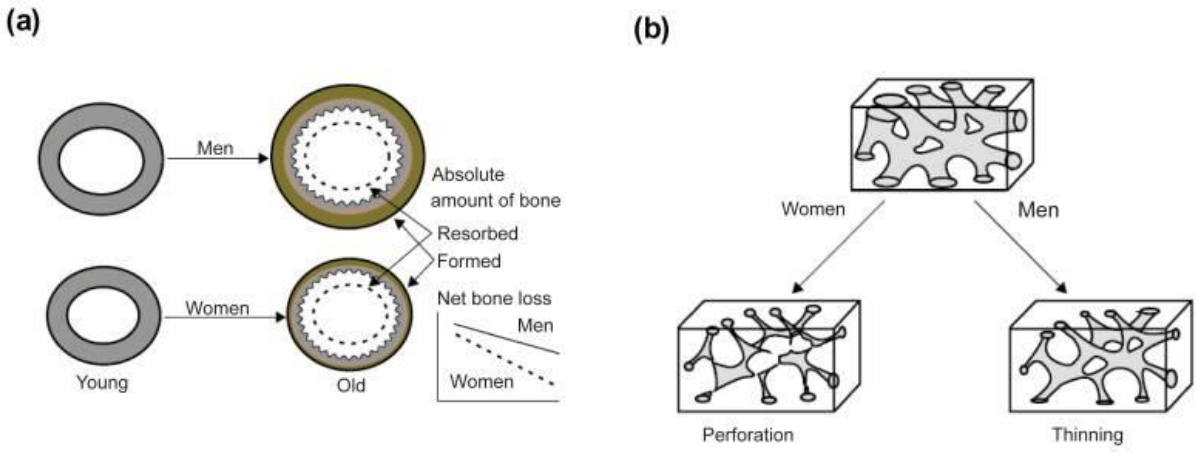

Figure 3: a: Cortical and b: trabecular bone loss changes in both sexes (Seeman, 2002).

1.3.2 Secondary osteoporosis

In both sexes, secondary osteoporosis is common in some (Ryan et al., 2011) but not in all studies (Romagnoli et al., 2011); it is more shared in men than women (Fitzpatrick, 2002). Hypogonadism, glucocorticoid usage, and immoderate alcohol consumption are mainly the causes of 85% of secondary osteoporosis occurrence in men (Ebeling, 1998; Gagnon et al., 2008). It is shown that these three aspects were found most in younger men with osteoporosis (Orwoll and Klein, 2001). Table (6) shows many examples of secondary osteoporosis.

Table 6: Examples of secondary osteoporosis.

Secondary osteoporosis	
Disorders	**Medications**
Hypogonadism	Oral glucocorticoids
Hypercalciuria	Androgen deprivation therapy
Hyperparathyroidism	Proton pump inhibitors
Hyperthyroidism	Selective serotonin reuptake inhibitors
Cushing's syndrome	Dopamine antagonists
Celiac disease	Thiazolidinediones
Inflammatory bowel disease	Enyzme-inducing anti-epileptics
Rheumatoid arthritis	Chronic opiate analgesics
Chronic obstructive pulmonary disease	Cancer chemotherapy (cyclophosphamide)
Alcohol abuse	
Chronic kidney disease	

1.3.2.1 Oral glucocorticoids

Glucocorticoid usage causes osteoporosis and increases the risk of bone fracture that can be showed directly after 3 months of the beginning of the therapy (van Staa et al., 2000). Minimal attention is given by health care professionals regarding the increase in bone fracture related to glucocorticoid therapy in men compared to women (Feldstein al., 2005).

1.3.2.2 Androgen deprivation therapy

Men going through androgen deprivation therapy (ADT) who had prostate cancer deserve attention from bone health professionals. ADT dramatically increases bone loss and bone fractures risk because of the low levels of some hormones (minimal serum levels of estradiol and testosterone) (Smith, 2007; Bienz and Saad, 2015). Only a minimal percentage of men are diagnosed and treated for osteoporosis that is caused by ADT.

1.3.2.3 Alcoholism

Optimal peak bone mass development in young people and the increase in bone loss in aged patients is adversely affected by long-term alcohol consumption. (Ulhøi et al., 2017; Ganry

et al., 2000; Kim et al., 2003; Kizilgul et al., 2016). Heavy and chronic abuse of alcohol is significantly correlated with a decrease in BMD and bone fracture risk. However, in some studies, significant correlation was found between moderate intake of alcohol and high BMD, but in others nothing was detected (Maurel et al., 2012; Jugdaohsingh et al., 2006 ; Wosje and Kalkwarf, 2007). In addition, the optimum quantity and frequency to produce beneficial effect of bone is not yet clear. Several studies had contradictory findings, depending on the selection of the subjects. Subjects' age, gender and, menopausal status affects the results of the studies. Maurel et al. (2012) found that a similar quantity of alcohol consumption negatively affected bone in premenopausal women but positively affected it in postmenopausal women. But to be sure, a high consumption of alcohol will lead to bone loss and increase the risk of bone fractures.

1.4 Epidemiology of Osteoporosis: Worldwide, Europe, middle east and Lebanon

1.4.1 Worldwide

Osteoporosis is a foremost rising worldwide health issue (Zaheer and LeBoff, 2000). Fragility osteoporosis fractures are some of the most well-known reasons for incapability, and they are considered significantly contributing to health care costs in numerous areas of the world. 200 million fractures worldwide are the result of osteoporosis (Cooper et al., 1992) which causes more than 9 million fractures each year (1 osteoporotic fracture every 3 seconds) (Johnel and Kanis, 2006). One over 3 women and one over 5 men above the age of 50 will encounter fractures related to osteoporosis in their lifetime. (Melton et al., 1998 ; Melton et al., 1992). Hip fractures are considered to be the most serious of these fractures because they are correlated to a high rate of morbidity and mortality (Zaheer and LeBoff, 2000). Half of the patients who had a hip fracture lose their capability to walk independently. Moreover, 33 % of men die in the first year after the presence of a hip fracture compared to 12 to 24 % of women (Chrischilles et al., 1991; Magaziner et al.,1997; Melton et al, 1997). Vertebral fractures are most of the times asymptomatic and found when searching for other health problems. They are associated with many other problems involving loss in height, restrictive lung disease, back pain, kyphosis and movement impairment. Patients with vertebral fracture have five times more risk for having a new vertebral fracture and 2 times more risk to have other fragility fractures (Zaheer and LeBoff, 2000). A decrease in 10% of vertebrae bone mass can multiply by 2 the risk of vertebral fractures. In addition, a decrease in 10% in hip

bone mass can increase hip fracture risk by 2.5 (Klotzbueche et al., 2000). A 310% and a 240% increase in hip fractures numbers is predicted to be present by the year 2050 in men and women respectively compared to the numbers of the year 1990 (Gullberg et al., 1997).

1.4.2 Europe

In 2010, an estimation of 27.6 million osteoporosis cases were present in Europe (Figure 4) (Hernlund et al., 2013).

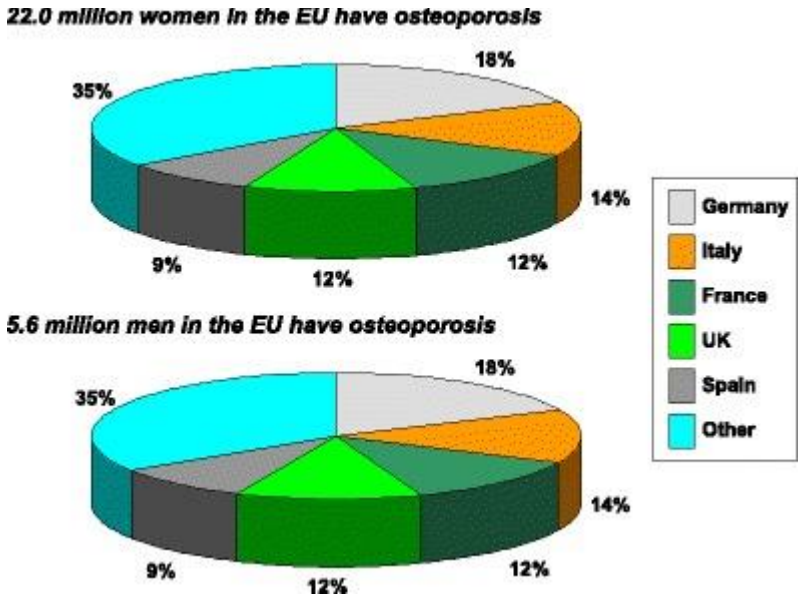

Figure 4: Distribution of osteoporosis cases in major European countries (2010) (Hernlund et al., 2013).

Approximately 22 million women and 5 million men with osteoporosis were distributed across 27 countries in Europe (EU27) in 2010. The number of women with osteoporosis was 4 times higher than that of men. The highest osteoporosis numbers with an approximation of 5 million osteoporotic cases of which 1 million were men and 4 million were females were found in Germany (Table 7). Collectively, 21 % of women and 6.6 % of men (>50 years) were the percentage of osteoporosis cases prevalent in all European populations (Hernlund et al., 2013).

Table 7 :The prevalence distribution of osteoporosis in 27 European contries.

Country	Men with osteoporosis	Women with osteoporosis	Men and women with osteoporosis	Prevalance in male population aged 50 or more (%)	Prevalance in female population aged 50 or more (%)	Prevalance in total population (%)
Austria	89 862	368 685	458 547	6.5	22.2	5.5
Belgium	120 695	476 875	597 570	6.6	22.4	5.6
Bulgaria	81 482	336 425	417 907	6.4	20.9	5.6
Cyprus	9 263	31 032	40 295	6.2	19.3	3.7
Czech Republic	103 114	425 944	529 058	6.0	20.4	5.0
Denmark	61 456	221 912	283 368	6.5	21.1	5.1
Estonia	11 642	65 789	77 431	6.2	22.2	5.8
Finland	61 054	243 399	304 453	6.4	21.5	5.7
France	691 112	2 784 198	3 475 310	6.7	22.5	5.5
Germany	1 006 652	4 017 260	5 023 912	6.6	22.6	6.1
Greece	135 202	507 505	642 707	6.9	22.3	5.7
Hungary	94 949	452 158	547 107	6.2	21.1	5.5
Ireland	37 127	129 309	166 436	6.2	20.0	3.7
Italy	749 237	3 042 794	3 792 031	6.9	23.4	6.3
Latvia	19 210	111 236	130 446	6.1	22.3	5.8
Lithuania	27 136	148 375	175 511	6.1	21.7	5.3
Luxembourg	4 541	17 422	21 963	6.1	21.0	4.3
Malta	4 190	16 074	20 264	5.9	19.8	4.9
Netherlands	175 244	643 258	818 502	6.3	20.8	4.9
Poland	338 756	1 509 772	1 848 528	5.8	20.1	4.8
Portugal	117 738	475 882	593 620	6.7	22.0	5.6
Romania	198 065	835 885	1 033 950	6.2	20.5	4.8
Slovakia	42 726	188 911	231 637	5.7	19.4	4.2
Slovenia	20 543	89 489	110 032	6.0	21.5	5.4
Spain	496 368	1 952 987	2 449 355	6.8	22.6	5.4
Sweden	113 722	409 373	523 095	6.9	22.4	5.6
UK	679 424	2 527 331	3 206 755	6.7	21.9	5.2
EU27	**5 490 510**	**22 029 280**	**27 519 790**	**6.6**	**22.1**	**5.5**

In addition, thousands of female deaths were directly correlated with vertebral and other fractures in the EU27 countries. Also, an approximate of 9,000 deaths were associated to hip fracture in men. Fewer deaths resulted from vertebral and other fractures (table 8) (Hernlund et al., 2013).

Table 8: Total numbers of osteoporosis related deaths in 27 European countries.

	Hip fractures		Vertebral fractures		Other fractures		All fractures	
Country	Women	Men	Women	Men	Women	Men	Women	Men
Austria	288	217	145	172	128	67	561	457
Belgium	259	233	137	173	106	71	502	477
Bulgaria	151	143	114	168	36	34	302	345
Cyprus	13	14	8	11	4	4	25	29
Czech Republic	268	233	159	221	90	63	517	518
Denmark	224	203	133	161	97	61	454	425
Estonia	37	27	23	27	12	7	72	62
Finland	103	106	55	89	41	31	199	226
France	1 103	994	527	729	547	333	2 178	2 056
Germany	2 503	1 782	1 439	1 526	1 042	484	4 984	3 793
Greece	310	256	160	192	133	77	604	525
Hungary	321	270	199	262	114	75	634	607
Ireland	56	47	31	36	24	15	111	98
Italy	1 507	1 271	784	875	628	411	2 919	2 557
Latvia	69	47	44	48	22	11	134	107
Lithuania	66	49	42	56	20	12	128	116
Luxembourg	8	6	5	5	3	1	16	12
Malta	9	6	6	5	3	2	17	13
Netherlands	219	212	126	159	90	65	435	436
Poland	586	497	377	564	191	128	1 154	1 189
Portugal	190	146	99	105	79	45	368	297
Romania	372	351	286	426	91	83	749	860
Slovakia	136	126	93	149	39	32	267	306
Slovenia	55	41	29	37	20	11	104	88
Spain	699	590	308	411	348	194	1 354	1 196
Sweden	321	268	170	192	140	79	631	540
UK	1 487	1 277	817	978	984	516	3 289	2 770
EU27	**11 358**	**9 413**	**6 313**	**7 779**	**5 034**	**2 911**	**22 706**	**20 103**

1.4.3 Middle east and Lebanon

The rate of mortality due to hip fracture is considered high in the middle-eastern populations compared to the western populations. In western populations, the rate of mortality after hip fracture varies from 25 to 30 % while in the middle east and north Africa, this number is higher by 2 to 3 times (Baddoura et al., 2011). The availability of DXA scanners in the middle east region is limited. For example, in Morocco, for 1 million inhabitants, there are only 0.6 DXA machines (International Osteoporosis Foundation, 2011). The fracture incidence rates among people (> 50 years) are the lowest in Morocco (43.7 / 100,000 and 52.1/ 100,000 in men and women respectively) (El Maghraoui et al., 2005). Kuwait showed the highest rates of fracture risk (200 and 295 per 100,000 in men and women respectively) (Azizieh, 2017). Low concentrations of Vitamin D were found in the middle east and regardless of the presence of sunshine in this region, the highest rates of rickets were registered (International Osteoporosis Foundation, 2011).

A study done by Sibai et al. (2011) used data taken from the Lebanese ministry of health which represented 50 % of the Lebanese population showed that the crude rates of incidence of hip fractures for people aged (>50 years) across the 2 years of 2006 and 2008 were as follows: 164-188 in women and 80-107 in men per 100,000 per year. The age-adjusted incidence rates of hip fractures were between 329 to 370 in women and 110 to 134 in men per year per 100,000. These incidence rates were lower than the rates found in the US and northern Europe and close to rates found in southern Europe. Also, the age-adjusted incidence rates of hip fractures in Lebanon were close to those found in Spain and France in women, and close to those in Portugal, in France, Mexico and Thailand for men (Sibai et al., 2011).

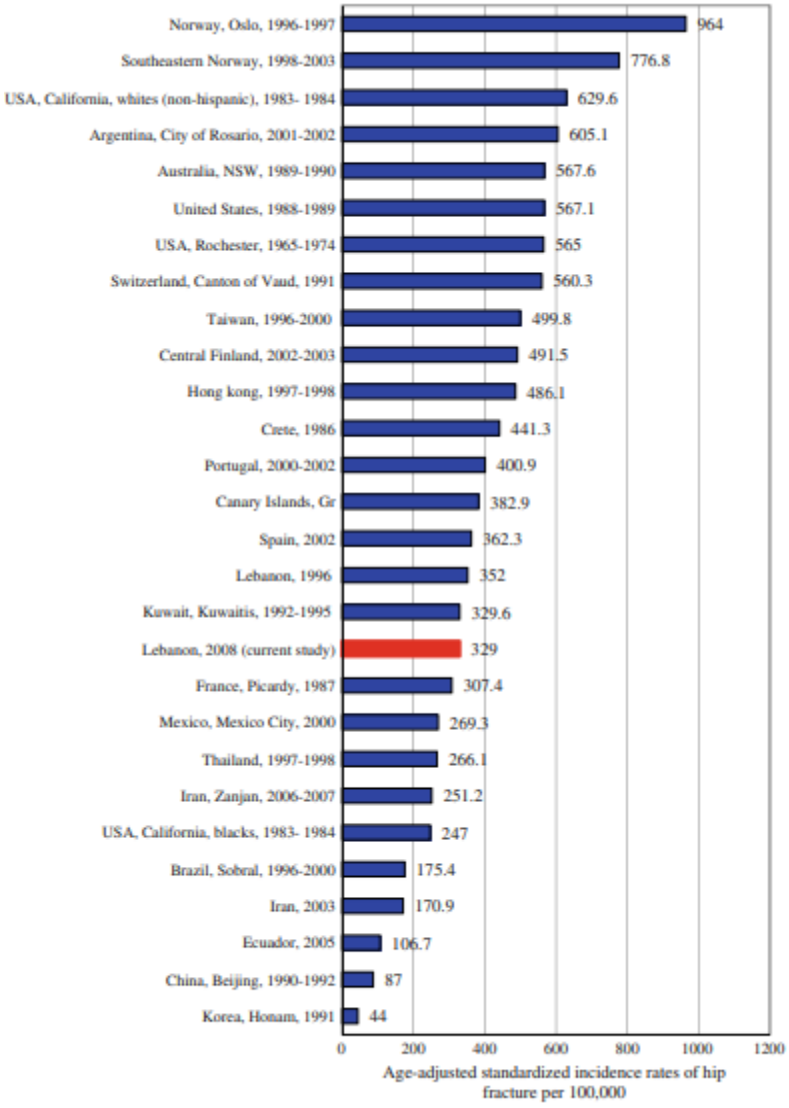

Figure 5: Representation of the age-adjusted indices rates in women in several countries in the world (Sibai et al. 2011).

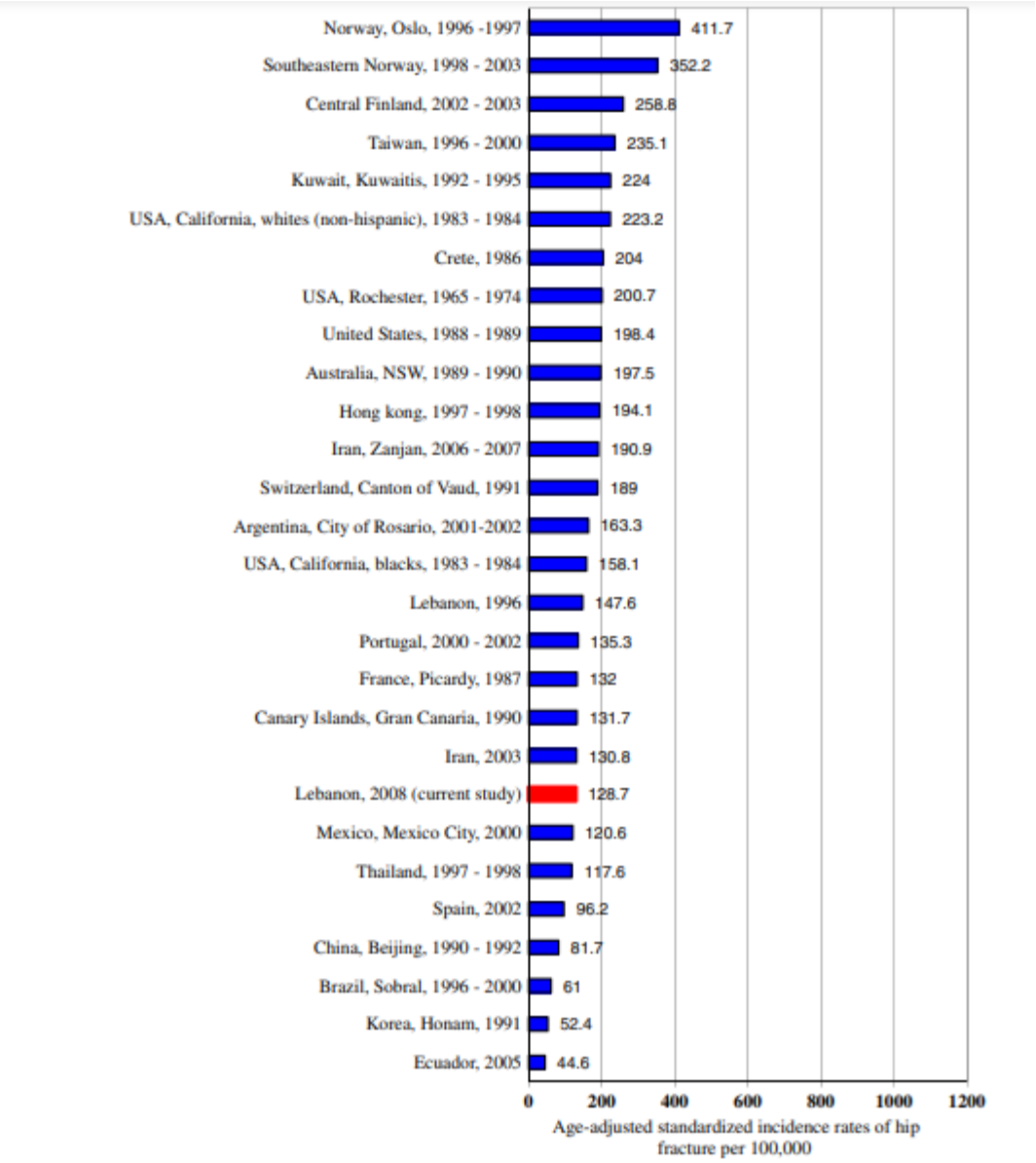

Figure 6: Representation of the age-adjusted indices rates in men in several countries in the world (Sibai et al. 2011).

Another study done by Baddoura et al. (2001) showed that in Lebanon, the annual incidence of osteoporotic fractures is estimated at 2.6%. It is higher for women (3.8%) than for men (1.4%). The incidence per site is 0.4% for the hip, 0.4% for the forearm, 0.3% for the spine and 1.5% for "other" sites. The incidence is higher in women for all sites. The lifetime risk of osteoporotic fractures is estimated at 9.3% for men and 16.7% for women (Baddoura et al., 2001). These estimates were also lower than those of northern European countries but higher than those of Asian countries, suggesting a West-East gradient of risk factors (Baddoura et

al., 2001). The prevalence of vertebral fractures in Lebanon is estimated at 19.9% for women and 12.0% for men (Baddoura et al., 2007).

1.4.4 Economic impact

The Ministry of Health (MOH) covers 50 %, the National Social Security Fund (NSSF) covers 25 %, the private insurances cover 12.5 % and the Co-ops, Army, Internal Security Forces cover 12.5% of the Lebanese medical care needs. According to the bulletin report from the WHO in 1999, direct hospital costs per person were estimated to be around 12000 $ in Australia to 8700 $ in Lebanon (Delmas and Fraser, 1999). This amount only represents the direct hospital charges. Nonetheless, it must be taken into consideration that the real cost of hip fractures could be 2 times higher than this amount due to additional care services. Consequently, a person's valued entire cost in Lebanon can reach 21750 $. Moreover, at the American University of Beirut's Medical Centre (a very well know care centre in Lebanon), the average cost of hip fracture surgical repair is around 12125 $. According to the Lebanese Osteoporosis Prevention Society, 10000$ is the cost of hip fracture treatments. An estimation of 7 million dollars per year is the cost for hip fractures spent by the health care providers mentioned in details above. Hip fracture expenses are estimated to increase and become close to 10 million dollars in 2021 and up to 18 million dollars in 2050.

2. Bone strength and fracture risk

From a mechanical viewpoint, structural failure of the bone leads to fractures. Fractures occur when the forces applied to the bone surpass its load-bearing capacity (Figure 7) (Bouxsein, 2005).

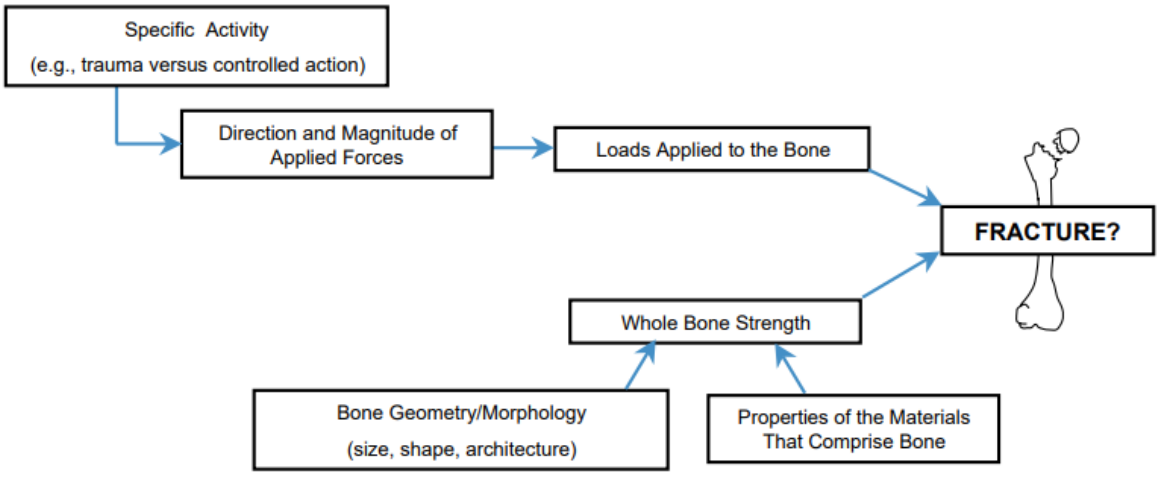

Figure 7: Causes of bone fractures.

Bone fracture is affected by the load that is applied to it. The load can vary depending on the direction and the magnitude of the applied force. For example, during a fall, the height, the direction of the fall (sideways, forward, backward), the type of the impact surface, the amount of soft tissue surrounding the bone and the ability of a person to react to the fall will affect the load applied on the bone and thus the fracture risk. (Bouxsein, 2008). In addition to these external factors, bone strength will affect the risk fracture. The ability of a bone to resist to applied loads is a function of three characteristics: the total mass, the geometric distribution of the mass, and the material properties (Figure 7) (Cole and van der Meulen, 2011).

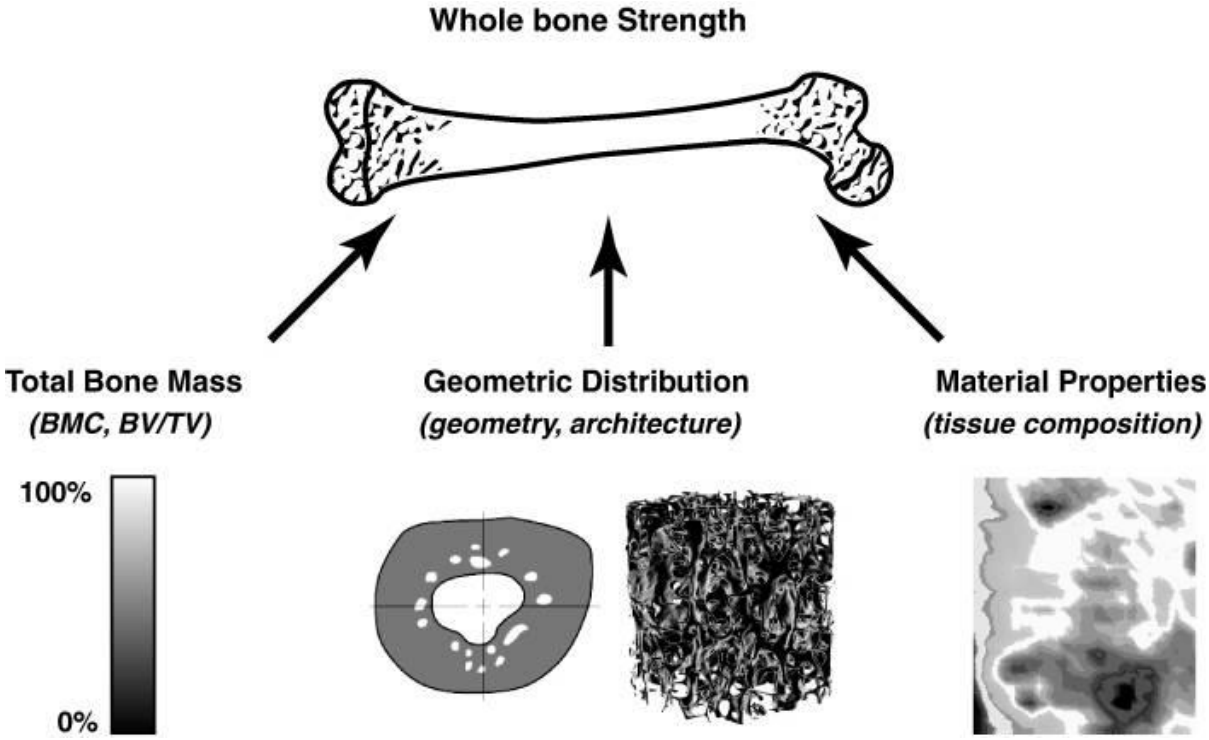

Figure 8: Characteristics of bones to resist to applied loads.

BMD measurements by DXA reflect some of the components of bone strength, including bone mass. Bone mineral density (BMD), measured by DXA, is an important determinant of bone stiffness at any age (Goulding et al., 2000). It is strongly correlated with bone strength and can define approximately 70% of its variability (Bouxsein, 2005). BMD measurements are moderately to strongly correlated with the strength of human cadaveric vertebrae, radii and femurs. BMD remains the best determinant of bone mechanical strength.

Bone geometry also affects bone strength. Figure 9 shows how different bones with the same BMD can present different levels of bending and compression mechanical resistance depending on their dimensions and geometry (Bouxsein, 2005).

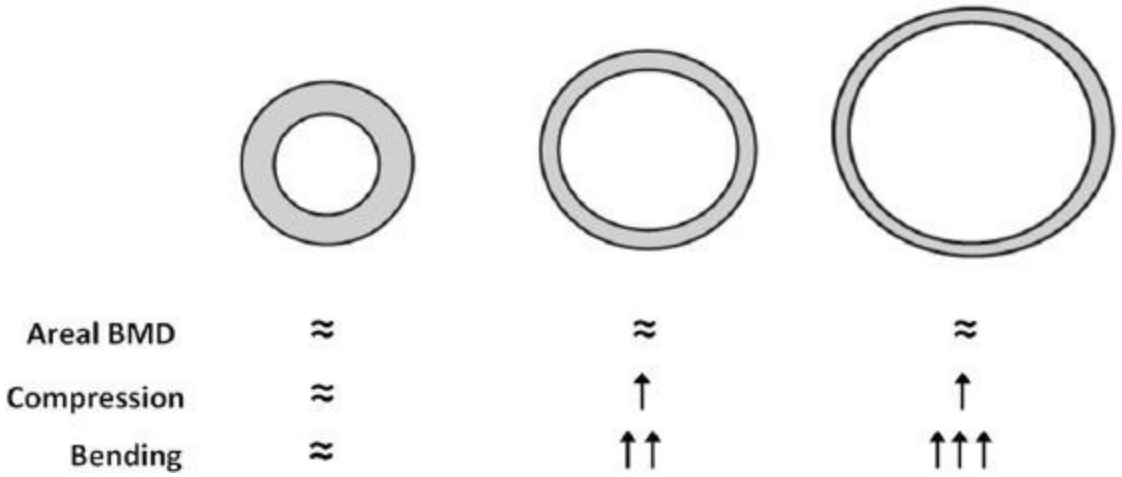

Figure 9: The effect of an increase in cortex diameter on bone compression and bending strength with no change in areal density (Bouxsein, 2005).

Moreover, bone microarchitecture influences bone strength as well (Dalle Carbonare and Giannini, 2004). The parameters of the bone microarchitecture such as the number of trabeculae, the thickness of the trabeculae, the orientation trabeculae (giving the anisotropy of the structure), their degree of connectivity, as well as the spacing between them contribute to the stiffness of the bones without a significant increase in bone mass (Bouxsein, 2005). Therefore, a decrease in one or more of these parameters will lead to a decrease in trabecular bone strength. This is shown in figure 10, which shows that increasing the number of horizontal trabeculae increases trabecular bone buckling strength without any significant change in bone mass.

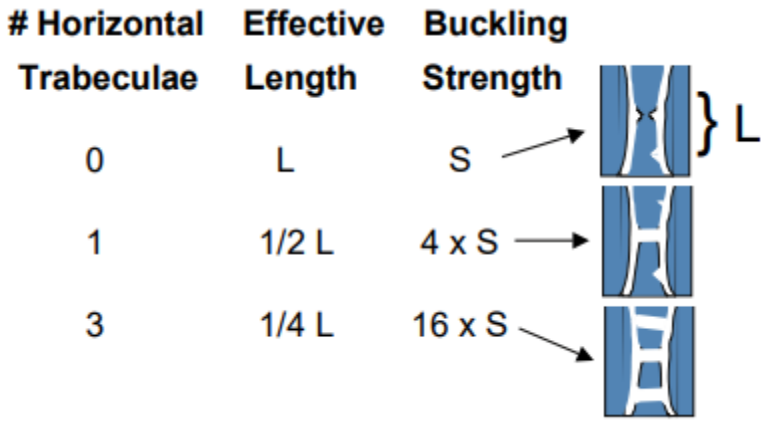

Figure 10: Effect of trabecular microarchitecture on buckling strength.

2.1 Peak bone mass

2.1.1 Definition of peak bone mass and prevention of osteoporosis

Peak bone mass (PBM) can be defined as "the amount of bony tissue present at the end of skeletal maturation" (Bonjour et al., 1994). After attaining PBM in the first 30 years of life, a 0.3 % and a 0.5 % of bone loss per year is shown in men and women respectively. During the first year of menopause, an increase of 2 % in bone loss is shown (due to deficiency in estrogen). This fast loss in bone mass continues for a period of 6 years (Dobbs et al., 1999). Because the bone loss that is related to aging is universal in both sexes, any factor that negatively affects reaching the maximum peak bone mass increases the chances of having fragility fractures related to osteoporosis later in life. Therefore, PBM is a strong predictor of osteoporosis later in life (Specker et al., 2010). This is why increasing PBM during growth is an important strategy to prevent future osteoporosis cases. To prevent the occurrence of osteoporosis early in life, peak bone mass must be the highest possible because the higher the bone mass at baseline is, the less significant the decrease of bone mass related to aging will be to reach osteoporosis. But if the PBM is low and bone mass at baseline is not very high, future decrease in bone mass related to aging will lead to high risk of fracture and osteoporosis earlier in life (figure 11). A 10 % increase in PBM would decrease the risk of fragility fracture by a half in postmenopausal women (Marshall et al. 1996) and will delay the appearance of osteoporosis by thirteen years (Hernandez et al., 2003). On the other hand, a reduction of 6.4 % in bone mass during childhood is related to an increase by 2 times higher in fracture risk during adulthood (Boreham and McKay, 2011).

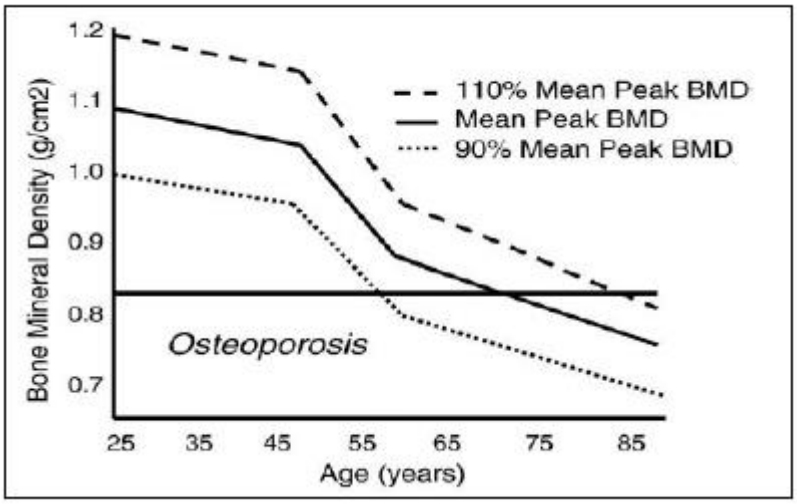

Figure 11: Influence of PBM on the onset of osteoporosis later in life (Rizzoli et al. 2010).

2.1.2 Age gender and peak bone mass

The development of bone mass begins in foetal life, continues throughout childhood and ends in the end of the third decade of life (Weaver et al., 2016). Age and sex affect bone growth evolution. Slow gain in bone mass is found in childhood. This gain significantly accelerates with puberty and then decelerates after it. (figure 12). The period of puberty (fast and strong bone growth) is very important and vital to reach PBM.

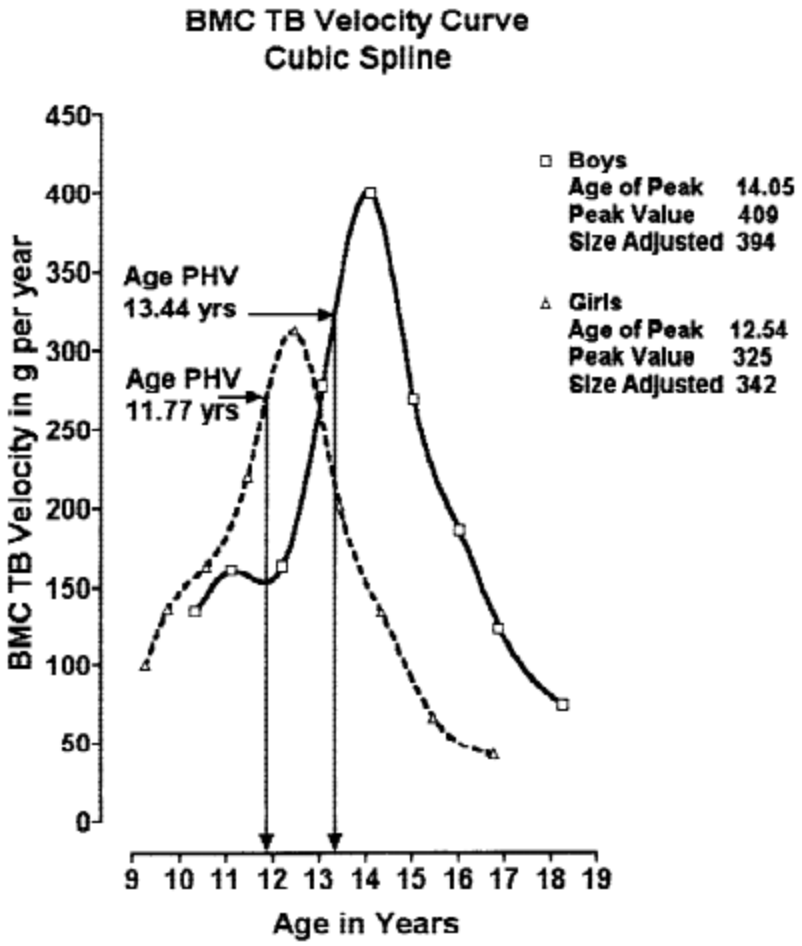

Figure 12: Bone mineral content gain in relation to age and sex (Bailey et al., 1999).

Difference in bone mass observed in adults in both sexes is first observed at puberty (Bonjour et al, 1994). Before puberty, both sexes do not differ in bone mass. Theintz et al. (1992) showed in their longitudinal study, a significantly noticeable increase in L2-L4 BMD and BMC and FN BMD from 11 to 14 years (3-year period) and an intense decrease after the age

of 16 in adolescent females. After menarche, gain in bone mass dropped rapidly and became not significant (2 years later). In contrast, an increase in BMD and BMC was significantly high for both L2-L4 and mid-femoral from the age of 13 to 17 (4-year period) in adolescent males then decreased but remained significant until the age of 20 (3 years) at the lumbar level and at the level of the femoral shaft but not at the level femoral neck (Theintz et al., 1992). Moreover, an increase in bone mass was only shown in men who were growing less than 1 cm per year and who reached pubertal age P5 (Weaver et al., 2016). A higher increase in bone mass development in males compared to females was shown during the pubertal phase leading to an important difference between men and women. This is not due to a higher maximal gain in bone bass but to a longer pubertal maturation period (Weaver et al., 2016).

2.3 Determinants of peak bone mass

Peak bone mass is influenced by several factors (figure 13) (genetics, hormonal factors, mechanical factors, and nutritional factors).

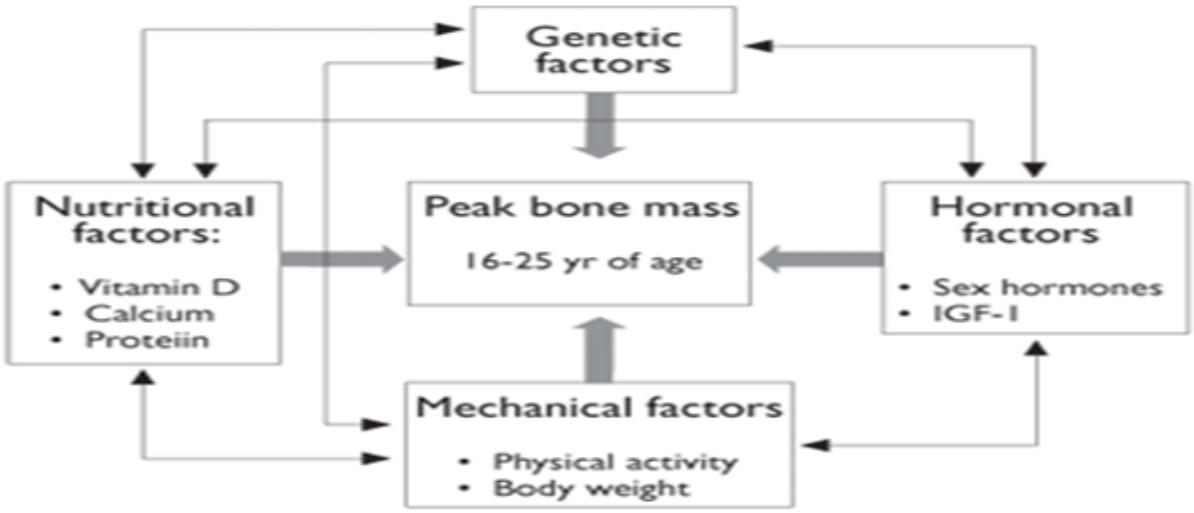

Figure 13: Determinant of peak bone mass (Bonjour et al. 2009).

2.3.1 Genetic factors

The role of genetic factors in the pathophysiology of osteoporosis has been confirmed by several authors (Bonjour et al. 2009; Eisman et al. 1999). A significant correlation between the BMD of mothers and daughters has been found before the start of pubertal maturation phase (Bonjour et al. 2009; Duren et al., 2007). 60 to 80 % of bone mass variability may be

influenced by genetic factors (Eisman, 1999). On the other hand, the other controlled factors such as the environmental factors are thought to account for 20 to 40 percent of BMD.

Lumbar spine BMD (rich in trabecular bone) in greatly influenced by genetic factors compared to femoral neck BMD (rich in cortical bone) that is more affected by mechanical factors.

2.3.2 Hormonal factors

Growth hormone (GH), IGF-1 and sex hormones play an essential role in the growth and the capability to achieve optimal PBM (Locatelli and Bianchi, 2014). Growth hormone insufficiency causes a decrease in bone mass in children and an increased risk of fracture in adults (Giustina et al., 2008).

In children, bone growth is primarily regulated by GH and IGF-1. IGF-1 mediates GH. A positive correlation between IGF-1 and BMD is observed in both sexes. A strong association is found between the decrease of the levels of these hormones and the increase of risk factures related to osteoporosis regardless of BMD (Garnero et al., 2000). In adolescents, sex hormones are thought to have the greatest influence on bone metabolism (Bass et al. 2007; Rizzoli et al. 2001). Sex steroids are responsible for the skeletal dimorphism that appears during and after adolescence (Compston, 2001). The role of estrogen is particularly important during the puberty phase (Riggs et al. 2002). Estrogen resistance and aromatase deficiency in men induce growth retardation and may delay attainment of maximum height despite the presence of normal testosterone levels (Bilezikian et al., 1998). Estrogen insufficiency is a critical element in the pathogenesis of osteoporosis in both sexes (Locatelli and Bianchi, 2014).

Testosterone explains the differences between the sexes in terms of bone geometry (longer growth and better periosteal apposition in boys compared to girls). In late adolescence, both BMC and areal BMD are superior in boys compared to girls (Riggs et al. 2002).

Androgens and estrogens positively affect bone mass in both sexes (Locatelli and Bianchi, 2014). Men's bones are larger in size, diameter and cortical thickness than those of women. This is a biomechanical advantage for men in whom the incidence of fractures is low compared to women (Compston, 2001)

2.3.3 Nutritional factors

2.3.3.1 Calcium intake

Several correlation studies in children and adolescents have been carried out between daily calcium consumption and bone mass (Rizzoli et al., 2010). Most of these studies done on different populations showed a significant correlation between daily calcium intake and bone mass (Rizzoli et al., 2010). The effect of calcium supplementation on height, BMC, and BMD at several bone sites has been investigated in several prospective studies (Rizzoli et al. 2010). The gains in BMC and BMD were greater in those who took calcium supplements compared to controls. Two meta-analyses confirmed the beneficial effect of calcium-rich products on bone mass during growth (Huncharek et al. 2008; Winzenberg et al. 2006).

2.3.3.2 Protein intake

Protein intake provides the human body with the amino acids necessary for the construction of the bone matrix (Rizzoli et al. 2010). Protein intake is an essential factor for bone growth since it influences the secretion of IGF-1 (Rizzoli et al., 2010). Proteins can therefore modulate the genetic potential of peak bone mass. Low protein intake can adversely affect bone mass by reducing the production of IGF-1. The beneficial effects of protein intake on BMC and BMD have been demonstrated in cross-sectional and longitudinal studies (Rizzoli et al. 2010).

2.3.3.3 Vitamin D

Vitamin D has positive effects on the skeleton. Physiologically, it stimulates the intestinal absorption of calcium. This vitamin has a fundamental role in phosphocalcic homeostasis and therefore in the process of bone growth. In the elderly, insufficient vitamin D increases the risk of osteopenia and osteoporosis. At the epidemiological level, the NHANES study showed the existence of a positive correlation between plasma vitamin D concentration and BMD in subjects whose values ranged from 22.5 to 94 nmol / L (Bischoff-Ferrari et al., 2004). A meta-analysis published in 2007 showed that vitamin D and calcium supplementation are important for the prevention of osteopenia and osteoporosis (Tang et al., 2007). On the other hand, several studies have shown that an increase in muscle weakness and an increase in the risk of falls are associated with a deficit in vitamin D (Bischoff-Ferrari, 2012; Janssen et al., 2002; Girgis et al., 2014).

2.3.4 Physical activity

Growing bones respond better to mechanical stress than adult bones. The practice of physical activities induces an increase in BMC and BMD in children and adolescents. This effect appears to be greater before and at the start of the puberty phase than after this phase (Santos et al., 2017). Exercising during childhood and adolescence is very important even after their termination (Santos et al., 2017). The timing of the initiation of the physical activity may be also important. A recent study showed that bone strength of adult individuals is affected by the age at which they started to walk (Ireland et al, 2017). This study also showed that a lower BMC (at the spine, hip and radius) was found in men that started to walk at a late age in their childhood compared to those men who started walking at an earlier age. Another systematic review showed that performing weight-bearing activities such as football, gymnastics and jumping during childhood positively affects bone strength while increasing bone mineral growth in pre and peri-pubertal children (MacKelvie et al. 2002). These results were also supported by a newer systematic review that studied the effect of weight bearing exercises and bone mineral gain in children and adolescents (Hind and Burrows 2007).

2.3.5 Body weight

Body weight and BMI are positive determinants of BMD of load-bearing bones in both sexes (Reid, 2010). The gain in body mass is associated with an increase in BMD values while its loss induces a decrease in its values (Shapses and Sukumar, 2012).

3. Bone adaptation to exercise

The main function of the skeleton is to support muscles to allow posture and movement in the space. Bone size, shape and rigidity are adapted to the habitual loads performed on it. Physical exercise leads to bone adaptation to a higher load compared to the habitual load. This procedure is regulated by cellular mechanotransduction (Goodman et al., 2015). During exercise, the new load of the exercise deforms the bone; this will lead to an alteration in the original conformation of the mechanosensors that are located throughout the cell such as integrins and stretch activated ion channels (Guilluy et al., 2014; Ross et al., 2013). A proper biochemical reaction is stimulated by this change through a flood of signals. Thus, bone formation and osteogenesis is present at bone sites that are deformed by the activity.

A signalling cascade is elicited by this change to produce a suitable biochemical response such as osteogenesis and bone accretion at the site of deformation (Goodman et al., 2015). Habitual load to bone principally comes from muscle contraction and gravity. In addition, physical exercise also puts the bone under a mechanical stress that is higher than the habitual load exerted by muscle contraction and the gravitational load (impact with the ground).

3.1 Gravitational loads

Gravitational loads are reactive loads that are the result of a contact between a weighted object (human body) and another object or substrate (ground) (Judex and Carlsonl, 2009). Gravitational loads are measured via ground reaction forces. These forces are the result of body mass (body weight) and the acceleration of the movement. During a high impact sport, such as gymnastics, a jump might have a ground reaction forces up to ten to twenty times of body weight. On the other hand, low impact activity such as walking has a ground reaction force almost similar to body weight (Judex and Carlsonl, 2009).

Gravitational load has a strong effect on bone health which is obvious by the noticeable decrease in bone mass in a weightless environment situation. For example, a decrease of 1 % in bone mass per week was observed in astronauts during their space flight. This loss is found to be the greatest in weight-bearing sites (Lang et al., 2004).

Similarly, bone loss was accelerated during the period of bed rest (Kohrt et al., 2009). Thus, these findings from space flight and bed rest studies showed that gravitational loading is necessary to preserve BMD at weight-bearing sites.

In real life situations, the majority of physical exercise stimulates both muscle contraction and gravitational loading forces on the skeleton. Therefore, it is very hard to isolate one form from the other. Cycling and swimming are non-weight bearing sports but involve muscle contraction forces on the bones. Many studies compared BMD of swimmers and cyclists to non-athlete controls and to weight-bearing athletes. They found that BMD values of the control group were significantly higher than those of swimmers and cyclists even after controlling for changes in lean mass or in body weight. Another study showed that cyclists had similar BMD compared to controls; however, weight lifters and runners had significantly higher BMD (Rector et al., 2008; Fehling et al., 1995; Nichols et al., 2003; Stewart and Hannan, 2000; Sabo et al., 1996; Warner et al., 2002; Heinonen et al., 1993).

Athletes who participated in sports that apply high impact loads on the skeleton such as gymnastics, volleyball and soccer have a higher BMD and stronger skeleton compared to controls (Orwoll et al., 2009). Moreover Creighton et al. (2001) found that athletes who participated in sports that apply the highest impact loads on the skeleton (such as basketball and volleyball) have the highest BMD and the highest markers of bone formation compared to athletes who participated in sports that apply moderate impact load on the skeleton (such as soccer and track) and to athletes that participated in non-bearing activities (such as swimming) and sedentary controls. Athletes of high and moderate impact load had higher hip BMD compared to athletes of non-impact sport and sedentary controls. The non-impact sport athletes were similar to the sedentary controls regarding BMD. Therefore, gravitational load exerted by impact sports may induce bone formation and enhance osteogenesis at weight-bearing skeleton sites.

3.2 Muscle Contraction Forces

It is recognised that bone adapts to the mechanical stress that is applied to it. Muscle contraction applies mechanical stress to the bone. This is found by corresponding changes in both muscle strength and bone size (Robling, 2009; Daly et al., 2004).

Daly et al. (2004) compared the BMD of the dominant arm of a tennis player to the non-dominant arm. They found that the dominant arm has higher muscle and bone mass compared to the other arm. This suggests that muscle contraction is associated to an increase in bone and muscle mass.

Rector et al. (2009) found that muscle mass of athletes who perform resistance training exercises for all major muscle groups (lower and upper body) was positively correlated to arm BMD, leg BMD, hip BMD and lumbar spine BMD. This proposes that there is a positive correlation between muscle mass and BMD of the arm (a non-weight bearing site) which highlights how muscle contraction without gravitational forces contributes to an increase in muscle mass that is correlated to an increase in BMD.

In addition, Carter (2012) found that a 12-month period of resistance training showed an improvement in the BMD of the arm. This change in arm BMD is positively related to the change in arm muscle mass. Thus, muscle contraction forces are beneficial for increasing bone mass and strength. Resistance training programs also influence bone health by increasing the levels of several anabolic hormones (GH, testosterone and IGF-1) which positively influence bone mass. Resistance training also decreases fat mass percentage and thus the level of inflammatory cytokines which are harmful for bone health.

3.3 Exercise interventions during childhood, adolescence, adulthood and older age

Meyer et al. (2013) showed in their longitudinal study that children who participated in school-based interventions presented a greater bone mineral content in their FN and TH and WB (8.1%, 7.7% and 6.2% respectively) compared to non-active controls. Moreover, BMC benefits remained after 3 years of the end of the intervention with a continuous BMC increase of 7 to 8% in FN and TH (Meyer et al., 2013). Among the choices of exercises, walking had a minimal positive effect on BMD because of its low impact nature and the minimal mechanical load that it exerts on the bones. This is supported by a recent systematic review by MacKelvie et al. (2002) that presented the effect of weight-bearing exercises on bone strength in children before and at puberty. On the other hand, strength training and high impact activities had additional effects on the prevention of bone loss (Gómez-Cabello et al., 2012). In addition to the effect of exercise on children, systematic reviews by Hamilton et al. (2010) and Bolam et al. (2015) showed that bone loading exercises have a beneficial effect on bone creation in middle-aged persons but in a smaller degree compared to children and adolescents (Hind and Burrows, 2007; Nogueira et al., 2014). According to Heinonen et al. (1996), practicing a high impact sport for a duration of 18 months performed by 35 to 45-year pre-menopausal women produced gradual increase in femoral neck BMD. Inactive controls

did not show any BMD changes. In addition, a meta-analysis showed that different exercise regimes lasting for a period of 24 weeks increase FN and lumbar spine BMD (Kelley et al., 2013). Studies investigating the effect of exercise on bone health in older people (>50 years) were less compared to children and adolescents. Weight bearing activities are effective in preserving bone mass in older individuals. Maddalozzo and Snow (2000) showed that high intensity training or moderate strength training for a 6-month period in men and women (50 years) increased spine BMD by 1.9 % in men, while women did not show any increase. In addition, a longer training duration of 12 months resulted in an increase in the geometry, BMD and BMC of the FN in elderly men aged between 65 to 80 years (Allison et al. 2013).

3.4 Principles of the American College of Sports Medicine

In order to achieve significant bone gains and induce osteogenic effect, the following principles should be taken into consideration while planning physical training programs (Kohrt et al., 2004):

Specificity: Only the bone sites associated to mechanical stresses undergo a positive bone adaptation.

Overload: An osteogenic response only takes place when the load exerted on the bone exceeds the habitual load that is imposed on it. A gradual increase in load or an overload is required to achieve this response.

Reversibility: If sports practice is interrupted or stopped, its positive effects on BMD do not persist. The volume and intensity of practice that maintains BMD remains to be determined.

Start-up capital: In general, the higher the baseline BMD of a subject is, the lower the benefits associated with physical training will be low. The lower a subject's baseline BMD is, the higher the benefits associated with physical training will be high.

Trainability: The maximum achievable BMD is affected by genetic factors and varies widely among individuals. This "ceiling" value determines the potential progress of each individual.

3.5 Principles of Burr, Robling and Turner

Burr et al. (2002) talked about 3 general rules that are related to the osteogenic adaptation to physical training:

Dynamic stresses generate a positive bone response unlike static stresses.

The relationship between the duration of the application of mechanical stresses and the osteogenic response is not linear. An excessive and prolonged duration of exercise can in some cases decrease the osteogenic response. Recovery between exercises (a few minutes) or between 2 training sessions (4 to 8 hours) is very important to optimize bone responses.

The bone response is superior after exercising with high biomechanical stress of a short duration than after exercising with low impact stress with high duration. Bone tissue quickly gets used to the type and intensity of exercise. Variation is very important to ensure not hitting a plateau. In practice, in order to avoid a stagnation of the bone response, it is necessary to change the type and intensity of exercise and increase the level of mechanical stress in the workouts performed.

4. Soccer and bone

4.1 Effects of soccer training on different bone parameters in males aged between 8 to 16 years

As mentioned in the previous chapters, PBM is considered as an important predictor of osteoporotic fractures later in the lifespan. Several studies showed that exercise interventions in children and adults are beneficial for bone growth and help to reach a higher PBM (Lívia Santos et al 2017). Many studies investigated the effect of soccer training on bone mass and showed that soccer training is beneficial for improving many bone parameters in children and adolescent males. Table 9 summarizes several longitudinal studies related to long soccer practice and its effect on bone health.

Table 9: Summary of longitudinal studies regarding the effects of soccer on bone in boys aged between 8 to 16 years.

Authors and year	Population	Methods	Results	Conclusion
Zouch et. al. (2014)	76 boys (10 to 13 years) were divided into: -48 soccer players 22 prepubescent players (F1) 26 entered puberty players (F2) -28 control subjects divided as: 13 Prepubescent control boys (C1) 15 entered puberty control boys (C2)	-Soccer players played for at least 3 years in a local club + completed 2-5 hours of training +1 competition game/week during the school year (1year study) + physical education at school. - BMC was measured by DPX in many sites at: T0 and T1	At T1: Higher BMC at WB and weight bearing sites were found in both F1 and F2 compared to C1 and C2	1 year period of soccer in young male showed that the combination of physical exercise and sexual impregnation stimulates more intensely bone formation at puberty compared to physical activity alone or sexual impregnation alone.

Seabra et al. (2016)	17 boys (8 to 12 years) participated in this study and were randomly assigned into: Football group (FG; n=9) Control group (CG; n=8)	Duration of the intervention: 6-month football program 4 times/week 60-90 min sessions. DXA scan measurements: Body composition, bone mass indicators included whole-body and lumbar spine bone mineral density (BMD) and bone mineral content (BMC)	After the training intervention (6 months): Compared to CG, FG had a greater increase in lumbar spine BMD.	A football intervention of 6-months showed to be beneficial in increasing lumbar spine BMD in overweight children.
Zouch et al. (2008)	52 children, (10 to 13 years) participated in this study and were distributed as follows: Group (F1): 21 trained (football) for 4 h + 1 competition game/week Group (F2): 18 trained (football) 2 h + 1 competition game/week Group Control (C): 13 control participated only school activities	Bone parameters in several bone sites were measured by DEXA and ELISA. Timing of testing: T0: in the middle of a sports period T1: after 6 months T3: beginning time of the new season	-BMC of many sites significantly increased by: 10 % increase in TH 10.5% lumbar spine 10.5% in legs in soccer players -F1 (high volume) had the greater improvement compared to F2 and C - a decrease of 4.6 % in Cranial BMC was found in soccer players after soccer cessation during. (T3)	a 1-year period of soccer training in children aged 10 to 13 years showed a higher increase in BMC at many sites compared to aged matched controls especially after a rest period.

Vicente-Rodriguez et al. (2004)	17 soccer players and 11 control matched boys for aged and are physically active participated in this study (at T0 they were Tanner 1–2)	Duration of intervention: 3 years BMC and aBMD were measured by DXA.	After the 3-year period, soccer players compared to control showed: -higher BMC in the legs and -higher BMD in all bone-loaded regions -higher femoral neck and intertrochanteric BMC.	A long duration of soccer training (3 years) beginning at a pre-pubertal age showed a greater gain in bone mass compared to aged matched physically active controls.
Zouch et al. (2015)	40 boys (Tanner II and III) joined this study and were assigned into: 23 soccer players (F) 17 controls (C)	F trained for 2 to 5 h + 1 competition game/week Duration of the intervention: 3 years Tested variables: DXA was used to measure BMD and BMC at different sites pre and post intervention	After 3 years: Soccer players had: higher BMD higher BMC at all weight-bearing-sites compared to controls. -no significant difference in between groups for BMD and BMC of the head and arms.	Soccer training for a 3-year duration in pubertal boys showed a significant gain in BMD and BMC in weight bearing sites.
Varley et al. (2017)	99 male elite footballers (16 years) adolescent participated in this study	-Duration of the training: 12 weeks of increased training volume -Tested variable: pQCT was used for Tibia scan -Timing of testing:	After 12 month of increased volume: 4 % increase in Trabecular density 14% increase in cortical density	An increase in football volume showed an increase in bone strength. This may be improved by the combination of physical training and sexual impregnation found in adolescents showing the important role of performing physical exercise

		T0: before the increase in soccer volume T1: 12-week after T0	14 % increase in cortical cross-sectional area 66% increase in total cross-sectional area 14 % increase in cortical thickness and strength strain index were found.	at early age for improving bone strength
Seabra et al. (2012)	151 young males joined this study and were assigned into: -117 soccer players (SG) (aged: 13.8 ±1.5 years) (3 up to 5 soccer training/week for at least 3 years) 34 control subjects (CG) (aged 13.3 ± 1.3)	Tested parameters: <u>Bone parameters: (DXA)</u> -BMD and BMC of the WB, L1-L4, and lower limbs were measured <u>Physical parameters:</u> -YY-IE2 test Knee extensors and flexors peak torque (PTE and PTF respectively) was measured for the lower limbs (90°/s) of the dominant and non-dominant lower limbs	- Compared to CG, SG had higher WB and legs BMD. - Significant changes were not shown for BMC. -Higher level of performance was found in the SG compared to CG for YY-IE2 test. SG exhibited higher PTE and PTF compared to CG.	Soccer practice has a positive effect on the muscle-skeletal structures in young males.

4.2 Effects of soccer training on several bone parameters in males aged between 20 and 54 years

Being physically inactive can lead to bone loss and could increase the risk of osteoporotic fractures. Increasing activity levels during any period throughout the lifespan will help to decrease the risk of bone loss thus decreasing the risk of osteoporotic fractures (Carter and Hinton, 2014). Several studies investigated the effects of soccer on bone health (table 10). Krustrup et al. (2009) showed that a 12-week period of recreational football in men aged 20-43 years improved bone leg mass, whereas another study conducted by Krustrup et al. (2013) showed that a 6-month period of soccer training in men aged between 31 and 54 years did not show any increase in bone mass but reduced blood pressure and improved aerobic fitness. Moreover, Andersen et al. (2014) showed that regular football training also did not increase bone mass but did help to maintain bone mass in middle aged men with T2DM. Summary of several studies are shown in table 2.

Table 10: Summary of longitudinal studies regarding the effects of soccer on bone in men aged between 20 and 54 years.

Authors and year	Population	Methods	Results	Conclusion
Krustrup et al. (2013)	33 (aged 31–54 years) mild to moderate hypertension untrained men participated in this study They were randomly distributed to: STG: Soccer training group	-STG subjects: participated in 1h of soccer training: 2x/week for 6 months -Subjects in DAG were instructed by a cardiologist to perform regular physical activity	There were no significant changes in: fat mass and lean body mass in the whole body and bone mineralization. -Noticeable reductions were observed in blood pressure.	A 6 month period of soccer training effectively reduced blood pressure but did not show any effect on body composition and bone mass in mild to moderate hypertension untrained men.

	n = 22 DAG: Doctor advice group n=11	-Timing of testing: before and after 3 and 6 months of the intervention. DXA: body composition, BMD and BMC were measured Blood pressure was tested		
Krustrup et al. (2009)	36 healthy untrained Danish men (20–43 years) joined this study and were randomly divided into 3 groups: -SO: soccer group; n=13 -RU: running group; n=12 -CO control group; n=11	Training: -2 or 3 times per week of recreational soccer for a duration of 1 h for 12 weeks Tests: -DXA scan were perfumed to identify body composition and bone mass Blood samples, Heart rate at rest and blood pressure were determined.	After 12-week of soccer training: a decrease in blood pressure, resting heart rate and fat percentage was noted. Compared to RU, SO had: -higher lean body mass -higher leg bone mass -lower LDL cholesterol	A 12-week program of recreational soccer training has a beneficial effect on bone leg mass in men.
Randers et al. (2010)	-17 healthy untrained males joined this study (20–43 years) and were divided into: FG: football group; n=10	-Duration of the intervention: 64-week Subjects of the FG trained an average of twice/week	after a 16-month period: In FG: 3.5 % increase in leg bone mass	Recreational football is beneficial for improving bone mass and density in healthy untrained males.

	CG: control group; n=7	for 3 months and an average of 1x/week for additional 13 months - Subjects of the control group did not perform any training -Whole body, regional fat, muscle and bone mass were determined by DXA scans	2 % increase in leg bone density were found compared to baseline After 3 months no difference in bone mass and bone density were found compared to baseline	
Helge et al. (2014)	32 homeless men joined this study and were assigned into: -Football group (FG): n=22 Age: 36.4 ± 10.0 Control group (C): n=10 Age: 42.7 ± 8.5	Participants of the FG trained for 12 weeks. Tests: DXA scanning was performed pre and post the 12 weeks of the intervention period	-In FG, T aBMD increased by 1.0% -WB aBMD remained the same -WB Z-score in FG tended to increase but in C, no significant changes were observed. -Trunk bone mineral density increased by 1.0%. No increase was found in C	Street football seems to have a beneficial effect on musculoskeletal health in homeless men.
Andersen et al . (2014)	21 middle-aged men (49.8±1.7 years) with type 2 diabetes mellitus (T2DM) participated in this study. -They were assigned into: FG: football training group $n = 12$ CG: inactive control group n= 9	Duration of the intervention: 24-week -Participant of FG: performed 60 min of training 2x/week CG:	-In FG: leg bone mass did not change -but in CG, after 24 weeks leg lean mass decreased by 3.5%	Regular football training maintains bone mass in middle-aged men with T2DM.

		Told to continue their sedentary lifestyle. After 0, 12, and 24 weeks, bone mass was determined by DXA scanning	and leg bone mass decreased by 1.6%	

4.3 Effects of soccer practice on bone parameters in male aged 60 years and above

While aging, bone loss is a universal phenomenal in both sexes. Physical activity may help to maintain or increase bone mass in elderly males. Many studies investigated the influence of soccer on bone health in elderly men. Helge et al. (2014) showed that a 4-month period of soccer training had a beneficial effect on bone formation and an additional benefit was observed after 12 months. In addition to healthy elderly men, soccer training in men with prostate cancer undertaking therapy showed an increase and a preservation of BMD at many bone sites. These studies are represented in table 11.

Table 11: Summary of longitudinal studies regarding the effects of soccer on bone parameters in elderly male (aged 60+ years).

Authors and year	Population	Methods	Results	Conclusion
Helge et al. (2014)	26 healthy sedentary men (68.2 ± 3.2 years) participated in this study -They were randomly assigned into 3 groups: -F: Football group; *n* = 9 -R: Resistance training group; *n* = 9 -C: non active Control group ; *n* = 8	Duration of the intervention: 12 months Duration of the training: 45–60 min training for 2 to 3 times per week. Tests: prior, at 4 and 12 months PF BMD and WB BMD were measured by DXA.	-In F: there were an increase in: 1.8% and 5.4 % in PF BMD after 4 and 12 months respectively WB-BMD did not change - BMD and bone turnover markers did not change in C and R.	An osteogenic effect was found in elderly men who participated in recreational football for a duration of 4 months and an additional benefit was observed after 12 months.
Uth et al. (2014)	Men having prostate cancer undertaking androgen deprivation therapy ADT participated in this study and were randomly assigned into: -FTG: Football training group *n* = 29; 67±7 years -C: Control group *n* = 28; 66 ± 5 years	Duration of the study 12-week 2 to 3x/week for 45–60 min. Tests: DXA scan: total body BMC leg BMC WB aBMD were determined	After a 12-week period: FTG had a statistically significant difference in total body BMC and leg BMC.	A 12-week duration of football training helps to maintain bone mass and induces an increase in the markers of bone formation in elderly men with PCa undergoing ADT.

Uth et al. (2016)	57 men receiving Androgen deprivation therapy (ADT)>6 months joined the study and were divided into: -FTG: football training group n = 29; 67.1±7.1 years -CON: care control group n=28; 66.5±4.9 years	Duration of the study: 32 weeks FTG practiced in 2–3 training/week x 45 to 60 min DXA: DXA was performed at many sites -Physical functioning tests: Vertical jump Repeated chair rise, Postural balance Stair climbing were evaluated.	After 32 weeks: Right and left total hip and right and left (0.024 g/cm2) femoral shaft BMD were significantly higher in FTG compared to CON Compared to CON, FTG had significantly higher Vertical jump height and higher performance in climbing the stair	Football training in men with prostate cancer, receiving Androgen deprivation therapy improves bone mineral density in important sites after a period of 8 months.
Uth et al. (2018)	22 men having prostate cancer accomplished ADT who participated in a previous 32 weeks of recreational football Uth et al. (2016) participated in this study.	FTG participants kept playing football without any supervision for approximately 2x/week for 4.5 years	At 5 years: right femoral neck BMD was improved in football group by 2.8%, right femoral neck BMD decreased in CON by 2.0%.	A 5-year period of recreational football in elderly men with PCa managed on ADT shows a preservation of BMD at the femoral neck.

	They were assigned to 2 groups: -Self-organized football group FTG (n=11) -Control group CON: n=11 Mean age: 71.3 ± 3.8 years.	whole-body (DXA) scan was performed for all participants.	No other significant between-group differences were observed.	
Skoradal et al. (2018)	50 men and women with prediabetes (age; 61 ± 9 years) were randomly assigned into: -FTG: football training group n = 27, 14 women) -CON: control group (n = 23, 11 women).	Duration of the training in FTG: 16-week 2x/week x 30-60 min Tests: DXA scan plasma bone turnover markers	-FTG: greater leg BMD greater leg BMC grater femur neck BMD greater femur shaft BMD compared to CON No changes were found in WB BMC and BMD in the 2 groups after the end of the training	A 16-week of football is beneficial to bone health in middle-aged and elderly prediabetes women and men.

4.4 Effects of soccer on bone parameters in females aged between 30 and 61 years

Several studies showed the effects of soccer training on bone parameters in female. In many studies (shown in table 4), long practice of soccer from 14-weeks to 1 year has a beneficial effect on bone parameters in healthy, mildly hypertensive, prediabetes women. Summary of these studies are shown in table 12.

Table 12: Summary of longitudinal studies investigating the effect of soccer practice on bone in female aged between 30 and 61 years.

Authors and year	Population	Methods	Results	Conclusion
Helge et al. (2010)	65 healthy untrained Danish premenopausal women (36.5 ±7.7 years) participated in this study. They were randomly assigned into 2 training groups: F: football; n=25 R: running; n=25 Control group n=15	-Duration of the intervention: 14 weeks Participants trained: 1 h twice a week Tests: -Measurements of the vBMD were performed using pQCT -aBMD in the total usingy DXA -Jumping and dynamic muscle strength were tested	-In F: Total vBMD in left tibia increased by 2.6±2.3% Total vBMD in the right tibia increased by 2.1±1.8% -In R: total vBMD in left tibia increased by 0.7±1.3% Total vBMDin the right tibia increased by 1.1±1.5% No significant changes in C. trabecular vBMD had same results. In F: a 3±6% increase in peak jump power. Increase in	A 14-week period of recreational football is beneficial in improving bone strength and decreasing fracture risk in premenopausal women.

			Hamstring strength. no significant changes in R and C	
Ferry et al. (2013)	26 girl swimmers (15.9 ± 2 years) 32 girl soccer players (16.2 ± 0.7 years) 15 non-active age-matched participated in this study	Tests: pre and post (8 month) The geometric indices of proximal femur strength were quantified using HSA BMC and BMD were measured at several sites using the DXA	After 8 months of training: BMD in soccer players increased but not in swimmers. Many geometric indices of femoral neck strength increased in soccer players but not is swimmers.	1 season of soccer training in adolescent girls creates a significant improvement in bone geometry.
Mohr et al. (2015)	83 premenopausal mildly hypertensive women (45 ± 6 years) joined this study They were randomized into: -SOC: Soccer group; n = 21 -HS: High-intensity intermittent swimming group; n = 21 -MS: Moderate-intensity swimming group; n = 21 -C: Control group; n = 20	The training groups completed: 15-week (3 sessions/week) DXA scans were performed pre- and post-intervention.	In SOC: -leg BMC increased ($P < 0.05$) by 3.1 ± 4.5 %, with a greater increase in SOC compared to C. -Femoral shaft and trochanter BMD increased by 1.7 ± 1.9 and 2.4 ± 2.9 % respectively, in SOC, with a stronger increase in SOC than in MS and C -Total body and total leg BMD remain the same in the groups.	A 15-week period of swimming training does not improve bone formation markers whereas soccer training shows an increase in leg bone mass and bone turnover markers in sedentary middle-aged women.
Barene et al. (2014)	Female hospital employees (n = 118) participated in this study They were randomly assigned either to:	Duration of training per week: Soccer and Zumba groups trained 2x/week for 1 h	-Soccer and Zumba decreased fat mass and fat percentage of WB compared to the control group ($P < 0.01$).	1 to 2 sessions per week of soccer or Zumba training during workplace may have beneficial effects on health among female hospital employees. In addition, soccer training is beneficial

	- Soccer group (n = 41) aged: 44.1 ±8.7 years - Zumba group (n = 38) aged: 45.9 ±9.6 years -Control group (n = 39). Aged: 47.4 ±9.5 years Their mean age 45.8± 9.3	each session outside working hours Duration of the intervention: 40 weeks. Tests: before and after the intervention period. VO_2 max blood pressure DXA (body composition and bone) blood samples	-In comparison to the control group: Soccer group, but not the Zumba group showed a significant difference in lower limb BMD and BMC. An only increase in Soccer group in plasma osteocalcin and decreased plasma leptin.	for improving lower limb BMD and BMC in these women.
Skoradal et al. (2018)	50 men and women with prediabetes (age; 61 ± 9 years) were randomly assigned into: -a football training group (FTG; n = 27, 14 women) -a control group (CON; n = 23, 11 women).	Duration of the training in FTG: FTG performed football training twice weekly 30-60-minute sessions in 16 weeks. Both FTG and CON received professional dietary advice. Pre- and post-intervention. Tests: DXA scan plasma bone turnover markers	-FTG: greater leg BMD greater leg BMC grater femur neck BMD greater femur shaft BMD compared to CON no changes were found in Whole-body BMC and BMD in both groups after the intervention.	A 16-week period of football training induces a strong osteogenic stimulus and improves bone health in 55- to 70-year-old prediabetes women and men.
Krustrup et al. (2017)	Physically inactive middle-aged women participated in this study and were assigned into: Soccer training group (SOC): n=19 (45±6 years)	Duration of the intervention: 1-year SOC trained for 3x1h/week	Over 1-year: SOC showed: -higher decrease in arterial pressure compared to CON -higher decrease in body fat mass	A period of 1-year of soccer training results in many health benefits (cardiovascular, metabolic, and musculoskeletal benefits) in untrained

	Control group (CON): n=12 (45±4 years)		-higher WB BMD and BMC -lower plasma triglycerides -higher HDL cholesterol -better Yo-Yo intermittent - endurance level 1 -better 20-m sprint performance compared to CON no significant change for lean body mass were observed in both groups .	pre-menopausal women with mild hypertension.

4.5 Cross sectional studies related to female soccer players and inactive controls aged between 15 and 27 years

Several cross-sectional studies were conducted on female soccer players and inactive aged matched controls. BMD in many sites, especially in weight bearing sites, was significantly higher in soccer players compared to controls (table 13). Soccer training seems to have a beneficial site specific effect on bone mass in young females.

Table 13: Summary of cross sectional studies related to young female soccer and aged matched inactive controls aged between 15 to 27 years.

Authors and year	Population	Methods	Results	Conclusion
Alfredson et al. (1996)	16 second-division female soccer players (20.9±2.2 years) (trained for about 6 h/week) 13 inactive females (25.0±2.4 years): not participated in any kind of physical activity.	DXA Scan: aBMD was measured in many different sites.	10.7 % increase in lumbar spine BMD -13.7 % increase in femoral neck BMD -19.6% increase in Ward's triangle BMD -8.2 % increase in femur BMD 8% increase in humerus BMD -12.6 % increase in distal femur BMD -12 % increase in proximal tibia BMD were shown in soccer players	Soccer training seems to have a beneficial site specific effect on bone mass in young females.
Ferry et al. (2011)	This study included: -26 female swimmers (SWIM) aged: 15.9 ± 2 years -32 female soccer players (SOC) aged: 16.2 ± 0.7 years - 15 female age-matched controls	DXA scan: Body composition BMD hip structure analysis (HSA) program were also used	SOC: -significantly higher BMDs compared to swimmers - CSMI, Z, BR were higher in all bone sites compared to swimmers -Swimmers had (HSA) Z-scores below the normal values of the controls	Soccer has a beneficial effect on bone geometry and strength compared to a non-impact sport like swimming.

El Hage (2013)	18 adult female football players (22.2±3.1 years) 18 adult sedentary females (20.7±3.7 years) joined this study.	-Many bone parameters were measured by DXA -femoral neck was analysed by the hip structure analysis (HSA) program	Football players: Higher: TH BMD FN BMD, FN CSA, FN Z, FN CT, IT CSA, IT Z, IT CT, FS CSA and FS Z compared to controls	Adult female football players greater bone geometry strength at the hip compared to controls.
Söderman et al. (2000)	51 female soccer players (age 16.3 ± 0. 3 years) 41 nonactive females (age 16.2 ±1.3 years) Participated in this cross sectional study	Soccer player had been playing soccer for 8.1 ± 2.1 years -DXA scan: sAreal BMD on many sites were assessed -Isokinetic dynamometer: Isokinetic muscle strength of the quadriceps and hamstrings muscles were tested.	Compared with the non-actives: Soccer players had significantly higher BMD of the: -total body (2.7%) -lumbar spine (6.1%) - the dominant and nondominant hip (all sites). The largest differences were found in the greater trochanter on both sides (dominant, 16.5%, nondominant, 14.8%). The soccer players had significantly higher	Soccer practice in adolescent females is associated with high bone mass in weight-bearing sites.

			concentric and eccentric peak torque of the thigh muscles.	

4.6 Cross-sectional studies related to male soccer players and inactive controls aged between 18 and 30 years

Several cross sectional studies were conducted on male soccer players and inactive aged matched controls. BMD in many sites, especially in weight bearing sites, was significantly higher in soccer players compared to controls (table 14). Soccer training seems to have a beneficial site specific effect on BMD in males aged between 18 to 30 years. In addition to BMD, geometric indices of hip bone strength are found to be higher in soccer players compared to controls (El Hage et al., 2014).

Table 14: Summary of cross sectional studies related to young male soccer and aged matched inactive controls aged between 18 and 30 years.

Authors and year	Population	Methods	Results	Conclusion
Calbet et al. (2001)	33 recreational male football players (23 ± 4 yr) played football for the last 12 year 19 non-active subjects (24 ± 3 years)	Total and regional body composition and many bone parameters at were evaluated by DXA	Compared to control subjects, football players showed: Higher total lean mass (8%) Higher whole-body 13% lower percentage body fat 13% higher L2–L4 BMC	Football training in pre-pubertal ages in boys has a beneficial effect on bone formation at weight-bearing sites.

	from the same population participated in this study.		10% higher, L2-L4 BMD higher femoral neck BMC and BMD 6–17% greater BMC in the whole leg	
Fredericson et al. (2007)	15 elite male soccer 15 elite male long-distance runners 15 sedentary male controls Participated in this study their mean age: 20–30 years.	BMD (g/cm^2) (DXA) -lumbar spine (L1–L4) -right hip, right leg -total body were assessed Scan of the right calcaneus was performed with a peripheral instantaneous x-ray imaging bone densitometer.	After adjustment for age, weight and percentage body fat: -Soccer players had significantly higher: whole body spine, right hip right leg calcaneal BMD than controls right hip and spine BMD than runners -Runners had higher calcaneal BMD than controls.	Soccer practice is associated with high BMD at many sites of the skeleton whereas running is associated with high BMD at the calcaneus) but not at the spine.
El Hage et al. (2014)	23 male professional soccer players 21 male sedentary subjects (ages range between 18 and 30 years) Participated in this study.	Hip BMD was measured by DXA Geometric indices were also measured by DXA (HSA)	Soccer players had higher: CSA CSMI Z CT of the three regions (NN, IT and FS) compared to controls. After adjustment for age, body weight, height or physical activity duration:	Soccer training is associated with greater geometric indices of hip bone strength in young males.

			CSA, CSMI, Z and CT remained higher in soccer players compared to controls.	
Wittich, et al. (2013)	46 male participated in this study. They were assigned into 2 groups: 24 professional male football players (22.6 ± 2.5 years) (1st division) 22 controls (age- and BMI-matched) (<3 hours of recreational sport activities/week)	Total skeletal BMC, BMD, bone size, and body composition were measured DXA	-Football players had grater: Total skeleton BMC (18.0%) Bone size of the legs and pelvis compared with controls - no difference at the level of the arms or head. -head BMC and BMD were equal for both groups.	Male professional football players have a significantly stronger bone at weight-bearing sites compared to matched untrained males.
Morel et al. (2001)	704 men with no history of chronic disease participated in this study. They (30 years; mean age) were engaged in 14 sports activities: team sports, running, combat sports, bodybuilding, swimming, cycling, and several mixed activities	BMD were measured at several sites by DXA	-Rowers and swimmers had low TB BMD and low leg BMD. -Participants in rugby, soccer, other team sports and fighting sports had a high TB BMD and high leg BMD -For head BMD, there was no statistical difference among the different groups. -soccer player and runners had a higher leg ratio; bodybuilders, fighters, climbers and swimmers had a higher arm ratio; rugby players had a higher spine ratio.	BMD and ratio differences between several sports seem to be site-specific and are created by the non-habitual load exerted by the sport on specific sites of the skeleton by muscle contractions and gravitational loads.

Wittich et al. (2001)	42 professional football players (23.2 ± 3.5 years) 33 age and BMI (matched control subjects participated in this study	fat, lean, and bone mass was determined by dual X-ray absorptiometry (DXA).	Significantly higher Fat mass was present in the controls Significantly higher lean mass and bone mass were present in football players compared to controls.	Professional young male football players have higher lean mass and lower fat mass compared to inactive matched controls.
Sutton et al. (2009)	64 male professional soccer players (26.2 ± 4.0 years) 24 male matched for age and BMI control group (26.8 ± 5.2 years) Participated in this study	BMD and the relative amounts of lean and fat mass were measured by DXA	-For all body composition compartments: soccer players recorded better values compared to the control group. -BMD was greater in the professional soccer group compared to the control group.	Soccer players have lower body fat % and higher lean mass and bone mass compared to inactive controls.

4.7 Cross sectional studies related to male soccer players and inactive controls aged between 10 to 17 years

Several cross-sectional studies were conducted on male soccer players and inactive aged matched controls. BMD in many sites, especially in weight bearing sites, was significantly higher in soccer players compared to controls (table 15). Soccer training seems to have a beneficial site specific effect on BMD in males aged between 10 to 17 years.

Table 15: Summary of cross sectional studies related to male soccer players and aged matched inactive controls aged between 10 to 15 years.

Authors and year	Population	Methods	Results	Conclusion
McCulloch et al. (1992) (cross male and female)	68 males and females participated in this study and were divided into: 23 soccer players (11 male) 20 swimmers (10 male) 25 controls (12 male) ages 13 to 17 years	Densitometric measurement at the right os calcis was the site selected was performed A standard SPA protocol was used to determine the BMC of many sites.	-the lowest os calcis density in both sexes was found in swimmers -whereas the soccer players had the highest bone density at this weight-bearing site -No differences in the distal radius BMC were observed among the group or between sexes.	Soccer training is associated with an increase in BMC values at weight-bearing sites in young males.
Seabra et al. (2017)	70 adolescent boys (aged 12-15 years) participated in this study. They were assigned into: -futsal players (FG) n=28 -swimmers (SG) n=20 - non-athletic adolescents n=22 used as control subjects (CG)	aBMD aBMC were measured by DEXA.	Futsal players had significantly higher aBMD and aBMC at the lumbar spine, -pelvis and lower limbs compared to SG and CG. .	Futsal, as a weight-bearing and a high-impact sport has a beneficial effect on bone formation in males during childhood and adolescence.
Nebigh et al. (2009)	152 young boys (age: 13.3+/-0.9 years) participated in this study and divided into 2 groups: Group1: 91 soccer players Group 2: 61 Controls (non-athletic)	BMD and BMC were measured by DXA	Soccer players had significantly higher: BMD and BMC for WB, lumbar spine, femoral neck, pelvis and lower limbs compared to controls	Soccer training is associated with an increased bone mass in boys which is mainly marked at early and late puberty.
Seabra et al. (2011)	151 young males participated in this study They were divided into:	Tested parameters: Bone parameters: (DXA)	-SG had higher WB BMD and dominant and non-	Soccer practice has a positive effect on the musculoskeletal structures in young males.

	-117 soccer players (SG) (aged: 13.8 ±1.5 years) 34 control subjects (CG) (aged 13.3 ± 1.3)	-BMD and BMC of the whole-body, lumbar spine, dominant/non-dominant lower limb Physical parameters: -YY-IE2 test -Peak torque of knee extensors (PTE) and flexors (PTF) was measured during isokinetic knee joint movement (90°/s) of the dominant and non-dominant lower limbs	dominant lower limb BMD compared to CG. -No significant differences were found for BMC. -SG performed better in the YY-IE2 test exhibited higher PTE and PTF muscles compared to CG	
Vicente-Rodriguez et al. (2003)	104 healthy white boys (9.3 ± 0.2 years, Tanner stages I–II) participated in this study and they were divided into: 53 footballers (playing football for at least 1 year and at least 3x/week) 51 controls. (physical education courses:2 weekly sessions of 45 min each)	Bone variables were measured by DXA.	The football players showed enhanced trochanteric BMC. Football players showed higher femoral and lumbar spine BMD compared to controls.	Football training helps to increase many physical parameters, improves body composition and bone mass in weight-bearing sites in pre-pubertal boys.

4.8 Cross sectional studies related to female soccer players and inactive controls aged between 10 to 18 years

Several cross sectional studies were investigated on female soccer players and inactive aged matched controls. BMD in many sites, especially in weight bearing sites, was significantly higher in female soccer players compared to controls (table 16). Soccer training seems to have a beneficial site specific effect on BMD in females aged between 10-18 years.

Table 16: Summary of cross sectional studies related to female soccer players and aged matched inactive controls aged between 10 to 18 years.

Authors and year	Population	Methods	Results	Conclusion
Bellew and Gehrig (2006)	64 female athletes (10 to 17 years) participated in this study and were divided into: Swimmers (n = 29) Soccer players (n = 16) weight lifters (n = 19)	aBMD of the dominant limb calcaneus was measured by DXA.	Soccer players showed significantly higher BMD compared to swimmers and weightlifters. -No difference between weight-lifters and swimmers. -BMD of soccer players were significantly higher than adult norms compared to normative data from the WHO. - BMD of swimmers were significantly lower than adult females.	Soccer participation in adolescent females has a beneficial effect on BMD.
Pettersson at al. (2000)	50 female participated in this study and were divided into:	BMD (g/cm(2)), BMC (g), and bone area (cm(2)) of many sites were measured	Both skipping and soccer participants had significantly higher BMD ($P < 0.05$) at	Soccer training and rope skipping have a beneficial effect on bone mass at weight-bearing sites.

	10 rope-skipping competitors (age 17.8 ± 0.8 years) 15 soccer players (age 17.4 ± 0.8 years) 25 controls (age 17.6 ± 0.8 years)	using dual-energy X-ray absorptiometry (DXA).	most loaded sites compared with the control group.	
Düppe et al. (1996)	62 active junior (13-17 years 34 senior players (18-28 years 25 former players (34-84 years) 90 matched controls for the active players 57 matched controls for the formers players. Participated in this study	Body composition and total body, lumbar spine and proximal femur BMD were measured by DXA.	Football players had significantly higher BMD than controls at all sites measured. The proximal femur sites (10.5-11.1%) had the greater differences in BMD compared to lumbar spine (4.8%) or the total body (3.5%). Greater differences were found for senior than for juniors.	Soccer training had a site-specific beneficial effect on bone formation in female players.

4.9 Cross-sectional studies related to male soccer players and inactive controls aged between 50 years and older

Former football practice is associated with higher BMD at different sites compared to aged matched controls (table 17). In addition, composite indices of femoral neck strength were found to be higher in former football players compared to their aged matched controls (Finianos et al., 2020).

Table 17: Summary of cross-sectional studies related to male soccer players and aged matched inactive controls aged between 50 years and older.

Authors and year	Population	Methods	Results	Conclusion
Finianos et al. (2020)	35 men (mean age 50 years) participated in this study and were divided into: 20 inactive men 15 former football players	DXA scan were done to determine body composition and several bone variables. CSI, ISI, BSI were calculated	Significantly Higher CSI, BSI and ISI Were found in former players compared to controls after adjusting for physical activity level.	Former football players had higher composite indices of femoral neck strength compared to inactive middle-aged men.
Hagman et al. (2018)	140 healthy men joined this study and were assigned into: FTE: 35 all-time football players (65 to 80 years) FTY: 35 elite football players (18 to 30 years) UE: 35 age matched elderly UY: 35 aged match young	DXA: Proximal femur and a WB BMD were determined.	Compared to UE, FTE had: -significantly higher FN, wards, shaft, and total proximal femur BMD -compared to UY, FTY had BMD in all femoral regions and total proximal femur in both legs compared to UY	Lifelong trained male football players (65-80 years) showed greater BMD at many sites compared to aged matched untrained men. In addition, they showed higher BMD in femoral trochanter and leg BMD than untrained young despite the 46 years of age difference.

			-same WB BMD and high leg BMD were shown in FTE compared to UY. A higher WB BMD and leg BMD values were shown in FTY compared to UY.	
Uzunca et al. (2005)	24 former football players (average age 52 years) 25 non athlete controls (average age 54 years) participated in this study	- Former players were retired for a minimum of 10 years from games -DXA scans were performed at many bone sites.	Higher L2-L4 BMD Higher proximal femur BMD were shown in previous football players compared to controls. No changes were found in the radius BMD.	Former football practice is associated with high bone mineral density in weight-loaded sites.

To summarize, the current literature review included several chapters related to osteoporosis, concepts of bone strength and peak bone mass, bone response to exercise and the effects of soccer practice on bone mineral density, bone geometry and other bone health parameters. Other than medication, physical exercise is an effective strategy to improve body balance and bone health and to diminish the risk of falls and bone fractures (Schwab and Klein, 2008). The fact that physical exercise could be done without high costs and with minimal side effects renders it easily applicable (Schwab and Klein, 2008). Being physically inactive leads to bone loss and could increase the risk of osteoporotic fractures. Increasing activity levels during any period throughout the lifespan could help to decrease the risk of bone loss, thus decreasing the risk of osteoporotic fractures (Carter and Hinton, 2014). Lately, osteoporosis has been classified as a health problem mainly related to the female population. However, recent studies are trying to comprehend the effects and the causes of osteoporosis on men (Madeoet al., 2007). Bone loss will occur with aging in both sexes (Demontiero et al., 2012), and one over 5 men above the age of 50 will encounter fractures related to osteoporosis in their lifetime (Melton et al., 1998). It is never too late to start practicing physical activity at the age of 50 years. In the contrary, it is a suitable time to prevent the normal loss of bone associated with aging. Knowing that the majority of Lebanese 50-year-old men are not used to doing physical activities due to the lack of school's physical education programs in that period of time characterised by conflicts and economic collapse related to civil wars, they tend to neglect the importance of physical activities on health. Moreover, hip fractures are considered to be the most serious of fractures because they are correlated to a high rate of morbidity and mortality (Zaheer and LeBoff, 2000). Half of the patients who had a hip fracture lose their capability to walk independently. So, it is important to incorporate strategies that help to prevent this type of fracture. Physical activity could be beneficial to increase bone mass and to prevent its loss. The choice of physical activity is very important, because some types of physical activities (high impact: running, soccer, gymnastics and volleyball) are superior to others (swimming and cycling) in positively affecting bone formation (Kohrt et al., 2004). Therefore, soccer is considered as a high-impact weight-bearing sport, and many studies showed that its practice increases bone formation at several sites (shown previously in the tables). Furthermore, football is dispersed everywhere in the world, and it is considered as being one of the sports with the highest number of enrolment in participants and players (Dvorak et al., 2004). Soccer participation is enjoyable and fun with moderate feeling of physical fatigue after its practice (Krustrup and Krustrup, 2018). It helps to build new friends with different socio-economic backgrounds and creates social

relationships. This will help to decrease the stress of life, and it positively affects mental and social health. However, all soccer related studies (chapter of bone and soccer) had a training time ranged between 45 to 60 minutes, 2 to 3 times per week. Middle-aged Lebanese people have many responsibilities due to the economic crisis, and the majority of them do not have plenty of time (2-3 x 60 min) to practice sport; therefore, creating a time efficient soccer training intervention should be investigated.

The aim of the study was to know the effectiveness of a 1-year recreational football protocol on bone mineral density and physical performance parameters in a group of healthy inactive 50-year-old men.

This PhD study will allow us to:

- Detect the effects of a short volume of recreational football (RF30: 2 times 30 min mini football game per week) on bone mineral density and physical parameters in a group of healthy inactive 50-year-old men.
- Compare the effects of two recreational football protocols (RF30: 2x30min vs RF60: 2x60min for 1 year) on bone mineral density and physical performance parameters.
- To know the effectiveness of a 1-year recreational football protocol on bone mineral density and physical performance parameters in a group of healthy 50-year-old men who played football regularly in the past 5 years and are still playing football till today.

The present thesis is based on several hypotheses:

- Recreational football increases bone mineral density and enhances physical performance parameters in both groups (RF60 and RF30).
- 2x30 min/week of recreational football is sufficient to increase bone mineral density and enhance physical performance in healthy 50-year-old men.
- Former football players have higher bone mineral density and higher physical performances before starting the intervention compared to the inactive participants.
- Muscular power, sprinting performance and VO_2 max are positively correlated to bone health parameters in healthy middle-aged men.

SECOND PART: PERSONAL CONTRIBUTION

GENERAL METHODOLOGY

1. Subjects

51 middle-aged men voluntarily participated in our PhD study. They were randomly recruited from Zgharta, a city located in North Lebanon. All subjects were healthy men aged between 41 and 58 years. They were non-smokers and had no history of major orthopedic problems or other disorders that affect bone metabolism including diabetes. Subjects 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 were excluded. All subjects were well informed about the objective of the study including the risks and benefits of participation. Written informed consent was signed by all subjects before participating in the study. 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. Anthropometric measurements

Body weight was measured using a standard mechanical scale with a precision of 0.1 kg. Height was measured in a vertical position to the nearest 0.5 cm using a standard stadiometer. BMI was calculated by dividing body weight to the height squared (kg/m2). Body composition including lean mass (kg), fat mass (kg) and body fat percentage (FM; %kg) was also assessed by using dual-energy X-ray densitometry (DXA; GE-Lunar iDXA, Madison, WI).

3. Bone measurements

BMC and BMD were assessed by DXA (DXA; GE-Lunar iDXA, Madison, WI). Geometric indices of femoral neck were calculated by the device according to the method of Beck et al. (1990). Geometric indices of femoral neck strength (CSI, BSI and ISI) were calculated using the method of Karlamangla et al. (2004).

4. Physical performance measurements

Time of the 10-m sprint, vertical jump height, horizontal jump distance, maximum power of the lower limbs, maximal oxygen consumption,1-RM Half-squat, 1-RM bench press and handgrip maximal isometric strength have been tested. More details concerning these tests are listed in study 1.

5. Validated questionnaires

Daily calcium consumption, daily protein consumption, the weekly volume of physical activity and the assessment of sleep quality and disturbances were evaluated by validated questionnaires (Buysse et al., 1989; Fardellone et al., 1991; Morin et al., 2005; Armstrong and Bull, 2006).

6. Football training

The first 2 studies were cross-sectional in nature. Study 3 was longitudinal. In this study, the training lasted for 1 year with 2 training sessions per week. 2 experimental groups (RF60 and RF30) were present in this study. For the RF60 group, participants played normal mini-football games 2 times per week for 60 min in total. For the RF30 group, participants also played mini football games 2 times per week for 30 min in total. More details are found in study 3.

7. Statistics

The mean and the standard deviation or standard error of the mean were calculated for each variable. Intergroup differences were judged by one-way analysis of variance. Correlations were made using the Pearson test. Multivariate linear regression tests were used to define the best determinants of bone parameters. In study 3, to judge possible longitudinal differences in the groups (RF60, RF30, FF and C) following training, we used a two-way repeated measure analysis of variance (two-way-RM-Anova). The percentages of variations in physical qualities and bone parameters were calculated for the 4 groups. A value of $p<0.05$ was required in order to confirm the significance of the results.

Table 18: Design of the three studies.

Title of the study	Objectives	Publication

Study1: Muscular power and maximum oxygen consumption predict bone density in a group of middle-aged men	The purpose of this study was to explore the relationships between several physical performance variables and bone parameters in a group of middle-aged men.	**Finianos B**, Sabbagh P, Zunquin G, El Hage R. Muscular power and maximum oxygen consumption predict bone density in a group of middle-aged men. J Musculoskelet Neuronal Interact. 2020 Mar 3;20(1):53-61.
Study 2: Composite Indices of Femoral Neck Strength in Middle-Aged Inactive Subjects Vs Former Football Players.	The purpose of this study was to compare composite indices of femoral neck strength ((compression strength index [CSI], bending strength index [BSI], and impact strength index [ISI]) in inactive middle-aged men and middle-aged former football players.	**Finianos B**, Zunquin G, El Hage R. Composite Indices of Femoral Neck Strength in Middle-Aged Inactive Subjects Vs Former Football Players [published online ahead of print, 2020 Jun 12]. J Clin Densitom. 2020;S1094-6950(20)30093-7.
Study 3: The Effects of a 1-year Recreational Football Protocol on Bone Mineral Density and Physical Performance Parameters in a Group of Healthy Inactive 50 year Old Men.	The purpose of this study was to compare the effects of two recreational football protocols (RF30: 2x30min vs RF60: 2x60min for 1 year) on bone health and physical performance parameters in a group of healthy middle-aged men.	Article in preparation.

Study 1: Muscular power and maximum oxygen consumption predict bone density in a group of middle-aged men

Abstract:

Objective: The purpose of this study was to explore the relationships between several physical performance variables and bone parameters in a group of middle-aged men. Methods: 50 middle-aged men participated in this study. Body composition and bone variables were evaluated by DXA. Bone mineral density (BMD) was measured at the whole body (WB), total radius (TR), lumbar spine (L1-L4), total hip (TH) and femoral neck (FN). Geometric indices of femoral neck (FN) strength were also calculated by DXA. Handgrip strength, vertical jump, maximum power of the lower limbs (watts), maximal half-squat strength, maximal bench-press strength, sprint performance (10 m) and maximum oxygen consumption (VO2 max, L/min) were evaluated using validated tests. Results: VO_2 max (L/min), maximum power of the lower limbs, maximal half-squat strength, maximal bench-press strength, handgrip and lean mass were positively correlated to many bone parameters. Lean mass was the strongest determinant of WB BMC. VO_2 max (L/min) was the strongest determinant of WB BMD, TH BMD and FN BMD. Maximum power was the strongest determinant of total radius BMD. Conclusion: The current study suggests that VO_2 max (L/min), lean mass and maximum power of the lower limbs are the strongest determinants of bone variables in middle-aged men.

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Original Article

Muscular power and maximum oxygen consumption predict bone density in a group of middle-aged men

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Abstract

Objective: The purpose of this study was to explore the relationships between several physical performance variables and bone parameters in a group of middle-aged men. **Methods:** 50 middle-aged men participated in this study. Body composition and bone variables were evaluated by DXA. Bone mineral density (BMD) was measured at the whole body (WB), total radius (TR), lumbar spine (L1-L4), total hip (TH) and femoral neck (FN). Geometric indices of femoral neck (FN) strength were also calculated by DXA. Handgrip strength, vertical jump, maximum power of the lower limbs (watts), maximal half-squat strength, maximal bench-press strength, sprint performance (10 m) and maximum oxygen consumption (VO_2 max, L/min) were evaluated using validated tests. **Results:** VO_2 max (L/min), maximum power of the lower limbs, maximal half-squat strength, maximal bench-press strength, handgrip and lean mass were positively correlated to many bone parameters. Lean mass was the strongest determinant of WB BMC. VO_2 max (L/min) was the strongest determinant of WB BMD, TH BMD and FN BMD. Maximum power was the strongest determinant of total radius BMD. **Conclusion:** The current study suggests that VO_2 max (L/min), lean mass and maximum power of the lower limbs are the strongest determinants of bone variables in middle-aged men.

Keywords: Men, Prevention of Osteoporosis, Muscular Power, Maximal Strength, Aerobic Endurance

Introduction

Osteoporosis in men is not a rare problem, and it is often ignored[1]. Even though traditionally considered a women's health issue, osteoporosis is a health problem for men as well[2]. Aging leads to a reduction in lean mass (LM) and bone mineral density (BMD) and an alteration of bone quality[2]. While advancing in age, men are estimated to lose bone mineral density (BMD) at a rate of up to 1% per year[3,4], and it is generally believed that one in eight men over the age of fifty will experience an osteoporosis-related fracture in his lifetime[5]. With the increasing size of our elderly population due to a better quality of life, osteoporosis in men will soon become an even bigger problem to society and health care systems worldwide[2]. Regular physical activity practice has been recommended as a low-cost and safe non-pharmacological strategy to counter the loss of bone mass associated with aging[6]. Resistance training alone or in combination with impact-loading activities is safe and may help in the prevention of osteoporosis in middle-aged and older men[6]. Further, recent cross-sectional studies demonstrated that higher physical performance levels are positively correlated to higher BMD values in both genders[7-11]. For instance, maximal oxygen consumption (VO_2 max; L/min) has been shown to be a strong positive predictor of bone mineral content (BMC) and BMD in young adults[11]. Also, maximum power calculated using a vertical jump test was shown to be a positive determinant of several bone parameters also in a group of young adults[9]. Further, maximal strength has been shown to be positively associated with BMD and geometric indices of hip bone strength in young adults and elderly women[10]. The majority of the studies that aimed at exploring the relationships between physical performance variables

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and bone characteristics were conducted on children, young adults and elderly subjects. Up to our knowledge, very few studies were conducted on middle-aged men. Hence, the aim of the current study was to explore the relationships between many physical performance parameters and bone variables (BMC, BMD and geometric indices of hip bone strength) in a group of middle-aged men. Given the previously demonstrated relationships between sarcopenia and osteoporosis in the elderly[12], we hypothesized that the fitness tests related to maximal power and strength would be major determinants of bone variables in our population.

Methods

Subjects and study design

Fifty middle-aged men voluntarily participated in this study. Their mean age was 50.2 ± 4.5. All participants were randomly recruited from Zgharta, a city located in North Lebanon. The participants were healthy men aged between 40 and 58 years and not suffering from any chronic health disease. All participants had no history of major orthopaedic problems or other disorders that affect bone metabolism including diabetes. Subjects 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 were excluded. This study included evaluation of anthropometric, bone and physical parameters. Before any evaluation, all subjects received a description of the study, its purpose and procedures, and they were well informed about the objective of the study including the risks and benefits of participation. Written informed consent was signed by all subjects before participating in the study. 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). The current study was approved by the University of Balamand Ethics Committee.

Anthropometric measurements

Body weight was measured using a standard mechanical scale with a precision of 0.1 kg. Height was measured in a vertical position to the nearest 0.5 cm using a standard stadiometer. The subjects were barefoot and wearing light clothes while measurements were taken. BMI was calculated by dividing body weight to the height squared (kg/m^2). Body composition including lean mass (kg), fat mass (kg) and body fat percentage (FM; %kg) was also assessed by using dual-energy X-ray densitometry (DXA; GE-Lunar iDXA, Madison, WI).

Bone measurements

Whole-body bone mineral content (WB BMC), whole-body bone mineral density (WB BMD), lumbar spine bone mineral density (L1-L4 BMD), total hip bone mineral density (TH BMD), femoral neck bone mineral density (FN BMD) and Total Radius BMD of the right side were determined using dual-energy X-ray densitometry (DXA; GE-Lunar iDXA, Madison, WI)[13,14]. Geometric indices of femoral neck (FN) strength (cross-sectional area (CSA), cross-sectional moment of inertia (CSMI), section modulus (Z), strength index (SI) and buckling ratio (BR)) were also determined by DXA. The use of these indices to evaluate bone geometry has been validated in obese and non-obese subjects[15-20]. The same certified technician (holder of a Bachelor of Science in medical imaging sciences) performed all the DXA scans using 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[21]. The coefficients of variation for CSA and Z evaluated by duplicate measurements in 10 subjects were <3%[21].

Procedures of physical performance tests

All subjects participated in a familiarizing session before evaluation. The objective of this session was to explain the procedures of the study and to familiarize the participants with the equipment used to perform the physical tests. Testing was done on three non-consecutive days. All the assessments were performed in the following order. During day one, time of the ten-meter sprint was measured by using photoelectric cells (BROWER Timing Systems), vertical jump was measured by using the Sargent test, horizontal jump was also tested and lower body maximal power was calculated by using the Lewis Formula[22]. On the second day, maximal oxygen consumption was calculated by using the Step tool protocol[23,24]. On the third day, one-repetition maximum (RM) of half-squat and bench press on a Smith machine was tested and determined by using the Brzycki equation[25]. The maximal isometric force of the right-handgrip was measured by a dynamometer; the right side was chosen because total Radius BMD was measured at the right side.

Sprint performance

Time of the 10-m sprint was measured by using two pairs of photoelectric cells that were connected to an electronic timer (BROWER Timing Systems). The height of the photocells was 1 m from the ground, and the time was recorded in hundredth of a second. The first pair was positioned at the starting line (0m) and the second pair at the ten-meter finish line. Before beginning the evaluation process, participants performed a specific warmup. The evaluation consisted of four 10 meter maximal sprints that were separated by 3 minutes of passive resting in between them. All participants began with the same standing starting position by putting one leg of their choice (right or left) on the line that was drawn on the floor, 15 cm before the starting line. The time of all four sprints was recorded, and the best time out of the four sprints was taken.

Jumping performance

Vertical jump height was measured by using the jump and reach Sargent test[22]. Before beginning the evaluation process, participants performed a specific warmup. All participants performed a counter movement jump with free movements of the upper limbs. The participants jumped three times, with a resting interval of 2 minutes between the jumps, and the highest value was considered. The highest value of the vertical jump was used to calculate the peak power of the lower limb by using the Lewis Formula[22].

Horizontal jump (HJ) was also calculated. All subjects performed the HJ starting from a standing position. They started the jump by performing a swing movement of their arms. A take-off line was drawn on the ground. Their feet were directly positioned before the line in a shoulder width position. The jump-length measurement was determined using a metric tape measure from the take-off line to the closest point of landing contact (back of the heels). Each participant performed 3 attempts, and the longest distance was considered.

Maximum oxygen consumption

Maximal oxygen consumption was calculated by using the STEP tool protocol[23,24]. This indirect test was chosen because the subjects were middle-aged and this test is more suitable for this population than a triangular maximal test; it is also valid and reliable in this kind of population[23,24]. VO_2 max was expressed either as an absolute rate (L/min) or as a relative rate (mL/min/Kg).

Maximal strength measurements

Half-squat on Smith machine was used as an exercise to identify lower limb maximal strength. Direct measure of 1-RM was not used since participants were afraid to perform squats with heavy weights. Furthermore, individuals with little or no experience using heavy weights in strength training increase their chance for accident and injuries. A prediction of one-repetition-maximum (1-RM) from a 4-6 RM submaximal strength test was used. A specific standardized warmup was done before starting the test. The test was stopped when the participant failed to perform a full range of motion of the exercise. In addition, participants who performed more than 6 repetitions were stopped and told to repeat the test after increasing the load. The test was successful when the subject reached his RM between 4 to 6-RM. Each participant performed the squat technique following the protocol established by the National Strength and Conditioning Association[26]. During all attempts, the participants were required to squat to a depth where a 90-degree knee angle was achieved. Bench press on Smith machine was used to evaluate upper limb maximal strength. The same protocol has been used to predict 1-RM from a 4-6 RM submaximal strength test. Each participant performed the bench press technique following the protocol established by the National Strength and Conditioning Association[26].

Questionnaires

Sleep quality

The Pittsburgh Sleep Quality Index (PSQI) was used to assess sleep quality and disturbances over a 1-month time interval. Seven "components" related to subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction were scored. The addition of scores for these seven components produces one global score[27]. Sleep quality was collected since previous studies have shown independent correlations between sleep and bone health parameters[28-30].

Daily calcium and protein intakes

Daily calcium intake (DCI) and daily protein intake (DPI) were evaluated by validated semi-quantitative food frequency questionnaires[31-33].

Physical activity

The duration of physical activity per week (hour/week) was evaluated using the global physical activity questionnaire (GPAC)[34].

Statistical analysis

The mean and standard deviations were calculated for all clinical, physical performance and bone parameters. All variables were evaluated for normality using the Shapiro-Wilk test. Univariate correlations between bone variables and anthropometric, clinical characteristics and physical parameters were computed using Pearson's Test. Multiple linear regression analysis models were used to test the relationship of WB BMC and Total Radius BMD with LM and maximal power of the lower limbs (watts). Multiple linear regression analysis models were also used to test the relationships of WB BMD, L1-L4 BMD, TH BMD, FN BMD, FN CSA and FN CSMI with lean mass and VO_2 max (L/min). The Data was analysed using Number Cruncher Statistical System software (NCSS, 2001, Kaysville, UT). A level of significance of $p < 0.05$ was used.

Results

Clinical characteristics and bone variables of the study population

Age, weight, height, BMI, lean mass, fat mass, fat mass percentage, daily calcium intake, daily protein intake, PSQI, Physical activity and bone variables are shown in Table 1.

Physical performance variables of the study population

CMJ, maximum power, horizontal jump, handgrip, 1-RM half-squat, 1-RM bench press, 10 m sprint performance, VO_2 max and bone variables are listed in Table 2.

Table 1. Clinical characteristics and bone variables of the study population.

	Mean ± Standard Deviation	Range (Min – Max)
Age (years)	50.2 ± 4.5	41 – 58
Weight (kg)	90.3 ± 13.4	59 – 126
Height (cm)	173.5 ± 6.1	159 – 190
BMI (kg/m^2)	29.9 ± 3.8	21.4 – 42.5
Lean mass (kg)	57.571 ± 6.844	35.999 – 70.593
Fat mass (kg)	30.3 ± 8.385	18.295 – 59.095
Fat mass percentage	32.9 ± 4.9	23.5 – 46.4
Daily calcium intake (mg/d)	646 ± 176	335 – 1076
Daily protein intake (g/d)	82.8 ± 15.5	45.9 – 113.6
PSQI	3.2 ± 2.0	0 – 10
Physical activity (min/week)	104.2 ± 37.4	50 – 180
WB BMC (g)	3071 ± 338	2321 – 3664
WB BMD (g/cm^2)	1.318 ± 0.097	1.162 – 1.535
L1-L4 BMD (g/cm^2)	1.238 ± 0.138	0.962 – 1.594
TH BMD (g/cm^2)	1.114 ± 0.109	0.898 – 1.350
FN BMD (g/cm^2)	1.059 ± 0.117	0.841 – 1.331
Total Radius BMD (g/cm^2)	0.804 ± 0.0657	0.675 – 0.972
CSA (mm^2)	180.6 ± 25.1	124 – 233
CSMI (mm^4)	17502 ± 4328	9530 – 29655
Z (mm^3)	1120 ± 1360	577 – 10461
SI	1.576 ± 0.382	0.8 – 2.6
BR	3.80 ± 1.62	1.6 – 9.1

Min: Minimum; Max: Maximum; BMI: body mass index; PSQI: Pittsburgh sleep quality 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; SI: strength index; BR: buckling ratio.

Table 2. Physical performance variables of the study population.

	Mean ± Standard Deviation	Range (Min – Max)
CMJ (cm)	35.4 ± 5.4	23 – 45
Maximum Power (Watts)	1159 ± 159	770 – 1506
HJ (m)	1.8 ± 0.25	1.15 – 2.5
HG (kg)	47.3 ± 6.7	36 – 67
1-RM half-squat (kg)	85.2 ± 22.6	50 – 149
1-RM bench press (kg)	54.5 ± 10.2	28 – 75
10 m sprint performance (s)	2.04 ± 0.16	1.75 – 2.46
VO_2 max (L/min)	3.5 ± 0.3	2.76 – 4.48
VO_2 max (ml/min/kg)	39.3 ± 4.8	29.1 – 51.0

Min: Minimum; Max: Maximum; CMJ: counter movement jump; HJ: horizontal jump; HG: handgrip; RM: Repetition Maximum; VO_2 max: maximal oxygen consumption.

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

Maximum power of the lower body was positively correlated to WB BMC (r=0.74; p<0.001), WB BMD (r=0.57; p<0.001), L1-L4 BMD (r=0.32; p<0.05), TH BMD (r=0.51; p<0.001), FN BMD (r=0.51; p<0.001), Total Radius BMD (r=0.50; p<0.001), CSA (r=0.58; p<0.001) and CSMI (r=0.46; p<0.001). Handgrip strength was positively correlated to WB BMC (r=0.45, p<0.001), WB BMD (r=0.31; p<0.5), FN BMD (r=0.29; p<0.05), Total Radius BMD (r=0.30; p<0.05), CSA (r=0.37; p<0.01) and CSMI (r=0.43; p<0.01). 1-RM half squat

Table 3. Correlations between physical performance variables and bone characteristics of the study population.

	WB BMC (g)	WB BMD (kg/m²)	L1-L4 BMD (kg/m²)	TH BMD (kg/m²)	FN BMD (kg/m²)	Total Radius BMD (kg/m²)	CSA (mm²)	CSMI (mm⁴)	Z (mm³)	SI	BR
CMJ (cm)	0.02	-0.01	0.13	0.06	0.26	0.12	0.20	0.04	0.07	0.31*	0.05
Maximum Power (watts)	0.74***	0.57***	0.32*	0.51***	0.51***	0.50***	0.58***	0.46***	0.08	-0.21	0.19
Handgrip (Kg)	0.45***	0.31*	0.22	0.23	0.29*	0.30*	0.37**	0.43**	0.07	0.02	0.15
1-RM half-squat (kg)	0.40**	0.40**	0.30*	0.42**	0.52**	0.25	0.53**	0.41**	0.21	0.13	0.00
1-RM BP (kg)	0.50***	0.45**	0.22	0.24	0.30*	0.32*	0.45**	0.40**	0.16	-0.05	-0.10
10m sprint performance (s)	-0.248	-0.22	-0.28*	-0.13	-0.40**	-0.20	-0.45***	-0.35*	-0.24	-0.38**	-0.09
VO_2 max (L/min)	0.66***	0.62***	0.37*	0.56***	0.56***	0.18	0.63***	0.47***	0.22	-0.06	0.01
VO_2 max (ml/min/kg)	-0.28	-0.14	0.01	-0.09	0.05	-0.34	-0.01	-0.08	0.14	0.42**	-0.16
HJ (m)	0.13	0.06	0.25	0.10	0.26	0.15	0.27	0.06	0.19	0.27	0.04

*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; SI: strength index; BR: buckling ratio; CMJ: Counter movement jump; RM: Repetition Maximum; BP: Bench press; VO_2 max: maximal oxygen consumption; HJ: Horizontal jump; * p<0.05; ** p<0.01; *** p<0.001.*

was positively correlated to WB BMC (r=0.40; p<0.01), WB BMD (r=0.40; p<0.01), L1-L4 BMD (r=0.30; p<0.05), TH BMD (r=0.42; p<0.01), FN BMD (r=0.52; p<0.01), CSA (r=0.53; p<0.01) and CSMI (r=0.41; p<0.01). 1-RM Bench press was positively correlated to WB BMC (r=0.50; p<0.001), WB BMD (r=0.45; p<0.01), FN BMD (r=0.30; p<0.05), Total Radius BMD (r=0.32; p<0.05), CSA (r=0.45; p<0.01) and CSMI (r=0.40; p<0.01). 10-m sprint was negatively correlated to L1-L4 BMD (r=-0.28; p<0.05), FN BMD (r=-0.40; p<0.01), CSA (r=-0.45; p<0.001), CSMI (r=-0.35; p<0.05) and SI (r=-0.38; p<0.01). VO_2 max (L/min) was positively correlated to WB BMC (r=0.66; p<0.001), WB BMD (r=0.62; p<0.001), L1-L4 BMD (r=0.37; p<0.05), TH BMD (r=0.56; p<0.001), FN BMD (r=0.56; p<0.001), CSA (r=0.63; p<0.001) and CSMI (r=0.47; p<0.001). VO_2 max (ml/min/kg) was positively correlated to SI (r=0.42; p<0.01). Horizontal jump was not correlated to bone variables (Table 3).

Correlations between clinical variables and bone characteristics of the study population

Body weight was correlated to WB BMC (r=0.69; p<0.001), WB BMD (r=0.56; p<0.001), TH BMD (r=0.47; p<0.001), FN BMD (r=0.35; p<0.05), Total Radius BMD (r=0.40; p<0.01), CSA (r=0.44; p<0.01) CSMI (r=0.40; p<0.01) and SI (r=-0.37; p<0.01). BMI was correlated to WB BMC (r=0.43; p<0.01), WB BMD (r=0.46; p<0.001), TH BMD (r=-0.43; p<0.01), Total Radius BMD (r=0.30; p<0.05), and SI (r=-0.43; p<0.01). LM was positively correlated to WB BMC (r=0.78; p<0.001), WB BMD (r=0.53; p<0.001), TH BMD (r=0.41; p<0.01), FN BMD (r=0.43; p<0.01), Total Radius BMD (r=0.43; p<0.01), CSA (r=0.57; p<0.001) and CSMI (r=0.52; p<0.001). FM was correlated to WB BMC (r=0.43; p<0.01), WB BMD (r=0.45; p<0.001), TH BMD (r=0.37; p<0.01), Total Radius BMD (r=0.27; p<0.05) and SI (r=-0.39; p<0.01). FM % was negatively correlated to SI (r=-0.35; p<0.05) (Table 4). DPI was positively correlated to WB BMD (r=0.38; p<0.01), L1-L4 BMD (r=0.30; p<0.05) and TH BMD (r=0.36; p<0.05). Physical activity (h/week) was positively correlated to L1-L4 BMD (r=0.29; p<0.05), TH BMD (r=0.36; p<0.01), FN BMD (r=0.60; p<0.001), CSA (r=0.57; p<0.001), CSMI (r=0.42; p<0.01) and SI (r=0.40; p<0.01) (Table 4).

Multiple linear regressions

Lean mass was the strongest determinant of WB BMC and CSMI. VO_2 max (L/min) was the strongest determinant of WB BMD, TH BMD, FN BMD and CSA. Maximum power was the strongest determinant of total radius BMD (Table 5).

Discussion

This study conducted on a group of middle-aged men mainly shows that VO_2 max (L/min), lean mass and maximum power of the lower limbs are the main predictors of bone mineral density and geometric indices of femoral neck strength.

LM was positively correlated to WB BMC, WB BMD, TH

Table 4. Correlations between clinical variables and bone characteristics of the study population.

	WB BMC (g)	WB BMD (kg/m²)	L1-L4 BMD (kg/m²)	TH BMD (kg/m²)	FN BMD (kg/m²)	Total Radius BMD (kg/m²)	CSA (mm²)	CSMI (mm⁴)	Z (mm³)	SI	BR
Age (years)	-0.08	-0.21	0.02	-0.26	-0.13	-0.04	-0.16	-0.24	-0.03	0.15	0.00
Weight (Kg)	0.69***	0.56***	0.24	0.47***	0.35*	0.40**	0.44**	0.40**	0.03	-0.37**	0.13
BMI (kg/m²)	0.43**	0.46***	0.17	-0.43**	0.22	0.30*	0.25	0.18	-0.00	-0.43**	0.00
LM (kg)	0.78***	0.53***	0.23	0.41**	0.43**	0.43**	0.57***	0.52***	0.09	-0.24	0.22
FM (Kg)	0.43**	0.45***	0.18	0.37**	0.16	0.27*	0.20	0.19	0.05	-0.39**	0.03
FM%	0.07	0.20	0.05	0.17	-0.07	0.10	-0.10	-0.05	0.02	-0.35*	-0.03
DCI (mg/d)	0.04	0.2	0.23	0.11	0.07	0.16	-0.00	0.02	-0.17	-0.06	0.23
DPI (g/d)	0.21	0.38**	0.30*	0.36*	0.31	0.23	0.26	0.22	-0.06	-0.11	0.18
PA (h/week)	0.25	0.22	0.29 *	0.36 **	0.60 ***	-0.05	0.57 ***	0.42 **	0.13	0.40 **	-0.14
PSQI	0.03	-0.08	0.03	-0.19	-0.10	-0.11	-0.06	0.05	-0.08	-0.05	0.17

*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; SI: strength index; BR: buckling ratio; BMI: Body mass index; LM: lean mass; FM: fat mass; FM%: fat mass percentage; DCI: daily calcium intake; DPI: daily protein intake; PA: Physical Activity; PSQI: Pittsburgh sleep quality index; *p<0.05; **p<0.01; ***p<0.001.*

BMD, FN BMD, total Radius BMD, CSA and CSMI. Our study confirms the importance of LM on bone health in middle-aged men. Our results are in accordance with those of previous studies conducted on adolescents, young adults and elderly subjects[8,10,35]. The multiple linear regression analysis demonstrated that LM was the strongest determinant of WB BMC and CSMI. Muscles are the load suppliers for bone; they provide mechanical stimuli to preserve skeletal mass[36]. Furthermore, muscle and bone do not only communicate at biochemical and molecular levels but also at a mechanical level[36]. Low muscle mass has been correlated with low bone density values in several populations[37]. Accordingly, this study supports the strategy of increasing lean mass as a prevention strategy against osteoporosis and osteopenia in men.

In addition to LM, body weight was positively correlated to WB BMC, WB BMD, TH BMD, FN BMD, total Radius BMD, CSA and CSMI but negatively correlated to SI. BMI was positively correlated to WB BMC, WB BMD, TH BMD and total Radius BMD but negatively correlated to SI. This result is in accordance with those of many studies that showed that being overweight or obese is associated with higher BMD values in both genders[7,8]. These higher values are observed because obesity and overweight are usually associated with higher lean mass and higher muscular strength. However, fat mass excess is usually associated with lower SI values[38]. According to Faulkner et al.[39], SI is the ratio of estimated compressive yield strength of the femoral neck to the expected compressive stress of a fall on the greater trochanter adjusted for the patient's age, height and weight. Accordingly, the positive association between VO_2 max (ml/min/kg) and SI may be in part mediated by body weight since body weight and SI are negatively correlated.

When assessing the relations between body composition parameters and bone indices, we found that LM is positively correlated to bone parameters and that body fat percentage was not positively correlated to any of the bone parameters. Beside muscle mass, our results confirm that muscle strength is a major determinant of bone health. Maximal muscle strength of the lower limbs was positively correlated to WB BMC, WB BMD, L1-L4 BMD, TH BMD, FN BMD, CSA and CSMI. 1-RM bench press was positively correlated to WB BMC, WB BMD, FN BMD, Total Radius BMD, CSA and CSMI. Handgrip strength was positively correlated to WB BMC, WB BMD, FN BMD, total Radius BMD, CSA and CSMI. These findings demonstrate that the correlations between muscle strength variables and bone parameters in middle-aged men are not necessarily site-specific. The relationship can be site-specific, depending on the mechanical loading, as well as general, depending on other factors such as hormones and growth factors[40].

Overall, the correlations between maximal strength indices and bone variables were weaker compared to those between VO_2 max (L/min) and bone variables or those between maximum power and bone variables. Furthermore, VO_2 max (L/min) was positively correlated to WB BMC, WB BMD, L1-L4 BMD, TH BMD, FN BMD, CSA and CSMI. These results are also in line with those of previous studies that showed that VO_2 max positively affects bone resistance[7,8,11,41,42]. The mechanisms to explain these associations are not completely understood. High values of VO_2 max 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. Furthermore, VO_2 max only showed positive correlations when expressed in L/min

Table 5. Multiple linear regression models.

	Coefficient ± SE	p-value
Dependent variable: WB BMC (R^2 = 0.649)		
Constant	801.840 ± 247.859	0.002
Power (Watts)	0.652 ± 0.325	0.051
Lean mass (Kg)	0.0263 ± 0.00760	0.001
Dependent variable: WB BMD (R^2 = 0.447)		
Constant	0.692 ± 0.104	<0.001
VO_2 max (L/min)	0.113 ± 0.0332	0.001
Lean mass (Kg)	0.00000409 ± 0.00000186	0.033
Dependent variable: L1-L4 BMD (R^2=0.139)		
Constant	0.773 ± 0.185	<0.001
VO_2 max (L/min)	0.120 ± 0.0618	0.058
Lean mass (Kg)	0.000000826 ± 0.00000351	0.815
Dependent variable: TH BMD (R^2 = 0.329)		
Constant	0.512 ± 0.130	<0.001
VO_2 max (L/min)	0.133 ± 0.0415	0.002
Lean mass (Kg)	0.00000240 ± 0.00000233	0.307
Dependent variable: FN BMD (R^2 =0.336)		
Constant	0.400 ± 0.139	0.006
VO_2 max (L/min)	0.138 ± 0.0445	0.003
Lean mass (Kg)	0.00000307 ± 0.00000249	0.225
Dependent variable: Total Radius BMD (R^2 =0.259)		
Constant	0.556 ± 0.0700	<0.001
Power (Watts)	0.000198 ± 0.0000920	0.037
Lean mass (Kg)	0.000000315 ± 0.00000215	0.884
Dependent variable: FN CSA (R^2 = 0.475)		
Constant	11.416 ± 26.433	0.668
VO_2 max (L/min)	28.418 ± 8.462	0.002
Lean mass (Kg)	0.00122 ± 0.000474	0.013
Dependent variable: FN CSMI (R^2 = 0.351)		
Constant	-6811.061 ± 5100.213	0.188
VO_2 max (L/min)	2328.856 ± 1632.725	0.161
Lean mass (Kg)	0.282 ± 0.0915	0.003

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; VO_2 max: maximal oxygen consumption.

but not in ml/min/kg. This may be explained by its correlation with LM because participants with higher lean mass showed higher maximal oxygen consumption. However, the multiple linear regression analysis revealed that VO_2 max (L/min) was the strongest predictor of WB BMD, TH BMD, FN BMD and CSA in our population. These results show the importance of high-intensity aerobic training and resistance training as methods to increase bone mass and protect against osteoporotic fractures in middle-aged men.

Sprint performance was significantly correlated to L1-L4 BMD, FN BMD, CSA and SI. However, these correlations were poor to moderate. A previous study conducted on a group of young women showed significant correlations between the 30-m running speed test and several bone parameters[43].

Physical performance variables were more strongly correlated to FN BMD than L1-L4 BMD. In fact, the cortical component of the femoral neck is more influenced by mechanical factors than the trabecular component of the lumbar spine; the latter is much more affected by genetic factors[44].

Maximum power of the lower limbs was positively correlated to WB BMC, WB BMD, L1-L4 BMD, TH BMD, FN BMD, Total Radius BMD, CSA and CSMI. The multiple linear regression analysis showed that maximum power was the strongest determinant of total Radius BMD. Although there is no direct mechanical relationship between maximum power of the lower limbs and total Radius BMD, this correlation may be in part mediated by body weight since

body weight and maximum power are strongly related (r=0.82; p<0.001). Hence, increasing maximal power of the lower limbs is beneficial for bone health in middle-aged men. In practice, increasing lean mass, maximal oxygen consumption (L/min), maximal power of the lower limbs and maximal strength may lead to the improvement of bone health in middle-aged men. Therefore, a combined high-intensity aerobic and resistance training may improve bone health and physical parameters in men.

Daily calcium intake and sleep quality were not correlated to bone variables. Mechanical factors seem to influence bone variables more than these two factors. Daily protein intake was positively correlated to WB BMD, L1-L4 BMD and TH BMD; however, these correlations were relatively weak to moderate. The positive influence of protein intake on bone health has been previously described[45]. Physical activity duration was positively correlated to many bone variables. Our result confirms the outcomes of previous studies regarding the osteogenic effect of physical activity[46].

Our study had some limitations. The cross-sectional nature of this study is a limitation because it cannot evaluate the confounding variables. The second limitation is the relatively small number of subjects in our study group. The third limitation is the 2-dimensional nature of DXA[13]. Finally, several bone health determinants (insulin-like growth factor, testosterone, insulin, leptin, vitamin D and PTH levels) were not controlled in this study. Up to our knowledge, it is one of the few studies that aimed at exploring the relationships between physical performance variables and bone indices in middle-aged men. In our study, several bone determinants are easily calculated when performing simple physical tests.

In conclusion, this study shows that VO_2 max (L/min), lean mass and maximal power of the lower limbs (watts) are the strongest determinants of bone parameters in middle-aged men. Our results may be useful for building new exercise programs for the prevention and early detection of osteoporosis or osteopenia in men. These programs must focus on combined high-intensity aerobic and resistance training.

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Study 2: Composite Indices of Femoral Neck Strength in Middle-Aged Inactive Subjects Vs Former Football Players

Abstract:

The purpose of this study was to compare composite indices of femoral neck strength ((compression strength index [CSI], bending strength index [BSI], and impact strength index [ISI]) in inactive middle-aged men (n = 20) and middle-aged former football players (n = 15). 35 middle-aged men participated in this study. Body composition and bone variables were evaluated by dual-energy X-ray absorptiometry. Composite indices of femoral neck strength (CSI, BSI, and ISI) were calculated. Handgrip strength, vertical jump, maximum power of the lower limbs (watts), horizontal jump, maximal half-squat strength, maximal bench-press strength, sprint performance (10 meters), and maximum oxygen consumption (VO2 max, ml/min/kg) were evaluated using validated tests. CSI, BSI, and ISI were significantly higher in football players compared to inactive men. Vertical jump, horizontal jump, maximal half-squat strength, VO_2 max and sprint performance were significantly different between the 2 groups. CSI, BSI, and ISI remained significantly higher in football players compared to inactive men after adjusting for physical activity level. The current study suggests that former football practice is associated with higher composite indices of femoral neck strength in middle-aged men.

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Composite Indices of Femoral Neck Strength in Middle-Aged Inactive Subjects Vs Former Football Players

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Abstract

The purpose of this study was to compare composite indices of femoral neck strength ((compression strength index [CSI], bending strength index [BSI], and impact strength index [ISI]) in inactive middle-aged men (n = 20) and middle-aged former football players (n = 15). 35 middle-aged men participated in this study. Body composition and bone variables were evaluated by dual-energy X-ray absorptiometry. Composite indices of femoral neck strength (CSI, BSI, and ISI) were calculated. Handgrip strength, vertical jump, maximum power of the lower limbs (watts), horizontal jump, maximal half-squat strength, maximal bench-press strength, sprint performance (10 meters), and maximum oxygen consumption (VO_2 max, ml/min/kg) were evaluated using validated tests. CSI, BSI, and ISI were significantly higher in football players compared to inactive men. Vertical jump, horizontal jump, maximal half-squat strength, VO_2 max and sprint performance were significantly different between the 2 groups. CSI, BSI, and ISI remained significantly higher in football players compared to inactive men after adjusting for physical activity level. The current study suggests that former football practice is associated with higher composite indices of femoral neck strength in middle-aged men.

Keywords: Soccer; team sports; sprinting performance; femoral neck geometry; osteoporosis.

Introduction

Osteoporosis is a worldwide disease characterized by a reduction in bone mineral density (BMD) and an alteration of bone microarchitecture resulting in an increased bone fragility and an increased fracture risk (1). Osteoporosis is considered a health issue for women, and it is often neglected for men. But in reality, osteoporosis is a health problem for men as well (2,3). The number of elderly men predisposed to osteoporotic fractures is increasing worldwide because of the increasing size of the elderly population (2). Thus, osteoporosis in men may become an even greater problem to society and health care systems worldwide. BMD measured by dual-energy X-ray absorptiometry (DXA) is considered as the reference standard to diagnose osteoporosis (4) and the best determinant of bone strength (5). Physical activity is known to be an important factor affecting BMD (6,7), and it is a low-cost and safe non-pharmacological strategy to counter the loss of BMD associated with aging (8). However, not all physical exercises or sports have equal repercussions on bone tissue (9). BMD improvements are strongly correlated with the practice of high-impact sports such as soccer or gymnastics but not correlated with the practice of non-weight-bearing ones such as swimming or cycling (6,10).

Periods of growth are thought to be the best time to increase BMD through increased loading owing to high rates of bone modelling and remodeling (11). Previous

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research has shown that exercise before puberty may confer residual benefits in BMD in adulthood (11–17).

Former professional players who remained physically active in their middle-age have a favorable body composition and reduced risk factors for osteoporosis compared with healthy age- and body mass index (BMI)- matched men (18). In addition, former footballer players have higher BMD values at weight loaded sites compared to non-athletic controls (19). Vicente-Rodriguez et al (17) found that long-term soccer participation, starting at a pre-pubertal age, resulted in greater acquisition of bone mass compared to controls. It seems that a continued practice of a high-impact sport such as soccer during growth could help to maintain these improvements and to attain high BMC and BMD further in older ages (12). As mentioned previously, BMD is considered as the reference standard to diagnose osteoporosis and the best determinant of bone strength (4,5). Nevertheless, only 50-70 % of bone strength can be explained by BMD (20). Femoral neck (FN) strength is affected by several factors other than BMD such as FN width and bending strength (21,22). Interestingly, Karlamangla et al (22) have indicated that the risk of hip fracture incident can be predicted by composite indices of FN strength (compression strength index [CSI], bending strength index [BSI], and impact strength index [ISI]) calculated from DXA scans of the hip. These indices incorporate FN size and body size with bone density (23). CSI, BSI, and ISI reflect the ability of the FN to withstand axial compressive and bending forces and to absorb energy from an impact (23). These bone indices have been shown to improve hip fracture risk assessment in the elderly population (22–24). It is now well-established that implementing strategies to increase peak BMD is an interesting way to prevent osteoporosis later in life (25). Two studies found that soccer players have higher composite indices of FN strength when compared to control subjects (26,27). Zakhem et al (28) found that adult active men have higher composite indices of FN strength compared to age-matched inactive men. Two studies demonstrated that maximum oxygen consumption (ml/mn/kg) is significantly correlated to composite indices of FN strength in young overweight and obese adults (29,30). A study conducted on pre-pubertal children has found that vigorous physical activity is positively associated with CSI, BSI, and ISI values (31). Up to our knowledge, there are no studies that explored the effect of former practice of football on composite indices of the FN in middle-aged men. The aim of the current study was to compare composite indices of FN strength (CSI, BSI, and ISI) in inactive middle-aged men and middle-aged former football players.

Methods

Subjects and Study Design

Thirty-five middle-aged men whose ages range from 42 to 55 years voluntarily participated in this study. All participants were healthy men who do not suffer from any chronic health disease. They were non-smokers and had no history of major orthopedic problems or other disorders that affect bone metabolism including diabetes. Subjects 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 were excluded. Subjects were divided into 2 groups: inactive men (n = 20) and former football players (n = 15). Participants were assigned to each group based on their former practice of football. Participants of the inactive group were inactive middle-aged men. Being inactive was defined as "performing less than 150 minutes of moderate intensity physical activity or 75 minutes of vigorous-intensity physical activity or an equivalent combination of moderate- and vigorous-intensity activity a week accumulated across work, home, transport or discretionary domains" (32). In addition, these participants did not have a former regular practice of any impact sport in their adolescence and young adulthood ages. Participants of the former football group were middle-aged men who had been practicing football regularly in their adolescence and young adulthood ages (for at least 10 years). The former football players were regular participants in national competitions. They had been training in their clubs 4 to 6 times per week, for 6–9 h/week for 10 years. Subjects who participated in this study were recruited from Zgharta, a city located in north Lebanon. All subjects were well informed about the objective of the study including the risks and benefits of participation. Written informed consent was signed by all subjects before participating in the study. 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 Measurements

Body weight and height were measured using a standard mechanical scale (precision of 100 g) and a standard stadiometer (vertical position to the nearest 0.5 cm) respectively. Subjects were wearing light clothes and were asked to remove their shoes while measurements were taken. BMI was calculated by dividing body weight to the height squared (kg/m^2). Body composition including lean mass (kg), fat mass (kg) and body fat percentage (FM; %kg) was also assessed by using dual-energy X-ray densitometry (DXA; GE-Lunar iDXA, Madison, WI).

Bone Measurements

BMD measurements were completed for the whole body (WB), the lumbar spine (L1-L4), the total hip (TH), the FN (FN) and Total Radius BMD of the right side using dual-energy X-ray densitometry (DXA; GE-Lunar iDXA, Madison, WI). Geometric indices of FN strength (cross-sectional area (CSA), cross-sectional moment of

inertia (CSMI), section modulus (Z), strength index (SI) and buckling ratio (BR)) were calculated by DXA. Composite indices of FN strength were calculated as previously described by Karlamangla et al (22). These indices can predict hip fracture risk in the elderly (22–24). 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 (23–25). The same certified technician (holder of a Bachelor of Science in medical imaging sciences) performed all the DXA scans using 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 Performance Tests

All subjects were familiarized with the procedures and the equipment needed to perform the physical tests by participating in an explanatory session prior to the evaluation procedures. Testing was done on 3 non-consecutive days. On the first day, time of the 10-meter sprint and the performances of both vertical jump and horizontal jump (HJ) were determined. On the second day, maximal oxygen consumption was determined. On the third day, one-repetition maximum (RM) of half-squat, bench press on a Smith machine and maximal isometric force of the right-handgrip were determined. The right side was chosen because total Radius BMD was measured at the right side.

Sprint Performance

Time of the 10-m sprint was measured by using 2 pairs of photoelectric cells that were connected to an electronic timer (BROWER Timing Systems). The first pair was positioned at the starting line (0 m) and the second pair at the 10-meter finish line. Before beginning the evaluation process, participants performed a specific warm-up. The evaluation consisted of four 10-meter maximal sprints that were separated by 3 minutes of passive resting in between them. The time of all 4 sprints was recorded, and the best time out of the 4 sprints was taken. In addition, the 10-meter average velocity (m/sec) of the best sprint was calculated. The protocol has been previously described by Finianos et al (33).

Jumping Performance

Vertical jump height was measured by using the jump and reach Sargent test (33). Before beginning the evaluation process, participants performed a specific warm-up. All participants performed a counter movement jump with free movements of the upper limbs. The participants jumped 3 times, with a resting interval of 2 minutes between the jumps, and the highest value was considered. The highest value of the vertical jump was used to calculate the peak power of the lower limb by using the Lewis Formula (34). HJ was also calculated. All subjects performed the HJ starting from a standing position. They started the jump by performing a swing movement of their arms. A take-off line was drawn on the ground. Their feet were directly positioned before the line in a shoulder width position. The jump-length measurement was determined using a metric tape measure from the take-off line to the closest point of landing contact (back of the heels). Each participant performed 3 attempts, and the longest distance was considered.

Maximum Oxygen Consumption

Maximal oxygen consumption was calculated by using the STEP tool protocol (35). This indirect test was chosen because the subjects were middle-aged, and this test is more suitable for this population than a triangular maximal test; it is also valid and reliable in this kind of population (35). VO_2 max was expressed either as an absolute rate (l/min) or as a relative rate (ml/min/Kg).

Maximal Strength Measurements

Half-squat on a Smith machine was used as an exercise to identify lower limb maximal strength. Direct measure of 1-RM was not used since participants were afraid to perform squats with heavy weights. Furthermore, individuals with little or no experience using heavy weights in strength training increase their chance for accident and injuries. A prediction of one-repetition-maximum (1-RM) from a 4–6 RM submaximal strength test was used (36). A specific standardized warm-up was done before starting the test. The test was stopped when the participant failed to perform a full range of motion of the exercise. In addition, participants who performed more than 6 repetitions were stopped and told to repeat the test after increasing the load. The test was successful when the subject reached his RM between 4 and 6-RM. Each participant performed the squat technique following the protocol established by the National Strength and Conditioning Association (37). During all attempts, the participants were required to squat to a depth where a 90-degree knee angle was achieved. Bench press on a Smith machine was used to evaluate upper limb maximal strength. The same protocol has been used to predict 1-RM from a 4 to 6 RM submaximal strength test (36). Each participant performed the bench press technique following the protocol established by the National Strength and Conditioning Association (37).

Questionnaires

Sleep Quality

The Pittsburgh Sleep Quality Index (PSQI) was used to assess sleep quality and disturbances over a 1-month

time interval. 7 "components" related to subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction were scored. The addition of scores for these 7 components produces one global score (38). Higher PSQI scores indicate worse sleep quality. Sleep quality was collected since previous studies have shown significant correlations between sleep and bone health parameters (39–41).

Daily Calcium and Protein Intakes

Daily calcium intake (DCI) and daily protein intake (DPI) were evaluated by validated semi-quantitative food frequency questionnaires (42–44). The DCI questionnaire assesses 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 (42). On the other hand, the DPI questionnaire allows one to appreciate the intake of food that provides the majority of proteins (44). DCI and DPI questionnaires can be completed without any help. None of the participants was receiving any supplement in our study.

Physical Activity

The duration of physical activity per week (hour/week) was evaluated using the global physical activity questionnaire (45). This questionnaire includes 16 questions; it provides information about intensity, duration and frequency of physical activities in 3 domains (activity at work, during travel and when performing recreational activities).

Statistical Analysis

The means and standard deviations were calculated for all clinical, physical performance and bone parameters. All variables were evaluated for normality using the Shapiro-Wilk test. Comparisons between the 2 groups (inactive group and football group) were made after checking for Gaussian distribution. If Gaussian distribution was found, parametric unpaired *t*-tests were used. In other cases, Mann-Whitney *U*-tests were used. Univariate correlations were computed using Pearson's Test. Bone variables were compared between the 2 groups after adjustment for sprint performance (first model) and for physical activity (second model) 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.

Results

Clinical Characteristics and Bone Variables of the Study Population

Age, weight, height, BMI, lean mass, fat mass, DCI, DPI, PSQI, total Radius BMD, SI and BR were not significantly different between the 2 groups. Fat mass percentage was higher in inactive men compared to football players. Physical activity level, WB BMC, WB BMD, L1-L4 BMD, TH BMD, FN BMD, CSA, CSMI, Z, CSI, BSI, and ISI were significantly higher in football players compared to inactive men (Table 1).

Physical Performance Variables of the Study Population

Handgrip and 1-RM bench press were not significantly different between the 2 groups. Vertical jump, maximum power of the lower limbs, HJ, 1-RM half-squat, 10-meter sprint performance, 10-meter average velocity and VO_2 max (ml/mn/kg) were significantly higher in football players compared to inactive men (Table 2).

Correlations Between Clinical Variables and Bone Characteristics of the Study Population

Weight, height and lean mass were positively correlated to WB BMC, WB BMD, FN BMD, CSA, CSMI, and Z. Fat mass was negatively correlated to CSI and ISI. Fat mass percentage was negatively correlated to CSI, BSI, and ISI. DPI was positively correlated to WB BMD, L1-L4 BMD, TH BMD, FN BMD, and CSA. Physical activity level was positively correlated to WB BMC, WB BMD, TH BMD, FN BMD, CSA, CSMI, Z, SI, CSI, BSI, and ISI (Table 3).

Correlations Between Physical Performance Variables and Bone Characteristics of the Study Population

Vertical jump was positively correlated to FN BMD, CSI, and ISI. Maximum Power was positively correlated to WB BMC, WB BMD, TH BMD, FN BMD, Total radius BMD, CSA, CSMI, and Z. HJ (m) was positively correlated to L1-L4 BMD, FN BMD, CSA, CSI, and ISI. Handgrip was positively correlated to WB BMC, FN BMD, CSA, CSMI, and Z. 1-RM half squat was positively correlated to WB BMC, WB BMD, TH BMD FN BMD, CSA, CSMI, Z, CSI, and ISI. 10m sprint performance was negatively correlated to WB BMC, WB BMD, L1-L4 BMD, TH BMD, FN BMD, CSA, CSMI, Z, SI, CSI, BSI, and ISI. VO_2 max (L/min) was positively correlated to WB BMC, WB BMD, TH BMD, FN BMD, CSA, CSMI, and Z. VO_2 max (ml/min/kg) was positively correlated to CSI and BSI (Table 4).

Bone Variables Adjusted for Several Covariates in the 2 Groups

After adjusting for sprint performance, WB BMD, L1-L4 BMD, TH BMD, FN BMD, CSA, CSI, BSI, and ISI remained significantly higher in former football players compared to inactive men. After adjusting for physical activity level, WB BMC, WB BMD, L1-L4 BMD, FN BMD, CSA, Z, CSI, BSI, and ISI remained significantly

Table 1
Clinical characteristics and bone variables of the study population

	Inactive men (n =20) Mean ± SD	Former football players (n = 15) Mean ± SD	*p* value
Age (years)	49.9 ± 3.5	49.5 ± 3.35	0.73
Weight (kg)	90.690 ± 9.680	89.933 ± 9.308	0.81
Height (m)	1.73 ± 0.05	1.76 ± 0.05	0.11
BMI (kg/m^2)	30.1 ±2.5	28.9 ± 2.6	0.18
Lean mass (kg)	57.685 ± 5.553	59.389 ± 4.616	0.34
Fat mass (kg)	30.711 ± 6.182	27.800 ± 6.040	0.17
Fat mass percentage	**33.4 ± 4.1**	**30.4 ± 4.2**	**0.04**
Physical activity (min/week)	**90.0 ± 33.5**	**131.3 ± 34.7**	**0.001**
Daily calcium intake (mg/d)	662 ± 206	592 ± 169	0.29
Daily protein intake (g/d)	79.8 ± 17.2	82.1 ± 16.7	0.70
PSQI	3.3 ±1.7	3.0 ±1.9	0.64
WB BMC (g)	**2978 ± 286**	**3279 ± 249**	**0.003**
WB BMD (g/cm^2)	**1.279 ± 0.088**	**1.381 ± 0.083**	**0.002**
L1-L4 BMD (g/cm^2)	**1.176 ± 0.127**	**1.332 ± 0.116**	**<0.001**
TH BMD (g/cm^2)	**1.071 ± 0.096**	**1.184 ± 0.096**	**0.002**
FN BMD (g/cm^2)	**0.998 ± 0.093**	**1.156 ± 0.106**	**<0.001**
Total Radius BMD (g/cm^2)	0.801 ± 0.067	0.814 ± 0.075	0.60
CSA (mm^2)	**170 ± 22**	**202 ± 17**	**<0.001**
CSMI (mm^2)^2	**16468 ± 4133**	**20818 ± 3887**	**0.003**
Z (mm^3)	**869 ± 173**	**1115 ± 171**	**<0.001**
SI	1.48 ± 0.36	1.72 ± 0.31	0.05
BR	3.62 ± 1.84	4.12 ± 1.49	0.39
CSI (g/kg-m)	**4.07 ± 0.38**	**4.90 ± 0.46**	**<0.001**
BSI (g/kg-m)	**1.29 ± 0.21**	**1.54 ± 0.19**	**0.001**
ISI (g/kg-m)	**0.275 ± 0.028**	**0.338 ± 0.032**	**<0.001**

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

higher in former football players compared to inactive men (Table 5).

Discussion

The current study conducted on a group of middle-aged men mainly shows that composite indices of FN strength (CSI, BSI, and ISI) are significantly higher in former football players compared to inactive subjects.

Age, weight, BMI, lean mass, fat mass, DCI, DPI and sleep quality were not significantly different between the 2 groups. Regarding bone health parameters, there were significant differences between the 2 groups: WB BMC, WB BMD, L1-L4 BMD, TH BMD, FN BMD, CSA, CSMI, Z, CSI, BSI, and ISI were significantly higher in former football players compared to inactive subjects. Interestingly, total radius BMD was not significantly different between the 2 groups. This result seems logical since football practice enhances BMD at the hip and the lumbar spine but not at the forearm (46).

As for the physical performance variables, 1-RM half-squat, vertical jump, HJ, sprinting performance, lower limb maximum power and maximum oxygen consumption were significantly higher in former football players compared to inactive subjects. Interestingly, handgrip and 1-RM bench press were not significantly different between the 2 groups. This result seems logical since football practice enhances lower limb strength, sprinting performance, jumping performance and maximum oxygen consumption but does not improve upper limb strength (46).

Regarding the correlations, body weight was not significantly correlated to composite indices of FN strength (CSI, BSI, and ISI). However, fat mass and fat mass percentage were negatively correlated to CSI and ISI. This result is in line with those of several recent studies conducted on adults (27,47). Fat mass excess seems to

Table 2
Physical performance variables of the study population

	Inactive men (n =20) Mean ± SD	Former football players (n = 15) Mean ± SD	*p* value
CMJ (cm)	**32.8 ±5.1**	**39.8 ± 2.8**	**<0.001**
Maximum power (Watts)	**1124 ± 129**	**1231 ± 126**	**0.02**
HJ (m)	**1.70 ± 0.22**	**2.00 ± 0.20**	**<0.001**
HG (kg)	46.6 ± 6.8	49.4 ± 6.5	0.24
1-RM half-squat (kg)	**74.4 ± 16.6**	**107.187 ± 19.712**	**<0.001**
1-RM bench press (kg)	54.6 ± 11.4	56.7 ± 8.6	0.55
10 m sprint performance (s)	**2.11 ± 0.15**	**1.90 ± 0.08**	**<0.001**
10 m average velocity (m/sec)	**4.75 ± 0.34**	**5.25 ± 0.22**	**<0.001**
VO_2 max (L/min)	**3.37 ± 0.30**	**3.73 ± 0.34**	**0.003**
VO_2 max (ml/min/kg)	**37.3 ± 3.1**	**41.7 ± 3.9**	**0.001**

CMJ, counter movement jump; HG, handgrip; HJ, horizontal jump; RM, repetition maximum; SD, standard deviation; VO_2 max, maximum oxygen consumption.
In bold, significant differences between the 2 groups.

negatively affect composite indices of FN strength. Accordingly, implementing strategies to reduce fat mass excess is important for middle-aged men to avoid the occurrence of osteoporotic fractures later in life. Many endocrine factors associated with increased fat mass such as reduced testosterone and growth hormone levels can negatively affect bone health parameters in men (48–50).

On the other hand, physical activity level was positively correlated to CSI, BSI, and ISI. This result confirms those of previous studies conducted on young adults (26–28).

Interestingly, PSQI score was negatively correlated to CSI. Higher PSQI scores indicate worse sleep quality. To our knowledge, this is the first study to demonstrate a negative correlation between PSQI score and CSI in men and to suggest that poor sleep quality index is associated with low CSI values. Future studies are necessary to investigate whether such correlations remain significant after controlling for BMI or fat mass. Our result confirms those of previous studies showing a negative effect of poor sleep quality on bone health parameters, and potential mechanisms have been discussed (39,41,51).

Weight, lean mass and physical activity level were positively correlated to BMC, BMD, and geometric indices of hip bone strength (CSA, CSMI. and Z). This result is in line with those of previous studies (33,52–62). Mechanical factors are well-known to stimulate bone formation (63). DPI was also positively correlated to BMD values. The positive effects of DPI on bone health parameters have been previously described (64).

Regarding physical performance variables, HJ and vertical jump were positively correlated to CSI and ISI. These 2 physical tests highlight the relative power. This is the first study to demonstrate positive correlations between jumping performances and composite indices of FN strength in-middle aged men. VO_2 max (ml/mn/kg) was also positively correlated to CSI and ISI. This result is in line with those of 2 recent studies conducted on young adults (29,65). Sprinting performance was correlated to CSI, BSI, and ISI. In fact, among all physical performance variables, sprinting performance was the best determinant of composite indices of FN strength. This is the first study to find significant correlations between sprinting performance and composite indices of FN strength. In addition, sprinting performance was the best determinant of 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 (66).

Future longitudinal studies should verify the impact of sprint training on SI, CSI, BSI, and ISI. 1-RM half squat was positively correlated to CSI and ISI. However, 1-RM bench press and handgrip were not correlated to composite indices of FN strength demonstrating a site-specific relation between muscular strength and bone strength indices. Accordingly, implementing strategies to increase jumping performance, maximal strength of the lower limbs, sprinting performance and maximal oxygen consumption seems crucial to prevent osteoporotic fractures in men. 1-RM half-squat was a stronger determinant of BMC, BMD and geometric indices of hip bone strength (CSA, CSMI, and Z) than handgrip. This result confirms those of 2 previous studies conducted on elderly subjects (67,68).

Maximum power calculated by the Sargent test was a strong determinant of BMC, BMD and geometric indices of hip bone strength (CSA, CSMI, and Z). The latter is in line with those of several studies conducted on young adults (33,54,69). Overall, the present study suggest that indices of absolute strength/power are correlated to BMC, BMD and geometric indices of hip bone strength (CSA, CSMI, and Z) while indices of relative strength/power are correlated to composite indices of FN strength

Table 3
Correlations between clinical variables and bone characteristics of the study population

	WB BMC (g)	WB BMD (kg/m^2)	L1-L4 BMD (kg/m^2)	TH BMD (kg/m^2)	FN BMD (kg/m^2)	Total Radius BMD (kg/m^2)	CSA (mm^2)	CSMI (mm^4)	Z (mm^3)	SI	BR	CSI (g/kg-m)	BSI (g/kg-m)	ISI (g/kg-m)
Age (years)	−0.11	−0.17	0.04	−0.19	−0.19	0.14	−0.23	−0.17	−0.19	0.01	0.07	−0.06	−0.08	−0.06
Weight (Kg)	0.59***	0.46**	0.18	0.43**	0.41*	0.33*	0.47**	0.42*	0.37*	−0.13	0.04	−0.18	−0.04	−0.17
Height (m)	0.65***	0.43**	0.19	0.30	0.49**	0.30	0.55***	0.45**	0.38*	0.26	0.14	0.23	0.20	0.18
BMI (kg/m^2)	0.26	0.26	0.08	0.31	0.16	0.18	0.19	0.20	0.19	−0.32	−0.04	−0.36*	−0.19	−0.32
LM (kg)	0.67***	0.49**	0.19	0.42*	0.55***	0.35*	0.65***	0.57***	0.53***	0.14	0.09	0.18	0.20	0.23
FM (kg)	0.29	0.26	0.09	0.23	0.09	0.18	0.11	0.11	0.11	−0.30	0.00	−0.45**	−0.26	−0.47**
FM %	-0.03	0.00	-0.02	0.01	-0.18	0.05	−0.21	−0.15	−0.15	−0.39*	−0.01	−0.58***	−0.38*	−0.62***
DCI (mg/d)	0.04	0.14	0.19	0.07	0.07	0.19	−0.01	−0.02	−0.05	−0.08	0.36*	−0.00	0.07	−0.05
DPI (g/d)	0.32	0.47**	0.41*	0.44**	0.43*	0.28	0.39*	0.25	0.25	−0.07	0.19	0.19	0.17	0.22
PA (h/week)	0.40*	0.36*	0.34	0.56***	0.72***	0.01	0.68***	0.47**	0.60***	0.36*	−0.18	0.61***	0.48**	0.56***
PSQI	−0.06	−0.11	−0.06	−0.20	−0.22	0.02	−0.24	−0.05	−0.19	−0.36*	0.16	−0.34*	−0.33	−0.27

Abbr: BMC, bone mineral content; BMD, bone mineral density; BMI, body mass index; BR, buckling ratio; BSI, bending strength index; CSA, cross sectional area; CSI, compression strength index; CSMI, cross-sectional moment of inertia; DCI, daily calcium intake; DPI, daily protein intake; FM, fat mass; FM%, fat mass percentage; FN, femoral neck; ISI, impact strength index; L1-L4, Lumbar spine; LM, lean mass; PA, physical activity; PSQI, Pittsburgh sleep quality index; SD, standard deviation; SI, strength index; TH, total hip; WB, whole body; Z, section modulus.
*$p < 0.05$;
**$p < 0.01$;
***$p < 0.001$.

Table 4
Correlations between physical performance variables and bone characteristics of the study population

	WB BMC (g)	WB BMD (kg/m^2)	L1-L4 BMD (kg/m^2)	TH BMD (kg/m^2)	FN BMD (kg/m^2)	Total Radius BMD (kg/m^2)	CSA (mm^2)	CSMI (mm^4)	Z (mm^3)	SI	BR	CSI (g/kg-m)	BSI (g/kg-m)	ISI (g/kg-m)
CMJ (cm)	0.15	0.11	0.14	0.27	0.38*	0.26	0.31	0.16	0.27	0.21	0.16	0.46**	0.29	0.47**
Maximum Power (watts)	0.60***	0.46**	0.23	0.55***	0.61***	0.48**	0.60***	0.47**	0.50**	0.03	0.15	0.14	0.14	0.15
HJ (m)	0.27	0.24	0.37*	0.27	0.38*	0.24	0.40*	0.19	0.32	0.30	0.09	0.51**	0.30	0.56***
Handgrip (Kg)	0.38*	0.25	0.21	0.27	0.38*	0.22	0.43**	0.36*	0.35*	0.16	0.09	0.18	0.14	0.23
1-RM half-squat (kg)	0.45**	0.47**	0.33	0.57***	0.66***	0.24	0.63***	0.46**	0.59***	0.18	0.02	0.51**	0.32	0.58***
1-RM BP (kg)	0.36*	0.31	0.02	0.08	0.21	0.23	0.37*	0.29	0.28	0.07	−0.04	−0.02	−0.13	0.10
10m sprint performance (s)	−0.44**	−0.39*	−0.35*	−0.35*	−0.55***	−0.29	−0.60***	−0.48**	−0.57***	−0.40*	−0.18	−0.58***	−0.44**	−0.61***
VO_2 max (L/min)	0.63***	0.62***	0.33	0.59***	0.63***	0.11	0.66***	0.41*	0.54***	0.12	−0.12	0.29	0.17	0.32
VO_2 max (ml/min/kg)	0.02	0.14	0.14	0.14	0.20	−0.24	0.17	−0.01	0.16	0.27	−0.16	0.48**	0.24	0.49**

Abbr: BP, bench press; BMC, bone mineral content; BMD, bone mineral density; BR, buckling ratio; BSI, bending strength index; CMJ, counter movement jump; CSA, cross-sectional area; CSI, compression strength index; CSMI, cross-sectional moment of inertia; FN, femoral neck; HJ, horizontal jump; ISI, impact strength index; L1-L4, Lumbar spine; RM, repetition maximum; SI, strength index; TH, total hip; VO_2 max, maximum oxygen consumption; WB, whole body; Z, section modulus.
*$p < 0.05$
**$p < 0.01$
***$p < 0.001$.

Table 5
Bone variables adjusted for several covariates in the 2 groups

	Adjusted for sprint performance (seconds)		Adjusted for physical activity (min/week)	
	Inactive men (n =20)	Former football players (n = 15)	Inactive men (n = 20)	Former football players (n = 15)
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
WB BMC (g)	3014 ± 60	3231 ± 69	3006 ± 60*	3242 ± 69
WB BMD (g/cm^2)	1.285 ± 0.019*	1.372 ± 0.022	1.248 ± 0.019*	1.373 ± 0.022
L1-L4 BMD (g/cm^2)	1.177 ± 0.029*	1.330 ± 0.032	1.182 ± 0.029**	1.324 ± 0.031
Total Radius BMD (kg/m^2)	0.816 ± 0.015	0.793 ± 0.017	0.799 ± 0.016	0.815 ± 0.018
TH BMD (g/cm^2)	1.074 ± 0.021*	1.180 ± 0.025	1.091 ± 0.020	1.157 ± 0.022
FN BMD (g/cm^2)	1.016 ± 0.021*	1.131 ± 0.025	1.028 ± 0.018*	1.115 ± 0.020
CSA (mm^2)	175 ± 4*	195 ± 5	176 ± 3*	194 ± 4
CSMI (mm^2)^2	17220 ± 881	19815 ± 1017	17097 ± 872	19979 ± 1008
Z (mm^3)	903 ± 34	1042 ± 40	910 ± 31*	1032 ± 36
SI	1.54 ± 0.07	1.63 ± 0.08	1.52 ± 0.07	1.66 ± 0.08
BR	3.76 ± 0.38	3.94 ± 0.44	3.34 ± 0.36	4.50 ± 0.42
CSI (g/kg-m)	4.14 ± 0.09***	4.81 ± 0.10	4.16 ± 0.08***	4.79 ± 0.10
BSI (g/kg-m)	1.31 ± 0.04*	1.51 ± 0.05	1.32 ± 0.04*	1.50 ± 0.05
ISI (g/kg-m)	0.280 ± 0.006***	0.330 ± 0.007	0.279 ± 0.006***	0.331 ± 0.007

Abbr: BMC, bone mineral content; BMD, bone mineral density; BR, buckling ratio; BSI, bending strength index; CSA, cross sectional area; CSI, compression strength index; CSMI, cross-sectional moment of inertia; DCI, daily calcium intake; DPI, daily protein intake; FM, fat mass; FM%, fat mass percentage; FN, femoral neck; ISI, impact strength index; L1-L4, Lumbar spine; SI, strength index; TH, total hip; Z, section modulus.
*$p < 0.05$;
**$p < 0.01$;
***$p < 0.001$.

(CSI, BSI and ISI). In parallel, absolute VO_2 max (L/mn) was a positive determinant of BMC, BMD and geometric indices of hip bone strength (CSA, CSMI, and Z) while relative VO_2 max (ml/mn/kg) was a positive determinant of CSI and ISI. These results should be interpreted with caution since the step test is an indirect test in which the performance could be affected by several factors such as strength of the lower limb, balance and leg length. However, several recent studies have shown that VO_2 max (L/mn) is one of the strongest determinants of BMC and BMD in young adults (33,65,70,71). Bone variables were compared between the 2 groups after adjusting for sprinting performance in the first model. The results showed that most of the studied bone variables (WB BMD, L1-L4 BMD, TH BMD, FN BMD, CSA, CSI, BSI, and ISI) remained significantly higher in former football players compared to inactive subjects. This result suggests that the differences between the 2 groups are not related to the differences in their sprinting performance levels but are most probably due to the former football practice. In the second model, bone variables were compared between the 2 groups after adjusting for physical activity. The results showed that several bone variables (WB BMC, WB BMD, L1-L4 BMD, FN BMD, CSA, Z, CSI, BSI, and ISI) remained significantly higher in former football players compared to inactive subjects. This result suggests that the differences between the 2 groups are not related to the differences in their physical activity level but are most probably due to the former football practice. Long-term football practice in adolescence and young adulthood seems to enhance composite indices of FN strength. This practice may confer residual benefits in composite indices of FN in middle-aged men.

Despite its originality, the current study has several limitations. Firstly, the cross-sectional nature of the study is a limitation since it cannot confirm a causal relationship between former football practice and present CSI, BSI, and ISI values. Secondly, the low number of subjects in each group is a limitation; however, power values were sufficient to run the analyses and to test the differences between the 2 groups regarding bone health parameters. Thirdly, several bone health correlates (hormones and vitamin D levels) were not evaluated in this study. Fourthly, visceral fat mass was not evaluated in this study; however, visceral fat has a well-known deleterious effect on bone variables (56–60). Finally, we did not use a physical activity questionnaire (72,73) to measure the effect of mechanical strain on BMD as previously described. However, up to our knowledge, this is the first study to compare composite indices of FN strength (CSI, BSI, and ISI) in inactive middle-aged men and middle-aged former football players.

In conclusion, the current study suggests that former football practice in adolescence and young adulthood is associated with increased composite indices of FN strength in middle-aged men. This is the first study which shows that regular football practice before the young adulthood period may confer residual benefits in composite indices of FN in middle-aged men. Consequently, the practice of football during adolescence and young adulthood may have a preventive effect against osteoporotic fractures later in life. The designation of exercise programs during adolescence and young adulthood should be adapted accordingly.

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BF, GZ, and REH discussed the concept, compiled the literature and wrote the paper. BF did the experimental work.

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Study 3: The Effects of a 1-year Recreational Football Protocol on Bone Mineral Density and Physical Performance Parameters in a Group of Healthy Inactive 50-year-Old Men.

1. Objective of the study

The main aim of the study was to compare the effects of two recreational football protocols (RF30: 2x30min vs RF60: 2x60min for 1 year) on bone health and physical performance parameters in a group of healthy inactive middle-aged men.

2. Materials and methods

2.1 Subjects

51 middle-aged men voluntarily participated in this study. Their mean age was 50.2 ± 4.5 years. They were healthy and had no history of major orthopaedic problems or other disorders that affect bone metabolism.

Subjects were divided into two major categories: inactive (n=37) and active men (former football players; n=14).

Former football players were assigned into the formal football group (FF) based on their former and recent practice of football. They had been practicing football regularly in their adolescence and young adulthood ages (for at least 10 years) and were regular participants in national competitions. They had been training in their clubs 4 to 6 times per week, for 6–9 h/week for 10 years.

Inactive middle-aged men were randomly assigned into 3 groups: Recreational football 60 (RF60; n = 13), Recreational football 30 (RF30; n = 14) and control group (C; n = 10). Being inactive was defined as "performing less than 150 minutes of moderate intensity physical activity or 75 minutes of vigorous-intensity physical activity or an equivalent combination of moderate- and vigorous-intensity activity a week accumulated across work, home, transport or discretionary domains" (WHO, 2010). In addition, these participants didn't have a former regular practice of any impact sport in their adolescence and young adulthood ages.

A total of 41 subjects completed the study, and 10 subjects dropped out for different reasons. Thus, 10 subjects from RF60, 10 subjects from RF30, 10 subjects from C and 11 subjects from FF completed the study.

Before the beginning of the intervention, the subjects who participated in the intervention group (RF60 and RF30) were checked by a specialised physician who gave them approval to perform physical activity at a high intensity.

2.2 Measurements

All measurements (anthropometric, body composition, bone and physical performance parameters) were performed in all 4 groups before and after the training period (duration: one year).

2.3 Recreational football protocol

The training lasted for 1 year with 2 training sessions per week. All participants played football on the same mini football artificial grass pitch. All recreational football games were supervised by the author of the thesis. Training time of play was progressively increased each 8 weeks by decreasing the rest period during the game.

For the RF60 group, participants played a normal mini-football game 2 times per week for 60 min in total. In the first 8 weeks of training, 15 min of rest (3 rest periods of 5 min) were taken. Therefore, the players played for four intervals of approximately 11 minutes separated by 5 minutes of active rest. From 8 to 16 weeks, 12 min of rest (3 rest period of 4 min) were taken. Therefore, subjects played for 4 intervals for 12 minutes separated by 4 minutes of active rest. From 16 to 24 weeks, 9 min of rest were taken (3 rest period of 3 min). Therefore, subjects played for 4 intervals for approximately 13 minutes by 3 minutes of active rest. From 24 to 32, 6 min of rest were taken (3 rest period of 2 min). Therefore, subjects played for 4 intervals for 13.5 minutes separated by 2 minutes of active rest. Finally, in the last 16 weeks, players played all the 60 min game with no rest. Players who were resting actively were asked to walk slowly.

For the RF30 group, participants also played a mini football game 2 times per week for 30 min in total. In the first 8 weeks of training, 5 min of rest were taken. Therefore, the players played 2 intervals of approximately 12 minutes separated by 5 minutes of active rest. From 8 to 16 weeks, 4 min of rest were taken. Therefore, subjects played for 2 intervals of 13 minutes

separated by 4 minutes of active rest. From 16 to 24 weeks, 3 min of rest were taken between the 13 minutes and 30 seconds time of play. From 24 to 32 weeks, only 2 minutes of rest were taken. Therefore, subjects played for 2 intervals of 14 minutes separated by 2 minutes of active rest. Finally, in the last 16 weeks, players played all the 30 min game with no rest. Players who were resting actively were asked to walk slowly.

Several rules were used in the recreational football games to ensure better safety for the participants. Participants were not allowed to have major physical contact with each other; for example, while stealing the ball from the opponent player, it is legal in a normal game to use the body (shoulder) to steal the ball, but in our protocol, we directly stopped the game considering this as a foul to prevent risk of falls or any injuries related to physical contact. Moreover, before each game, instructions were given to players such as, play for fun, try to win but not aggressively, play with no major physical contacts, play fairly and enjoy the game. All participants performed a specific warm-up before starting the games. In all recreational football games, the two goal keepers were not from the study population and did not participate in the study.

2.4 Statistical analysis

The mean and the standard deviation or standard error of the mean were calculated for each variable. Intergroup differences were judged by one-way analysis of variance. Correlations between the percentage of variations of clinical, bone and physical parameters and the percentage of attendance were performed using the Pearson test. To judge possible longitudinal differences in the groups (RF60, RF30, FF and C) following training, we used a two-way repeated measure analysis of variance (two-way-RM-Anova). The percentages of variations in physical qualities and bone parameters were calculated for the 4 groups. A value of $p<0.05$ was required in order to confirm the significance of the results.

3. Results

3.1 Clinical characteristics and bone variables of the study population at baseline

Former football players were significantly taller than the control subjects. WB BMC and CSMI were significantly higher in FF compared to C. FN BMD, CSA, CSI and ISI were

significantly higher in FF compared to C and RF30. Z was significantly higher in FF compared to C and RF60.

Table 19: Clinical characteristics and bone variables of the study population at baseline.

	C n=10	FF n=11	RF30 n=10	RF60 n=10	p-value
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
Age (years)	51.8 ± 4.7	48.7 ± 3.1	48.8 ± 5.4	51.07 ± 5.1	P = 0.348
Weight (kg)	84.8 ± 13.4	90.9 ± 9.5	94.3 ± 11.5	93.4 ± 18.0	P = 0.404
Height (m)	**1.68 ± 0.06[a]**	**1.76 ± 0.05**	**1.74 ± 0.02**	**1.75 ± 0.07**	**P= 0.004**
BMI (kg/m^2)	29.7 ± 4.2	29.1 ± 2.8	31.0 ± 3.4	30.3 ± 4.9	P = 0.713
Lean mass (Kg)	53.6 ± 5.8	60.3 ± 4.9	59.2 ± 6.2	57.3 ± 7.6	P = 0.097
Fat mass (Kg)	29.0 ± 9.3	27.4 ± 6.0	32.5 ± 7.7	33.3 ± 1.1	P = 0.372
Fat mass percentage	33.4 ± 5.7	29.9 ± 4.2	34.0 ± 4.8	34.9 ± 5.0	P = 0.124
Physical activity (min/week)	101.0 ± 23.3	132.2 ± 33.4	110.0 ± 26.6	105.5 ± 32.8	P = 0.088
WB BMC (g)	**2836 ± 266[a]**	**3283 ± 243**	**3087 ± 295**	**3095 ± 429**	**P= 0.002**
WB BMD (g/cm^2)	1.281 ± 0.0788	1.383 ± 0.0885	1.295 ± 0.0898	1.310 ± 0.137	P = 0.109
L1-L4 BMD (g/cm^2)	1.206 ± 0.138	1.332 ± 0.134	1.203 ± 0.0840	1.241 ± 0.158	P = 0.100

TH BMD (g/cm^2)	1.075 ± 0.119	1.172 ± 0.0968	1.104 ± 0.0799	1.093 ± 0.158	P = 0.257
FN BMD (g/cm^2)	**1.006 ± 0.121[a,c]**	**1.157 ± 0.0910**	**1.009 ± 0.0568**	**1.067 ± 0.143**	**P= 0.007**
Total Radius BMD (g/cm^2)	0.795 ± 0.0706	0.804 ± 0.0810	0.806 ± 0.0563	0.807 ± 0.0561	P = 0.980
CSA (mm^2)	**163.7 ± 2.2[a,c]**	**202.5 ± 16.1**	**174.3 ± 15.5**	**185.6 ± 28.9**	**P=0.001**
CSMI $(mm^2)^2$	**13894 ± 2355[a]**	**21164 ± 4128**	**17280 ± 2652**	**18095 ± 4928**	**P<0.001**
Z (mm^3)	**768 ± 101[a,d]**	**1092 ± 151**	**923 ± 90**	**964 ± 237**	**P<0.001**
SI	1.570 ± 0.340	1.655 ± 0.330	1.360 ± 0.357	1.720 ± 0.402	P = 0.141
BR	4.060 ± 2.021	4.255 ± 1.373	3.130 ± 1.396	3.630 ± 1.683	P = 0.420
CSI (g/kg-m)	**4.19 ± 0.57[a,c]**	**4.89 ± 0.48**	**4.04 ± 0.62**	**4.26 ± 0.58**	**P = 0.007**
BSI (g/kg-m)	1.32 ± 0.21	1.53 ± 0.22	1.27 ± 0.28	1.38 ± 0.23	P = 0.093
ISI (g/kg-m)	**0.27 ± 0.04[a,c,d]**	**0.34 ± 0.03**	**0.27 ± 0.04**	**0.28 ± 0.04**	**P = 0.001**

Significant difference in Bold: FF vs C[a]; RF30 vs C[b]; FF vs RF30 [c]; FF vs RF60 [d]; RF60 vs RF30 [e]; 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; SI: strength index; BR: buckling ratio; CSI: compression strength index; BSI: bending strength index; ISI: impact strength index.

3.2 Physical performance variables of the study population before the intervention

CMJ and 10-m sprint were significantly higher in FF compared to C and RF30. HG was significantly higher in FF and RF30 compared to C. 1-RM half squat was significantly higher in FF compared to C, RF30 and RF60 and was higher in RF30 and RF60 compared to C. VO2 max (L/min) was significantly higher in FF compared to C.

Table 20: Physical performance variables of the study population before the intervention.

	C n=10	FF n=11	RF30 n=10	RF60 n=10	p-value
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
CMJ (cm)	**32.6 ± 5.8[a,c]**	**40.0 ± 3.0**	**34.3 ± 4.1**	**36.1 ± 4.2**	**P=0.004**
Maximum Power (Watts)	**1042.35 ± 129.9[a,f]**	**1247.20 ± 135.50**	**1193.09 ± 131.08**	**1228.46 ± 183.60**	**P = 0.013**
HG (kg)	**43.1 ± 4.9[a,b]**	**50.6 ± 6.9**	**52.0 ± 6.7**	**46.6 ± 5.5**	**P = 0.011**
1-RM half-squat (kg)	**61.6 ± 12.5[a,b,c,d,f]**	**110.1 ± 21.0**	**86.6 ± 12.2**	**81.6 ± 12.9**	**P<0.001**
1-RM bench press (kg)	50.4 ± 11.0	59.1 ± 7.3	53.8 ± 9.7	53.3 ± 11.2	P = 0.266
10 m sprint performance (s)	**2.166 ± 0.176[a,c]**	**1.891 ± 0.0813**	**2.072 ± 0.132**	**2.023 ± 0.109**	**P = <0.001**
VO_2 max (L/min)	**3.26 ± 0.43[a]**	**3.73 ± 0.34**	**3.52 ± 0.31**	**3.55 0.37**	**P=0.045**
VO_2 max (ml/min/kg)	38.843 ± 4.143	41.377 ± 4.191	37.970 ± 5.308	38.175 ± 5.143	P = 0.332

Significant difference in bold: F vs C[a]; CF30 vs C[b]; F vs CF30[c]; F vs RF60[d]; RF60 vs RF30[e]; RF60 vs C[f]; SD: standard deviation; CMJ: counter movement jump; HG: handgrip; RM: Repetition Maximum; VO_2 max: maximum oxygen consumption.

3.3 Clinical characteristics and bone variables of the Former football group and the inactive controls (C, RF30 and RF60 combined) at baseline

Body fat mass % was significantly lower in FF compared to control group (C+RF60+RF30). Physical activity (min/week), WB BMC, WB BMD, L1-L4 BMD, FN BMD, CSA, CSMI, Z. CSI, BSI and ISI were significantly higher in FF compared to the control group.

Table 21: Clinical characteristics and bone variables of the Former football group and the inactive controls (C, RF30 and RF60 combined) at baseline.

	C + RF30 + RF60 n=30	FF n=11	p-value
	Mean ± SD	Mean ± SD	
Age (years)	50.5 ± 5.1	48.7 ± 3.1	P = 0.279
Weight (kg)	90.8 ± 14.7	90.9 ±9.5	P = 0.993
Height (m)	172.63 ± 6.32	176.63 ± 5.98	P = 0.076
BMI (kg/m^2)	30.4 ± 4.1	29.1 ± 2.8	P = 0.361
Lean mass (kg)	56.7 ± 6.7	60.1 ± 4.9	P= 0.120
Fat mass (kg)	31.6 ± 9.3	27.4 ± 6.0	P= 0.176
Fat mass percentage	**34.1 ± 5.0**	**29.9 ± 4.2**	**P=0.019**
Physical activity (min/week)	**105.5 ± 26.9**	**132.2 ± 33.4**	**P=0.012**
WB BMC (g)	**3006 ± 348**	**3283 ± 243**	**P=0.021**
WB BMD (g/cm^2)	**1.295 ± 0.102**	**1.383 ± 0.0885**	**P=0.016**
L1-L4 BMD (g/cm^2)	**1.217 ± 0.127**	**1.332 ± 0.134**	**P=0.015**
TH BMD (g/cm^2)	1.091 ± 0.119	1.172 ± 0.0968	P=0.050

FN BMD (g/cm^2)	**1.027 ± 0.113**	**1.157 ± 0.0910**	**P=0.001**
Total Radius BMD (g/cm^2)	0.803 ± 0.0595	0.804 ± 0.0810	P=0.952
CSA (mm^2)	**174.5 ± 23.9**	**202.5 ± 16.1**	**P = <0.001**
CSMI (mm^2)^2	**16423 ± 3855**	**21164 ± 4128**	**P = 0.001**
Z (mm^3)	**885 ± 175**	**1092 ± 151**	**P = 0.001**
SI	1.550 ± 0.385	1.655 ± 0.330	P=0.429
BR	3.607 ± 1.703	4.255 ± 1.373	P=0.265
CSI (g/kg-m)	**4.02 ± 0.92**	**4.89 ± 0.48**	**P= 0.006**
BSI (g/kg-m)	**1.33 ± 0.24**	**1.53 ± 0.22**	**P= 0.023**
ISI (g/kg-m)	**0.28 ± 0.03**	**0.34 ± 0.03**	**P< 0.001**

In bold, significant differences; 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; SI: strength index; BR: buckling ratio; CSI: compression strength index; BSI: bending strength index; ISI: impact strength index.

3.4 Physical performance variables of the Former football group and the inactive controls (C, RF30 and RF60 combined) at baseline

CMJ, 1-RM half squat, 1-RM Bench press, 10m sprint, absolute and relative VO2 max were significantly higher in the FF group compared to the control group (C+RF30+RF60).

Table 22: Physical performance variables of the study population before the intervention.

	C +RF30+RF60 n=30	FF n=11	p-value
	Mean ± SD	Mean ± SD	

CMJ (cm)	**34.2 ± 4.8**	**40.0 ± 3.0**	**P = <0.001**
Maximum Power (Watts)	1152.09 ± 165.40	1247.20 ± 135.50	P = 0.097
HG (kg)	47.3 ± 6.7	50.6 ±6.9	0.117
1-RM half-squat (kg)	**76.6 ± 16.3**	**110.1 ± 21.0**	**P = <0.001**
1-RM bench press (kg)	52.5 ± 10.3	59.1 ± 7.3	P = 0.066
10 m sprint performance (s)	**2.089 ± 0.150**	**1.891 ± 0.0813**	**P = <0.001**
VO_2 max (L/min)	**3.45 ± 0.38**	**3.73 ± 0.34**	**P = 0.034**
VO_2 max (ml/min/kg)	**38.335 ± 4.720**	**41.377 ± 4.191**	**P = 0.069**

In bold, significant differences; SD: standard deviation; CMJ: counter movement jump; HG: handgrip; RM: Repetition Maximum; VO_2 max: maximum oxygen consumption.

3.5 Clinical and bone parameters at baseline and after the 1-year period in the control group

Whole body bone mineral density significantly decreased in the control group after a 1-year period. No significant changes were found concerning the other clinical and bone parameters.

Table 23: Clinical and bone parameters before and after the training period in the control group.

Control (n=10)	Before intervention	After intervention	p-value
	Mean ± SD	Mean ± SD	

Weight (kg)	84.8 ± 13.4	84.8 ± 13.0	P = 0.828
BMI (kg/m^2)	29.7 ± 4.2	29.7 ± 4.2	P = 0.950
Lean mass (kg)	53.6 ± 5.8	53.3 ± 5.9	P = 0.418
Fat mass (kg)	29.0 ± 9.3	29.2 ± 9.5	P = 0.733
Fat mass percentage	33.4 ± 5.7	33.6 ± 6.0	P = 0.663
Physical activity (min/week)	101.0 ± 23.3	100.5 ± 21.4	P = 0.840
WB BMC (g)	2836.500 ± 266.563	2853.800 ± 292.065	P = 0.380
WB BMD (g/cm^2)	**1.281 ± 0.0788**	**1.231 ± 0.0820**	**P = 0.006**
L1-L4 BMD (g/cm^2)	1.206 ± 0.138	1.228 ± 0.120	P = 0.268
TH BMD (g/cm^2)	1.075 ± 0.119	1.091 ± 0.133	P = 0.149
FN BMD (g/cm^2)	1.006 ± 0.121	0.988 ± 0.125	P = 0.232
Total Radius BMD (g/cm^2)	0.795 ± 0.0706	0.803 ± 0.0645	P = 0.257
CSA (mm^2)	163.7 ± 22.2	162.8 ± 23.0	P = 0.734
CSMI (mm^2)^2	13894 ± 2355	13603 ± 2571	P = 0.550
Z (mm^3)	768 ± 101	749 ± 121	P = 0.468
SI	1.570 ± 0.340	1.510 ± 0.446	P = 0.546
BR	4.060 ± 2.021	3.660 ± 2.038	P = 0.401
CSI (g/kg-m)	4.19 ± 0.57	4.14 ± 0.60	P = 0.489
BSI (g/kg-m)	1.32 ± 0.21	1.30 ± 0.23	P = 0.468

ISI (g/kg-m)	0.27 ± 0.04	0.27 ± 0.04	P = 0.361

In bold, significant difference; 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; SI: strength index; BR: buckling ratio; CSI: compression strength index; BSI: bending strength index; ISI: impact strength index.

3.6 Physical performance variables at baseline and after the 1-year period in the control group

Handgrip strength was significantly decreased. No significant changes were found for the other physical parameters.

Table 24: Physical performance variables at baseline and after the 1-year period in the control group.

CONTROL (n=10)	Before intervention	After intervention	p-value
	Mean ± SD	Mean ± SD	
CMJ (cm)	32.6 ± 5.8	32.1 ± 5.7	P = 0.248
Maximum Power (Watts)	1042.35 ± 129.94	1033.70 ± 127.91	P = 0.266
HG (kg)	**43.1 ±4.9**	**40.4 ±4.4**	**P = <0.001**
1-RM half-squat (kg)	61.6 ± 12.5	60.0 ± 12.2	P = 0.195
1-RM bench press (kg)	50.4 ± 11.0	45.3 ± 11.8	P = 0.123
10 m sprint performance (s)	2.166 ± 0.176	2.188 ± 0.180	P = 0.091
VO_2 max (L/min)	3.26 ± 0.43	3.23 ± 0.44	P = 0.060

VO_2 max (ml/min/kg)	38.843 ± 4.143	38.428 ± 4.061	P = 0.234

In bold, significant differences; SD: standard deviation; CMJ: counter movement jump; HG: handgrip; RM: Repetition Maximum; VO_2 max: maximum oxygen consumption.

3.7 The effect of recreational football on clinical and bone parameters in the former football group (FF)

Whole body bone mineral density significantly decreased (**P = 0.009**) in FF after a 1-year period. No significant changes were found concerning the other clinical and bone parameters.

Table 25: Clinical and bone parameters before and after the training period in the former football group.

FF (n=11)	Before intervention	After intervention	p-value
	Mean ± SD	Mean ± SD	
Weight (kg)	90.9 ± 9.5	89.0 ± 10.5	P = 0.104
BMI (kg/m^2)	29.1 ± 2.8	28.5 ± 3.2	P = 0.094
Lean mass (kg)	60.3 ± 4.9	59.5 ± 4.1	P = 0.410
Fat mass (kg)	27.4 ± 6.0	27.1 ± 7.5	P = 0.707
Fat mass percentage	29.9 ± 4.2	29.7 ± 5.3	P = 0.766
Physical activity (min/week)	132.2 ± 33.4	135.9 ± 32.8	P = 0.267
WB BMC (g)	3283 ± 243	3304 ± 235	P = 0.244
WB BMD (g/cm^2)	**1.383 ± 0.0885**	**1.327 ± 0.102**	**P = 0.009**
L1-L4 BMD (g/cm^2)	1.332 ± 0.134	1.328 ± 0.133	P = 0.777

TH BMD (g/cm^2)	1.172 ± 0.0968	1.173 ± 0.0943	P = 0.880
FN BMD (g/cm^2)	1.157 ± 0.0910	1.143 ± 0.0926	P= 0.181
Total Radius BMD (g/cm^2)	0.804 ± 0.0810	0.806 ± 0.0808	P = 0.667
CSA (mm^2)	202.5 ± 16.1	205.4 ± 17.9	P = 0.245
CSMI $(mm^2)^2$	21164 ± 4128	21433 ± 5425	P = 0.723
Z (mm^3)	1092 ± 151	1116 ± 204	P = 0.553
SI	1.655 ± 0.330	1.782 ± 0.322	P = 0.105
BR	4.255 ± 1.373	3.282 ± 1.165	P = 0.067
CSI (g/kg-m)	4.89 ± 0.48	5.11 ± 0.72	P = 0.214
BSI (g/kg-m)	1.53 ± 0.22	1.71 ± 0.42	P = 0.309
ISI (g/kg-m)	0.34 ± 0.03	0.36 ± 0.05	P = 0.217

In bold, significant difference; 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; SI: strength index; BR: buckling ratio; CSI: compression strength index; BSI: bending strength index; ISI: impact strength index.

3.8 Physical performance parameters before and after the training period in the former football group

No significant changes were found concerning the physical performance variables in FF after 1 year of recreational football.

Table 26: Physical performance parameters before and after the training period in the former football group.

FF (n=11)	Before intervention	After intervention	p-value

	Mean ± SD	Mean ± SD	
CMJ (cm)	40.0 ± 3.0	40.7 ± 4.2	P = 0.233
Maximum Power (Watts)	1247.20 ± 135.50	1232.37 ± 151.58	P = 0.266
HG (kg)	50.6 ± 6.9	45.7 ± 11.0	P = 0.091
1-RM half-squat (kg)	110.1 ± 21.0	111.0 ± 19.3	P = 0.755
1-RM bench press (kg)	59.1 ± 7.3	60.2 ± 7.1	P = 0.246
10 m sprint performance (s)	1.891 ± 0.0813	1.875 ± 0.108	P = 0.413
VO_2 max (L/min)	3.73 ± 0.34	3.73 ± 0.36	P = 0.958
VO_2 max (ml/min/kg)	41.377 ± 4.191	42.349 ± 5.289	P = 0.101

In bold, significant differences; SD: standard deviation; CMJ: counter movement jump; HG: handgrip; RM: Repetition Maximum; VO_2 max: maximum oxygen consumption.

3.9 The effect of recreational football on clinical and bone parameters in the Recreational Football 30 group (RF30)

After the 1-year intervention period, Physical activity (minutes/week), WB BMC, FN BMD, CSA, CSMI, Z, SI, CSI, BSI and ISI significantly increased in the RF30.

Table 27: Clinical and bone parameters before and after the training period in the recreational football 30 group.

RF30 (n=10)	Before intervention	After intervention	p-value
	Mean ± SD	Mean ± SD	

Weight (kg)	94.3 ± 11.5	93.6 ± 11.6	P = 0.346
BMI (kg/m^2)	31.0 ± 3.4	30.8 ± 3.5	P = 0.355
Lean mass (kg)	59.2 ± 6.2	59.2 ± 6.4	P = 0.911
Fat mass (kg)	32.5 ± 7.7	31.8 ± 7.4	P = 0.070
Fat mass percentage	34.0 ± 4.8	33.4 ± 4.5	P = 0.131
Physical activity (min/week)	**110.0 ± 26.6**	**165.0 ± 26.6**	**P = <0.001**
WB BMC (g)	**3087 ± 295**	**3139 ± 287**	**P = 0.004**
WB BMD (g/cm^2)	1.295 ± 0.0898	1.265 ± 0.103	P = 0.098
L1-L4 BMD (g/cm^2)	1.203 ± 0.0840	1.260 ± 0.0692	P = 0.058
TH BMD (g/cm^2)	1.104 ± 0.0799	1.122 ± 0.0676	P = 0.05
FN BMD (g/cm^2)	**1.009 ± 0.0568****	**1.066 ± 0.0620**	**P = 0.003**
Total Radius BMD (g/cm^2)	0.806 ± 0.0563	0.800 ± 0.0534	P = 0.374
CSA (mm^2)	**174.3 ± 15.5**	**188.3 ± 14.9**	**P = 0.004**
CSMI (mm^2)^2	**17280 ± 2652**	**18479 ± 2783**	**P = 0.011**
Z (mm^3)	**923 ± 90**	**975 ± 101**	**P = 0.019**
SI	**1.360 ± 0.357****	**1.630 ± 0.455**	**P = 0.009**
BR	3.130 ± 1.396	3.360 ± 1.380	P = 0.524
CSI (g/kg-m)	**4.04 ± 0.62**	**4.42 ± 0.80**	**P = 0.002**
BSI (g/kg-m)	**1.27 ± 0.28**	**1.45 ± 0.46**	**P = 0.038**

ISI (g/kg-m)	**0.27 ± 0.04**	**0.30 ± 0.05**	**P = 0.003**

In bold, significant difference; 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; SI: strength index; BR: buckling ratio; CSI: compression strength index; BSI: bending strength index; ISI: impact strength index.

3.10 The effect of recreational football on physical performance parameters in the recreational football 30 group (RF30)

Concerning physical performance parameters, CMJ, 1RM half squat, absolute and relative VO_2 max significantly increased. On the other hand, HG significantly decreased.

Table 28: Physical performance parameters before and after the training period in the recreational football 30 group.

RF30 (n=10)	Before intervention	After intervention	p-value
	Mean ± SD	Mean ± SD	
CMJ (cm)	**34.3 ± 4.1**	**36.7 ± 5.2**	**P = 0.026**
Maximum Power (Watts)	1193.09 ± 131.08	1222.55 ± 110.78	P = 0.151
HG (kg)	**52.0 ± 6.7**	**47.5 ± 6.3**	**P = <0.001**
1-RM half-squat (kg)	**86.6 ± 12.2**	**91.7 ± 15.0**	**P = 0.046**
1-RM bench press (kg)	53.8 ± 9.7	53.5 ± 7.8	P = 0.773
10 m sprint performance (s)	2.072 ± 0.132	2.013 ± 0.139	P = 0.067
VO_2 max (L/min)	**3.52 ± 0.31**	**3.75 ± 0.30**	**P = <0.001**

VO_2 max (ml/min/kg)	**37.970 ± 5.308*** **	**40.608 ± 5.760**	**P = <0.001**

In bold, significant differences; SD: standard deviation; CMJ: counter movement jump; HG: handgrip; RM: Repetition Maximum; VO_2 max: maximum oxygen consumption.

3.11 The effect of recreational football on clinical and bone parameters in the Recreational Football 60 group (RF60)

After the 1-year intervention period, physical activity (min/week), WB BMC, L1-L4 BMD, TH BMD, FN BMD, CSMI, CSI, BSI and BSI significantly increased in RF60. On the other hand, WB BMD significantly decreased.

Table 29: Clinical and bone parameters before and after the training period in the recreational football 60 group.

RF60 (n=10)	Before intervention	After intervention	p-value
	Mean ± SD	Mean ± SD	
Weight (kg)	93.4 ± 18.0	91.9 ± 18.2	P = 0.154
BMI (kg/m^2)	30.3 ± 4.9	29.8 ± 5.0	P = 0.164
Lean mass (kg)	57.3 ± 7.6	57.4 ± 8.1	P = 0.814
Fat mass (kg)	33.3 ± 1.1	32.4 ± 1.1	P = 0.118
Fat mass percentage	34.9 ± 5.0	34.2 ± 4.8	P = 0.095
Physical activity (min/week)	**105.5 ± 32.8**	**175.5 ± 21.2**	**P = <0.001**
WB BMC (g)	**3095 ± 429**	**3158 ± 428**	**P = 0.016**
WB BMD (g/cm^2)	**1.310 ± 0.137**	**1.256 ± 0.0972**	**P = 0.018**

L1-L4 BMD (g/cm^2)	**1.241 ± 0.158**	**1.277 ± 0.183**	**P = 0.012**
TH BMD (g/cm^2)	**1.093 ± 0.158**	**1.119 ± 0.144**	**P = 0.015**
FN BMD (g/cm^2)	**1.067 ± 0.143**	**1.116 ± 0.121**	**P = 0.029**
Total Radius BMD (g/cm^2)	0.807 ± 0.0561	0.815 ± 0.0561	P = 0.124
CSA (mm^2)	185.6 ± 28.9	190.4 ± 39.4	P = 0.521
CSMI $(mm^2)^2$	**18095 ± 4928**	**19101 ± 5005**	**P = 0.019**
Z (mm^3)	964 ± 237	997 ± 207	P = 0.229
SI	1.720 ± 0.402	1.830 ± 0.432	P = 0.137
BR	3.630 ± 1.683	2.770 ± 1.313	P = 0.155
CSI (g/kg-m)	**4.26 ± 0.58**	**4.56 ± 0.59**	**P = 0.006**
BSI (g/kg-m)	**1.38 ± 0.23**	**1.47 ± 0.18**	**P = 0.023**
ISI (g/kg-m)	**0.28 ± 0.03**	**0.30 ± 0.04**	**P = 0.016**

In bold, significant difference; 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; SI: strength index; BR: buckling ratio; CSI: compression strength index; BSI: bending strength index; ISI: impact strength index.

3.12 The effect of recreational football on physical performance parameters in the recreational football 60 group (RF60)

Absolute and relative VO_2 max significantly increased but HG significantly decreased.

Table 30: Physical performance parameters before and after the training period in the recreational football 60 group.

RF60 (n=10)	Before intervention	After intervention	p-value

	Mean ± SD	Mean ± SD	
CMJ (cm)	36.1 ± 4.2	37.6 ± 5.6	P = 0.127
Maximum Power (Watts)	1228.46 ± 183.60	1228.99 ± 202.65	P = 0.972
HG (kg)	**46.6 ± 5.5**	**43.4 ± 5.5**	**P = <0.001**
1-RM half-squat (kg)	81.6 ± 12.9	84.7 ± 8.3	P = 0.171
1-RM bench press (kg)	53.3 ± 11.2	54.8 ± 11.9	P = 0.224
10 m sprint performance (s)	2.023 ± 0.109	1.978 ± 0.0894	P = 0.094
VO_2 max (L/min)	**3.55 ± 0.37**	**3.78 ± 0.43**	**P = <0.001**
VO_2 max (ml/min/kg)	**38.175 ± 5.143**	**41.538 ± 6.051**	**P = 0.001**

In bold, significant differences; SD: standard deviation; CMJ: counter movement jump; HG: handgrip; RM: Repetition Maximum; VO_2 max: maximum oxygen consumption.

3.13 The effect of recreational football on clinical and bone parameters in the recreational football groups (RF30+RF60 combined)

After the 1-year intervention period, physical activity (min/week), WB BMC, L1-L4 BMD, TH BMD, FN BMD, CSA, CSMI, Z, SI, CSI, BSI and BSI significantly increased. On the other hand, WB BMD significantly decreased.

Table 31: Clinical and bone parameters before and after the training period in the recreational football group (RF30+ RF60).

RF30 + RF60 (n=20)	Before intervention	After intervention	p-value

	Mean ± SD	Mean ± SD	
Weight (kg)	93.8 ± 14.7	92.7 ± 14.9	P = 0.077
BMI (kg/m^2)	30.7 ± 4.1	30.3 ± 4.2	P = 0.084
Lean mass (kg)	58.2 ± 6.8	58.3 ± 7.2	P = 0.808
Fat mass (kg)	**32.9 ± 9.4**	**32.1 ± 9.1**	**P = 0.016**
Fat mass percentage	**34.4 ± 4.8**	**33.8 ± 4.5**	**P = 0.019**
Physical activity (min/week)	**107.8 ± 28.9**	**170.0 ± 24.2**	**P = <0.001**
WB BMC (g)	**3091 ± 359**	**3149 ± 355**	**P = <0.001**
WB BMD (g/cm^2)	**1.302 ± 0.113****	**1.261 ± 0.0978**	**P = 0.003**
L1-L4 BMD (g/cm^2)	**1.222 ± 0.125**	**1.269 ± 0.135**	**P = 0.004**
TH BMD (g/cm^2)	**1.098 ± 0.122**	**1.120 ± 0.109**	**P = 0.001**
FN BMD (g/cm^2)	**1.038 ± 0.110**	**1.091 ± 0.0972**	**P = <0.001**
Total Radius BMD (g/cm^2)	0.806 ± 0.0547	0.808 ± 0.0539	P = 0.770
CSA (mm^2)	**179.9 ± 23.3**	**189.3 ± 29.0**	**P = 0.032**
CSMI (mm^2)^2	**17688 ± 3874**	**18790 ± 3954**	**P = <0.001**
Z (mm^3)	**944 ± 176**	**17688 ± 3874**	**P = <0.001**
SI	**1.540 ± 0.413**	**1.730 ± 0.444**	**P = 0.003**
BR	3.380 ± 1.527	3.065 ± 1.346	P = 0.368
CSI (g/kg-m)	**4.15 ± 0.60**	**4.49 ± 0.69**	**P = <0.001**

BSI (g/kg-m)	**1.33 ± 0.26**	**1.46 ± 0.35**	**P = 0.005**
ISI (g/kg-m)	**0.2 7± 0.03**	**0.30 ± 0.04**	**P = <0.001**

In bold, significant difference; 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; SI: strength index; BR: buckling ratio; CSI: compression strength index; BSI: bending strength index; ISI: impact strength index.

3.14 The effect of recreational football on physical performance parameters in the recreational football groups (RF30+RF60 combined)

Concerning the physical parameters, CMJ, 1 RM half squat, 10 m sprint, absolute and relative VO_2 max significantly increased but HG significantly decreased.

Table 32: Physical performance parameters before and after the training period in the recreational football 30 and 60 combined group.

RF30+RF60 (n=20)	Before intervention	After intervention	p-value
	Mean ± SD	Mean ± SD	
CMJ (cm)	**35.1 ± 4.2**	**37.1 ± 5.2**	**P = 0.005**
Maximum Power (Watts)	1209.84 ± 154.60	1225.60 ± 156.20	P = 0.215
HG (kg)	**49.4 ± 6.6**	**45.5 ± 6.1**	**P = <0.001**
1-RM half-squat (kg)	**84.1 ± 12.5**	**88.2 ± 12.3**	**P = 0.013**
1-RM bench press (kg)	53.6 ± 10.1	54.1 ± 9.7	P = 0.539
10 m sprint performance (s)	**2.049 ± 0.121**	**1.996 ± 0.117**	**P = 0.010**

VO_2 max (L/min)	**3.53 ± 0.33**	**3.77 ± 0.36**	**P = <0.001**
VO_2 max (ml/min/kg)	**38.067 ± 5.085**	**41.049 ± 5.752**	**P = <0.001**

In bold, significant differences; SD: standard deviation; CMJ: counter movement jump; HG: handgrip; RM: Repetition Maximum; VO_2 max: maximum oxygen consumption.

3.15 Differences in the percentages of variation related to clinical and bone parameters among the groups

The percentage of variation in Physical activity (min/week) was significantly higher in RF60 and RF30 compared to C and F and in RF60 compared to RF30. FN BMD percentage of variation was significantly higher in the RF30 and RF60 compared to C and F. SI, CSI and ISI percentages of variation were significantly higher in RF30 compared to C.

Table 33: Differences in the percentages of variation of the clinical and bone variables among control, former football and recreational football 30 and recreational football 60 groups.

	C n=10	FF n=11	RF30 n=10	RF60 n=10	p-value
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
Weight	-0.02 ± 1.59	-2.06 ± 3.71	-0.74 ± 2.40	-1.62 ± 3.70	P = 0.432
BMI	-0.02 ± 1.59	-2.06 ± 3.71	-0.74 ± 2.40	-1.62 ± 3.70	P = 0.432
Lean mass	-0.59 ±2.23	-1.03 ±4.49	0.10 ± 2.71	0.15 ± 2.38	P = 0.801
Fat mass	0.39 ± 4.63	-2.13 ± 10.94	-2.04 ± 3.46	-2.44 ± 5.59	P = 0.782
Fat mass %	0.47 ± 4.30	-1.06 ± 8.75	-1.41 ± 3.01	-1.75 ± 3.36	P = 0.810
Physical activity (min/week)	**-0.01 ± 7.71[b,e,f,g,h]**	**3.25 ± 8.62**	**53.16 ± 14.85**	**76.87± 38.38**	**P = <0.001**
WB BMC	0.55 ± 2.02	0.66 ± 1.65	1.71 ± 1.31	2.09 ± 2.20	P = 0.168

WB BMD	-3.908 ± 3.442	-4.046 ± 4.053	-2.318 ± 3.983	-3.755 ± 4.740	P = 0.760
L1-L4 BMD	2.072 ± 4.787	-0.239 ± 3.447	5.037 ± 7.127	2.686 ± 2.542	P = 0.108
TH BMD	1.343 ± 2.845	0.0994 ± 1.530	1.735 ± 2.369	2.653 ± 3.014	P = 0.144
FN BMD	**-1.711 ± 4.19[b, h,g,f]**	**-1.185 ± 2.772**	**5.805 ± 4.690**	**5.071 ± 7.012**	**P<0.001**
Total Radius BMD	0.99 ± 2.33	0.29 ±1.95	-0.70 ± 2.54	1.10 ± 2.03	P = 0.257
CSA	-0.48 ± 4.99	1.43 ± 4.00	8.30 ± 6.79	2.46± 13.52	P = 0.107
CSMI	-1.85 ± 10.92	0.77 ± 9.59	7.20 ± 7.08	5.94 ± 6.63	P = 0.083
Z	-2.34 ± 10.59	1.99 ± 10.25	5.76 ± 6.31	4.56 ± 8.50	P = 0.217
SI	**-3.69 ± 17.77[b]**	**9.25 ± 16.53**	**20.73 ± 18.38**	**6.67 ± 12.88**	**P = 0.020**
BR	-2.70 ± 41.40	-17.78 ± 30.67	12.17 ± 34.76	-12.52 ± 47.61	P = 0.332
CSI	**-1.70 ± 5.42[b]**	**4.81 ± 11.80**	**9.17 ± 5.85**	**7.20 ± 6.02**	**P = 0.029**

BSI	-2.04 ± 8.08	9.97 ± 28.78	12.47 ± 12.86	6.72 ± 6.97	P = 0.293
ISI	**-1.45 ± 5.14[b]**	**5.08 ± 11.88**	**8.92 ± 6.24**	**8.43 ± 8.05**	**P = 0.042**

In bold, significant difference: FF vs C[a]; RF30 vs C[b]; FF vs RF30[c]; FF vs RF60[d]; RF60 vs RF30[e]; RF60 vs C[f]; RF30 vs FF[g]; RF60 vs FF[h]; 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; SI: strength index; BR: buckling ratio; CSI: compression strength index; BSI: bending strength index; ISI: impact strength index.

3.16 Differences in the percentages of variation related to physical performance parameters among the groups

Concerning the physical performance parameters, the percentage of variation of the CMJ was significantly higher in RF30 compared to C. 1-RM bench press percentage of variation was significantly higher in RF60 and FF compared to C. In addition, absolute and relative VO_2 max percentages of variation were significantly higher in RF30 and RF60 compared to FF and C.

Table 34: Differences in the percentages of variation of the clinical and bone variables among control, former football and recreational football 30 and recreational football 60 groups.

	C n=10	FF n=11	RF30 n=10	RF60 n=10	p-value
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
CMJ	**-1.45 ± 3.83[b]**	**1.69 ± 4.81**	**7.31± 8.26**	**3.59 ± 7.22**	**P = 0.026**
Maximum Power	-0.78± 2.18	-1.29 ± 3.43	2.79 ± 5.52	-0.12 ± 3.43	P = 0.090
HG	-6.31 ± 1.95	-9.76 ± 16.73	-8.64 ± 4.63	-6.90 ± 3.24	P = 0.827

1-RM half-squat	-2.66 ± 5.89	1.32 ± 8.51	5.81 ± 7.52	4.83 ± 8.57	P = 0.103
1-RM bench press	**-9.66 ± 13.77[a,f]**	**2.09 ± 5.46**	**0.17 ± 7.15**	**2.85 ± 6.21**	**P=0.012**
10 m sprint performance	1.02 ± 1.69	-0.83 ± 3.13	-2.79± 4.14	-2.15 ± 3.45	P = 0.059
VO_2 max (L/min)	**-0.82 ± 1.25[b, f,g,h]**	**-0.02 ± 1.03**	**6.56± 1.75**	**6.65 ± 1.76**	**P = <0.001**
VO_2 max (ml/min/kg)	**-1.02 ± 2.55[b,f,g,h]**	**2.19 ± 4.11**	**6.97 ± 3.30**	**8.76 ± 4.76**	**P = <0.001**

Significant difference in bold: F vs C[a]; CF30 vs C[b]; F vs CF30[c]; F vs RF60[d]; RF60 vs RF30[e]; RF60 vs C[f]; RF30 vs FF[g]; RF60 vs FF[h]; SD: standard deviation; CMJ: counter movement jump; HG: handgrip; RM: Repetition Maximum; VO_2 max: maximum oxygen consumption.

3.17 Differences in the percentages of variation related to clinical and bone parameters among the control, former football and the combination of the two recreational football groups

Physical activity (min/week) and FN BMD percentages of variation were significantly higher in the RF (30+60) compared to C and FF. SI percentage of variation was significantly higher in RF (30+60) compared to C. CSI and ISI percentages of variation were significantly higher in RF (30+60) compared to C.

Table 35: Differences among control, former football and recreational football groups combined in the percentages of variation of clinical and bone variables.

	C n=10	FF n=11	RF (30+60) n=20	p-value
	Mean ± SD	Mean ± SD	Mean ± SD	
Weight	-0.02 ± 1.59	-2.06 ± 3.71	-1.18 ± 3.07	P = 0.309

BMI	-0.02 ± 1.59	-2.06 ± 3.71	5.39 ± 27.96	P = 0.568
Lean mass	-0.59 ± 2.23	-1.03 ± 4.49	0.12 ± 2.49	P = 0.602
Fat mass	0.39 ± 4.63	-2.13 ± 10.94	-2.24 ± 4.53	P = 0.584
Fat mass %	0.47 ± 4.30	-1.06 ± 8.75	-1.58 ± 3.11	P = 0.620
Physical activity (min/week)	**-0.01 ± 7.71[a,b]**	**3.25 ± 8.62**	**61.5 ± 31.97**	**P<0.001**
WB BMC	0.55 ± 2.02	0.66 ± 1.65	1.90 ± 1.77	P = 0.086
WB BMD	-3.908 ± 3.442	-4.046 ± 4.053	-3.036 ± 4.324	P = 0.757
L1-L4 BMD	2.072 ± 4.787	-0.239 ± 3.447	3.861 ± 5.346	P = 0.085
TH BMD	1.343 ± 2.845	0.0994 ± 1.530	2.194 ± 2.680	P = 0.091
FN BMD	**-1.711 ± 4.191[a,b]**	**-1.185 ± 2.772**	**5.438 ± 5.818**	**P = <0.001**
Total Radius BMD	0.997 ± 2.336	0.297 ± 1.956	0.201 ± 2.430	P = 0.657
CSA	-0.48 ± 4.99	1.43 ± 4.00	5.38 ± 10.83	P = 0.164
CSMI	**-1.85 ± 10.92[b]**	**0.77 ± 9.59**	**6.57 ± 6.71**	**P = 0.036**
Z	-2.34 ± 10.59	1.99 ± 10.25	5.16 ± 7.31	P = 0.110
SI	**-3.69 ± 17.77[b]**	**9.25 ± 16.53**	**13.70 ± 17.05**	**P = 0.041**

BR	-2.70 ± 41.40	-17.78 ± 30.67	-0.17 ± 42.50	P = 0.484
CSI	**-1.704 ± 5.429[b]**	**4.815 ± 11.808**	**8.24 ± 5.85**	**P = 0.012**
BSI	-2.04 ± 8.08	9.97 ± 28.78	9.75 ± 10.63	P = 0.199
ISI	**-1.45 ± 5.14[b]**	**5.08 ± 11.88**	**8.69 ± 6.95**	**P = 0.016**

Significant difference in Bold: RF(30+60) vs FF[a]; RF(30+60) vs C[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; SI: strength index; BR: buckling ratio; CSI: compression strength index; BSI: bending strength index; ISI: impact strength index.

3.18 Differences in the percentages of variation related to physical performance parameters among control, formal football and the combination of the two recreational football groups

Concerning the physical performance parameters, the percentages of variations of the CMJ and the 1-RM half squat were significantly higher in RF (30+60) compared to C. 1-RM bench press percentage of variation was significantly higher in RF (60+30) and FF compared to C. In addition, absolute and relative VO_2 max percentages of variations were significantly higher in RF (30 + 60) compared to FF and C.

Table 36: Differences in the percentages of variation related to physical performance parameters among control, formal football and the combination of the two recreational football groups.

	C n=10	FF n=11	RF (30+60) n= 20	p-value
	Mean ± SD	Mean ± SD	Mean ± SD	

CMJ	**-1.45 ± 3.83[b]**	**1.69 ± 4.81**	**5.74 ± 7.89**	**P = 0.018**
Maximum Power	-0.78 ± 2.18	-1.29 ± 3.43	1.40 ± 4.84	P = 0.155
HG	-6.31 ± 1.95	-9.76 ± 16.73	-7.81 ± 4.02	P = 0.691
1-RM half-squat	**-2.66 ± 5.89[b]**	**1.32 ± 8.51**	**5.32 ± 7.84**	**P = 0.045**
1-RM bench press	**-9.66 ± 13.77[b,c]**	**2.09 ± 5.46**	**1.44 ± 6.68**	**P = 0.005**
10 m sprint performance	**1.02 ± 1.69[b]**	**-0.83± 3.13**	**-2.49± 3.74**	**P = 0.025**
VO_2 max (L/min)	**-0.82 ± 1.25[a,b]**	**-0.02 ±1.03**	**6.60 ± 1.71**	**P = <0.001**
VO_2 max (ml/min/kg)	**-1.02 ± 2.55[a,b]**	**2.19 ± 4.11**	**7.82 ± 4.04**	**P = <0.001**

Significant difference in Bold: RF(30+60) vs FF[a]; RF(30+60) vs C[b]; FF vs C[c]; SD: standard deviation; CMJ: counter movement jump; HG: handgrip; RM: Repetition Maximum; VO2 max: maximum oxygen consumption.

3.19 Differences in the percentages of variation related to clinical and bone parameters among control, recreational football 30 and recreational football 60

The percentage of variation in Physical activity (min/week) was significantly higher in RF60 and RF30 compared to C and in RF60 compared to RF30. FN BMD percentage of variation was significantly higher in the RF30 and RF60 compared to C. SI percentage of variation was significantly higher in RF30 compared to C. CSI and ISI percentages of variation were significantly higher in RF30 and RF60 compared to C. BSI percentage of variation was significantly higher in RF30 compared to C.

Table 37: Differences in the percentages of variation related to clinical and bone parameters among control, recreational football 30 and recreational football 60 groups.

	C n=10	RF30 n=10	RF60 n=10	p-value
	Mean ± SD	Mean ± SD	Mean ± SD	
Weight	-0.02 ± 1.59	-0.74 ± 2.40	-1.62 ± 3.70	P= 0.431
BMI	-0.02 ± 1.59	-0.74 ± 2.40	-1.62 ± 3.70	P= 0.431
Lean mass	-0.59 ± 2.23	0.10 ± 2.71	0.15 ± 2.38	P= 0.653
Fat mass	0.39 ± 4.63	-2.04 ± 3.46	-2.449 ± 5.596	P= 0.349
Fat mass %	0.47 ± 4.30	-1.41 ± 3.01	-1.75± 3.36	P= 0.344
Physical activity (min/week)	**-0.010 7.71[a, b,c]**	**53.16 14.85**	**76.87 38.38**	**P< 0.001**
WB BMC	0.550 ± 2.027	1.713 ± 1.318	2.092 ± 2.204	P= 0.183
WB BMD	-3.908 ± 3.442	-2.318 ± 3.983	-3.755 ± 4.740	P= 0.636
L1-L4 BMD	2.072 ± 4.787	5.037 ± 7.127	2.686 ± 2.542	P= 0.412
TH BMD	1.343 ± 2.845	1.735 ± 2.369	2.653 ± 3.014	P= 0.559
FN BMD	**-1.711 ± 4.191 [a,b]**	**5.805 ± 4.690**	**5.071 ± 7.012**	P= **0.008**
Total Radius BMD	0.997 ± 2.336	-0.705 ± 2.548	1.107 ± 2.037	P= 0.166

CSA	-0.48 ± 4.99	8.30 ± 6.79	2.46 ± 13.52	P= 0.113
CSMI	-1.85 ± 10.92	7.20 ± 7.08	5.94 ± 6.63	P= 0.049
Z	-2.34 ± 10.59	5.76 ± 6.31	4.56 ± 8.50	P= 0.096
SI	**-3.69 ± 17.77 [b]**	**20.73 ±18.38**	**6.67 ± 12.88**	P= **0.010**
BR	-2.70 ± 41.40	12.17 ±34.76	-12.52±47.61	P= 0.421
CSI	**-1.70 ± 5.42[a,b]**	**9.17 ± 5.85**	**7.20 ± 6.02**	P<**0.001**
BSI	**-2.04 ± 8.08[b]**	**12.47 ± 12.86**	**6.72 ± 6.97**	P= **0.013**
ISI	**-1.45 ± 5.14[a,b]**	**8.92 ± 6.24**	**8.43 ± 8.05**	P= **0.003**

In bold, significant difference: RF60 vs C[a]; RF30 vs C[b]; RF60 vs RF30[c]; 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; SI: strength index; BR: buckling ratio; CSI: compression strength index; BSI: bending strength index; ISI: impact strength index.

3.20 Differences in the percentages of variation related to physical performance parameters among control, recreational football 30 and recreational football 60

Concerning the physical performance parameters, the percentage of variation of the 1-RM bench press was significantly higher in RF60 compared to C. The percentages of variation of

the CMJ and 10-m sprint were significantly higher in RF30 compared to C. Absolute and relative VO_2 max percentages of variation were significantly higher in RF30 and RF60 compared to C.

Table 38: Differences in the percentages of variation related to physical performance parameters among control, recreational football 30 and recreational football 60 groups.

	C n=10	RF30 n=10	RF60 n=10	p-value
	Mean ± SD	Mean ± SD	Mean ± SD	
CMJ	**-1.45 ± 3.83[b]**	**7.31 ± 8.26**	**3.59 ± 7.22**	**0.025**
Maximum Power	-0.78 ± 2.18	2.79 ± 5.52	-0.12 ± 3.43	0.130
HG	-6.31 ± 1.95	-8.64 ± 4.63	-6.90 ± 3.24	0.315
1-RM half-squat	-2.66 ± 5.89	5.81± 7.52	4.83 ± 8.57	0.045
1-RM bench press	**-9.66 ± 13.77[a]**	**0.17 ± 7.15**	**2.85 ± 6.21**	**0.025**
10 m sprint performance	**1.02 ± 1.69[b]**	**-2.79± 4.14**	**-2.15 ± 3.45**	**0.033**
VO_2 max (L/min)	**-0.82 ± 1.25[a,b]**	**6.56 ± 1.75**	**6.65 ± 1.76**	**<0.001**
VO_2 max (ml/min/kg)	**-1.02 ± 2.55[a, b]**	**6.97 ± 3.30**	**8.76 ± 4.76**	**<0.001**

In bold, significant difference: RF60 vs C[a]; RF30 vs C[b]; RF60 vs RF30[c]; SD: standard deviation; CMJ: counter movement jump; HG: handgrip; RM: Repetition Maximum; VO2 max: maximum oxygen consumption.

3.21 Group * time effects on clinical and bone parameters in 4 groups (FF, C, RF30 and RF60)

There was a group * time interaction in FN BMD and PA.

Table 39: A two-way repeated measures ANOVA of the clinical and bone parameters among all 4 groups.

	FF		C		RF30		RF60		F	P
	PRE	POST	PRE	POST	PRE	POST	PRE	POST		
Lean mass (Kg)	60.1 ± 1.0	59.7 ± 1.0	53.6 ± 1.1	53.3 ± 1.1	59.2 ± 1.1	59.2 ± 1.1	57.3 ± 1.1	54.4 ± 1.1	0.686	0.566
Fat mass (kg)	27.4 ± 393	27.14 ± 393	29.0 ± 412	29.2 ± 412	32.5 ± 412	31.8 ± 412	33.3 ± 412	32.4 ± 412	0.616	0.609
Fat mass %	29.9 ± 0.3	29.7 ± 0.3	33.4 ± 0.3	33.6 ± 0.3	34.0 ± 0.3	33.4 ± 0.3	34.9 ± 0.3	34.2 ± 0.3	0.541	0.657
Physical activity (min/week)	132.2 ± 2.1	135.9 ± 2.1	101.0 ± 2.2	100.5 ± 2.2	110.0 ± 2.2	165.0 ± 2.2	105.5 ± 2.3	175.5 ± 2.3	126.112	**<0.001**

WB BMC (g)	3283 ± 12	3304 ± 12	2836 ± 12	2853 ± 12	3087 ± 12	3139 ± 12	3095 ± 12	3158 ± 12	1.602	0.205
L1-L4 BMD (g/cm^2)	1.332 ± 0.0125	1.328 ± 0.0125	1.206 ± 0.0131	1.228 ± 0.0131	1.203 ± 0.0131	1.260 ± 0.0131	1.241 ± 0.0131	1.277 ± 0.0131	2.015	0.129
TH BMD (g/cm^2)	1.172 ± 0.00544	1.173 ± 0.00544	1.075 ± 0.00571	1.091 ± 0.00571	1.104 ± 0.00571	1.122 ± 0.00571	1.093 ± 0.00571	1.119 ± 0.00571	1.799	0.164
FN BMD (g/cm^2)	1.157 ± 0.00975	1.143 ± 0.00975	1.006 ± 0.0102	0.988 ± 0.0102	1.009 ± 0.0102	1.066 ± 0.0102	1.067 ± 0.0102	1.115 ± 0.0102	7.806	**<0.001**
Total Radius BMD (g/cm^2)	0.804 ± 0.00385	0.806 ± 0.00385	0.795 ± 0.00404	0.803 ± 0.00404	0.806 ± 0.00404	0.800 ± 0.00404	0.807 ± 0.00404	0.816 ± 0.00404	1.368	0.268
CSA (mm^2)	202.5 ± 2.9	205.4 ± 2.9	163.7 ± 3.0	162.8 ± 3.0	174.3 ± 3.0	188.3 ± 3.0	185.6 ± 3.0	190.4 ± 3.0	2.120	0.114
CSMI $(mm^2)^2$	21164 ± 356	21433 ± 356	13894 ± 374	13603 ± 374	17280 ± 374	18479 ± 374	18095 ± 374	19101 ± 374	1.693	0.185

Z (mm^3)	1092 ± 19	1116 ± 19	768 ± 20	749 ± 20	923 ± 20	975 ± 20	964 ± 20	997 ± 20	1.097	0.363
SI	1.655 ± 0.0543	1.782 ± 0.0543	1.570 ± 0.0569	1.510 ± 0.0569	1.360 ± 0.0569	1.630 ± 0.0569	1.720 ± 0.0569	1.830 ± 0.0569	2.821	0.052
BR	4.255 ± 0.317	3.282 ± 0.317	4.060 ± 0.332	3.660 ± 0.332	3.130 ± 0.332	3.360 ± 0.332	3.630 ± 0.332	2.770 ± 0.332	1.386	0.262
CSI (g/kg-m)	4.96 ± 0.08	5.19 ± 0.08	4.13 ± 0.09	4.12 ± 0.09	4.04 ± 0.08	4.42 ± 0.08	4.26 ± 0.08	4.56 ± 0.08	1.868	0.154
BSI (g/kg-m)	1.56 ± 0.05	1.71 ± 0.05	1.29 ± 0.06	1.29 ± 0.06	1.27 ± 0.05	1.45 ± 0.05	1.38 ± 0.06	1.47 ± 0.06	0.752	0.529
ISI (g/kg-m)	0.34± 0.00	0.36 ± 0.00	0.27 ± 0.00	0.27± 0.00	0.27 ± 0.00	0.30 ± 0.00	0.28± 0.00	0.30± 0.00	1.654	0.196

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; SI: strength index; BR: buckling ratio; CSI: compression strength index; BSI: bending strength index; ISI: impact strength index.

3.22 Group * time effects on physical performance parameters in 4 groups (FF, C, RF30 and RF60)

A group * time interaction was found in CMJ, 1-RM bench press and VO_2 max (L/min and ml/min/kg).

Table 40: A two-way repeated measure ANOVA of the physical performance variables among all 4 groups.

	FF		C		RF30		RF60		F	P
	PRE	POST	PRE	POST	PRE	POST	PRE	POST		
CMJ (cm)	40.0 ± 0.4	40.7 ± 0.4	32.6 ± 0.5	32.1 ± 0.5	34.3 ±0.5	36.7 ± 0.5	36.1 ± 0.5	37.6 ± 0.53	3.076	**0.040**
Maximum Power (Watts)	1247.20 ± 9.37	1232.37 ± 9.37	1042.35 ± 9.83	1033.70 ± 9.83	1193.09 ± 9.83	1222.55 ± 9.83	1228.46 ± 10.36	1228.99 ± 10.36	2.033	0.127
HG (kg)	50.6 ± 1.0	45.7 ± 1.0	43.1 ± 1.0	40.4 ± 1.0	52.0 ± 1.0	47.5 ± 1.0	46.6 ± 1.1	43.4 ± 1.1	0.464	0.709
1-RM half-squat (kg)	110.1 ± 1.4	111.0 ± 1.4	61.6 ± 1.6	60.0 ± 1.6	86.6 ± 1.6	91.7 ± 1.6	81.6 ± 1.6	84.7 ± 1.6	1.629	0.201
1-RM bench press (kg)	59.1 ± 1.1	60.2 ± 1.1	50.4 ± 1.2	45.3 ± 1.2	53.8 ± 1.1	53.5 ± 1.1	53.3 ± 1.2	54.8 ± 1.2	3.162	**0.037**
10 m sprint	1.891 ± 0.0143	1.875 ± 0.0143	2.166 ± 0.0150	2.188 ± 0.0150	2.072 ± 0.0150	2.013 ± 0.0150	2.023 ± 0.0158	1.978 ± 0.0158	2.845	0.051

performance (s)										
VO_2 max (L/min)	3.73 ± 0.01	3.73 ± 0.01	3.26 ± 0.01	3.23 ± 0.01	3.52 ± 0.01	3.75 ± 0.01	3.55 ± 0.01	3.789 ± 0.0126	70.910	**<0.001**
VO_2 max (ml/min/kg)	41.377 ± 0.334	42.349 ± 0.334	38.843 ± 0.350	38.428 ± 0.350	37.970 ± 0.350	40.608 ± 0.350	38.175 ± 0.369	41.538 ± 0.369	11.383	**<0.001**

CMJ: counter movement jump; HG: handgrip; RM: Repetition Maximum; VO2 max: maximum oxygen consumption.

3.23 Group * time effects on clinical and bone parameters in 3 groups (FF, C, RF (30+60)

There was a group * time interaction in FN BMD, CSI, ISI and PA.

Table 41: A two-way repeated measure ANOVA of the clinical and bone parameters among the former football, control and the combination of the recreational football groups.

	FF		C		RF (30+60)		F	P
	PRE	POST	PRE	POST	PRE	POST		

Fat mass (Kg)	27.4 ± 388	27.1 ± 388	29.0 ± 407	29.2 ± 407	32.9 ± 288	32.1 ± 288	0.916	0.409
Fat mass percentage	29.9 ± 0.3	29.7 ± 0.3	33.4 ± 0.3	33.6 ± 0.3	34.4 ± 0.2	33.8 ± 0.2	0.816	0.450
Lean mass (Kg)	60.3 ± 1089	59.5 ± 1089	53.6 ± 1142	53.3 ± 1142	58.2 ± 807	56.8 ± 807	0.172	0.843
Physical activity (min/week)	132.2 ± 2.3	135.9 ± 2.3	101.0 ± 2.5	100.5 ± 2.5	107.8 ± 1.8	170.0 ± 1.8	145.545	**<0.001**
WB BMC (g)	3283 ± 12	3304 ± 12	2836 ± 12	2853 ± 12	3091 ± 8	3149 ± 8	2.354	0.109
L1-L4 BMD (g/cm^2)	1.332 ± 0.0124	1.328 ± 0.0124	1.206 ± 0.0130	1.228 ± 0.0130	1.222 ± 0.00921	1.269 ± 0.00921	2.708	0.080
TH BMD (g/cm^2)	1.172 ± 0.00540	1.173 ± 0.00540	1.075 ± 0.00567	1.091 ± 0.00567	1.098 ± 0.00401	1.120 ± 0.00401	2.493	0.096
FN BMD (g/cm^2)	1.157 ± 0.00964	1.143 ± 0.00964	1.006 ± 0.0101	0.988 ± 0.0101	1.038 ± 0.00715	1.091 ± 0.00715	11.857	**<0.001**
Total Radius BMD (g/cm^2)	0.804 ± 0.00397	0.806 ± 0.00385	0.795 ± 0.00416	0.803 ± 0.00416	0.806 ± 0.00294	0.808 ± 0.00294	0.349	0.708

CSA (mm^2)	202.545 ± 2.983	205.455 ± 2.983	163.700 ± 3.128	162.800 ± 3.128	179.950 ± 2.212	189.350 ± 2.212	1.999	0.149
CSMI ($(mm^2)^2$)	21164.1 ± 352.5	21433.6 ± 352.5	13894.6 ± 369.7	13603.1 ± 369.7	17688.2 ± 261.4	18790.5 ± 261.4	2.568	0.090
Z (mm^3)	1092 ± 19	1116 ± 19	768 ± 20	749 ± 20	944 ± 14	986 ± 14	1.568	0.222
SI	1.655 ± 0.0549	1.782 ± 0.0549	1.570 ± 0.0576	1.510 ± 0.0576	1.540 ± 0.0407	1.730 ± 0.0407	3.163	0.054
BR	4.255 ± 0.324	3.282 ± 0.324	4.060 ± 0.340	3.660 ± 0.340	3.380 ± 0.240	3.065 ± 0.240	0.702	0.502
CSI (g/kg-m)	4.96 ± 0.08	5.19 ± 0.08	4.13 ± 0.08	4.12 ± 0.08	4.15 ± 0.05	4.49 ± 0.05	3.953	**0.028**
BSI (g/kg-m)	1.56 ± 0.05	1.71 ± 0.05	1.29 ± 0.06	1.29 ± 0.06	1.33 ± 0.04	1.46 ± 0.04	1.462	0.246
ISI (g/kg-m)	0.34 ± 0.00	0.36 ± 0.00	0.27 ± 0.00	0.27 ± 0.00	0.27 ± 0.00	0.30 ± 0.00	3.500	**0.041**

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; SI: strength index; BR: buckling ratio; CSI: compression strength index; BSI: bending strength index; ISI: impact strength index.

3.24 Group * time effects on physical performance parameters in 3 groups (FF, C, RF (30+60)

A group * time interaction was found in CMJ, 1-RM bench press, 10-m sprint, and VO_2 max (L/min and ml/min/kg).

Table 42: A two-way repeated measure ANOVA of the physical performance variables among the former football, control and the combination of the recreational football groups.

	FF		C		RF30 + RF60		F	P
	PRE	POST	PRE	POST	PRE	POST		
CMJ (cm)	40.0 ± 0.4	40.7 ± 0.4	32.6 ± 0.5	32.1 ± 0.5	35.1 ± 0.3	37.1 ± 0.3	4.188	**0.023**
Maximum Power (Watts)	1247.20 ± 9.50	1232.37 ± 9.50	1042.35 ± 9.97	1033.70 ± 9.97	1209.84 ± 7.23	1225.60 ± 7.23	1.969	0.154
HG (kg)	50.6 ± 1.0	45.7 ± 1.0	43.1 ± 1.0	40.4 ± 1.0	49.4 ± 0.7	45.5 ± 0.7	0.530	0.593
1-RM half-squat (kg)	110.1 ± 1.4	111.0 ± 1.4	61.6 ± 1.6	60.0 ± 1.6	84.1 ± 1.1	88.2 ± 1.1	2.280	0.117
1-RM bench press (kg)	59.1 ± 1.0	60.2 ± 1.0	50.4 ± 1.2	45.3 ± 1.2	53.6 ± 1.2	54.1 ± 0.8	4.499	**0.018**
10 m sprint performance (s)	1.891 ± 0.0141	1.875 ± 0.0141	2.166 ± 0.0148	2.188 ± 0.0148	2.049 ± 0.0108	1.996 ± 0.0108	4.265	**0.022**

VO_2 max (L/min)	3.73 ± 0.01	3.73 ± 0.01	3.26 ± 0.01	3.23 ± 0.01	3.53 ± 0.00	3.77 ± 0.00	108.718	**<0.001**
VO_2 max (ml/min/kg)	41.377 ± 0.334	42.349 ± 0.334	38.843 ± 0.350	38.428 ± 0.350	38.067 ± 0.254	41.049 ± 0.254	16.559	**<0.001**

CMJ: counter movement jump; HG: handgrip; RM: Repetition Maximum; VO2 max: maximum oxygen consumption.

3.25 Group * time effects on clinical and bone parameters in 3 groups (C, RF30 and RF60)

There was a group * time interaction in FN BMD, CSMI, CSI, BSI, ISI, SI and PA.

Table 43: A two-way repeated measure ANOVA of the clinical and bone parameters among the control, recreational 60 and recreational 30 groups.

	C		RF30		RF60		F	P
	PRE	POST	PRE	POST	PRE	POST		
Fat mass (kg)	29.0 ± 412	29.2 ± 412	32.5 ± 412	31.8 ± 412	33.3 ± 412	32.4 ± 412	1.698	0.202

Fat mass percentage	33.4 ± 0.3	33.6 ± 0.3	34.0 ± 0.3	33.4 ± 0.3	34.9 ± 0.3	34.2 ± 0.3	1.548	0.231
Lean mass (Kg)	53. 6 ± 1132	53.3 ± 1132	59.2 ± 1132	59.2 ± 1132	57.3 ± 1132	54.4 ± 1132	0.805	0.457
Physical activity (min/week)	101.0 ± 2.2	100.5 ± 2.2	110.0 ± 2.2	165.0 ± 2.2	105.5 ± 2.3	175.5 ± 2.3	137.832	**<0.001**
WB BMC (g)	2836 ± 12	2853 ± 12	3087 ± 12	3139 ± 12	3095 ± 12	3158 ± 12	1.722	0.198
L1-L4 BMD (g/cm^2)	1.206 ± 0.0131	1.228 ± 0.0131	1.203 ± 0.0131	1.260 ± 0.0131	1.241 ± 0.0131	1.277 ± 0.0131	0.818	0.452
TH BMD (g/cm^2)	1.075 ± 0.00571	1.091 ± 0.00571	1.104 ± 0.00571	1.122 ± 0.00571	1.093 ± 0.00571	1.119 ± 0.00571	0.395	0.677
FN BMD (g/cm^2)	1.006 ± 0.0102	0.988 ± 0.0102	1.009 ± 0.0102	1.066 ± 0.0102	1.067 ± 0.0102	1.115 ± 0.0102	6.796	**0.004**
Total Radius BMD (g/cm^2)	0.795 ± 0.00404	0.803 ± 0.00404	0.806 ± 0.00404	0.800 ± 0.00404	0.807 ± 0.00404	0.816 ± 0.00404	1.911	0.167
CSA (mm^2)	163.7 ± 3.0	162.8 ± 3.0	174.3 ± 3.0	188.3 ± 3.0	185.6 ± 3.0	190.4 ± 3.0	2.384	0.111

CSMI $(mm^2)^2$	13894 ± 374	13603 ± 374	17280 ± 374	18479 ± 374	18095 ± 374	19101 ± 374	4.048	**0.029**
Z (mm^3)	768 ± 20	749 ± 20	923 ± 20	975 ± 20	964 ± 20	997 ± 20	2.500	0.101
SI	1.570 ± 0.0569	1.510 ± 0.0569	1.360 ± 0.0569	1.630 ± 0.0569	1.720 ± 0.0569	1.830 ± 0.0569	4.009	**0.030**
BR	4.060 ± 0.332	3.660 ± 0.332	3.130 ± 0.332	3.360 ± 0.332	3.630 ± 0.332	2.770 ± 0.332	1.418	0.260
CSI (g/kg-m)	4.13 ± 0.09	4.12 ± 0.09	4.04 ± 0.08	4.42 ± 0.08	4.26 ± 0.08	4.56 ± 0.08	8.860	**0.001**
BSI (g/kg-m)	1.29 ± 0.06	1.29 ± 0.06	1.27 ± 0.05	1.45 ± 0.05	1.38 ± 0.06	1.47 ± 0.06	3.873	**0.034**
ISI (g/kg-m)	0.27 ± 0.00	0.27 ± 0.00	0.27 ± 0.00	0.30 ± 0.00	0.28 ± 0.00	0.30 ± 0.00	6.945	**0.004**

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; SI: strength index; BR: buckling ratio; CSI: compression strength index; BSI: bending strength index; ISI: impact strength index.

3.26 Group * time effects on physical performance parameters in 3 groups (C, RF60 and RF30)

A group * time interaction was found in CMJ, 1-RM half squat, 10-m sprint, and VO_2 max (L/min and ml/min/kg).

Table 44: A two-way repeated measure ANOVA of the physical performance variables among the control, recreational 60 and recreational 30 groups.

	C		RF30		RF60		F	P
	PRE	POST	PRE	POST	PRE	POST		
CMJ (cm)	32.6 ± 0.5	32.1 ± 0.5	34.3 ± 0.5	36.7 ± 0.5	36.1 ± 0.5	37.6 ± 0.5	4.016	**0.030**
Maximum Power (Watts)	1042.35 ± 9.83	1033.70 ± 9.83	1193.09 ± 9.83	1222.55 ± 9.83	1228.46 ± 10.36	1228.99 ± 10.36	1.961	0.161
HG (kg)	43.1 ± 1.0	40.4 ± 1.0	52.0 ± 1.0	47.5 ± 1.0	46.6 ± 1.1	43.4 ± 1.1	2.580	0.095
1-RM half-squat (kg)	61.6 ± 1.6	60.0 ± 1.6	86.6 ± 1.6	91.7 ± 1.6	81.6 ± 1.6	84.7 ± 1.6	3.544	**0.045**
1-RM bench press (kg)	50.4 ± 1.2	45.3 ± 1.2	53.8 ± 1.1	53.5 ± 1.1	53.3 ± 1.2	54.8 ± 1.2	3.075	0.064
10 m sprint performance (s)	2.166 ± 0.0150	2.188 ± 0.0150	2.072 ± 0.0150	2.013 ± 0.0150	2.023 ± 0.0158	1.978 ± 0.0158	3.857	**0.034**

VO_2 max (L/min)	3.26 ± 0.01	3.23 ± 0.01	3.52 ± 0.01	3.75 ± 0.01	3.55 ± 0.01	3.78 ± 0.01	65.633	**<0.001**
VO_2 max (ml/min/kg)	38.843 ± 0.350	38.428 ± 0.350	37.970 ± 0.350	40.608 ± 0.350	38.175 ± 0.369	41.538 ± 0.369	18.015	**<0.001**

CMJ: counter movement jump; HG: handgrip; RM: Repetition Maximum; VO2 max: maximum oxygen consumption.

3.27 Differences in the time of attendance to game between both recreational groups

The percentage of attendance to the training protocol was significantly higher in the recreational football 30 compared to the recreational football 60. On the other hand, subjects of the RF60 significantly played more hours compared to the RF30 groups.

Table 45: Differences in players' attendance to game between both recreational groups.

	RF30	RF60	P value
% attendance	**89.063 ± 5.038**	**70.208 ± 5.646**	**<0.001**
Attendance time (hours)	**42.750 ± 2.418**	**67.400 ± 5.420**	**<0.001**

The significant differences are in bold.

3.28 Correlations between the percentage of variation of clinical and bone variables and the percentage of attendance of the recreational groups

The percentages of variations of FN BMD, CSA and SI were significantly correlated to the percentage of attendance. No significant correlation was found concerning the other parameters.

Table 46: Correlations between the percentage of variation of the clinical and bone performance variables and percentage of attendance of the study population.

	% of attendance
Weight	0.277
Lean mass	0.304
Fat mass	0.0481
Fat mass %	-0.0200
WB BMC	-0.168
WB BMD	0.383
L1-L4 BMD	0.250

TH BMD	0.173
FN BMD	**0.455***
Total Radius BMD	-0.347
CSA	**0.593****
CSMI	0.286
Z	0.329
SI	**0.623****
BR	0.170
CSI	0.324
BSI	0.201
ISI	0.205

In bold, significant difference: *p < 0.05; **p < 0.01; ***p < 0.001; 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; SI: strength index; BR: buckling ratio; CSI: compression strength index; BSI: bending strength index; ISI: impact strength index.

3.29 Correlations between the percentage of variation of physical performance variables and the percentage of attendance of the recreational groups

There was no significant correlation found between the percentage of variation of physical performance variables and the percentage of attendance.

Table 47: Correlations between the percentage of variation of the physical performance variables and percentage of attendance of the recreational groups.

	% of attendance
CMJ	0.0502
Maximum Power	0.226
Handgrip	-0.0655

1-RM half-squat	0.0220
1-RM BP	-0.332
10m sprint performance	-0.181
VO_2 max (L/min)	-0.110
VO_2 max (ml/min/kg)	-0.345

In bold, significant difference: *p < 0.05; **p < 0.01; ***p < 0.001; CMJ: counter movement jump; HG: handgrip; RM: Repetition Maximum; VO2 max: maximum oxygen consumption.

3.30 Correlations between the percentage of variation of the physical performance variables and the percentage of variation of bone variables in RF60 and RF30

The percentage of variation of the 10-m sprint performance was negatively correlated to FN BMD, CSMI and ISI. VO_2 max (L/min) was negatively correlated to CSI and ISI.

Table 48: Correlations between the percentage of variation of the physical performance variables and the percentage of variation of bone variables in RF60 and RF30.

	WB BMC (g)	TH BMD (kg/m^2)	FN BMD (kg/m^2)	CSMI (mm^4)	SI 48	CSI (g/kg-m)	BSI (g/kg-m)	ISI (g/kg-m)
CMJ (cm)	-0.0247	-0.389	-0.174	-0.384	0.0956	0.274	0.269	0.418
Maximum Power (watts)	0.283	-0.327	0.0106	-0.433	0.0540	0.152	0.347	0.197
Handgrip (Kg)	-0.0378	0.0628	0.0219	-0.116	-0.00782	-0.433	-0.495	-0.284
1-RM half-squat (kg)	-0.164	-0.100	-0.0376	0.249	0.218	-0.118	-0.0483	-0.312
1-RM BP (kg)	-0.168	-0.0584	-0.234	-0.0893	-0.210	0.121	0.0626	0.287

10m sprint performance (s)	0.400	-0.0756	**-0.489***	**-0.490***	-0.322	**-0.531***	-0.297	**-0.538***
VO_2 max (L/min)	0.0637	-0.250	-0.336	-0.257	0.0738	**-0.473***	-0.322	**-0.524***
VO_2 max (ml/min/kg)	-0.524	-0.0858	-0.372	0.0616	-0.00118	-0.127	-0.288	-0.0882

WB: whole body; BMC: bone mineral content; BMD: bone mineral density; TH: total hip; FN: femoral neck; CSMI: cross-sectional moment of inertia; CSI: compression strength index; BSI: bending strength index; ISI: impact strength index; CMJ: counter movement jump; RM: repetition maximum; BP: bench press; VO_2 max: maximum oxygen consumption* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

4. Main outcomes and conclusions

To our knowledge, our study is the first to compare the effects of two recreational football protocols (30 vs 60 min) on clinical, bone and physical parameters in middle-aged healthy Lebanese men. Our results are clinically important as we provide strategies to increase bone mass or prevent bone loss in subjects who will be at risk for osteoporosis later in life. In conclusion, it appears that both recreational football groups (RF60 and RF30) are effective in increasing WB BMC, FN BMD and absolute and relative VO_2 max in middle-aged healthy inactive Lebanese men.

GENERAL DISCUSSION

The main purpose of the PhD thesis was to compare the effect of two recreational football protocols (RF30: 2x30min vs RF60: 2x60min for 1 year) on bone health and physical performance parameters in a group of healthy middle-aged men.

The first study has defined new determinants of bone health parameters in middle-aged men. Lean mass was the strongest determinant of WB BMC, VO_2 max (L/min) was the strongest determinant of WB BMD, TH BMD and FN BMD while maximum power of the lower limbs was the strongest determinant of total radius BMD. Accordingly, VO_2 max (L/min), lean mass and maximum power of the lower limbs are the strongest determinants of bone variables in middle-aged men.

The second study has mainly shown that former football practice is associated with higher composite indices of femoral neck strength (CSI, BSI and ISI) in middle-aged men. Hence, regular football practice before the young adulthood period may confer residual benefits in composite indices of femoral neck strength in middle-aged men.

The third study compared the effects of two recreational football protocols (RF30: 2x30min vs RF60: 2x60min for 1 year) on bone health and physical performance parameters in a group of middle-aged healthy men.

1.1 Analysis conducted on 3 groups (RF60, RF30 and C)

1.1.1 Between group differences

1.1.1.1 Group * time effects

We found group * time interactions in FN BMD, CSMI, SI, CSI, BSI, ISI, CMJ, 1-RM half-squat, 10-meter sprint and VO_2 max (L/min and ml/min/kg). Accordingly, the response of several bone health and physical performance variables to the training was different among the three groups. One year of soccer practice seems sufficient to increase several bone health parameters especially at the femoral neck in middle-aged men. This result is clinically important since femoral neck fractures are the most dangerous in men and can significantly increase the risk of mortality. The training protocol was also sufficient to increase VO_2 max in both experimental groups. This result is in accordance with our second cross-sectional study which

showed that former football players have higher FN BMD and VO_2 max values compared to controls.

1.1.1.2 Comparing the percentages of variations

FN BMD percentage of variation was significantly higher in RF30 and RF60 compared to C. This study shows that 2x30 and 2x60 minutes per week of recreational football was capable of increasing FN BMD compared to controls. SI percentage of variation was significantly higher in RF30 compared to C. CSI and ISI percentages of variation were significantly higher in RF30 and RF60 compared to C. BSI percentage of variation was significantly higher in RF30 compared to C. The results of this analysis are in line with those of our previous analysis in which we used a 2-way-RM-Anova.

Concerning the physical performance parameters, the percentages of variation of the CMJ and 10-m sprint were significantly higher in RF30 compared to C. Absolute and relative VO_2 max percentages of variation were significantly higher in RF30 and RF60 compared to C. overall, there were no significant differences between both experimental groups (RF60 and RF30) concerning the percentages of variations in bone health parameters and in physical performance variables. Hence, most of the health benefits can occur in response to 2*30 minutes of recreational football per week. It is interesting to mention that adherence was significantly higher in RF30 compared to RF60.

1.1.2 Within group differences

After the 1-year intervention period, we did not find any significant change in clinical and bone parameters in the control group except for a decrease in the whole body bone mineral density.

Bone loss with ageing is normal in this age group. The decrease was only observed at the whole body BMD. Concerning physical performance variables, we only find a significant decrease in handgrip strength. No significant changes were found in the other physical parameters.

Concerning the RF30 group, WB BMC, FN BMD, CSA, CSMI, Z, SI, CSI, BSI and ISI significantly increased after the 1-year intervention period. This is the first study that shows that a low volume of recreational football (2x30 min/week) is effective in improving several

bone parameters in middle-aged men. A significant increase was found in the FN BMD but not in the L1-L4 BMD. This could be explained by the fact that the cortical component of the femoral neck is more influenced by mechanical factors than the trabecular component of the lumbar spine; the latter is much more affected by genetic factors (Eisman, 1999). Moreover, the low volume of training (2x30 min/week) could also be the reason for not finding a significant change in L1-L4 BMD.

On the other hand, WB BMC, L1-L4 BMD, TH BMD, FN BMD, CSMI, CSI, BSI and ISI significantly increased in RF60 group after a 1-year intervention period. These improvements are seen in weight bearing sites which is logical because soccer is a weight-bearing high impact sport. These results support the principle of specificity of bone adaptation to exercise (Kohrt et al., 2004). These results are with accordance with many studies that investigated the effect of football on bone health (Zouch et. al., 2014; Skoradal et al., 2018; Ferry et al., 2013). L1-L4 BMD and TH BMD were significantly increased only in RF60 but not in RF30. This may be related to the fact that the subjects of the RF60 group performed a higher volume of training. It is recognised that bone adapts to the mechanical stress that is applied to it. Higher training volumes are associated with higher mechanical stress that may lead to higher bone adaptations that are shown in RF60.

Concerning physical performance parameters, CMJ, 1RM half-squat, absolute and relative VO2 max significantly increased in RF30. On the other hand, only the absolute and relative VO2 max significantly increased in RF60. The adherence to the training was higher in RF30 compared to RF60. In addition, training intensity might be higher in the RF30 compared to the RF60; this might explain the absence of improvement in the strength parameters in the RF60 group. Finally, fatigue caused by the higher volume in the RF60 group might explain the absence of improvement in the strength parameters.

HG significantly decreased in both groups (RF30 and RF60). This result is not surprising since the training protocol targeted the lower limbs.

1.2 Analysis conducted on 4 groups (RF60, RF30, FF and C)

1.2.1 Between group differences

1.2.1.1 Group * time effects

We found group * time interactions in FN BMD, CMJ, 1-RM bench press, and VO_2 max (L/min and ml/min/kg). Consequently, the response of several bone health and physical performance variables to the training was different among the four groups.

1.2.1.2 Comparing the percentages of variations

FN BMD percentage of variation was significantly higher in the RF30 and RF60 compared to C and FF. In addition, absolute and relative VO_2 max percentages of variations were significantly higher in RF30 and RF60 compared to FF and C. This study shows that 2x30 minutes and 2x60 minutes per week of recreational football are capable of increasing FN BMD and VO_2 max contrary to controls and to formal football players in whom BMD and VO_2 max did not significantly change. Despite the participation of the FF group in recreational football, BMD and physical performance percentages of variations were not significantly different between the former football players and the control group. This may be explained as we mentioned before in the "within group differences" paragraph, that FF participants are adapted to this type of stimulus and had higher baseline BMD compared to controls, so the benefits associated with physical training will be low. In addition, SI, CSI and ISI percentages of variation were significantly higher in RF30 compared to C. SI, CSI and ISI are related to the ratio FN BMD/weight; this ratio tends to increase in response to football training (El Hage et al., 2014b; El Hage, 2014). Concerning the physical performance parameters, the percentage of variation of the CMJ was significantly higher in RF30 compared to C but not in the RF60 and FF group. This may be due to the probability of having a higher training intensity in RF30 compared to the RF60 and the FF. Overall, there were no significant differences between both experimental groups (RF60 and RF30) concerning the percentages of variations in bone health parameters and in physical performance variables. Hence, most of the health benefits can occur in response to 2*30 minutes of recreational football per week.

1.2.2 Within group differences

The longitudinal changes within groups for the control group, RF30 and RF60 have been previously discussed.

Concerning the former football group, we did not find any significant changes concerning the clinical and bone parameters except a decrease in the whole body bone mineral density after a 1-year period. Also, no significant changes were found concerning the physical performance parameters. The participants of this group are players that played football for many consecutive years. Osteogenic response only takes place when the load exerted on the bone exceeds the habitual load that is imposed on it. A gradual increase in load or an overload is required to achieve this response. In the FF group, there were no changes in intensity or volume of the training for many years. The players of the FF group might be adapted to the type of stimulus elicited by the football games. This adaptation may explain the fact that there are no significant changes in bone and physical parameters after this one-year intervention. Furthermore, these former players had higher baseline BMD compared to controls, so the benefits associated with physical training will be low. The higher a subject's baseline BMD is, the lower the benefits associated with physical training will be low. Baseline BMD is negatively correlated to the increase of BMD in response to exercise (Kohrt et al., 2004). Moreover, according to Burr et al. (2002), bone tissue quickly gets used to the type and intensity of exercise. The variation is very important to avoid reaching a plateau. In practice, in order to avoid a stagnation of the bone response, it is necessary to change the type and intensity of exercise and increase the level of mechanical stress in the workouts performed. Finally, osteogenic response to exercise is stronger in adolescents compared to middle-aged men (Santos et al., 2017).

1.3 Limitations

First, the cross-sectional nature of the first two studies is a limit because it does not allow us to assert a causal relationship between the anthropometric and physical performance parameters and bone parameters, and it cannot confirm a causal relationship between former football practice and present CSI, BSI and ISI values. Second, DXA measurements are 2-dimensional in nature, but the true nature of bone is three-dimensional. Moreover, several bone health determinants (insulin-like growth factor, testosterone, insulin, leptin, vitamin D and PTH levels) were not controlled in these studies. Another limitation is the relatively small number of subjects. Moreover, heart rate and GPS monitoring (running speed, distance covered at different speed, etc.) were absent in our study; we were not able to quantify each training session of recreational football. Finally, we did not use a physical activity questionnaire to measure the effect of mechanical strain on BMD.

1.4 Originality and strengths of the study

Up to our knowledge, this is the first study to compare the effects of two recreational football training programs in middle-aged men. The results obtained showed that these types of training programs are sufficient to increase several bone health parameters as well as VO_2 max. Accordingly, such types of training programs should be recommended to middle-aged men to improve their cardiovascular and musculoskeletal health.

CONCLUSIONS AND PERSPECTIVES

This PhD thesis conducted on a group of middle-aged men mainly shows that:

- First, lean mass was the strongest determinant of WB BMC, VO_2 max (L/min) was the strongest determinant of WB BMD, TH BMD and FN BMD while maximum power of the lower limbs was the strongest determinant of total radius BMD. Accordingly, VO_2 max (L/min), lean mass and maximum power of the lower limbs are the strongest determinants of bone variables in middle-aged men.
- Second, former football practice is associated with higher composite indices of femoral neck strength (CSI, BSI and ISI) in middle-aged men. Hence, regular football practice before the young adulthood period may confer residual benefits in composite indices of femoral neck strength in middle-aged men.
- Last, we compared the effects of two recreational football protocols (RF30: 2x30min vs RF60: 2x60min for 1 year) on bone health and physical performance parameters in a group of healthy middle-aged men. We found that after the 1-year intervention period, WB BMC, FN BMD, CSMI, CSI, BSI and ISI significantly increased in both experimental groups but not in the control group nor in the former football group. Moreover, absolute and relative VO_2 max significantly increased in both experimental groups but not in the control group nor in the former football group. We noticed group * time interactions in FN BMD, CMJ and VO_2 max (L/mn and ml/mn/kg). The percentages of variations in bone health parameters and in physical performance variables were not significantly different in both experimental groups.

In view of our results and limitations, it would be interesting in the future to conduct several studies. First, it would be interesting to conduct a similar longitudinal study with higher numbers of participants and a longer duration of training, adding several questionnaires related to bone loading score, sleep quality, quality of life, protein intake and calcium consumption, and blood tests for the evaluation of lipid profile, glucose regulation and inflammatory cytokines.

Second, it would be useful to study the effects of the cessation of training (detraining) on these parameters in the same population.

Third, investigating the effects of recreational football on bone health parameters in age-matched females would be clinically relevant. Such studies can allow us to investigate the sex-difference osteogenic response to football in this age group.

Fourth, it would be also interesting to investigate the effects of the practice of other team sports (handball, basketball and volleyball) on clinical, bone and physical performance variables in the same age population.

Fifth, it would be clinically pertinent to explore the effectiveness of soccer practice (walking football) on body composition, functional strength, bone health parameters and quality of life in elderly subjects with sarcopenia.

Finally, since metabolic syndrome is becoming very common in young adults whose ages are below 40 years, it would be judicious to explore the effects of soccer practice on body composition, blood glucose, blood lipid profile, blood pressure and physical performance variables in young adults (30-39 years old) with metabolic syndrome.

SUMMARY OF THE THESIS IN FRENCH/ RÉSUMÉ DE LA THÈSE EN FRANÇAIS

I-Introduction et revue de littérature :

L'ostéoporose se caractérise par une faible densité minérale osseuse (DMO) et une détérioration de la microarchitecture osseuse conduisant à un risque accru de fracture (OMS, 1994). L'ostéoporose est traditionnellement considérée comme un problème de santé pour les femmes mais c'est un problème de santé pour les hommes aussi (Khosla S et al. 2008) et est souvent ignorée (Madeo B et al., 2007). De plus, c'est la maladie osseuse la plus courante chez l'être humain, représentant un problème majeur de santé publique (Tümay et al. 2017). Environ 9 millions de fractures chaque année sont liées à l'ostéoporose (1 fracture ostéoporotique a lieu toutes les 3 secondes) (Johnel et Kanis, 2006). Une femme sur 3 et 1 homme sur 5 âgés de plus de 50 ans rencontreront des fractures liées à l'ostéoporose au cours de leur vie (Melton et al., 1998 ; Melton et al., 1992). Les fractures de la hanche sont considérées comme les plus graves de ces fractures car elles sont corrélées à un taux élevé de morbidité et de mortalité et surtout chez les hommes (Zaheer et LeBoff, 2000). 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 fractures » (NIH, 2001). La résistance osseuse est influencée par trois facteurs majeurs qui sont la DMO, la répartition géométrique de la masse osseuse et les propriétés des matériaux (Cole et van der Meulen, 2011). La DMO mesurée par DXA est un déterminant important de résistance osseuse à tout âge (Goulding et al., 2000). La DMO est fortement corrélée à la résistance osseuse et peut définir environ 70% de sa variabilité. La DMO reste le meilleur déterminant de la résistance mécanique osseuse (Bouxsein, 2005). La géométrie osseuse affecte également la résistance osseuse. Des sujets ayant la même DMO peuvent présenter différents niveaux de résistance osseuse en fonction de leurs dimensions osseuses et de leur géométrie osseuse (Bouxsein, 2005). De plus, la microarchitecture osseuse influence également la résistance osseuse (Dalle Carbonare et Giannini, 2004). Des sujets ayant une DMO normale mais une microarchitecture détériorée (mauvaises propriétés des matériaux), peuvent être sujets aux fractures (Dalle Carbonare et Giannini, 2004). En plus de la DMO, d'autres variables densitométriques prédisent également les fractures ostéoporotiques telles que les indices de résistance du col fémoral et les indices géométriques du col fémoral de Beck. Les indices de résistance du col fémoral peuvent être bénéfiques dans la prédiction du risque fracturaire au niveau de la hanche. Ces indices reflètent la capacité du col fémoral à résister à un impact en flexion ou en compression axiale et à absorber l'énergie (Karlamangla et al. 2004). Les indices

géométriques du col fémoral sont des déterminants positifs de la résistance mécanique et sont utilisés dans la prédiction du risque de fracture (Kaptoge, 2008 ; Beck, 2009).

L'ostéoporose peut être classée en ostéoporose primaire et ostéoporose secondaire. Il y a deux types d'ostéoporose primaire : type 1 et type 2 (Dobbs et al., 1999). L'ostéoporose de type 1 est appelée ostéoporose post-ménopausique car elle apparaît généralement chez les femmes à un âge pas si longtemps après la ménopause (Gallagher et Tella, 2014). De plus, elle peut être trouvée chez les hommes à âge moyen. L'ostéoporose de type 2 ou ostéoporose sénile est liée au vieillissement. Avec le vieillissement, l'équilibre entre la formation et la résorption de l'os est déplacé favorisant une plus grande résorption osseuse et une moindre formation osseuse (Demontiero et al., 2012). L'ostéoporose secondaire est liée à des facteurs tels que des troubles médicaux ou l'utilisation d'un certain type de médicaments (Dobbs et al., 1999).

La détérioration osseuse liée au vieillissement est accélérée par la présence de plusieurs facteurs de risque (Pouresmaeili et al., 2018). Afin de réduire le risque de fractures, il est important de réduire les facteurs de risque d'ostéoporose (tabagisme, mode de vie sédentaire, absence d'activité physique, alcoolisme, perte de poids, prise de certains médicaments) tout au long de la vie et d'augmenter le pic de masse osseuse. Le pic de masse osseuse (PMO) est «la quantité du tissu osseux présent à la fin de la maturation squelettique » (Bonjour et al., 1994). Après avoir atteint la PMO, la perte osseuse avec le vieillissement est universelle chez les deux sexes et se produira. L'augmentation du PMO pendant la croissance est une stratégie importante pour prévenir les futurs cas d'ostéoporose. L'augmentation des niveaux d'activité physique à n'importe quelle période de vie réduit le risque de perte osseuse et de fractures ostéoporotiques (Carter et Hinton, 2014). L'os s'adapte à la contrainte mécanique qui lui est appliquée. L'exercice physique soumet l'os à une contrainte mécanique supérieure à la charge habituelle exercée par la contraction musculaire et la charge gravitationnelle (contact entre un objet pondéré (corps humain) et un autre objet ou substrat (sol) (Judex et Carlsonl, 2009).

L'activité physique pourrait être bénéfique pour augmenter la masse osseuse et éviter sa perte mais le choix de l'activité physique est très important, parce que certains types d'activités physiques (à fort impact : course à pied, football, gymnastique et volleyball) sont supérieurs aux autres (natation et cyclisme) pour affecter la santé osseuse (Kohrt et al., 2004). Par conséquent, le football est considéré comme un sport à fort impact biomécanique, et de nombreuses études ont montré que sa pratique dans plusieurs populations augmente la formation osseuse à plusieurs sites (indiqués précédemment dans les tableaux). De plus, le football est pratiqué partout dans le monde. En effet, la participation au football est agréable et

amusante avec une sensation modérée de fatigue physique après sa pratique (Krustrup et Krustrup, 2018). Cependant, les études longitudinales visant à étudier les effets de la pratique du football sur les paramètres de santé osseuse chez les hommes d'âge moyen sont rares. De plus, les études liées au football avaient un temps d'entraînement compris entre 45 et 60 minutes à raison de 2 à 3 fois par semaine. Mais, de nombreux hommes d'âge moyen n'ont pas suffisamment de temps (2-3 x 60 min) pour pratiquer le sport. Par conséquent, la création d'un programme d'entraînement en football efficace en termes de temps devrait être étudiée. De plus, la meilleure fréquence d'entraînement pour stimuler l'adaptation ostéogénique doit être définie dans cette tranche d'âge.

Les objectifs de la thèse

Le premier objectif de la thèse était d'explorer les relations entre plusieurs paramètres de performance physique et les paramètres osseux chez un groupe d'hommes cinquantenaires.

Le deuxième objectif était de comparer les indices de résistance osseuse du col fémoral chez un groupe d'hommes cinquantenaires inactifs et des anciens joueurs de football de même âge.

Le troisième objectif était d'explorer les effets d'un an de 2 protocoles de football récréatif (2x30min et 2x60min par semaine) sur la densité minérale osseuse et les paramètres de performance physique chez un groupe d'hommes cinquantenaires.

Les hypothèses de la thèse :

Notre thèse se base sur les hypothèses suivantes :

La consommation maximale d'oxygène et la force maximale des membres inférieurs sont positivement corrélées à la DMO chez les hommes d'âge moyen.

La pratique antérieure du football est associée à des indices de résistance osseuse du col fémoral plus élevés chez les hommes cinquantenaires en bonne santé.

Les deux protocoles de football récréatif (2x30min et 2x60min par semaine) améliorent la santé osseuse et les variables de performance physique chez les hommes d'âge moyen en bonne santé.

II- Conditions expérimentales et Méthodologie Générale

Sujets

51 hommes ont participé aux 3 études. Tous les sujets étaient des hommes en bonne santé âgés en moyenne de 50,2 ± 4,5 ans. Ils étaient non-fumeurs et n'avaient pas d'antécédents de

problèmes orthopédiques majeurs ou d'autres troubles qui affectent le métabolisme osseux, y compris le diabète.

Design des 3 études

Les 3 études comprenaient l'évaluation des paramètres anthropométriques, des paramètres osseux et des paramètres physiques.

Le poids corporel a été mesuré en utilisant une balance mécanique standard avec une précision de 0,1 kg. La taille a été mesurée en position verticale à 0,5 cm près en utilisant un stadiomètre standard. L'IMC a été calculé en divisant le poids corporel par la taille au carré (kg / m^2). La composition corporelle [MM (Kg) / MG (%, kg)] a été évaluée par DXA.

Le CMO (g) et la DMO (g/cm^2) ont été évalués dans différentes parties du corps. Le CMO corps entier (CE), la DMO corps entier (CE), la DMO rachis lombaire (L1-L4), la DMO hanche entière (HE), la DMO col fémoral (CF) et la DMO du radius (main droite) ont été évalués par DXA. De plus, les indices géométriques du col fémoral (CSA, CSMI, Z, SI et BR) ont été calculés par DXA. Les indices de résistance osseuse du col fémoral (CSI, BSI et ISI) ont été calculés par leurs formules spécifiques.

Le temps du sprint de 10 m, la détente verticale (DV), le saut horizontal (HJ), la puissance des membres inférieurs, la consommation maximale d'oxygène, la force concentrique maximale des membres inférieurs : 1-RM demi-squat, la force concentrique maximale des membres supérieurs : 1-RM : développé couché et la force de préhension de la main droite ont été évaluées.

La consommation calcique journalière (CCJ) (Fardellone et al. 1991), la consommation protéique journalière (CPJ) (Morin et al. 2005), la qualité de sommeil (PSQI) (Buysse et al. 1989) et le niveau hebdomadaire d'activité physique (Armstrong, 2006) ont été évalués par des questionnaires validés pour tous les participants des études 1 et 2.

Analyses statistiques :

Les données ont été exprimées en moyenne ± la déviation standard pour tous les paramètres étudiés. Les différences entre les groupes ont été évaluées par une analyse de variance à une voie (ANOVA). Les corrélations ont été précisées par le test de Spearman pour les distributions non normales et par le test de Pearson pour les distributions normales, les valeurs de r ont été retenues. Des modèles d'analyse de régressions linéaires multiples ont été utilisés pour définir les meilleurs déterminants des paramètres osseux et les valeurs de r^2 ont été rapportées (étude

1). Des analyses de covariance à une voie (ANCOVA) ont été utilisées afin de comparer les variables osseuses entre les groupes après ajustement pour des covariants. Dans l'étude 3, pour juger d'éventuelles différences longitudinales dans les 4 groupes (RF60, RF30, FF et C) à la suite de l'entrainement, nous avons utilisé une analyse de mesure répétée bidirectionnelle de la variance (two-way-RM-Anova). Les pourcentages de variations des qualités physiques et des paramètres osseux ont été calculés pour les 4 groupes. Une valeur de $p < 0,05$ était exigée afin d'affirmer le caractère significatif des résultats. Les analyses statistiques ont été effectuées à l'aide du programme SigmaStat 3.1 (Jandel Corp., San Rafael, Californie).

III- Contribution personnelle :

1. Étude 1 :

La puissance musculaire et la consommation maximale d'oxygène prédisent la densité osseuse dans un groupe d'hommes d'âge moyen.

1.1 Objectif :

Explorer les relations entre plusieurs variables de performance physique et les paramètres osseux dans un groupe d'hommes d'âge moyen.

1.2 Méthodes :

50 hommes d'âge moyen ont participé à cette étude. Les paramètres anthropométriques, osseux et physiques ont été évalués. Les corrélations entre les variables de performance physique et les caractéristiques osseuses de la population étudiée ont été calculées. De plus, les corrélations entre les variables cliniques et les caractéristiques osseuses de la population étudiée ont été calculées.

1.3 Résultats *:*

1.3.1 Corrélations entre les variables cliniques et les caractéristiques osseuses

Le poids corporel a été corrélé aux plusieurs paramètres osseux : CMO CE, DMO CE, DMO HE, DMO CF, DMO radius, CSA, CSMI et SI. L'IMC était corrélé aux plusieurs paramètres osseux : le CMO CE, la DMO CE, la DMO HE, la DMO du radius total et le SI. La MM était positivement corrélée au CMO CE, DMO CE, DMO HE, DMO CF, DMO radius, CSA et CSMI. La MG était corrélée au CMO CE, la DMO CE, la DMO HE, la DMO radius et le SI. Le pourcentage de la MG était négativement corrélé au SI. La consommation protéique journalière était positivement corrélé à la DMO CE, à la DMO L1-L4 et à la DMO HE. L'activité

physique (h/semaine) était positivement corrélée à la DMO L1-L4, la DMO HE, la DMO CF, la CSA, le CSMI et le SI.

1.3.2 Corrélations entre les variables physiques et les caractéristiques osseuses.

La puissance maximale des membres inférieurs était positivement corrélée à la CMO, la DMO CE, la DMO L1-L4, la DMO HE, DMO CF, DMO radius, CSA et CSMI. La force de la poignée (*handgrip*) était positivement corrélée au CMO CE, la DMO CE, la DMO CF, la DMO Radius, la CSA et le CSMI. La 1-RM demi-squat était positivement corrélé au CMO CE, la DMO CE, la DMO L1-L4, la DMO HE, DMO CF, CSA et CSMI. 1-RM Bench press était positivement corrélée au CMO CE, la DMO CE, la DMO CF, la DMO radius total, la CSA et le CSMI. Le sprint de 10 m était négativement corrélé à la DMO L1-L4, la DMO CF, la CSA, le CSMI et le SI. La VO_2 max (L / min) était positivement corrélée à la BMC WB, la DMO CE, la DMO L1-L4, la DMO HT, la DMO CF, la CSA et le CSMI. Le VO_2 max (ml / min / kg) était positivement corrélé au SI. Le saut horizontal n'était pas corrélé aux variables osseuses.

1.3.3 Régressions linéaires multiples

La masse maigre était le déterminant le plus fort du CMO CE et du CSMI. La VO_2 max (L/min) était le déterminant le plus fort de la DMO CE, la DMO HE, la DMO CF et la CSA. La puissance maximale était le déterminant le plus fort de la DMO radius.

1.4 Conclusion :

La VO_2 max (L / min), la masse maigre et la puissance maximale des membres inférieurs (watts) sont les déterminants les plus puissants des paramètres osseux chez les hommes d'âge moyen. Nos résultats peuvent être utiles pour construire de nouveaux programmes d'exercices pour la prévention et la détection précoce de l'ostéoporose et/ou de l'ostéopénie chez les hommes. Par conséquent, un entraînement aérobie à haute intensité peut améliorer la santé des os et les paramètres physiques chez les hommes (par exemple : Football).

2. Étude 2 :

Indices de résistance osseuse du col fémoral chez des sujets inactifs d'âge moyen par rapport aux anciens joueurs de football.

2.1 Objectif :

Comparer les indices de résistance osseuse du col fémoral chez un groupe d'hommes cinquantenaires inactifs et des anciens joueurs de football de même âge.

2.2 Méthodes :

35 hommes d'âge moyen ont participé à cette étude et ont été divisés en deux groupes : le groupe inactif (n = 20) et le groupe d'anciens joueurs de football (n = 15). Les participants du groupe inactif ont effectué moins de 150 minutes d'activité physique d'intensité modérée ou 75 minutes d'activité physique d'intensité vigoureuse ou une combinaison équivalente d'activité d'intensité modérée et vigoureuse par semaine. Les anciens joueurs de football ont pratiqué le football régulièrement à l'adolescence et au jeune âge adulte (pendant au moins 10 ans). Dans cette étude, les paramètres anthropométriques, osseux, physiques ont été évalués.

2.3 Résultats

2.3.1 Caractéristiques cliniques de la population étudiée

L'âge, le poids, la taille, l'IMC, la masse maigre, la masse grasse, l'apport quotidien en calcium, l'apport quotidien en protéines, le PSQI**,** n'étaient pas significativement différents entre les 2 groupes. Le pourcentage de masse grasse était plus élevé chez les hommes inactifs que chez les anciens joueurs de football. Le niveau d'activité physique était plus élevé chez les anciens joueurs de football que chez les hommes inactifs.

2.3.2 Variables osseuses de la population étudiée

La DMO du radius, le SI et le BR n'étaient pas significativement différents entre les 2 groupes. Le CMO CE, la DMO CE, la DMO L1-L4, la DMO HE, la DMO CF, la CSA, le CSMI, le Z, le CSI, le BSI et l'ISI étaient significativement plus élevés chez les anciens joueurs de football que chez les hommes inactifs.

2.3.3 Variables de performance physique de la population étudiée

La force de préhension et la 1-RM développé couché n'étaient pas significativement différents entre les 2 groupes. Le saut vertical, la puissance maximale des membres inférieurs, le saut horizontal, le demi-squat 1-RM, les performances de sprint de 10 mètres et la VO_2 max étaient significativement plus élevés chez les anciens joueurs de football que chez les hommes inactifs.

2.3.4 Corrélations entre les variables cliniques et les caractéristiques osseuses de la population étudiée

Le poids, la taille, la masse maigre, la CPJ et l'AP étaient positivement corrélés à de nombreux paramètres osseux. La masse grasse était négativement corrélée au CSI et à l'ISI. Le pourcentage de masse grasse était négativement corrélé au CSI, au BSI et à l'ISI. Le niveau

d'activité physique était positivement corrélé au CSI, au BSI et à l'ISI. Le PSQI et l 'IMC étaient négativement corrélés au CSI et à l'ISI.

2.3.5 Corrélations entre les variables de performance physique et les caractéristiques osseuses de la population étudiée

Le saut vertical, le saut horizontal (HJ), 1-RM squat, 10-m sprint et la VO_2 max (ml/min/kg) étaient significativement corrélées aux indices de résistance osseuse du col fémoral.

2.3.6 Variables osseuses ajustées pour plusieurs covariants dans les 2 groupes

Après ajustement pour la VO_2 max (ml/min /kg) et la performance au sprint : la majorité des paramètres osseux est restée significativement plus élevée chez les anciens joueurs de football que chez les hommes inactifs. Après ajustement pour l'activité physique (min/semaine) et le pourcentage de graisse corporelle, la majorité des paramètres osseux est restée significativement plus élevée chez les anciens joueurs de football que chez les hommes inactifs.

2.4 Conclusion

La pratique antérieure du football à l'adolescence est associée à une augmentation des indices de résistance osseuse du col fémoral chez les hommes d'âge moyen. La pratique du football à l'adolescence semble avoir un effet anti-fracturaire plus tard dans la vie. Par conséquent, l'élaboration des programmes d'exercices pendant l'adolescence doit être adaptée.

3. Étude 3 :

Les effets d'un protocole de football récréatif d'un an sur la densité minérale osseuse et les paramètres de performance physique dans un groupe d'hommes sains et inactifs de 50 ans.

3.1 Objectif

Comparer les effets de deux protocoles de football récréatif (RF30 : 2x30min vs RF60 : 2x60min pendant 1 an) sur la santé osseuse et les paramètres de performance physique dans un groupe d'hommes d'âge moyen inactifs en bonne santé.

3.2 Méthodes :

51 hommes d'âge moyen ont participé à cette étude. Ils ont été divisés en 4 groupes :

Groupe d'hommes actifs (anciens joueurs de football ; FF n = 14), groupe de football récréatif 60 (RF60 ; n = 13), groupe de football récréatif 30 (RF30 ; n = 14) et le groupe témoin (C ; n = 10). 10 sujets ont abandonné pour différentes raisons (7 blessures dont 3 dans RF30 ; 3 dans

RF60 ; 1 dans FF et 3 pour des raisons personnelles et de voyage (1 RF30 et 2 FF)). 41 sujets ont terminé l'étude : hommes actifs (anciens joueurs de football ; FF n = 11), football récréatif 60 (RF60 ; n = 10), football récréatif 30 (RF30 ; n = 10) et groupe témoin (C ; n = 10).

L'entraînement a duré 1 an à raison de 2 séances d'entraînement par semaine (RF60 : 2x 60 min/semaine ; RF30 : 2x30 min/semaine). Tous les participants ont joué au football sur le même terrain de mini-football de 35*22m en gazon artificiel. Tous les matchs de football récréatifs ont été supervisés par l'auteur de la thèse. Tous les participants ont effectué un échauffement spécifique avant de commencer les jeux. Dans tous les matchs de football récréatif, les deux gardiens de but ne faisaient pas partie de la population étudiée et n'ont pas participé à l'étude. Dans le football récréatif sur un petit terrain, tous les participants ont joué dans toutes les positions (défense et attaque).

3.3 Résultats

3.3.1 Caractéristiques cliniques de la population étudiée au départ

Les anciens footballeurs étaient plus grands de taille que les participants du groupe témoin.

3.3.2 Variables osseuses de la population étudiée au départ

Le CMO CE et le CSMI étaient significativement plus élevés chez FF par rapport à C. la DMO CF, la CSA, le CSI et l'ISI étaient significativement plus élevés chez FF par rapport à C et RF30. Le Z était significativement plus élevé chez FF par rapport au C et au RF60.

3.3.3 Paramètres cliniques et osseux au départ et après la période d'un an dans le groupe témoin

La DMO CE a significativement diminué dans le groupe témoin après une période d'un an. Aucun changement significatif n'a été trouvé concernant les autres paramètres cliniques et osseux.

3.3.4 Variables de performance physique au départ et après la période d'un an dans le groupe témoin

La force de préhension a considérablement diminué après la période d'un an. Aucun changement significatif n'a été trouvé pour les autres paramètres physiques.

3.3.5 L'effet du football de loisir sur les paramètres cliniques et osseux dans l'ancien groupe de football (FF)

La DMO CE a significativement diminué (p = 0,009) dans le groupe FF après une période d'un an. Aucun changement significatif n'a été trouvé concernant les autres paramètres cliniques et osseux.

3.3.6 Paramètres de performance physique avant et après la période d'entraînement dans FF groupe

Aucun changement significatif n'a été trouvé concernant les variables de performance physique en FF après 1 an de football récréatif.

3.3.7 L'effet du football récréatif sur les paramètres cliniques et osseux dans le groupe du football récréatif 30 (RF30)

Après la période d'intervention d'un an, l'activité physique (minutes / semaine), le CMO CE, la DMO CF, la CSA, le CSMI, le Z, le SI, le CSI, le BSI et l'ISI ont augmenté de manière significative dans le RF30.

3.3.8 L'effet du football récréatif sur les paramètres de performance physique dans le groupe de football récréatif 30 (RF30)

La DV, l'1RM demi squat et le VO_2 max absolu et relatif ont augmenté de manière significative. D'autre part, la force de préhension a diminué de manière significative.

3.3.9 L'effet du football récréatif sur les paramètres cliniques et osseux dans le groupe du football récréatif 60 (RF60)

Après la période d'intervention d'un an, l'activité physique (min / semaine), le CMO CE, la DMO L1-L4, la DMO HE, la DMO CF, le CSMI, le CSI, le BSI et l'ISI ont augmenté de manière significative dans RF60. En revanche, la DMO CE a considérablement diminué.

3.3.10 L'effet du football récréatif sur les paramètres de performance physique dans le groupe du football récréatif 60 (RF60)

La VO_2 max absolue et relative a augmenté de manière significative mais la force de préhension a significativement diminué.

3.3.11 Différences entre les groupes ; Interactions groupe* temps concernant les paramètres osseux dans les 4 groupes (C, RF60, RF30 et FF).

Une interaction groupe * temps a été trouvée pour la DMO CF et l'AP.

3.3.12 Interactions groupe* temps concernant les paramètres physiques dans les 4 groupes

Une interaction groupe * temps a été trouvée pour la DV, 1-RM bench press et VO_2 max (L/min and ml/min/kg).

3.3.13 Pourcentages de variations des paramètres cliniques et osseux dans les 4 groupes

Le pourcentage de variation de l'activité physique (min/semaine) était significativement plus élevé dans RF60 et RF30 par rapport aux groupes C et FF et dans RF60 par rapport à RF30. Le pourcentage de variation de la DMO CF était significativement plus élevé dans le RF30 et le RF60 par rapport aux groupes C et FF. Les pourcentages de variation de SI, de CSI et d'ISI étaient significativement plus élevés dans RF30 par rapport au C.

3.3.14 Pourcentages de variation des paramètres de performance physique dans les 4 groupes

Le pourcentage de variation de la DV était significativement plus élevé dans RF30 par rapport à C. Le pourcentage de variation du 1-RM bench press était significativement plus élevé dans RF60 et FF par rapport au C. Les pourcentages de variation de la VO_2 max absolus et relatifs étaient significativement plus élevés dans RF30 et RF60 par rapport aux groupes FF et C.

3.4 Discussion et Conclusion

Un an de pratique du football semble suffisant pour augmenter plusieurs paramètres de santé osseuse, en particulier au niveau du col fémoral chez les hommes d'âge moyen. Ce résultat est cliniquement important car les fractures du col du fémur sont les plus dangereuses chez l'homme et peuvent augmenter considérablement le risque de mortalité. Il semble que les deux groupes de football récréatif (RF60 et RF30) sont efficaces pour augmenter la DMO CF et la VO_2 max absolue et relative chez les hommes libanais inactifs en bonne santé d'âge moyen. La plupart des bienfaits peut survenir en réponse à 2*30 minutes de football récréatif par semaine.

3.6 Originalité et points forts de l'étude

À notre connaissance, il s'agit de la première étude à comparer les effets de deux programmes d'entraînement de football récréatif chez des hommes d'âge moyen. Les résultats obtenus ont montré que ces types de programmes d'entraînement sont suffisants pour augmenter plusieurs paramètres de santé osseuse ainsi que la VO_2 max. En conséquence, de tels types de programmes d'entraînement devraient être recommandés aux hommes d'âge moyen afin d'améliorer leur santé cardiovasculaire et musculo-squelettique.

4. Cette thèse de doctorat menée sur un groupe d'hommes d'âge moyen montre principalement que :

La VO_2 max (L/min), la masse maigre et la puissance maximale des membres inférieurs sont les déterminants les plus puissants des variables osseuses chez les hommes d'âge moyen.

La pratique antérieure du football est associée à des indices de résistance osseuse du col fémoral plus élevés (CSI, BSI et ISI) chez les hommes d'âge moyen.

Le football récréatif à raison de 2 séances par semaine est une méthode efficace pour l'amélioration des paramètres de santé osseuse chez les hommes cinquantenaires.

5. Perspectives :

1er axe : il serait intéressant de mener une étude longitudinale similaire avec un nombre plus élevé de participants et une durée d'entraînement plus longue dans laquelle nous ajouterons plusieurs questionnaires (liés au score de contraintes mécaniques, à la qualité de sommeil, à la qualité de vie, à l'apport en protéines et à la consommation de calcium) et plusieurs évaluations (comme l'évaluation du profil lipidique, de la régulation du glucose et des cytokines inflammatoires). Il serait également intéressant d'étudier les effets de l'arrêt de l'entraînement (désentraînement) sur ces paramètres dans la même population, d'étudier les effets du football récréatif sur les paramètres de santé osseuse chez les femmes du même âge et d'étudier les effets de la pratique d'autres sports collectifs (handball, basketball et volleyball) sur la performance physique et les paramètres de santé osseuse dans la même population.

2ème axe : il serait cliniquement important d'explorer l'efficacité de la pratique du football (Walking football) sur la composition corporelle, la force fonctionnelle, les paramètres de santé osseuse et la qualité de vie chez les sujets âgés sarcopéniques.

3ème axe : Comme le syndrome métabolique devient très fréquent chez les jeunes adultes âgés de moins de 40 ans, il serait judicieux d'explorer les effets de la pratique du football sur la composition corporelle, la glycémie, le profil lipidique sanguin, la pression artérielle et les variables de performance physique chez les jeunes adultes (30-39 ans) ayant un syndrome métabolique.

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ANNEX

Publications

Published articles:

Finianos B, Sabbagh P, Zunquin G, El Hage R. Muscular power and maximum oxygen consumption predict bone density in a group of middle-aged men. J Musculoskelet Neuronal Interact. 2020 Mar 3;20(1):53-61.

Finianos B, Zunquin G, El Hage R. Composite Indices of Femoral Neck Strength in Middle-Aged Inactive Subjects Vs Former Football Players [published online ahead of print, 2020 Jun 12]. *J Clin Densitom*. 2020;S1094-6950(20)30093-7.

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Rizkallah M, Bachour F, Khoury M, Sebaaly A, **Finianos B**, El Hage R, Maalouf G. Comparison of morbidity and mortality of hip and vertebral fragility fractures: Which one has the highest burden? Osteoporosis and Sarcopenia. 2020;6(3):146–50.

Published abstracts:

Finianos B, Zunquin G, Devanne H, El Hage R. Relations entre paramètres de performance physique et variables osseuses chez des hommes âgés entre 40 et 55 ans. Actes du 18ème congrès de l'ACAPS, 2019; page 177.

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Finianos B, Zunquin G, El Hage R. Physical performance variables and composite indices of femoral neck strength in a group of middle-aged men (P678). World Congress on Osteoporosis, Osteoarthritis and Musculoskeletal Diseases (WCO-IOF-ESCEO 2020); Abstract book page 404.

Summary

Effects of a 1-year recreational football protocol on bone mineral density and physical performance parameters in a group of healthy inactive 50-year-old men

The aims of this PhD thesis were to explore the relationships between several physical performance variables and bone parameters in a group of middle-aged men, to compare composite indices of femoral neck strength in inactive middle-aged men and aged-matched former football players and to explore the effects of a 1-year recreational football protocol on bone mineral density and physical performance parameters in a group of healthy inactive 50-year-old men. Three main studies have been conducted. The first study has shown that VO_2 max (L/min), lean mass and maximum power of the lower limbs are the strongest determinants of bone variables in middle-aged men. The second study has shown that former football practice is associated with higher composite indices of femoral neck strength in middle-aged men. The third study has demonstrated that WB BMC, FN BMD, CSMI, CSI, BSI and ISI increased in both experimental groups (RF30 and RF60) but not in the control group. The percentages of variations in bone health parameters and in physical performance variables were not significantly different in both experimental groups. Recreational football is an effective method to improve bone health in middle-aged men.

Keywords: Team sport; Prevention of osteoporosis; Men; Physical activity and bone; Muscular power; Aerobic fitness; Femur.

Résumé

Effets d'un protocole de football récréatif d'un an sur la densité minérale osseuse et les paramètres de performance physique chez un groupe d'hommes sains, inactifs et âgés de 50 ans

Les buts de cette thèse de doctorat étaient d'explorer les relations entre plusieurs paramètres de performance physique et les paramètres osseux chez un groupe d'hommes cinquantenaires, de comparer les indices de résistance osseuse du col fémoral chez un groupe d'hommes cinquantenaires inactifs et des anciens joueurs de football de même âge et d'explorer les effets d'un an de football récréatif sur la densité minérale osseuse et les paramètres de performance physique chez un groupe d'hommes cinquantenaires. Trois principales études ont été menées. La première étude a démontré que la VO_2 max (L/min), la masse maigre et la puissance maximale des membres inférieurs sont les meilleurs déterminants des paramètres osseux chez les hommes cinquantenaires. La deuxième étude a démontré que l'ancienne pratique du football est associée à une augmentation des indices de résistance osseuse du col fémoral chez les hommes cinquantenaires. La troisième étude a démontré que le CMO CE, la DMO CF, le CSMI, le CSI, le BSI et l'ISI ont augmenté dans les deux groupes expérimentaux (RF30 et RF60) mais pas dans le groupe témoin. Les pourcentages de variation des paramètres osseux et des performances physiques n'étaient pas significativement différents entre les deux groupes expérimentaux. Le football récréatif est une méthode efficace pour l'amélioration des paramètres de santé osseuse chez les hommes cinquantenaires.

Mots clés : Sports collectifs ; Prévention de l'ostéoporose ; Hommes ; Activité physique et os ; Puissance musculaire ; Qualité aérobie ; Fémur.