BONE HEALTH STATUS, MUSCULAR PERFORMANCE, AEROBIC AND ANAEROBIC CAPACITIES OF MALAYSIAN YOUNG MALE STATE LEVEL WEIGHTLIFTING, CYCLING AND SQUASH ATHLETES

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By

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CERTIFICATE

This is to certify that the dissertation entitled

BONE HEALTH STATUS, MUSCULAR PERFORMANCE, AEROBIC AND ANAEROBIC CAPACITIES OF MALAYSIAN YOUNG MALE STATE LEVEL WEIGHTLIFTING, CYCLING AND SQUASH ATHLETES

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated and duly acknowledged. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at Universiti Sains Malaysia or other institutions. I grant Universiti Sains Malaysia the right to use the dissertation for teaching, research and promotional purposes.

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Date: 14 August 2018

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STATUS KESIHATAN TULANG, PRESTASI OTOT, KAPASITI AEROBIK DAN ANAEROBIK DALAM KALANGAN ATLIT-ATLIT NEGERI ANGKAT BERAT, BERBASIKAL DAN SKUASY LELAKI MUDA MALAYSIA

ABSTRAK

Kajian ini telah dijalankan untuk mengkaji perbezaan dalam status kesihatan tulang, prestasi otot, kapasiti aerobik dan anaerobik dalam kalangan atlit-atlit negeri dalam angkat berat, berbasikal dan skuasy lelaki muda Malaysia. Seramai 44 peserta (umur purata: 17.1 ± 1.6 tahun) telah dibahagikan kepada kumpulan kawalan sedentari, angkat berat, berbasikal dan skuasy dengan 11 peserta bagi setiap kumpulan. 'Speed of sound' (SOS) tulang 'tibia' dan 'radius' bagi lengan dan kaki dominan dan bukan dominan peserta-peserta telah diukur. Tambahan pula, kekuatan dan kuasa otot isokinetik, kekuatan genggaman tangan, kekuatan belakang dan kaki, anggaran pengambilan oksigen maksima (VO_{2max}) anggaran, kapasiti-kapasiti anaerobik Wingate peserta-peserta telah ditentukan. Analisis statistik telah dijalankan dengan meggunakan One way ANOVA. Kajian ini mendapati bahawa atlit-atlit angkat berat, berbasikal dan skuasy mempamerkan SOS tulang tibia dan radius yang lebih besar secara signifikan ($p<0.01$) berbanding dengan kumpulan kawalan sedentari. Atlit-atlit angkat berat menunjukkan SOS tulang lengan yang paling tinggi. Pada masa yang sama, atlit-atlit berbasikal menunjukkan SOS tulang kaki yang paling tinggi. Atlit-atlit angka berat menunjukkan nilai-nilai 'peak torque' (kekuatan) dan kuasa purata ($p<0.05$) yang lebih tinggi secara signifikan bagi isokinetik 'knee extension', 'shoulder extension' dan 'shoulder flexion' berbanding dengan atlit-atlit berbasikal dan squasy. Atlit-atlit angkat berat juga menunjukkan kekuatan genggaman tangan yang lebih besar ($p< 0.001$), begitu juga kekuatan belakang dan kaki ($p< 0.001$) berbanding dengan atlit-atlit berbasikal dan skuasy. Atlit-atlit berbasikal dan squasy menunjukkan kapasiti aerobik, iaitu anggaran pengambilan oksigen maksima (VO_{2max}) ($p<0.001$) yang lebih tinggi secara signifikan berbanding dengan atlit-atlit angka berat dan skuasy. Atlit-atlit angkat berat mempamerkan kuasa kemuncak ($p< 0.05$) yang lebih besar secara signifikan berbanding dengan atlit-atlit berbasikal dan skuasy. Di samping itu, atlit-atlit berbasikal menunjukkan kapasiti anaerobik dan kuasa yang lebih tinggi ($p< 0.001$), tahap kepenatan yang lebih rendah ($p< 0.05$) secara signifikan berbanding dengan atlit-atlit angka berat dan skuasy. Atlit-atlit angka berat dan berbasikal menunjukkan masa yang lebih singkat untuk mencapai kuasa kemuncak ($p< 0.01$) berbanding dengan atlit-atlit skuasy. Hasil kajian ini melambangkan status kesihatan tulang dan ‘profile’ fisiologi atlit-atlit adalah bergantung kepada jenis sukan yang mereka terlibat. Adalah diharapkan bahawa keputusan kajian ini dapat diaplikasikan untuk memudahkan pembangunan program latihan spesifik bagi atlit-atlit angkat berat, berbasikal dan skuasy, serta menggalakkan gaya hidup aktif dengan melibatkan diri dalam sukan angkat berat, berbasikal dan skuasy.

BONE HEALTH STATUS, MUSCULAR PERFORMANCE, AEROBIC AND ANAEROBIC CAPACITIES OF MALAYSIAN YOUNG MALE STATE LEVEL WEIGHTLIFTING, CYCLING AND SQUASH ATHLETES

ABSTRACT

This study was carried out to determine the differences in bone health status, muscular performance, aerobic and anaerobic capacities of Malaysian young male state level weightlifting, cycling and squash athletes. Forty four participants (mean age: 17.1 ± 1.6 years old) were divided into sedentary control, weightlifting, cycling and squash groups with 11 participant for each group. Participants' tibial and radial bone speed of sound (SOS) of dominant and non-dominant arms and legs were measured. In addition, participants' isokinetic muscular strength and power, hand grip strength, back and leg strength, estimated maximal oxygen uptake (VO_{2max}), and Wingate anaerobic capacities were determined. One way ANOVA was performed for statistical analysis. The present study found that weightlifting, cycling and squash athletes exhibited significantly greater tibial and radial bone SOS ($p<0.01$) compared to the sedentary control group. Bone SOS of the arm was highest in weightlifting athletes. Meanwhile, bone SOS of the leg was highest in cycling athletes. Weightlifting athletes showed significantly higher values of isokinetic knee extension, shoulder extension and shoulder flexion peak torque (strength) and average power ($p<0.05$) than cycling and squash athletes. Weightlifting athletes also showed significantly greater hand grip strength ($p< 0.001$), as well as back and leg strength ($p< 0.001$) compared to cycling and squash athletes. Cycling and squash athletes showed significantly higher aerobic capacity, i.e. estimated VO_{2max} ($p<0.001$) compared to weightlifting and squash athletes. Weightlifting athletes exhibited significantly greater peak power ($p< 0.05$) than cycling and squash athletes. Besides, cycling athletes showed significantly higher anaerobic capacity and power ($p< 0.001$), and significantly lower fatigue index ($p< 0.05$) than weightlifting and squash athletes.

Weightlifting and cycling athletes showed significantly shorter time to reach peak power ($p < 0.01$) than squash athletes. The present study findings implying that bone health status and physiological profiles of the athletes are dependent on sport events they were involved in. It is hoped that the results of the present study can be applied and help to facilitate the development of specific training programmes for achieving optimal performance of weightlifting, cycling and squash athletes, as well as promoting healthy lifestyle by engaging in sports like weightlifting, cycling and squash sports.

CHAPTER 1

INTRODUCTION

Weight-bearing exercise has been recognised to be beneficial for long-term bone health (Boreham & McKay, 2011). It is also known that exercises involving high peak force of loading or impact loading can have greater influence on bone mass and tend to be effective in osteogenic stimulus. Most of the mechanical forces that act on the skeleton during physical activities are generated either through impact with the ground, i.e. gravitational or ground reaction forces or through skeletal muscle contractions, i.e. muscle or joint-reaction forces. Generally, the effects of physical activity on bone mineral density (BMD) are primarily related to the mechanisms of mechanical loading that impose on skeleton (Suva *et al*., 2005; Zernicke *et al*., 2006). BMD is the most common indicator of bone strength (Ammann & Rizzoli, 2003) and also a predictor of fracture risk (Kanis *et al*., 2005; Turner, 2002; Johnell *et al*., 2005). Skeletal adaptations to loading appear to be site-specific (Kanis *et al*., 2005; Skerry, 2006), and bone is a highly dynamic tissue that adapts its mass and architecture to the physiological and mechanical environment (Skerry, 2008).

Weight bearing sport activities are associated with high bone mass in lumbar spine, hip, femur, proximal tibia, and calcaneus (Fehling *et al*., 1995; Heinonen *et al*., 1995), however athletes participating in non-weight bearing sports such as swimming have been shown not to differ (Taaffe *et al*., 1995) or even have lower (Risser *et al*., 1990) bone mass in the lumbar spine than non-active controls. Different types of physical activity created different strain demands on the skeletal bones (Slemenda & Johnston, 1993; Heinonen *et al*., 1995). It has been suggested that for obtaining greatest osteogenic effect, mechanical loading imposes on a specific bone site should produce high strains in unusual patterns during short periods that are repeated regularly (Lanyon, 1992).

Weightlifting is well known as a type of weight bearing sport that involves high-intensity loading forces and demands a dynamic strength and power which requires multi-joint movement and whole body lifts (Storey & Smith, 2012). During the two competitive lifts which are the snatch and the clean and jerk (C&J), weightlifters are able to generate extremely high peak forces and contractile rates of force development which consequently produce high peak power outputs and contractile impulses (Garhammer, 1991; Garhammer, 1993).

A study conducted by Conroy *et al.* (1993) examined the relationship of bone mineral density (BMD) to muscular strength of elite junior weightlifters and age-matched control groups in order to gain insights concerning the influence of heavy resistance training on BMD. It was found that the BMD values for the junior lifters to be significantly greater at all sites compared to control group. The BMD values of the spine and femoral neck of the junior weightlifters when compared with adult reference data were found to be significantly greater. The authors suggested that in elite junior weightlifters, muscle strength, highly specific to the sport of weightlifting, had a major influence on BMD due to the influence of the chronic overloads experienced in training. Weightlifting involves additional skeletal loading and exposes to skeleton intermittent loads beyond body weight, however, weightlifting lacks of repetitive, prolonged impact of ground reaction forces as can be seen in other sports such as squash.

Cycling is an aerobic and non-weight-bearing sport which involves repetitive intensity motion. Nagle and Brooks (2011) mentioned that prone position of cyclist may be inadequate to stimulate bone formation, especially at the spine and hip. During cycling, the spine of the cyclist is suspended evenly between the seat and the handlebars. The feet of cyclist do not contact the surface of the ground while cycling. Therefore, normal weight-bearing ground reaction forces are absent. However, it is believed that cyclist are involved in prolonged cycling training, and the muscle contraction caused by cycling movements during prolonged training will impose great force on bone, subsequently bone health can be increased. In addition, high muscular strength and aerobic capacity are believed can be achieved by involvement in prolonged cycling training in cyclists.

According to Nichols *et al.* (2003) and Stewart & Hannan, (2000), the biomechanics of cycling that is relatively fixed body position and its lack of impact on the skeleton resulted in relatively low strain magnitudes. Therefore, cycling provides little osteogenic stimulus to bones. Cyclists with low BMD may put themselves at risk for osteoporosis at a younger age because their peak bone mass is attenuated and they may experience bone loss due to the low mechanical loading nature of their sport. The cyclists may experience greater mechanical loading at the hip than at the spine, possibly from the stress induced by high-intensity contractions by the leg and hip musculature during cycling. The leg lean tissue in cyclists was found to be greater than controls, therefore there is more muscle mass to exert force on the leg and hip areas. The authors also mentioned that demands in sports like cycling where only part of the body mass, i.e. lower extremities is used dynamically and cyclically without high accelerations and impacts, and most of the rest of the body is carried passively sitting on the saddle and being fixed by the arms are considered too low to induce a remarkable osteogenic stimulation at the axial skeleton and the proximal femur.

Squash involves repetitive weight-bearing, impact loading, as well as accelerating and decelerating movements (Heinonen *et al*., 1995). The playing arm of squash players is mostly loaded by impacts during the stroke in conjunction with frequent, rapid, and multidirectional leg movements, therefore it is believed that the bone of squash players are imposed with great force to produce high bone formation (Heinonen *et al*., 1995). Squash is primarily aerobic in nature, with intermittent bursts of activities being provided from anaerobic energy sources (Gillam *et al*., 1990). Squash athletes need high standard of fitness such as endurance, strength, and physical agility besides the demand of high technical skill (Hawkey, 1984).

Squash is an indoor game and complex sport that requires superior coordination, endurance, speed and power (David, 1992). Wollstein & Ellis. (1995) mentioned that cardiovascular endurance, muscular endurance, and speed endurance are collectively important as the energy's demands to the sport of squash. Krasilshchikov (2014) stated that squash game requires high demand on physical fitness of elite players. Squash at elite level has been reported as being predominantly aerobic and anaerobic component (Sharp, 1988).

In a study carried out by Heinonen *et al.* (1995) which determined bone mineral density representing sports with different loading characteristics of the skeleton, it was found that squash athletes had higher BMD compared to aerobic dancers, speed skaters and sedentary individuals. The squash athletes whose training caused high strain magnitude and rates had the highest weight-adjusted BMD values at all measured sites, with 18.5% higher calcaneal BMD than the sedentary individuals. Therefore, the authors concluded and supported the concept that training, including high strain rates with versatile movements and high peak forces, is more effective in bone formation than training with a large number of low-force repetitions.

Weightlifting, cycling and squash are popular activities among youth. The amount of bone loading in these sports varies greatly as weightlifting involves additional bone loading beyond body weight but without repetitive impact movements, cycling is non-weight bearing with repetitive motion, and squash is weight bearing involves repetitive impact loading of the bone. The extent to which bony stresses from these sports affect bone health status in Malaysian young males is unclear. In addition, there are variations in physiological demands such as muscular performance, aerobic and anaerobic capacities of these three types of sports. Therefore, the present study was proposed to investigate bone health status, muscular performance, aerobic and anaerobic capacity of Malaysian young male weightlifting, cycling and squash athletes.

1.1 OBJECTIVES OF THE STUDY

General objective

To investigate bone health status, muscular performance, aerobic and anaerobic capacities among Malaysian young male state level weightlifting, cycling and squash athletes.

Specific objectives

1) To determine the differences of bone health status among Malaysian young male sedentary controls, state level weightlifting, cycling and squash athletes.
2) To determine the differences of isokinetic muscular strength and power, handgrip strength, and back and leg strength among Malaysian young male sedentary controls, state level weightlifting, cycling and squash athletes.
3) To determine the differences of aerobic and anaerobic capacities among Malaysian young male sedentary controls, state level weightlifting, cycling and squash athletes.

1.2 HYPOTHESES OF THE STUDY

H_{O1}: There are no differences of bone health status among sedentary control, weightlifting, cycling and squash groups.

H_{A1}: There are differences of bone health status among sedentary control, weightlifting, cycling and squash groups.

H_{O2}: There are no differences of isokinetic muscular strength and power among sedentary control, weightlifting, cycling and squash groups.

H_{A2}: There are differences of isokinetic muscular strength and power among sedentary control, weightlifting, cycling and squash groups.

H_{O3}: There are no differences of handgrip, back and leg strength among sedentary control, weightlifting, cycling and squash groups.

H_{A3}: There are differences of handgrip, back and leg strength among sedentary control, weightlifting, cycling and squash groups.

H_{O4}: There are no differences of aerobic capacity among sedentary control, weightlifting, cycling and squash groups.

H_{A4}: There are differences of aerobic capacity among sedentary control, weightlifting, cycling and squash groups.

H_{O5}: There are no differences of Wingate anaerobic capacities among sedentary control, weightlifting, cycling and squash groups.

H_{A5}: There are differences of Wingate anaerobic capacities among sedentary control, weightlifting, cycling and squash groups.

1.3 SIGNIFICANCE OF THE STUDY

Weightlifting, cycling and squash are sports with different mechanical loading characteristics. The extent to which bony stresses from these three sports affect bone health status in Malaysian young male athletes is uncertain. In addition to our knowledge, to date information of muscular strength and power, aerobic and, anaerobic capacities of young male weightlifting, cycling and squash athletes in Malaysia are lacking, therefore the present study was proposed. The results of the present study will add new scientific information on the bone health status, muscular strength and power as well as aerobic and anaerobic capacities of Malaysian young male weightlifting, squash and cycling athletes in the field of sport science and sport medicine. The results obtained from this study can be applied in selection of potential weightlifting, squash and cycling athletes, and help to facilitate the development of specific training programmes for optimal performance of weightlifting, squash and cycling athletes. It is hoped that sport organisation, coaches and athletes can apply the results obtained from this study for maximising an individual potential in the field of weightlifting, squash and cycling.

CHAPTER 2

LITERATURE REVIEW

2.1 SPORTS AND BONE HEALTH

Osteoporosis is a systemic and skeletal disease that is characterised by low bone density and micro-architectural deterioration of bone tissue which consequently increase in bone fragility (Kanis *et al*., 1994). Thus, there is a large emphasis on measures to combat or offset osteoporosis and fracture. One of the major preventive measures is the optimisation of peak bone mass in the early years. Peak bone mass can be defined as the greatest amount of bone mass achieved during life at a given skeletal site. There is increase of bone mass during childhood and puberty, subsequently bone mass consolidates during young adulthood and declines with age (Matkovic *et al*., 1994; Heaney *et al*., 2000).

In general, it is well known that physical activities with mechanical loading imposes on bone is important for skeletal strength and development. French *et al*. (2000) mentioned that one of the most effective osteoporosis prevention strategies is by adopting weight-bearing physical activity in childhood and adolescence which can maximise BMD and bone mineral content (BMC) during the growing years. Weight-bearing exercise is related to force-generating activity that provides loading to skeletal regions provided by activities of daily living (Mackelvie *et al*., 2002). Examples of weight-bearing exercises include aerobics training, circuit training, jogging, jumping, volleyball and other sports that generate impact to the skeleton. It is believed that the years of childhood and adolescence represented an opportune period during which bone adapts efficiently to mechanical loading on bone (Bass, 2000; Khan *et al.,* 2000). Previous studies have indicated that exercises with high impact loading could elicit great beneficial effects for bones by enhancing bone mineral density (BMD) (Wallace & Cumming, 2000; Wolff *et al*., 1991). It was also reported that impact loading, loading consisting of highly accelerating and decelerating movements, and involving changing of direction can produce sufficiently high load magnitudes and loading rates exceeding the threshold level required for osteogenic stimulus (Hsieh *et al*., 2001; Mosley & Lanyon, 1998; Judex & Zernicke, 2000). It has been suggested by Lanyon (1992) that for obtaining greatest osteogenic effect, mechanical loading imposes on a specific bone site should produce high strains in unusual patterns during short periods that are repeated regularly.

Dynamic loading at high strain rates and/or from unusual directions, i.e. odd impact loading seems to be particularly osteogenic (Nikander *et al*., 2009). Similarly, application of high magnitude loading such as heavy weight-bearing appears effective as well (Heinonen *et al*., 1993; Heinonen *et al*., 1995). According to Morseth *et al.* (2011), sports activities that consist of heavy load, or producing impact loading on the skeleton such as gymnastics are associated with higher bone density than sports that generate mechanical loads without additional loads imposed by gravitational forces such as swimming.

Effects of loading on skeleton produces by physical activity is an important factor affecting bone density and its architecture. Bone cells react on mechanical loads which produce balance between formation and resorption of bones which results in increase of bone mass (Lanyon, 1987). The greater the load, the bigger bone mass are produced (Bubanj & Obradovic, 2002). Inversely, when the skeleton is not under load as in non-active state, bone mass is reduced (Bubanj & Obradovic, 2002). Although the importance of mechanical loading-induced bone strains as an adaptive stimulus to promote skeletal integrity has been acknowledged since the late 1800s (Wolff, 1892), the type, intensity, frequency, and duration of loading that are most effective to enhance bone strength are still uncertain. It has been believed that exercise-induced dynamic loading especially impact type that can generate high-intensity loading forces, leads to beneficial bone adaptations that increase in bone mineral density (Turner & Pavalko, 1998, Turner & Robling, 2003). It is believed that the mechanical loads applied to the skeleton need to be in excess of those encountered in daily activity for optimum osteogenic effect on bone (Frost, 1988). Athletes who involved in high-impact and odd impact sports such as hurdling, volleyball and squash elicit greater bone density than those involved in lower impact sports such as orienteering or skiing (Nikander *et al*., 2005).

Different sports activities are believed to have high peak bone mass particularly at the loaded bone sites (Nevill & Stewart, 2004), and some loading types, such as high-impact, odd-impact and high-magnitude loading has been shown to be more effective in bone modelling (Heinonen *et al*., 1993; Heinonen *et al*., 1995; Helge & Kanstruf, 2002; Proctor *et al*., 2002). However, relatively little is known about the relationships between different loading types and structural characteristics of bone, which principally determine the whole bone strength (Jarvinen *et al*., 2005). It has been reported that the lower extremities, the strongest bone structures appear in the athletes representing high-impact and odd-impact loading sports (Faulkner *et al*., 2003; Liu *et al*., 2003; Nikander *et al*., 2005), while the athletes in non- weight bearing sports, such as swimmers do not seem to have improved bone structure at the femoral neck (Nikander *et al*., 2005; Duncan *et al*., 2002). In contrast, at the upper extremities, athletes that participate in sports involve high-magnitude loading, such as weightlifting, or impact loading, such as tennis may have strongest bone structures and bone density (Haapsalo *et al*., 2000; Heinonen *et al*., 2002; Kontulainen *et al*., 2003). The important element of bone adaptation is the mechanism by which the load is transmitted to and absorbed within the given musculoskeletal structure. Body weight and skeletal loading induced by ground reaction forces impose on bone and directed acting through the closed kinetic chain apparently play a key role for increasing bone health status in lower extremities (Heinonen *et al*., 2002).

Ooi *et al.* (2009) mentioned that for stimulating osteogenesis, muscle contraction plays an important role. During exercise or training, it is believed that bone metabolism can be increased, and osteogenesis can be promoted by the strong forces generated from the muscle contraction which impose on bone tissue. Therefore, it is speculated that strong muscles can generate high force, which subsequently produce strong bone, and there is a close relationship between muscular strength and bone health status.

Bone health status can be represented by bone mineral density (BMD). Besides, bone speed of sound can reflect bone health status as well. Quantitative ultrasound measurement of bone can be performed by using bone sonometer for measuring bone speed of sound (SOS) (Barkmann *et al*., 2000). Sunlight MiniOmni ultrasound bone sonometer can be used to assess the participant's bone health status.

Physical activity appears to play an important role in maximising bone mass during childhood and adolescence in attenuating bone loss with aging, reducing falls and bone fractures. Reduced in bone strength can be caused by decrease in bone mass and impaired bone architecture and resulting osteoporosis fracture later in life (Nguyen *et al*., 2004). In the present study, quantitative ultrasound measurements (QUS) of bone were carried out. According to Njeh *et al.* (2001), QUS applies mechanical wave that can be influenced by bone structure in addition to bone mineral density (BMD). Nguyen *et al.*

(2004) reported that QUS may reflect certain architectural aspects of bone that has been shown to be associated with fracture. In their study which was designed to examine the contribution of QUS and BMD measurements to prediction of fracture risk in postmenopausal Caucasian women, it was found that lower values of quantitative of ultrasound, i.e. speed of sound are associated with increased risk of fracture, independent of BMD and age. Therefore, they concluded that a combination of QUS and BMD measurements may improve, albeit modestly, the accuracy of identification of women who sustain a bone fracture.

Bone adapts to the mechanical stresses imposed upon it, such as external loads from ground reaction forces and forces exerted by muscular contraction (Skerry, 2008; Scott et al., 2008). During adulthood, bone is constantly renewed, which bone mass and architecture are maintained by bone remodeling (Robling *et al*., 2006). Robling *et al.* (2006) mentioned that remodeling process involves bone resorption and bone formation, it is a continuous process in which bone cells removing and replacing bone tissue are involved, and an imbalance in the remodeling process can cause osteoporosis. The bone cells involved in remodelling are osteoclasts for removing bone and osteoblasts for producing new bone, forming the "basic multicellular unit".

Wolff’s’ law (1892) stated that bone tissue accommodates to stress that is imposed on it (Frost, 1998). “Mechanostat theory” has been proposed to explain the loading mechanism (Frost, 2003; Frost, 1987a; Frost, 1987b). It is generally acknowledged that loads applied to bone affect bone mass (Suva *et al*., 2005) and morphology, i.e. cross-sectional area and thickness of cortical bone (Turner & Robling, 2003) through a mechanism called "mechanotransduction”. Mechanotransduction involves conversion of a mechanical force into a cellular response which detect mechanical strain and transduce the applied strain to the cells on the surface, where bone remodeling occurs (Zernicke *et al*., 2006; Turner & Pavalko, 1998).

In addition, Frost's mechanostat theory (Frost, 1987a; Frost, 1987b) mentioned that there is a lower and an upper strain threshold, creating a range where strain stimuli maintains homeostasis of the remodeling process and bone mass. Below the lower threshold, i.e. 200 microstrain, the "minimum effective strain for remodeling", the stimuli is insufficient to maintain formation, and resorption will be the overriding process, resulting in bone loss. However, above the upper threshold, i.e. 2000 microstrain, the "minimum effective strain for bone modeling", the formation of bone is dominant resulting in bone gain. Therefore, these thresholds may be related to the individual's habitual loads (Skerry, 2008). The intensity and type of activity involved should be increased beyond the normal habitual level.

Robling *et al.* (2000) stated that bone's optimum response and adaptation to an applied load or strain during exercise depends on many factors which are, characteristics of the strain, i.e. static versus dynamic strain, strain magnitude, strain rate, strain frequency or duration, and distribution of the strain stimulus. In addition, high impact dynamic loading activities, which involve high bone strain magnitude, rate, and with short duration of repeated bone loading and/or versatile strain distribution can provide large osteogenic stimulus in humans (Heinonen *et al.*, 1995). Uneven distribution of the strain seems to have a higher potential for increasing osteogenesis (Judex & Rubin, 2010; Fehling *et al*., 1995; Lanyon, 1984; Lanyon, 1996). Moreover, the adaptive response decreases after a few loading cycles (Rubin & Lanyon, 1984; Umemura *et al*., 1997).

A study conducted by Bellew & Gehrig (2006) examined the bone mineral density in adolescent female swimmers, soccer players, and weightlifters. It was found that BMD was significantly greater in the soccer group compared to the weight lifting and swimming groups, but there was no difference between weightlifting and swimming groups. Soccer group was the only sport whose participants' BMDs were significantly greater than adult norms when compared to normative data from the WHO, while those of the swimmers were significantly less than adult females, and the weightlifters were not different. The authors concluded that participation in sports such as soccer or weight lifting with significant skeletal loading may enhance BMD in adolescent females and participation in sport and physical activity should be encouraged. The results of this study also offer support for participation in impact-loading sports such as soccer and sports such as weight lifting with skeletal loading in excess of body weight.

A previous study carried out by Bellew *et al.* (2002) compared bone mineral density in adolescent female weightlifters, swimmers, and tennis players. This study found that there were no significant differences between sports. However, the mean BMD of the swimmers was significantly less than expected value of a reference adult female when compared to WHO norms while the mean values of the weightlifters and tennis players were not significantly different than WHO norms, for an adult female. Therefore, these data support the concept that loading stresses of weight bearing activities such as weight lifting and tennis may facilitate bone accrual in adolescent females to adult level sooner than in a non-weight bearing activity such as swimming.

The skeletal structures of weightlifters undergo significant adaptations in response to the large compressive and shear forces that are encountered during training and competition (Garhammer & Gregor, 1992). A previous study carried out by Karlsson *et* *al.* (1993) on effect of intense physical training on the bone mineral content (BMC) found that the BMD was significantly higher in the weight lifters compared with the controls, i.e. 10%, in the total body, 12% in the trochanteric region and 13% in the lumbar spine. All the measured regions except the head showed significant higher bone mass in the weight lifters compared with the controls. It is evident that the head is the only region not trained in weight lifting. Therefore, they suggested that the higher BMD in the other regions is the result of the training programme, and not because of any genetic or acquired higher bone density in the lifters during childhood.

Rector *et al.* (2008) studied the effects of regular non-weight-bearing exercise on bone health. It was revealed that the cycling athletes had significantly lower BMD of the whole body and spine than the running athletes, despite having similar age, weight, body mass index, body composition, hormonal status, current activity level, and nutrient intakes. Sixty-three percent of cycling athletes had osteopenia of the spine or hip, compared with 19% of running athletes. Cyclists were 7 times more likely to have osteopenia of the spine than runners, controlling for age, body weight, and bone-loading history. The authors mentioned that bone-loading activity should be sustained during adulthood to maintain bone mass.

Calbet *et al.* (1998) studied on bone mineral content and density in professional tennis players. This study consisted of 9 male professional tennis players and 17 non-active subjects. The result found that the participation in tennis is associated with increased BMD in the lumbar spine, arm region and femoral neck compared to non-active subjects. Physical requirements when playing tennis are mostly anaerobic in nature entailing rapid accelerations and decelerations, with twisting components acting on the spine and femoral neck which, in some circumstances, can produce ground reaction forces 5–10 times a person's body weight (Alexander, 1985). Thus, it is likely that the forces generated during participation in tennis could elicit cellular reactions which subsequently activate osteogenesis not only in the bones of the dominant arm but also in the spine and leg bones. Moreover, BMD showed a tendency to be greater in the left leg than in the right suggesting that the left leg supports more mechanical stress, perhaps due to its role in counterbalancing the rotational torques generated when hitting the ball with the right arm. Therefore, the author concluded that these results may have implications for devising exercise strategies in young and middle-aged persons to prevent involution osteoporosis later in life.

Volleyball is the sport which probably imposes the highest impact and weight-bearing load upon the axial skeleton and neck of the femur. A previous study conducted by Calbet *et al.* (1999) assessed bone mass in male elite athletes participating in an impact loading sport of volleyball. Fifteen male volleyball players and non-active control subjects participated in this study. The study found that male professional volleyball players showed remarkably high BMD in the femoral neck and lumbar spine regions than non-active subjects. Extremely high impact forces are sustained during jumping and landing with volleyball training is generally complemented with weight training to increase smash and jumping power. These characteristics suggest that volleyball is an adequate exercise model to investigate the adaptation of different skeletal regions to high impact and weight-bearing exercise. The result also indicated that the great osteogenic effect is produced when high-intensity strains are repeated in unusual patterns and directions during short periods in vollleyball. Volleyball combines both high impact and weight-bearing activity. In volleyball, ground reaction forces equivalent to 6–7 times body weight have been observed at landing in volleyball players during ordinary jumps of only 60 cm height (Bobbert et al., 1987). Much greater ground reaction forces may be generated by smashing jumps i.e., 80–90 cm height and plyometric training. Thus, the increased of

BMD in volleyball players observed at the level of the axial skeleton, hip, dominant arm and left leg probably reflect bone adaptation to the extreme forces acting upon the skeleton during this kind of exercise. Therefore, the authors highlighted the importance of impact forces acting upon the skeleton to increase bone mass and density.

Alfredson *et al.* (1996) investigated bone mass in female athletes participating in impact-loading sport of soccer, and evaluated whether any changes in bone mass could be related to the type of weight-bearing loading and muscle strength. In this study, soccer players consisted of 16 second-division female players and the reference group consisted of 13 non-active females who did not participate in any kind of regular or organised sport activity. The study found that soccer players had significantly higher BMD in the lumbar spine (10.7%), femoral neck (13.7 %), ward's triangle (19.6%), non-dominant femur and humerus (8.2 and 8.0%, respectively), distal femur (12.6%), and proximal tibia (12.0%) compared with the non-active women. Soccer players have lower extremities which are subjected to high ground reaction forces, fast runs in different directions, landing from jumping, starts and stops which produce ground reaction forces 3-6 times the body weight (Nigg, 1988) which are believed can produce high osteogenic effect on bone. Therefore, the authors mentioned that soccer playing and training appear to have a beneficial effect on bone mass in young females, and it seems that there is a site-specific skeletal response to the type of loading subjected to each BMD site.

Rebai *et al.* (2012) evaluated bone mass in female basketball players and the relationship between bone mineral density (BMD) and isokinetic muscle strength. The study involved 29 female basketball players, and the reference group consisted of 22 non-active females. In this study, it was found that basketball group had significantly higher BMD in total body (11.6%), lumbar spine (9.83%), dominant femur (16.8%), non-dominant femur (15.8%) and dominant humerus (8.47%) compared to control group. This is because basketball is a sport activity that involves high muscular and ground reaction forces on the skeleton during running with rapid change of directions, starts, stops and vertical jump-landing (Dook *et al*., 1997) that generate action strain and compressive forces, and stimulate bone remodelling process (Creigthon *et al*., 2001). The authors concluded that practice of basketball is associated with the improvement of bone mass.

Chang *et al.* (2013) also compared bone density and body composition measurements in women participating in elite level netball and golf with contrasting loading characteristics. Fourteen state-level netball players, 11 single-digit handicap golf players and 18 control group who did not perform training for sport were involved in this study. The result from this study showed that netball players had significantly higher total body, lumbar spine and hip BMD than the golf players and control subjects. Besides, golf players had higher BMD than the control subjects only in the lumbar spine. The authors mentioned that this observation may be due to netball provides dynamic, high-strain, supra-threshold and variable loading stimuli which are considered important to promote the adaptive bone responses to exercise (Borer, 2005), whereas golf swing generates very high loading of the lumbar spine over a short duration, due to high trunk rotation velocities and trunk muscle contraction forces (Dorado *et al*., 2002; Myers *et al*., 2008). Therefore, contrasting skeletal responses to elite-level participation in netball and golf in young women have been identified in this study. The authors suggested that the high intensity and dynamic loadings associated with netball convey more global benefits to skeletal development, while the responses to golf are more site-specific in the lumbar spine.

Bennell *et al*. (1997) compared bone mass and bone turnover in elite and sub-elite track and field athletes and less active controls. The cohort comprised 50 power athletes (sprinters, jumpers, hurdlers, multi-event athletes; 23 women, 27 men), 61 endurance athletes (middle-distance runners, distance runners; 30 women, 31 men), and 55 non-athlete controls (28 women, 27 men) aged 17-26 years. This study found that power athletes had higher regional BMD at lower limb, lumbar spine, and upper limb sites compared to controls, whereas endurance athletes had higher BMD than controls in lower limb sites only. Maximal differences in BMD between athletes and controls were noted at sites loaded by exercise. Male and female power athletes had greater bone density at the lumbar spine than endurance athletes. Bone mass differences were greatest at the sites subjected to mechanical loading. When considered together, these results provide evidence for an osteogenic effect of mechanical loading, particularly at the lumbar spine, and suggesting that strain magnitude may be a more potent stimulus than strain frequency. It is suggested that the most effective form of exercise for the skeleton is dynamic and weight-bearing activity.

The load forces on the skeleton vary with the type of physical activity being performed. The activities that produced ground reaction forces are typically known as impact loading sports, such as gymnastics and running, whereas activities that generate non-gravitational mechanical loading are classified as active loading sports include those performed in the water, such as swimming, which no high impact produced on the skeletal system although the muscular system is actively loaded (Fehling *et al*., 1995).

A previous study conducted by Lima *et al.* (2001) studied effect of impact load and active load on bone metabolism in adolescent athletes. This study consisted of three groups which were impact, active loading and control groups. The results indicated that male adolescents practicing in impact load sports presented a significantly higher BMD at all sites studied when compared with sedentary controls and active loading group. The ground-reaction force generated in the impact load group was possibly related to this BMD differences. The data indicated that male adolescent involved in sports producing significant impact loading on the skeleton had greater femoral neck bone density and a tendency to have greater spinal bone density. Therefore, these findings supported the importance of ground-reaction force activities for peak bone mass acquisition during adolescence.

The main stresses applied during locomotion at the level of the calcaneus are ground reaction forces as the heel strikes on the ground (Marcus, 1996). Based on the ground reaction bone, swimming, dancing and soccer can be classified as low, moderate, and high impact exercise respectively. The level of impact has been identified as it became an important determinant of the skeleton's adaptive response to mechanical loading. When bones are subjected to progressively greater magnitudes of strain, more osteogenesis effect can be seen.

Yung *et al.* (2005) investigated bone properties using heel quantitative ultrasound (QUS) in young adults participating in various sports. The subjects were categorised according to their main sporting activities, including soccer (a high impact, weight bearing exercise), dancing (a low impact, weight bearing exercise), swimming (non-weight bearing exercise) and sedentary group acted as control. They found that soccer group had higher mean value of QUS measurement compared to other groups. More effect of osteogenesis on bone was found when bones were subjected to progressively greater magnitudes of strain or high impact loading exercise, subsequently, beneficial to bones. If a load is imposed, the bone will accommodate and undergo an alteration in mass, external geometry, and internal micro-architecture. The author found that all QUS parameters were higher in exercise groups compared with the control group. There was a trend towards better QUS parameters in high impact exercise. This finding supported the importance of high impact, weight bearing exercise at a young age in maximising peak bone mass with better mechanical strength. Therefore, the authors suggested that such exercises should be promoted to maximise and optimise their bone mass and quality and, hence, prevent osteoporosis in later life.

The muscle contraction that occurs during exercise provides tension on the skeleton, which modifies structure and geometry in both cortical and trabecular bones. Agostinete *et al.* (2016) investigated the effect of different sports on bone mineral density (BMD) accrual among male adolescent athletes. The participants comprised of 82 boys (control [n = 13], basketball [n = 14], karate [n = 9], soccer [n = 18], judo [n = 12], and swimming [16]). The result revealed that basketball group had significantly higher BMD gains than the control group and other sports groups in lower limb, upper limb, spine region and whole body. Basketball is known as impact sport and could enhance bone health. Elevated BMD in basketball players is an indicator of responsive loaded sites to the significant amount of mechanical loads induced by basketball practice. During running, sprinting, starts, stops, and jumping actions, loading bones are under tensile, compressive, shear, bending, and torsional stress, which produce high strain stimulus. Also, the BMD gains observed in basketball players' upper limbs draw attention to the effect of handling the ball that may elicit bone formation. Therefore, the author suggested that basketball training may elicit bone formation and reduced the osteoporosis risk of fracture due to bones subjected to compressive, tensile, bending and torsional loads that produce high impact load on bone.

Platen *et al.* (2001b) studied the influence of muscle strength, training specific and anthropometric parameters on bone mineral density in male top athletes of different sports. The participants consisted of individual sport athletes (runners, *n* = 21; cyclists, *n* = 12; triathletes, *n* = 18), team sport athletes (handball, soccer, basketball, volleyball, *n* = 25); 44 unspecific trained sport students and 25 untrained controls. The study found that team sport athletes had higher BMD value compared to other sport and control groups. Explanations for this observation is that there was a sport-specific loads on bone.

Fredericson *et al.* (2007) investigated the association of soccer playing and long-distance running with total and regional bone mineral density. The result indicated that soccer players had significantly higher whole body, spine, right hip, right leg and calcaneal BMD than controls and runner groups. Runners had higher calcaneal BMD than controls. Soccer involves intermittent and high-intensity activities that include sprinting, jumping, accelerating, and decelerating, as well as transverse and torsional loads brought about by fast changes in body displacement direction (Bobbert et al., 1987). These changes create high peak strains on the skeleton that are known to stimulate bone mineral acquisition. This finding suggested that long-term exposure to these loading patterns is beneficial to bone density at all sites measured. Running primarily loads the foot and leg in a repetitive manner in which site-specific of bone loading plays a vital role in skeletal adaptation. Therefore, the author suggested that ball sports such as soccer has been shown to create higher peak strains than running and therefore might stimulate higher bone mineral acquisition and better structural properties.

Leigey *et al.* (2009) investigated the effect of participation in high-impact sports in predicting bone mineral density in senior Olympic athletes. This study found that athletes involved in high impact sport had higher BMD than non-high impact sport. High-impact exercise may have improved bone health and reduced hip fracture. Morbidities such as osteoarthritis and heart disease should be accounted to determine the appropriate role for high impact exercise in the general elderly population. High-impact sports should be used cautiously in elderly with hip or knee osteoarthritis. Low-impact sports may be of use in these instances, not only for bone health, but also for pain reduction, improved function, and attenuating progression of the osteoarthritis. The authors suggested that high-impact sports can be a significant part of healthy bone aging. These data imply that high-impact exercise is a vital tool to maintain healthy BMD with active aging.

2.2 SPORT AND MUSCULAR PERFORMANCE

Isokinetic contraction is the muscular contraction that accompanies constant velocity limb movements around a joint. The velocity of movement is maintained constantly by a special dynamometer. The resistance of the dynamometer is equal to the muscular forces applied throughout the range of movement and this method allows the measurement of the muscular forces in dynamic conditions and provides optimal loading of the muscles (Baltzopoulos & Brodie, 1989).

The most frequently used isokinetic parameters are the maximum torque and the angular position, the torque output at different angular velocities of movement, the torque ratio of reciprocal muscle groups and the torque output during repeated contractions. The unique features of isokinetic dynamometry are optimal loading of the muscles in dynamic conditions and constant preselected velocity of movement. Isokinetic dynamometry has also been used for the training of various muscle groups in order to improve the muscular performance in dynamic conditions (Baltzopoulos & Brodie, 1989). The movement velocity of different activities can be simulated during training in order to improve the training effect. Furthermore, the use of results of an isokinetic assessment