2001

# The Effect of Moderate +Gz Force on the Cervical Spine Bone Mineral Density in RAAF PC-9 Pilots

Meghan C. Grant
*Edith Cowan University*

# THE EFFECT OF MODERATE +GZ FORCE ON THE CERVICAL SPINE BONE MINERAL DENSITY IN RAAF PC-9 PILOTS

By

Meghan C. Grant

BACHELOR OF SCIENCE HONOURS (SPORTS SCIENCE)

A thesis submitted in partial fulfilment of the
requirements for the award of
Bachelor of Science (Sports Science) with Honours

Date of Submission:

9th November, 2001

# USE OF THESIS

## Abstract

Previous research on exercise and bone mineral density (BMD) has established that increases in BMD are site specific, responding to unusual strain and particularly to high magnitude loading. The positive Gz forces generated during high performance flying provide all three variables.

Naumann, Bennell and Wark (2000) investigated the effects of moderate gravitational force on the BMD of fighter pilots. The pilots in this study had significant increases in BMD and bone mineral content (BMC) for the thoracic spine, pelvis and total body. However, it is now suspected that the cervical spine, which was unable to be analysed at that time endures the majority of the compressive stresses during flight. This is due to the forces acting on the weight of the head, helmet and oxygen mask. The purpose of this research was to analyse the cervical spine bone response to moderate +Gz loading generated during high performance flying.

The bone response to +Gz force loading was monitored in 9 high performance RAAF pilots and 10 gender, age, height, weight matched control subjects. The pilots were stationed at the RAAF base at Pearce, Western Australia, all completing the 8 month flight training course. The pilots flew the Pilatus PC-9 aircraft, routinely sustaining between 2.0 and 6.0 +Gz. BMD and BMC were measured for the cervical spine and whole body at baseline and 32 weeks, using the Hologic QDR 4500 bone densitometer.

The pilots were found to have significantly greater increases in bone mass for total body BMC and cervical spine BMD. While not significant, thoracic BMD showed a definite increase in bone mass in comparison to the control group. No significant difference in bone mass existed between the two groups for any other measured site.

The findings from this study support the principals of bone loading discussed and studied by so many researchers. This study has reinforced the notion of a site specific bone response to high magnitude and unaccustomed mechanical loading. Taking into account that an osteogenic response was found from flying under moderate +Gz force for a duration of 8 months, it is possible that such greater increases in bone mass are occurring for pilots flying at higher +Gz forces for greater lengths of time.

**Declaration**

I certify that this thesis does not, to the best of my knowledge and belief:

(i) incorporate without acknowledgment any material previously submitted for a degree or diploma in any institution of higher education;

(ii) contain any material previously published or written by another person accept where due reference is made in the text; or

(iii) contain any defamatory material.

Signature .

Date ..........4/3/02........

## Acknowledgments

I would like to thank the following people for their contribution to this research:

My supervisor, Dr. Fiona Naumann for her continual support, encouragement and enthusiasm throughout the year.

Kevin Netto and Elissa Burton for their patience and assistance in the analysis of the EMG data.

Satvinder Dhaliwal for his advice in the procedure and statistical analysis of the reliability study.

Sarah Henzell for her assistance with the bone scanning at Sir Charles Gairdner Hospital.

To fellow researchers for making time spent in the honours office more enjoyable.

A special thanks to the RAAF pilots, control subjects and reliability study subjects for giving up their time to be part of this research.

Finally, to my parents for their support during the stressful times. I am ever so grateful for their understanding and continual support of anything I choose to do.

# Table of Contents

## List of Tables

## List of Figures

# CHAPTER ONE

## Introduction

Although there has been substantial research in the area of the enhancement of bone mass through mechanical loading, it is through the research of Naumann, Bennell and Wark (2000) that a different form of mechanical loading (+Gz force) has been recognised for its ability to increase bone mineral density (BMD). The reported magnitude of increased bone mass in this study was found to be greater than any other intervention strategy.

Naumann et al, (2000) investigated the effects of moderate gravitational force on the BMD of fighter pilots. The pilots in this study had significant increases in BMD and bone mineral content (BMC) for the thoracic spine, pelvis and total body, after periodic exposure of 2- 6 +Gz during one year of high performance flying in a PC-9 aircraft.

G force in aviation is usually referring to the force exerted on the long (or vertical) axis of the body, but it can also affect the horizontal and transverse axis. The intensity, duration and direction of flying determine how these G forces affect the pilot. The pilots are exposed to positive G forces, which occur when the body is accelerated in the headward direction and is forced downward into the seat (Reinhart, 1996).

Previous research on exercise and bone mineral density has established that increases in bone mineral density are site specific, responding to unusual strain and particularly to high magnitude loading (Skerry, 1997) (Judex & Zernicke, 2000). Positive Gz loading provides all three variables. It is for this reason that Naumann et al (2000) found such significant increases in bone mass in the fighter pilots.

BMD increases at the portion of the skeleton that is subjected to the greatest loading. The osteogenic response to mechanical loading is site specific; that is, the effects of exercise are not homogeneous, but reflect the strains imposed at individual sites (Prince, Devine, Dick, 1995). It is the sites that are loaded during activity that receive the osteogenic benefit. Secondly, past research suggests that bone responds to unusual loading patterns. Loads applied in an unaccustomed manner result in bone adaptations, increasing their mass, density and structural properties (Cowin, Moss-Salentijin, Moss, 1991). Mechanical loads generated during the flight school are of a high magnitude (2.0- 6.0

+Gz) and would not be loads to which the pilots would be accustomed to in their daily routine.

Karlsson, Magnusson, Karlsson and Seeman (2001) found that the intensity rather than the duration of exercise is the main determinant of BMD. So, if the aim of exercise is to increase BMD, high impact loading rather than a longer duration of exercise is favourable. Numerous studies have shown that high loads with few repetitions produces a greater osteogenic response as opposed to moderate loads with numerous cycles (Kerr, Morton, Dick, Prince, 1996).

The only other similar study to this was a two month centrifuge study conducted by Kalyanin, Bukhtiyarov and Vasiliev (1996) in Russia. The purpose of this study was to investigate the effects of systematic exposure to a high level of +Gz acceleration of the lumbar vertebrae. The subjects underwent 10 tests over a duration of 2 months, experiencing loads between 2 and 9 +Gz. The results of the study showed that systematic exposure to flight g-loads brought about an increase in mineralisation of the vertebral osseous tissue, particularly in the lumbar region. Both this study and the study by Naumann et al (2000) demonstrated that exposure to +Gz force loading brings about a substantial increase in BMD at the skeletal sites subjected to the greatest loading.

The significant increases in BMD are extremely beneficial for the pilots in terms of prevention of skeletal fractures that so often occur in the later stages of life. Osteoporosis is a condition of generalised skeletal fragility in which bone is sufficiently weak that fractures occur with minimal trauma, often no more than is applied by daily activity (Marcus, 1996). The most common fracture sites of osteoporosis are the thoracic spine, lumbar spine, hip and wrist (Osteoporosis Australia, 2001). It is now evident that +Gz force loading increases the thoracic spine and pelvis BMD significantly.

This will be the first time the cervical spine has been analysed in terms of its response to this form of mechanical loading. The cervical spine was selected for analysis, as it is the site suspected of being exposed to the greatest loading. High performance flying generates high mechanical loads on the vertebrae, particularly during the performance of aerial combat manoeuvres. The greatest portion of the load is absorbed by the cervical spine due to the +Gz forces acting on the weight of the head, helmet and oxygen mask worn by the pilots during flight (Kikukawa, Tachibana and Yagura, 1995). If the mass of

the head and helmet is 6kg and the head position is neutral, during sustained G-force at +8.0 Gz, a static force of 48 kg stresses the cervical spine (Hamalainen, Vanharanta, 1992).

The purpose of this study is to gain further insight into the bone response to moderate gravitational force experienced by pilots flying the Pilatus PC-9 aircraft, specifically in the area of the cervical spine. This data can be used in conjunction with previous research to better understand the bone response at various sites of the skeleton, in particular the spine. However, BMD for the total body and individual regions of the body will also be measured. Dual Energy X-ray absorptiometry (DEXA) provides a convenient, non-invasive method of measuring skeletal bone mass. It will be used to assess bone mineral density and to perform body composition analysis.

**Significance of the Study**

As previously mentioned there has been little research in the area of +Gz force and bone mineral density in fighter pilots. Naumann et al (2000) found that maximal stress was applied to the cervical spine, but unfortunately, their BMD measure did not specifically isolate the cervical vertebrae. With the knowledge that previous studies have found that BMD increases at the portion of the skeleton that is subjected to the greatest loading, it is highly likely that the bone mineral density of the cervical spine in each pilot will significantly increase.

This study will add to the existing body of knowledge with regard to the effects of various forms of mechanical loading of bone and how such information is being used to advance our understanding of preventing and treating the condition of generalised skeletal fragility known as osteoporosis. It is also expected that this research will confirm that the loading of bone is site specific, with BMD increasing at the portion of the skeleton that is subjected to the greater loading, that being the cervical spine.

**Purpose of the Study**

The purpose of this study is to gain further insight into the bone response to +Gz force experienced by the pilots flying the PC-9 aircraft. It is expected that such regions of the body as the thoracic spine, pelvis and particularly the cervical spine will have an osteogenic response to this form of mechanical loading. This study will confirm if +Gz

force can provide the necessary variables of high magnitude and unusual loading to induce a site specific response on bone.

**Research Questions**

i) Does moderate +Gz loading of the magnitude 2.0 - 6.0 +Gz increase bone mass in RAAF trainee pilots?

ii) Does moderate +Gz loading generate the greatest osteogenic benefit at the cervical spine, the site suspected of being subjected to the greatest loading?

**Hypotheses**

i) +Gz force loading will increase the BMD of the cervical spine, thoracic spine and pelvis and BMC of the total body in the pilots flying the PC-9 aircraft.

ii) +Gz force loading will generate the greatest increase in BMD at the cervical spine in pilots flying the PC-9 aircraft.

iii) The control group will have little to no change in bone mass at any of the measured sites.

**Limitations**

The greatest limitation was the number of pilots available to participate in the study. The gruelling nature of the flight training course was the basis for the low number of pilots who successfully passed all necessary components and consequently were available to participate in the entire study. The duration between baseline and post scanning was also limited due to the schedule of the flight training course. It may have been beneficial to allow more time for the bone remodelling process and have a post scan at 12 months.

# CHAPTER TWO

## Review of Literature

### Osteoporosis

Osteoporosis is a major public health problem that is predicted to worsen over the next decade (Keen, 1999). In response to the worsening situation, preventative strategies that increase bone strength have become the focus of substantial research (Judex et al, 2000). "Osteoporosis is a condition of generalised skeletal fragility in which bone is sufficiently weak that fractures occur with minimal trauma, often no more than is applied by routine daily activity" (Marcus, 1996). There is no cure but in many cases it can be prevented or contained. Fracture sites are usually of the wrist, hip or spine (Osteoporosis Australia, 2001).

Maximum or peak bone mass is achieved by the mid 20s. After the mid 30s, bones start to lose more calcium than is deposited and gradually lose strength. With increasing age, more bone is lost than is replaced so the outer shell gradually becomes weaker and the inner material develops larger holes. Eventually a danger level is reached and the risk of fracture increases. Therefore maximising peak bone mass development during childhood and adolescence means greater protection against fractures in later life (Osteoporosis Australia, 2001).

Hospital costs alone of Osteoporosis in Australia are currently over $800 million each year. One in 2 women over 60 and one in 3 men will sustain a fracture due to osteoporosis with 17% of people with hip fractures dying within 4 months. On current rates we can expect an 83% increase in hip fractures by 2011 causing 1 in 3 hospital beds to be occupied by elderly women with fractures by 2020. The cost of osteoporosis nationally will be $1 billion plus on current trends by 2010 (Osteoporosis Australia, 2001).

Exercise programs and resistance training of moderate to high intensity may contribute to the prevention of osteoporosis by increasing peak bone mineral density, reducing age related bone loss, or restoring bone already lost in the elderly (Karlsson et al, 2001).

**Bone Response to Mechanical Loading**

The organic and mineral components of the bone matrix are continually being recycled and renewed through the process of remodelling. Bone remodelling involves the interplay between the activities of bone cells; osteocytes, osteoblasts and osteoclasts (Martini, 1998). The way in which exercise is thought to act on the skeleton is through gravitational forces or mechanical pull producing strain within the skeleton which are perceived by bone cells as osteogenic. This input to those cells of the skeleton is necessary for the maintenance and adjustment of bone architecture (Kerr et al, 1996 ).

It is proposed that this skeletal adaptation to strain is dependent upon the relationship of that strain to the strain thresholds for that bone. This is known as the mechanostat theory (Frost, 1964). The mechanostat theory incorporates a feedback control system where a minimum effective strain (MES) threshold exists before bone formation or modelling will occur (approximately 1000 microstrain) and another minimum strain threshold exists which controls bone loss or remodelling (approximately 50 microstrain) (Lanyon, 1993).

The turnover and recycling of minerals give each bone the ability to adapt to new stresses. "Osteoblast sensitivity to electrical events has been theorized as the mechanism that controls the internal organization and structure of bone"(Martini, 1998). Mineral crystals generate minute electrical fields whenever a bone is stressed. These electrical fields attract osteoblasts, and once in the area, they begin to produce bone (Martini, 1998).

Mechanical loads, greater than those habitually encountered by the skeleton, effect adaptations in cortical and cancellous bone, reduce the rate of turnover, and activate new bone formation on cortical and trabecular surfaces, and in doing so, increases bone strength (Forwood, 2001). Because bones are adaptable, their shapes reflect the forces applied to them. Bumps and ridges on the surface of bone exist where tendons attach to bone. If muscle becomes more powerful, the corresponding bumps and ridges enlarge to withstand the increased forces and subsequently, heavily stressed bones become thicker and stronger (Martini, 1998).

During life, bone is continually optimised for its load bearing role by a process of functionally adaptive (re) modelling. In human bone, the bone remodelling process takes approximately three to four months, but a further three months is required for

bone to mineralise and increase its strength (Reeve, 1987). This process is dominated by high magnitude, high-rate strains, presented in an unusual distribution. Adaptation occurs at an organ level, involving changes in whole bone architecture and bone mass. Cells of the osteocyte/osteoblast network are best placed to appreciate mechanical strain (Mosley, 2000).

Muscles cause the largest loads and the largest bone strains, and these strains help to control the biological mechanisms that determine whole bone strength (Frost, Schonau, 2000). Judex and Zernicke (2000) compared the mechanical milieus produced by running and drop jumps in roosters. Drop jumping was found to significantly elevate peak strain rates, consequently increasing bone formation rates. Robling, Burr and Turner (2000) also touched on this principal, concluding that loading cycles applied at intervals represent a more osteogenic stimulus than cycles applied all at once, and that mechanical loading is more osteogenic when divided into discrete loading bouts. This can be explained by the presumption that bone cells become increasingly "deaf" to the mechanical stimulus as loading cycles persist uninterrupted, and by and by allowing a rest period between loading bouts, the osteogenic effectiveness of subsequent cycles can be increased.

Mechanical strain and its potential impact on bone mass is dependant on the fluid flow to the bone cells. The mechanical stimuli from the tissue to the cellular level is mediated by fluid flow. Low strain rates would cause relatively sluggish fluid movements, while high strain rates could cause rapid local fluid movements with potentially greater effectiveness in initiating cellular events. It is suggested that loading causes flow which either affects the cells directly by local deformation, or by some electrical effect related to screaming potentials (Skerry, 1997). Current biomechanical and in vivo as well as in vitro experiments agree that the three dimensional network of osteocytes and bone lining cells provides the cellular mechanosensing in bone, leading to adaptive bone (re) modelling (Burger, Klein-Nulen, 1999). Burger et al (1999) agrees that the flow of interstitial fluid through the lacunar-canalicular porosity of bone due to mechanical loading, most likely provides the stimulus for mechanosensing, and informs the bone cells about the adequacy of the existing bone structure.

The effect of muscular activity on bone mineral density has been assumed to be site specific. Given this assumption, back strength would predict spine BMD, hip strength

would predict hip BMD, and forearm strength would predict radial BMD (Marcus et al, 1991). Kerr et al, (1996) found that increasing muscle strength was correlated with an increase in bone mass at several hip sites for the strength group. This suggests that that the mechanism by which the osteogenesis occurred is by muscle pull. "This action of muscle pull is mediated through the force of the muscular contraction at the site of attachment of the tendon onto the bone, thus the bone may respond locally to rearrange the forces generated from the muscle at the site of loading" (Kerr at al 1996).

Mosely, Arch, Lynch and Lanyon, (1997) hypothesised that the major stimulus controlling adaptive remodelling is the mismatch between the distribution of the applied and the habitually encountered strains. This finding led to the "strain distribution error" hypothesis, which states that, " strains presented in a novel distribution are more osteogenic than the equivalent strains presented in the customary distribution" (Mosely et al, 1997).

The +Gz loading experienced by the trainee pilots during the flight school constitutes all the necessary variables that have been discussed to have an osteogenic effect on BMD.

**Loading induced by flying under +Gz force**

Fighter pilots are exposed to high and sometimes sustained accelerative forces. During any manoeuvre that produces positive G forces, the weight of the body is increased in direct proportion to the magnitude of the force (Reinhart, 1996). The high gravitational forces generated during flight can cause muscle stress on the trunk and extremities, in particular the cervical spine (Oska, Hamalainen, Rissanen, Myllyniemi, Kuronen, 1996). So it is not surprising that Hamalainen et al (1996) reported in their study that fighter pilots frequently complain of flight related pain in the cervical and lumbar spine. It is mentioned that repeated exposure to high +Gz forces may cause premature cervical disk degeneration. This information supports a case report by Newman (1996) on the cervical intervertebral disk protrusion in a Royal Australian Air Force (RAAF) pilot. The effects of +Gz load on the cervical spines of pilots have been well documented. Newman (1996) states that, "the higher the aircraft performance, the heavier the helmet, and the higher the peak +Gz and its rate of onset, the higher is the incidence of neck injury.

Knudson et al (1988) researched the effects of introducing the F/A-18 Hornet into the Navy and Marine Corps. This jet fighter is capable of over 9 +Gz and a G-onset rate of

greater than 18 G per second. This placed a greater load and stress on the pilot than any previous Navy aircraft. Taking this into consideration, it is important to note that in two separate studies, Newman (1996) has discussed the concerning fact that +Gz induced injuries are likely to become more common in the future with the introduction of helmet mounted display and sighting systems and also a fourth generation advanced tactical fighter capable of very high +Gz loads, possibly +10Gz and beyond. Kikukawa et al, (1995) discuss that the severity of the injuries extend beyond muscle strains, with such injuries as herniated discs, compression fractures, ligament tear and the possibility of loss of consciousness due to impairment of cerebral perfusion.

It is quite obvious that cervical spine injuries due to exposure to high +Gz levels are a significant occupational and aerospace medicine problem. One of the most important factors of a pilot's exposure to accelerations directing head to seat (+Gz) is the high risk of vertebral traumatisation (Newman, 1996). Neck strengthening programs for fighter pilots have only recently been recommended for the prevention of spinal injuries (Knudson et al, 1988).

This is a clear indication of the significant mechanical loading and stress imposed on the cervical spine. This review also demonstrates that the vast majority of research in this area has been based on muscular injuries. There is a greater need for continuing research on +Gz forces and its effect on bone mass to answer questions such as; do +Gz forces (> 6 +Gz) induce a greater osteogenic effect and are there long term benefits of +Gz force exposure?

**Electromyography and Muscle Strain**

Electromyography (EMG) is the technique used to record changes in the electrical potential of a muscle when it is caused to contract by a motor nerve impulse (McArdle, Katch, Katch, 1996). A fighter pilots work is known to cause muscle stress on the trunk and extremities because of the frequent exposure to high +Gz forces. Various studies have been conducted to investigate the muscular strain occurring in different muscles during aerial combat manoeuvring exercises. One particular study concluded that the level and frequent occurrence of peak strain episodes means that fighter pilots muscular strength and muscular endurance, especially in the neck and shoulder area, are subjected to demands clearly higher than those of the average population (Oska et al, 1996). The majority of EMG research in this field has concluded that the neck area is subjected to the

greatest demands when exposed to +Gz forces.

Although EMG does not directly show the stress on the skeleton, there is a relationship between muscular activity and the compressive forces on bone. Consequently, this type of data will be used in conjunction with this particular study as an indirect measurement of the strain on the cervical vertebrae.

**Exercise and Bone**

It is not until recently that researchers have investigated the effects of exercise and its positive impact on bone mineral density (Kannus, Sievanen, Vuori, 1996). The effect of exercise on the skeleton is beneficial in that it can reduce loss of bone and increase bone mass (Judex et al, 2000). Most studies have used weight bearing activity (walking, jogging, running and dancing) as the exercise intervention. However, when the program has been more intense, of longer duration, or included exercises that overload the muscular system, a better osteogenic stimulus has been observed (Skerry, 1997). Bone hypertrophy is related to the level of sport participation, specific training regimes, intensity, duration, and frequency that recreational or competitive athletes pursue (Smith, Gilligan, 1996).

In a study by Sinaki, McPhee and Hodgson (1986), the results showed that women with higher physical activity had greater isometric back strength and higher spinal bone densities than those women with lower activity levels. These results suggest that a relationship does exist between strength of a specific muscle group and the corresponding bone. For example, in power and weight lifters, increases in bone mass occur in almost all of bones of the skeleton. In tennis players, only the bones of the dominant arm show significant gains in BMD and in dancers, skaters, gymnasts and hockey players, greater increments in bone mass occur primarily in the legs, especially the distal parts (Loro et al., 2000). A review of numerous studies by Layne and Nelson (1997) has shown that weight lifters have greater bone mineral density than non athletes. This effect is site specific, based on the higher total body BMD and higher BMD in all sites measured, when compared to the control group. When comparing weight lifters to runners and cross trainers, upper arm BMD was highest in the weight lifters and cross trainers (who performed upper body weight training) when compared with runners who did not include upper body training (Layne et al, 1997). These results also support the theory that the effects of resistance training on bone are site specific.

Skerry et al (1997) highlights the fact that various modes of exercise are more likely to increase bone mass than others. High impact exercise can be osteogenically more effective than lower impact aerobic exercise. Layne et al (1997) point out that although aerobic exercise and weight bearing physical activity are important in maintaining overall health and healthy bone, resistance training exercise has a greater impact in increasing bone mass. Cross sectional studies have demonstrated that physical activities providing the greatest strain magnitude are the most effective in stimulating bone mass (Smith et al, 1996). Athletes exposed to resistance training or high impact activity, such as weight lifting, gymnastics or ice skating have greater bone mineral density when compared to those engaged in non resistance, endurance based training such as swimming or distance running (Taaffe et al, 1995). Similarly, weight lifters who were capable of lifting heavier loads throughout training, reported higher BMD in comparison to those weight lifters who were not as strong (Granhad et al, 1987).

Bone should be loaded with high peak forces and high strain rates, consist of short repetitions and training sessions, and be long term and progressive in nature (Kannus, 1996). To influence BMD, the physical activity must be performed two to three times per week, with a training intensity between 70-80% of your maximum strength (Forwood & Larson, 2000). Stress or mechanical loading applied to the bone via the muscles and tendons has a direct effect on bone formation and remodelling (Layne et al, 1997).

Data obtained from animal models also demonstrate that altering the normal distribution of strain on the bone surface provides a strong osteogenic stimulus for bone formation (Rubin, 1984). When strain distribution was altered in the radius of sheep by the removal of the ulna, new bone was deposited to compensate for the structural loss (Lanyon, 1984). Rubin & Lanyon (1984) also found that loading an avarian ulna in an unusual direction, despite a low strain magnitude, stimulated new bone formation, suggesting that the strain required to elicit an adaptive response may be lower if the manner of loading is different from the usual loading pattern.

Many human and animal exercise studies have failed to demonstrate any beneficial effect on bone mass, since physiological exercise tends to load the skeleton repeatedly with strain cycles of moderate magnitude and low strain rate, presented in a normal distribution (Skerry et al, 1997). The exercise studies that consistently show a beneficial effect have been those involving impact loading which is unusual and involves strain

delivered with high rates and high magnitude (Mosely, 2000). The gravitational forces generated during flight are a form of mechanical loading and effect the skeleton of the pilot in the same manner as do the exercise principals discussed above.

**The Effect of Spaceflight on Bone Mass**

Astronauts exposed to weightlessness for extended periods experience significant decreases in bone mineral density. Long term weightlessness decreases the bone mass of the weight bearing bones, whereas no change or an increase is observed in non weight bearing bones. Through research on animals, it is recognised that the loss of bone is due to both a lasting decrease of osteoblastic activity and a transient increase of osteoclastic activity (Collet et al., 1997). This leads to demineralisation and disorganisation of the structure of bone.

Collet et al (1997) studied the effects of 1 and 6 month spaceflight on bone mass and biochemistry in two humans. After one month, there was a slight decrease of trabecular bone mass. However, after six months, there was a more marked loss of trabecular and cortical bones. This loss in the trabecular compartment was still significant after six months of recovery. It is thought that recovery of weight bearing bones requires a longer period of time than the duration of the spaceflight.

Brief periods of inactivity can also cause degenerative changes to occur in the skeleton (Martini, 1998). For example if you were to use a crutch to take the weight off an injured leg while you wear a cast, the unstressed bones will lose up to a third of their mass. However, as soon as normal weight loading is resumed, the bones rebuild just as quickly. Nonetheless, the removal of calcium salts can be a potentially serious health hazard for astronauts remaining in a weightless environment and for bedridden or paralysed patients who spend months or years without stressing their skeleton (Martini, 1998).

These conditions are the opposite of what pilots flying under +Gz are exposed to. This type of research exemplifies the importance of sufficiently loading bone to maintain bone mass.

# CHAPTER THREE

## Materials and Methods

Subjects comprised of 9 male RAAF pilots enrolled in an 8 month high performance flight training course. All pilots were stationed at the RAAF flight training school at Pearce, Western Australia. The pilots ranged in age from 20 to 27 years. The control group consisted of 10 male students recruited from the Aviation degree and Sports Science degree at Edith Cowan University. They were matched at baseline for age, height, body weight, calcium intake and exercise participation.

All subjects completed a medical questionnaire. Exclusion from participation in the program consisted of anyone with a history of disease (diabetes, renal disease, heart disease, asthma) or the current use of medication with the possibility that this would affect bone density. Other factors were also taken into account such as; previous neck injury/pain, exercise regime and whether they smoked cigarettes. Based on these criteria, no subject was excluded. A calcium food frequency questionnaire was completed by both control and RAAF subjects, which involved stating the type and quantity of food consumed per day and per week in as much detail as possible.

The flight training course consisted of 8 weeks of ground school, followed by 20 weeks of basic flight training. This involved general flying, instrument flying, navigational flying and night flying. This stage was followed by advanced flying routines for a duration of 24 weeks. This included general flying, instrument flying, navigational flying, night flying and formation flying. The course was concluded with 9 weeks of applied flying which generated the highest +Gz forces. All flight training was performed in a Pilatus PC-9 aircraft.

All pilots involved in the study are exposed to frequent +Gz forces, ranging from 2 to 6 +Gz. The specific G load that is generated during aerial combat manoeuvres is monitored on the g meter, located in the cockpit. The flight school program was structured in a way that all pilots underwent very similar +Gz force exposure and number of flying hours. The pilots flew an average of 156 hours over the duration of the course.

For the purpose of this research, Dual Energy X-ray Absorptiometry (DEXA) was utilized, involving two low radiation dose x-rays, which emits a radiation dose of 3.6 μSv for the whole body scan and 0.8 μSv for the cervical spine scan. These x-rays are less than 1/10th the strength of a chest x-ray and well below the prescribed National Health and Medical Research committee guidelines for subjects participating in biomedical research (Ring, 1992). DEXA was used to measure bone mineral content (BMC) (grams) within a given area, and bone mineral density (BMD) which is calculated as BMC/ area and expressed in grams $\cdot$ cm $^{-2}$.

Measurements were made for total body BMD and BMC, regional BMD, total fat and lean mass, regional fat and lean mass, cervical spine BMD and cervical spine area. All subjects were scanned using a QDR 4500A bone densitometer (Hologic, MA, USA) in array fan beam mode using the standard whole body (version 8.26a).

Total body scans involved the subject lying in a supine position as straight as possible on the scanning table. Analysis of whole body scans involved "independent" analysis. This enabled the second whole body scan (post scan) to be analysed without reference to the first scan. Cervical spine measurements involved the subject to remain of their back, but with their lower legs hanging off the end of the table at right angles to the floor. Their chin was slightly tilted towards the ceiling (resuscitation position) to enable a clear scan of the cervical vertebrae starting at the base of the sternomastoid notch (C7) to approximately C2. The positioning of the body on the table was a result of the lumbar scan protocol being used. A cervical scan protocol did not exist because it was the first time it has been used for research. C4 to C7 was analysed using low density spine analysis (LDSA) and "compare" analysis. LDSA provides a better edge detection of bone mass, which is necessary considering the smaller size of the cervical vertebrae. The "compare" function works by superimposing the regions of interest determined from the first scan onto the second scan image and is recommended by the manufacturer for follow up scans of individuals. The baseline measurements were taken after the completion of the 8 weeks ground school. Post data collection commenced 32 weeks from baseline.

Statistical analysis involved the use of the computer software package Statistical Package for Social Sciences (SPSS) for Windows (version 10.0). A "difference score" was calculated between the pre and post bone mineral content and bone mineral density values for the experimental and control group. The difference score values of the

experimental and control group was compared via an independent t- test. This was done for the measured sites of total body, cervical spine, thoracic spine, lumbar spine, pelvis, arms and legs. Analysis of variance was conducted on the mean BMD changes for C4 to C7 to see if a significant difference of BMD existed between the individual vertebrae. A scatterplot of the cervical spine BMD baseline values against the corresponding change between baseline and post scans was carried out to determine if a relationship existed between the two. If it were evident that lower BMD baseline values for the cervical spine resulted in greater increases in BMD, an ANCOVA would be required. A $p<0.05$ level of significance was used for all analyses.

**EMG data collection**

EMG data was collected for the sternocleidomastoid and the erector spinae muscles during a left turn in a PC-9 aircraft at 3 +Gz. One male RAAF pilot participated in this section of the study.

<u>In-flight data collection and processing for EMG</u>

The sequence for the in-flight data collection session was as follows:

1. Subject finished pre flight brief and "suited-up" to the waist.
2. Neck area was prepared for EMG data collection.
3. Ag-AgCl surface electrodes were placed on eight sites of the subject's neck.
4. Data logger was secured in the leg pocket of the subjects flight suit and the trigger secured to the subject's arm. All wires were placed inside the subjects flight suit so as to minimise the interference.
5. MVC EMG data was measured and downloaded.
6. Subject finished final suit-up and proceeded to aircraft.
7. Data logger and camera was checked once the subject had finished all pre flight procedures.
8. Take-off.
9. Subject triggered data logger once he was about to begin manoeuvres.
10. Subject commenced pre-set flight manoeuvres with head in different positions.
11. Landed.
12. All data was downloaded after landing. This included video, EMG and Gz data from the flight recorder.

All data was processed in a genetic lab view program and smoothed at 5 hertz (hz).

Surface electrodes were placed on four muscles: sternocleidomastoid, erector spinae, levator scapularis and trapezius. Data from levator scapularis and trapezius was not used. The levator scapularis electrode fell off during flight and the processed data from trapezius did not represent true values. Subsequently, only sternocleidomastoid and erector spinae (cervical region) was used. Both muscle's EMG data were normalised to a maximum voluntary contraction to enable comparisons between muscles and other individuals. Prior to flight MVC's for each muscle were recorded, so EMG data could be expressed as percentages of MVC.

The %MVC for sternocleidomastoid and erector spinae were calculated for three head positions; left twist, right twist and extension. Mean values of %MVC were taken over 88 seconds of aerial combat manoeuvring for sternocleidomastoid and erector spinae. The 88 second time frame included movement of the head in all previously analysed head positions. These movements were performed during a left turn at +3Gz. After 88 seconds, the plane levelled off and consequently, muscle activity was minimized. This section of the study was an indirect method of assessing the flight loads placed on the neck.

**Reliability Study: Precision Error of Fan-Beam Dual X-Ray Absorptiometry Scan of Cervical Spine.**

Bone scans of the cervical spine using DEXA have never been used for research purposes. This study sought to validate the cervical spine scan. Fifteen male subjects ranging in age from 18 to 27 years were scanned twice each in fast array fan beam mode at the cervical spine on a Hologic QDR 4500A. To allow for errors introduced by variable subject positioning, each subject was removed from the scanning table and repositioned between scans. Each of the two scans was analyzed using the compare function and low density spine analysis. Co-efficient of variation (CV) and measurement error were respectively 1.02% and $0.019 g.cm^2$.

**Statistical Analysis of Reliability Study**

The mean of the two independent assessments $x$i was calculated as follows:

$x_i = (x_1 + x_{2i})/2$

Coefficient of variation (CV) was calculated using the following equation:

$CV\% = (\sqrt{S_w^2} / x) \times 100$ In which $S_w^2 = \Sigma d^2/(2n)$

"The measurement error is represented as the value below which the absolute difference between the two measurements would lie with 95% probability. This represents the biological, operator and machine variation between successive measurements. The difference between two successive values for a particular patient would be considered significant if greater than the measurement error" (Henzell et al, 2000). Measurement error $[x1 - x2] = 1.96 \times \sqrt{2S_w^2}$

# CHAPTER FOUR

## Results

Table 1 illustrates the physical characteristics of the pilots and control group. No significant group difference existed at baseline for age, height, total body weight, calcium intake, or physical activity. At the completion of the 8 months, there were no significant differences in total body weight, lean mass or fat mass.

Table 1
Baseline age, height, calcium intake and physical activity levels for the RAAF pilots and control subjects (mean ± SE). Baseline and 8 month change in soft tissue composition (total body weight, lean mass, fat mass) for the RAAF pilots and control subjects (mean ± SE)

| Characteristics | Pilots (n = 9) | Controls (n = 10) | p Value |
|---|---|---|---|
| Age (yrs) | 21.77 ± 0.32 | 22.30 ± 1.35 | 0.72 |
| Height (cm) | 184.35 ± 1.21 | 180.96 ± 1.68 | 0.13 |
| Calcium Intake (mg) | 1055 ± 304 | 1020 ± 301 | 0.80 |
| Physical Activity (hrs/wk) | 3.0 ± 0.52 | 5.1 ± 1.50 | 0.22 |
| Total Body Weight (kg) | 80.19 ± 1.73 | 75.55 ± 2.36 | 0.14 |
| △ weight (kg) | - 1.41 ± 0.78 | - 0.23 ± 0.91 | 0.34 |
| Total Lean Mass (kg) | 62.80 ± 1.20 | 59.39 ± 1.70 | 0.13 |
| △ lean mass (kg) | - 1.00 ± 0.44 | 0.10 ± 0.30 | 0.06 |
| Total Fat Mass (kg) | 11.12 ± 0.70 | 10.26 ± 1.27 | 0.57 |
| △ fat mass (kg) | - 0.31 ± 0.40 | - 0.39 ± 0.69 | 0.93 |

Table 2
Mean change in BMD across 8 months for pilots individual cervical vertebrae (C4-C7), standard error and p value.

| Cervical vertebrae | Mean Difference (g.cm2) | Std. Error |
|---|---|---|
| c4 | 0.018 | 0.015 |
| c5 | 0.017 | 0.019 |
| c6 | 0.036 | 0.016 |
| c7 | 0.038 | 0.013 |
| **p Value** | **0.807** | |

Analysis of variance resulted in a p value of 0.807 indicating that there was no significant change in BMD between individual cervical vertebrae. As a consequence, cervical spine bone data was presented as a single value (C4-C7).

Table 3

Baseline and 8 month change in total body BMC (g) and BMD ($g.cm^2$), regional BMD ($g.cm^2$) in the pilots and control subjects. (Mean ± SE) ( $p<0.05$ * )

| Site | Pilots Baseline | 8 Month Δ | p Value | Control Baseline | 8 Month Δ | p Value | Pilot/ Control Δ |
|---|---|---|---|---|---|---|---|
| TB BMD | 1.27 ± 0.04 | 0.011 ± 0.005 | 0.04 * | 1.26 ± 0.04 | 0.015 ± 0.008 | 0.11 | 0.72 |
| **TB BMC** | 3078.5 ± 128.2 | **30.4** ± 14.5 | 0.07 | 3063.5 ± 135.2 | **- 17.0** ± 16.8 | 0.34 | **0.05** * |
| **CS BMD** | 0.65 ± 0.03 | **0.025** ± 0.01 | 0.04 * | 0.70 ± 0.04 | **- 0.011** ± 0.01 | 0.35 | **0.03** * |
| TS BMD | 0.88 ± 0.04 | 0.030 ± 0.02 | 0.10 | 0.96 ± 0.05 | 0.013 ± 0.02 | 0.55 | 0.57 |
| LS BMD | 1.13 ± 0.06 | - 0.117 ± 0.03 | 0.32 | 1.21 ± 0.07 | 0.014 ± 0.03 | 0.63 | 0.24 |
| PEL BMD | 1.41 ± 0.05 | - 0.016 ± 0.01 | 0.25 | 1.40 ± 0.08 | - 0.039 ± 0.01 | 0.02 * | 0.25 |
| ARM BMD | 0.90 ± 0.03 | -0.014 ± 0.006 | 0.06 | 0.87 ± 0.02 | 0.003 ± 0.009 | 0.78 | 0.13 |
| LEG BMD | 1.49 ± 0.04 | -0.007 ± 0.02 | 0.71 | 1.38 ± 0.05 | 0.030 ± 0.02 | 0.25 | 0.25 |

The pilots were found to have significantly greater increases in bone mass for total body BMC and cervical spine BMD. The pilots had an increase of $0.025g.cm^2$ for the cervical spine, whereas the controls had a mean loss of $0.011g.cm^2$. This trend was also apparent for the total body BMC, whereby the pilots gained 30.39g and the control group lost 17.06g. The measurement error of the cervical spine reliability study ($0.019g.cm^2$) reinforces the significance of the $0.025g.cm^2$ mean increase in the pilots' cervical spine. Pelvic BMD decreased for both the pilots and the controls, however, no significance difference existed between the two groups. No significant difference existed between the two groups for total body, thoracic spine, lumbar spine, arm or leg bone mineral density.

Figure 1 and 2 illustrate the significant increase of the pilots CS BMD and TB BMC respectively.

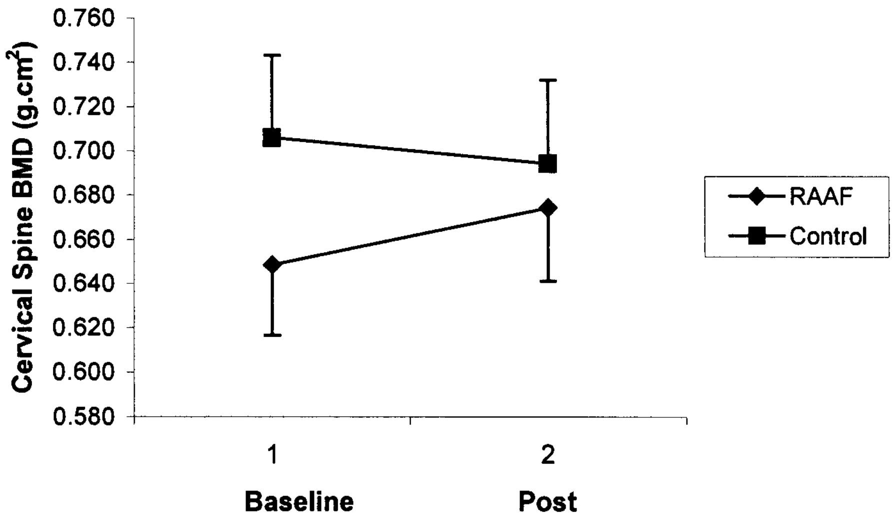


Figure 1. Absolute Change in Cervical Spine Bone Density across 8 Months for RAAF and Control Group (Mean ± SE).

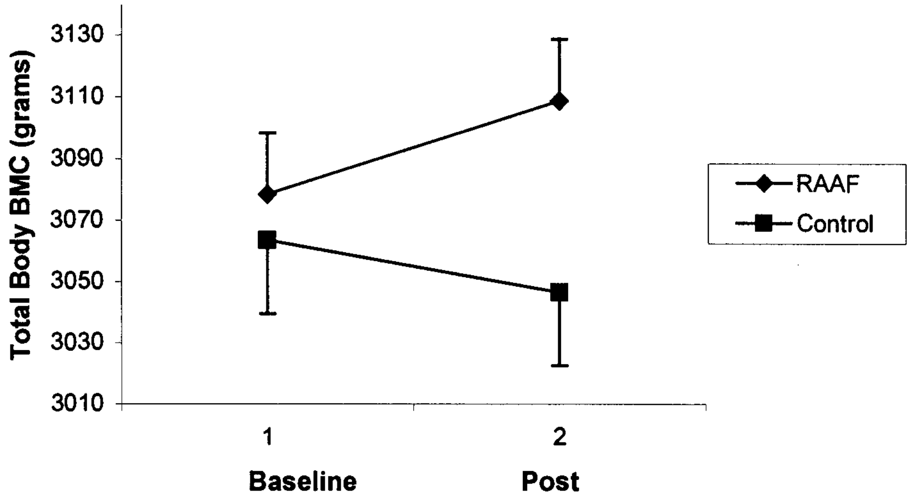


Figure 2. Absolute Change in Total Body Bone Mineral Content across 8 Months for RAAF and Control Group (Mean ± SE).

Table 4
% MVC of sternocleidomastoid and erector spinae muscles for different head positions during flight at +3Gz.

| Movement | Muscle | %MVC |
|---|---|---|
| Extension | Sternocleidomastoid | 52.9 |
| | Erector Spinae | 56.2 |
| Left Twist | Sternocleidomastoid | 26.1 |
| | Erector Spinae | 44.8 |
| Right Twist | Sternocleidomastoid | 97.8 |
| | Erector Spinae | 35.0 |

During flight, the demands on the cervical spine musculature ranges from 26.1% through to 97.8% above resting demands. The highest muscle strain occurred in the sternocleidomastoid during a right twist. The sternocleidomastoid also produced the lowest %MVC during a left twist. The variance between the muscle activity for sternocleidomastoid during a left and right twist is a result of the data being collected during a left turn manoeuvre. This consequently places the sternocleidomastoid under greater strain when twisting the head to the right side.

Table 5
Mean EMG activity for sternocleidomastoid and erector spinae muscles during a left turn at +3Gz.

| Muscle | Mean %MVC |
|---|---|
| Sternocleidomastoid | 13 |
| Erector Spinae | 89.5 |

As illustrated in table 5, the mean strain for the two muscles was vastly different. Minimal muscle activity was produced by sternocleidomastoid as opposed to the significant activation of erector spinae over the 88 seconds of aerial combat manoeuvering at 3+Gz.

# CHAPTER FIVE

## Discussion

Research Question 1: Does moderate +Gz loading of the magnitude 2.0 - 6.0 +Gz increase bone mass in RAAF trainee pilots?

Moderate +Gz loading of the magnitude 2.0-6.0 +Gz was found to significantly increase the cervical spine bone mineral density in RAAF PC-9 pilots. This was the first time that the cervical spine had been examined in terms of the bone accrual response to +Gz force loading and thus was a major finding. The pilots were also found to have a significantly greater total body bone mineral content accrual than the controls after 8 months of moderate +Gz force flying.

As mentioned in chapter one, Naumann et al (2000) did not investigate the effects of moderate +Gz force on the cervical spine, but found significant gains in bone mass at the thoracic spine, pelvis and total body. In addition to the cervical spine and total body increases, we expected to see significant gains in thoracic and pelvic bone mass to occur in this study too. This did not happen for either of these sites, which does not support the hypothesis.

Although the change in thoracic BMD for the pilots was not found to be significant, there was a definite increase in bone mass in comparison to the control group. With further flying under moderate +Gz force, it is possible that further increases in bone mass would have occurred. It was also possible that this site was still in the bone remodelling process. Bone remodelling continues throughout life and is undertaken by "basic multicellular units" (BMU) consisting of osteoblasts and osteoclasts "coupled" together to integrate bone turnover. Gains in bone mass occur by altering normal bone growth, modelling or remodelling activities. Such processes bring about structural or material alterations to the skeleton in response to various stimuli such as mechanical loading (Forwood, 2001). In human bone, the bone remodelling process takes approximately three to four months (Reeve, 1987). A second post scan 4 months later may have shown even greater gains in bone mass and consequently shown a significant increase in thoracic BMD.

Another possible explanation for the insignificant findings in the thoracic and pelvic regions was the grounding of the pilots towards the end of the flight training course. Post scanning was subsequently done before the majority of the higher +Gz force flying. Numerous studies have shown that high magnitude loading is needed to produce an osteogenic response (Kerr et al, 1996). It was likely that this study would have found more significant findings if the pilots were exposed to the highest +Gz force component of the flying training program. Kannus, Sievanen and Vuori (1996) concluded from their study that bone should be loaded with high peak forces and high strain rates, consist of short repetitions and training sessions, and be long term and progressive in nature. The flight training course consisted of all of these variables. However, with additional flying under moderate +Gz force for a duration greater than 8 months, it is probable that further increases would occur. Naumann et al (2000) found more substantial increases in BMD and BMC for RAAF pilots over a longer period of time (12 months).

It is now apparent that significant differences in the magnitude of +Gz loading occur between the upper and lower spine. The insignificant finding for the lumbar BMD was in contrast to a 2 month centrifuge study conducted in Russia. It was reported that average rises of 4.6% and 4.2% for L2 BMD and L4 BMD respectively, were found. It is likely that such differences between the studies occurred because the centrifuge was able to systematically load the spine in a more intensive manner with +Gz forces ranging from 2.0 to 9.0 +Gz, resulting in more substantial increases in BMD for the lumbar spine.

The findings from this study exemplify the importance of high magnitude bone loading and unusual loading to induce an increase in bone mass. The magnitude of loading experienced by the pilots was great enough to positively affect the bone architecture of some regions of the body. Those sites that were not affected were simply not exposed to strains or forces great enough to induce bone mass gains.

A minimum effective strain (MES) threshold exists before bone formation or modelling will occur (approximately 1000 microstrain) and another minimum strain threshold exists which controls bone loss or remodelling (approximately 50 microstrain) (Frost, 1964). No matter how frequent a particular strain occurs, the MES for that bone must be exceeded before the tissue's adaptive mechanisms change the architecture of the bone. Skerry (1997) states that "high loads are the primary determinant for effectiveness in increasing bone mass". Numerous studies conducted on animals have reinforced this

theory, demonstrating clearly that increasing strain magnitude initiates a dose dependant elevation of bone mass (Mosely et al, 1997) (Smith et al, 1996).
Facilitating the increased bone mass of the cervical spine and total body was the unusual loading patterns experienced by the pilots. Loads applied in an unaccustomed manner result in bone adaptations, increasing their mass, density and structural properties. The pilots in the flight training course would not be accustomed to the magnitude or form of mechanical loading generated during the high performance flying. Mosely et al (1997), stated that "strains presented in a novel distribution are more osteogenic than the equivalent strains presented in the customary distribution". The theory that bone detects mechanical stimuli as the difference between a newly imposed mechanical milieu and the habitual mechanical milieu is widely accepted by researchers (Forwood, 2001) (Mosely et al, 1997) (Reeve, 1987).

The mature age of the pilots makes the findings of increased bone mass of even more importance. It has been proposed that the effect of mechanical loading is about two times better if the activity is started before or at puberty than after it (Kannus et al, 1996). Growing bones are more responsive to mechanical loading since it is easier to modify the ongoing modelling process of a growing bone (Mosely, 2000). The results from the study by Judex et al, 2000 also emphasised the sensitivity of immature bone to mechanical loading. Taking into account that the average age of the pilots was 22 years, this notion emphasises the extent to which moderate +Gz flying can influence bone remodelling.

Research Question 2: Does moderate +Gz loading generate the greatest osteogenic benefit at the cervical spine, the site suspected of being subjected to the greatest loading?

The cervical spine of the pilots was the site that increased its bone mineral density the greatest over the 8 months of moderate +Gz flying. This site was suspected to develop the greatest gains in bone mass due to the severe mechanical loading of the neck region in moderate +Gz force flying. The loading on the cervical spine is the direct result of the +Gz forces acting on the weight of the head, helmet and oxygen mask worn by the pilots during flight. Assuming that the mass of the head and helmet is 6kg and the head position is neutral, during sustained G-force at +8.0 Gz, a static force of 48kg stresses the cervical spine (Hamalainen et al 1992).

Oska et al (1996) found that the magnitude of muscular strain seems to be higher the closer to the neck and shoulder it is recorded. Hamalainen et al (1996) and Newman (1996) both reported in their studies that pilots frequently complain of flight related pain and injuries in the cervical spine region. Such information proposes that the cervical vertebrae are exposed to the majority of the forces and subsequent strain during flight. It is for these reasons that the cervical spine was the site that benefited the most from the +Gz force loading. This finding also reinforces that the loading of bone is site specific. Prince et al (1995), like many researchers, believe that BMD increases at the portion of the skeleton that is subjected to the greatest loading. The effect of mechanical loading is site specific to the working muscles and the bones to which they attach (Layne et al 1997). The effect of physical activity on the skeleton of tennis players has been studied numerous times due to the uni-lateral and intensive loading of the skeleton (Loro et al., 2000). The notion of site specificity is reinforced time after time when only the bones of the dominant arm show significant gains in BMC and BMD (Kannus et al 1994). Likewise, greater increments in bone mass occur primarily in the legs of dancers, skaters and gymnasts. Power lifters and weight lifters experience gains in bone mass in practically all bone of the skeleton (Loro et al, 2000).

The EMG data are an indirect measurement of the magnitude of strain imposed on the spine of the pilots. Oska et al (1996) measured muscle strain during aerial combat manoeuvring and like this study, found that the greatest strain occurred in the lateral neck muscle. The level measured was 257% MVC at +7 Gz. This caused an acute neck injury. Newman (1996) states that, "the higher the aircraft performance, the heavier the helmet, and the higher the peak +Gz and its rate of onset, the higher is the incidence of neck injury". There are certainly implications of higher +Gz force flying for the cervical muscles, however, neck strength programs for RAAF pilots are being devised to prevent such injuries. Oska et al (1996) also documented that mean muscle strain in the cervical erector spinae muscles during +4 Gz was 17.8%. The current study recorded a more significant mean strain of 89.5% for the erector spinae muscle in the neck under +3Gz. The neck muscles of the pilots are exposed to such forces frequently when flying, even at 2-3 +Gz. The extreme muscular strain encountered by the pilots produce forces within the skeleton that are perceived by bone cells as osteogenic (Kerr et al, 1996). Muscles cause the largest loads and the largest bone strains, and these strains determine whole bone strength (Frost et al 2000). There is importance in discussing such EMG research due to

the relationship between muscle activity and strain and the associated load applied to the bones (Keen, 1999).

While our EMG study certainly confirmed that there is significant activation of the cervical muscles, it did not prove that it was the site that has the greatest muscle activation during flight. A study by Hewson, McNair and Marshall (2001) investigated the activity of several muscles including the vastus lateralis, deltoid and triceps during flight with a C-130 Hercules. The mean EMG activity across all muscles was 26% MVC, indicating that there was minimal activation of those muscles in comparison to the research conducted on the spinal muscles.

**Future Research Questions**

Numerous aviation studies have researched the effect of +Gz force and subsequent injuries arising from the compressive forces. Such research has enhanced our understanding of the sites of the body that are exposed to the greatest strains. With this in mind, there is also a need for continuing research on +Gz force and its effect on bone mass. Recommendations for future studies include researching the effect of higher +Gz forces (>+ 6 Gz ) on bone mass such as those generated when flying the FA-18 Hornet. A second recommendation would be the long term effects of moderate/high +Gz force exposure and to determine if the bone mass gains are maintained post flying. It also remains to be determined whether high performance flying would increase bone mass at sites of the skeleton previously not affected by moderate +Gz force exposure. "Many interesting questions concerning adaptation of bone to mechanical loading are still unanswered because of the insufficient information about the type, intensity, frequency and duration of the activity that provides maximum anabolic stimulus to bone" (Kannus et al, 1996). This study and future research on the effect of moderate/high +Gz force on bone mass will enhance our understanding of the above variables. Ultimately, such research will aid in creating exact exercise programs that would best enhance bone mineralisation at the most characteristic sites of osteoporotic fractures.

## Conclusion

Exposure to the +Gz forces brought about a substantial increase in BMD in the cervical vertebrae and BMC of the total body. While not significant, there was evidence of bone mass gains in thoracic BMD. It is possible that the lumbar and pelvic regions were not sufficiently loaded to induce a bone response. The findings from this study support the principals of bone loading discussed and studied by so many researchers. It is the nature of the mechanical loading investigated that makes this study and its results unique. This study has reinforced the notion of a site specific bone response to high magnitude and unaccustomed mechanical loading. Taking into account that an osteogenic response was found from flying under moderate +Gz force for a duration of 8 months, it is possible that such greater increases in bone mass are occurring for pilots flying at higher +Gz forces for greater lengths of time.

## References

Bennell, K., Page, C., Khan, K., Warmington, S., Plant, D., Thomas, D., Palamara, J., Williams, D., & Wark, J.D. (2000). Effects of resistance training on bone parameters in young and mature rats. Clinical Exp Pharmacol Physiol, 27(1-2), 88-94.

Burger, E.H., & Klein-Nulen, J. (1999). Responses of bone cells to biomechanical forces in vitro. Adv Dent Res, 13, 93-98.

Collet, P., Uebelhart, D., Vico, L., Moro, L., Hartman, D., Roth, M., & Alexandre, C. (1997). Effect of 1- and 6 month spaceflight on bone mass and biochemistry in two humans. Bone, 20, 547-551.

Cowin, S.C., Moss-Salentijin, L., & Moss, M.L. (1991). Candidates for the mechanosensory system on bone. Journal of Biomechanics England, 113, 191-197.

Forwood, M.R. (2001). Mechanical effects on the skeleton: are there clinical implications? Osteoporosis International, 12 (1), 77-83.

Forwood, M.R., & Larsen, J.A. (2000). Exercise recommendations for osteoporosis. Australian Family Physician, 29 (8), 761-764.

Frost, H.M. (1964). The laws of bone structure. Springfield: Charles C. Thomas.

Frost, H.M., & Schonau, E. (2000). Journal of Paediatric Endocrinology Metabolism, 13 (6), 571-90.

Granhad, H., Jonson, R., & Hansson, T. (1987). The loads on the lumbar spine during extreme weight lifting. Spine, 12, 146-149.

Hamalainen, O., & Vanharanta, H. (1992). Effect of Gz forces and head movements on cervical erector spinae muscle strain. Aviation, Space, and Environmental Medicine, 63, 709-16.

Hamalainen, O., Vanharanta, H., Hupli, M., Karhu, M., Kuronen, P., & Kinnunen, H. (1996). Spinal shrinkage due to +Gz forces. Aviation, Space and Environmental Medicine, 67 (7), 659-661.

Henzell, S., Dhaliwal, S., Pontifex, R., Gill, F., Price, R., Retallack, R., & Prince, R. (2000). Precision error of fan beam dual x-ray absorptiometry scans at spine, hip and forearm. Journal of Clinical Densitometry, 3 (4), 359-364.

Hewson, D.J., McNair, P.J., Marshall, R.N. (2001). Aircraft control forces and EMG activity in a C-130 Hercules during strength-critical manoeuvres. Aviation, Space and Environmental Medicine, 72 (5), 437-442.

Judex, S., & Zernicke, R.F. (2000). High impact exercise and growing bone: relation between high strain rates and enhanced bone formation. Journal of Applied Physiology, 88 (6), 2183-91.

Kalyanin, V.V., Bukhtiyarov, I.V., & Vasiliev, A.Y. (1996). Research of mineral saturation of osseous tissue in lumbar vertebrae in the course of systematic exposure to +Gz accelerations. Aerospace and Environmental Medicine, 30 (5), 9-13.

Kannus, P., Sievanen, H., & Vuori, I. (1996). Physical loading, exercise and bone. Bone, 18 (1), 1-3.

Karlsson, M.K., Magnusson, H., Karlson, C., & Seeman, E. (2001). The duration of exercise as a regulator of bone mass. Bone, 28 (1), 128-131.

Keen, R.W. (1999). Effects of lifestyle interventions on bone health. The Lancet, 354 (9194), 1923-1924.

Kerr, D., Morton, A., Dick, I., & Prince, R. (1996). Exercise effects on bone mass in postmenopausal women are site specific and load dependant. Journal of Bone and Mineral Research, 11 (2), 218-225.

Kikukawa, A., Tachibana, S., & Yagura, S. (1995). G- related musculoskeletal spine symptoms in Japan air self defence force F-15 pilots. Aviation, Space and Environmental Medicine, March, 269-272.

Knudson, R., McMilllan, D., Doucette, D., & Seidel, M. (1988). A comparative study of G induced neck injury in pilots of the F/A-18, A-7, and A-4. Aviation, Space and Environmental Medicine, August, 758-760.

Lanyon, L.E. (1984). Functional strain as a determinant for bone remodelling. Calc Tissue International, 36, 56-61.

Lanyon, L.E. (1993). Osteocytes, strain detection, bone remodelling and remodelling. Calc Tissue International, 53, 102-106.

Layne, J.E., & Nelson, M.E. (1997). The effects of progressive resistance training on bone density: a review. Medicine and Science in Sports and Exercise, June, 25-30.

Loro, M.L., Sayre, J., Roe. T.F., Goran, M.I., Kaufman, F.R., & Gilsanz, V. (2000). Early identification of children predisposed to low peak bone mass and osteoporosis later in life. Journal of Endocrinology and Metabolism, 85 (10), 3908.

Marcus, R. (1996). The nature of osteoporosis. Journal of Clinical Endocrinology and Metabolism, 81, 1-5.

Marcus, R., Drinkwater, B., Dalsky, G., Dufek, J., Raab, D. Slemenda, C., & Snow-Harter, C. (1991). Osteoporosis and exercise in women. Medicine and Science in Sport and Exercise, 24 (6), 301-307.

Martini, F.H. (1998). Fundamentals of Anatomy and Physiology. New Jersey: Prentice Hall.

McArdle,W.D., Katch, F.I.., & Katch, V.L. (1996). Exercise Physiology: Energy, Nutrition and Human Performance. Maryland: Williams and Wilkins.

Mosley, J.R. (2000). Osteoporosis and bone functional adaptation: Mechanobiological

regulation of bone architecture in growing and adult bone, a review. Journal of Rehab and Research and Development, 37 (2), 189-199.

Mosely, J.R., March, B.M., Lynch, J., & Lanyon, L.E. (1997). Strain magnitude related changes in whole bone architecture in growing rats. Bone, 20 (3), 191-198.

Naumann, F.L., Bennell, K.L., & Wark, J.D. (2000). The effect of +Gz force on the bone mineral density of fighter pilots. Aviation Space and Environmental Medicine, 72 (2), 1-5.

Newman, D.G. (1996). Cervical intervertebral disc protrusion in an RAAF F-111C pilot: A case report. Aviation, Space and Environmental Medicine, 67 (4), 351-353.

Oska. J., Hamalainen, O., Rissanen, S., Myllyniemi, J., & Kuronen, P. (1996). Muscle strain during aerial combat manoeuvring exercise. Aviation, Space and Environmental Medicine, 67 (12), 1138-1143.

Osteoporosis Australia. (2001). [On-line]. Available WWW: http://www.osteoporosis.org.au/ [2001, 23 May]

Prince, R., Devine, A., & Dick, I. (1995). The effects of calcium supplementation and exercise on bone density in postmenopausal women. Journal Bone Mineral Research, 10, 1068-75.

Reeve. (1987). Bone turnover and trabecular plate survival after artificial menopause. British Medical Journal, 295, 757-760.

Reinhart, R.O. (1996). Basic Flight Physiology. New York: McGraw-Hill.

Ring, E.F. (1992). Current Research in Osteoporosis and Bone Mineral Measurement II:1992. London: British Institute of Radiology.

Robling, A.G., Burr, D.B., & Turner, C.H. (2000). Partitioning a daily mechanical stimulus into discrete loading bouts improves the osteogenic response to loading. Journal of Bone Mineral Research, 15 (8), 1596-602.

Rubin, C.T. (1984). Skeletal strain and the functional significance of bone architecture. Calcif Tissue International, 36, 11-18.

Rubin, C.T., & Lanyon, L.E. (1984). Regulation of bone formation by applied dynamic loads. Journal of Bone Joint Surgery, 66, 397-402.

Skerry, T.M. (1997). Mechanical loading and bone: What sort of exercise is beneficial to the skeleton? Bone, 20 (3), 179-181.

Smith, E.L., & Gilligan, C. (1996). Dose response relationship between physical loading and mechanical competence of bone. Bone, 18 (1), 45-50.

Sinaki, M., McPhee, M.C., & Hodgson, S.F. (1986). Relationship between bone mineral density of the spine and strength of back extensors in health of premenopausal women. Mayo Clinical Proc, 61, 116-122.

Taaffe, D.R., SnowHarter, C., Connolly, D.A., Robinson, T.L., Brown, M.D., & Marcus, R. (1995). Differential effects of swimming versus weight bearing activity on bone mineral status of eumenorrheic athletes. Journal of Bone Mineral Research, 10, 586-593.

# Appendix A

# Medical Questionnaire

# Fighter Pilot Neck Strengthening Study

## Confidential Medical Questionnaire

NAME: ______________________ DATE: ____ / ____ / _____

AGE: __________ yrs DATE OF BIRTH: ____ / ____ / _____

HEIGHT: __________ cm WEIGHT: __________ kg

RAAF FIGHTER / RAAF / CONTROL ( circle appropriate group)

**1. Have you ever suffered or suffer from any of the following conditions:**

Asthma: Yes / No Diabetes: Yes / No

Renal Disease: Yes / No Heart Disease: Yes / No

**2. On an average basis, how many hours per week would you currently spend engaged in physical activity and exercise?**

hrs/wk

Type of Exercise: ______________________ ______________________

______________________ ______________________

______________________ ______________________

**3. Are you a smoker?** Yes / No

If YES, How many cigarettes per day do you smoke. _______ per/day

**4. Have you ever experienced any neck injury or neck pain in the past.**

If YES, what was the nature of the injury or pain.

______________________________________________________________

______________________________________________________________

**5. Are you currently experiencing any neck pain?**

Please circle:

No Pain Very Mild Pain Moderate Pain

Fairly Severe Very Severe

# Appendix B

# Calcium Food Frequency Questionnaire

**6. Over the past week, how frequently did you consume the following foods? Please indicate the approximate number of standard serves per day or week. If you rarely have the item, just tick rarely or never.**

| FOOD | Standard Serve | Per Day | Per Week | Rarely or Never | Type |
|---|---|---|---|---|---|
| **Milk** Plain | 1 glass (200ml) | | | | |
| **Milk** Flavoured | 1 glass (200ml) | | | | |
| **Milk** On Cereal | 1/2 cup | | | | |
| **Milk** In Tea/Coffee | 30 ml | | | | |
| **Milkshake** | Regular size | | | | |
| **Thickshake** | Regular size | | | | |
| **Yoghurt** | 1 tub (200g) | | | | |
| **Ice-Cream** | 1 scoop (50g) | | | | |
| **Cream** | 1 tablespoon | | | | |
| **Cheese** Hard | 1 slice (20g) | | | | |
| **Cheese** Soft | 1 serve (20g) | | | | |
| **Chocolate** | 1 bar (60g) | | | | |
| **Fish** | 1 med fillet 100g | | | | |
| **Meat** | 1 med steak 100g | | | | |
| **Chicken** | med fillet 100g | | | | |
| **Nuts** | 20g | | | | |
| **Fruit** | 1 average | | | | |
| **Vegetables** | 1 serve | | | | |
| **Cereals** | 1 serve | | | | |
| **Bread** | 1 slice 30 g | | | | |

Thank-you

# Appendix C

# Consent Form

EDITH COWAN UNIVERSITY
PERTH WESTERN AUSTRALIA

**Injury Prevention in RAAF Fighter Pilots: A Neck Strengthening Program for High Performance Pilots**

# INFORMED CONSENT FORM – CONTROL PILOT GROUP

Thank-you for expressing interest in volunteering to take part in this study. The following information is presented in order to enable you to make an informed decision as to whether you wish to participate in the study. The information included outlines the procedures involved, together with the risk and safeguards associated with participation in the study.

This study is being conducted with the aim of gaining an understanding of the possibility of neck injury prevention and of the bone health status of RAAF aircrew. Ultimately, by gaining such information, we hope to be able to enhance our knowledge in the aviation medical field, in addition to applying the knowledge to public and community health field.

Should you volunteer to participate in the study, you will be asked to undergo two neck strength and two bone mineral density scans over a 9 month period. Medical and nutritional questionnaires will also be administered at the commencement of the study. All data will remain confidential to the research team. The results of the tests will be made available to you at the end of the testing period.

I, ______________________________ give my consent to participate in the research titled: Injury Prevention in RAAF Fighter Pilots: A Neck Strengthening Program for High Performance Pilots, on the following basis:

- I acknowledge that the procedure has been explained to me, including the anticipated length of time it will take, the frequency with which the procedure will be performed and an indication of any discomfort which may be expected.

- I understand that my involvement in this study is voluntary and that I am free to withdraw from the study at any stage without penalty or detriment to my career.

- I am co-operating in this project on condition that:
    - The information I provide is kept confidential
    - The information will be used only for this project
    - The results will be made available to me at my request and any published reports of this study will preserve my anonymity.
    - I have been given a copy of the information sheet and this form, signed by me and by the principal researcher, Dr Fiona Morris, to keep.

- I have been given a copy of the information sheet and this form, signed by me and by the principal researcher, Dr Fiona Morris, to keep.

Signed (Subject) __________________________________________ date ____ / ____ / ____

Before me (Principal Researcher) ________________________________ date ____ / ____ / ____

# Appendix D

# BMD/BMC Data Used for Statistics

## CONTROLS

### *Cervical BMD (g.cm$^{2}$)*

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 0.686 | 0.682 | -0.004 |
| 2 | 0.691 | 0.693 | 0.002 |
| 3 | 0.662 | 0.652 | -0.010 |
| 4 | 0.881 | 0.894 | 0.013 |
| 5 | 0.626 | 0.588 | -0.038 |
| 6 | 0.601 | 0.618 | 0.017 |
| 7 | 0.840 | 0.736 | -0.104 |
| 8 | 0.722 | 0.745 | 0.023 |
| 9 | 0.515 | 0.482 | -0.033 |
| 10 | 0.837 | 0.852 | 0.015 |
| Average | **0.706** | **0.694** | **-0.012** |

### *Total Body BMC (g)*

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 2724.99 | 2667.93 | -57.06 |
| 2 | 2846.81 | 2860.11 | 13.30 |
| 3 | 2868.97 | 2937.62 | 68.65 |
| 4 | 3606.08 | 3539.10 | -66.98 |
| 5 | 3000.32 | 2933.57 | -66.75 |
| 6 | 3100.15 | 3032.64 | -67.51 |
| 7 | 3040.36 | 3018.10 | -22.26 |
| 8 | 3843.16 | 3911.55 | 68.39 |
| 9 | 2354.21 | 2354.40 | 0.19 |
| 10 | 3250.60 | 3209.98 | -40.62 |
| Average | **3063.57** | **3046.50** | **-17.07** |

### *Total Body BMD (g.cm$^{2}$)*

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 1.118 | 1.120 | 0.002 |
| 2 | 1.319 | 1.320 | 0.001 |
| 3 | 1.235 | 1.270 | 0.035 |
| 4 | 1.446 | 1.442 | -0.004 |
| 5 | 1.167 | 1.178 | 0.011 |
| 6 | 1.230 | 1.250 | 0.020 |
| 7 | 1.283 | 1.306 | 0.023 |
| 8 | 1.458 | 1.524 | 0.066 |
| 9 | 1.073 | 1.105 | 0.032 |
| 10 | 1.360 | 1.325 | -0.035 |
| Average | **1.269** | **1.284** | **0.015** |

## RAAF

### *Cervical BMD (g.cm$^{2}$)*

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 0.758 | 0.782 | 0.024 |
| 2 | 0.671 | 0.746 | 0.075 |
| 3 | 0.589 | 0.652 | 0.063 |
| 4 | 0.570 | 0.584 | 0.014 |
| 5 | 0.766 | 0.779 | 0.013 |
| 6 | 0.654 | 0.670 | 0.016 |
| 7 | 0.591 | 0.558 | -0.033 |
| 8 | 0.494 | 0.529 | 0.035 |
| 9 | 0.745 | 0.768 | 0.023 |
| Average | **0.649** | **0.674** | **0.026** |

### *Total Body BMC (g)*

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 3258.83 | 3329.27 | 70.44 |
| 2 | 3332.83 | 3355.32 | 22.49 |
| 3 | 2556.56 | 2567.98 | 11.42 |
| 4 | 2868.62 | 2906.38 | 37.76 |
| 5 | 3389.00 | 3351.30 | -37.70 |
| 6 | 3331.74 | 3345.85 | 14.11 |
| 7 | 2563.17 | 2602.40 | 39.23 |
| 8 | 2807.29 | 2807.99 | 0.70 |
| 9 | 3598.33 | 3713.43 | 115.10 |
| Average | **3078.49** | **3108.88** | **30.39** |

### *Total Body BMD (g.cm$^{2}$)*

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 1.337 | 1.354 | 0.017 |
| 2 | 1.372 | 1.371 | -0.001 |
| 3 | 1.206 | 1.214 | 0.008 |
| 4 | 1.147 | 1.158 | 0.011 |
| 5 | 1.313 | 1.347 | 0.034 |
| 6 | 1.408 | 1.429 | 0.021 |
| 7 | 1.165 | 1.153 | -0.012 |
| 8 | 1.159 | 1.181 | 0.022 |
| 9 | 1.410 | 1.413 | 0.003 |
| Average | **1.280** | **1.291** | **0.011** |

## CONTROLS BMD (g.cm$^2$)

### *THORACIC SPINE*

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 0.846 | 0.834 | -0.012 |
| 2 | 0.969 | 1.034 | 0.065 |
| 3 | 0.948 | 0.996 | 0.048 |
| 4 | 1.212 | 1.225 | 0.013 |
| 5 | 0.817 | 0.985 | 0.168 |
| 6 | 0.954 | 0.860 | -0.094 |
| 7 | 1.043 | 0.997 | -0.046 |
| 8 | 1.114 | 1.080 | -0.034 |
| 9 | 0.709 | 0.720 | 0.011 |
| 10 | 0.994 | 1.014 | 0.020 |
| Average | **0.961** | **0.975** | **0.014** |

### *LUMBAR SPINE*

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 1.002 | 1.000 | -0.002 |
| 2 | 1.289 | 1.444 | 0.155 |
| 3 | 1.139 | 1.130 | -0.009 |
| 4 | 1.624 | 1.609 | -0.015 |
| 5 | 1.004 | 1.041 | 0.037 |
| 6 | 1.249 | 1.156 | -0.093 |
| 7 | 1.341 | 1.222 | -0.119 |
| 8 | 1.272 | 1.440 | 0.168 |
| 9 | 0.905 | 0.914 | 0.009 |
| 10 | 1.352 | 1.365 | 0.013 |
| Average | **1.218** | **1.232** | **0.014** |

### *PELVIS*

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 1.151 | 1.078 | -0.073 |
| 2 | 1.518 | 1.377 | -0.141 |
| 3 | 1.317 | 1.274 | -0.043 |
| 4 | 1.690 | 1.654 | -0.036 |
| 5 | 1.266 | 1.270 | 0.004 |
| 6 | 1.195 | 1.172 | -0.023 |
| 7 | 1.404 | 1.358 | -0.046 |
| 8 | 1.808 | 1.782 | -0.026 |
| 9 | 1.106 | 1.133 | 0.027 |
| 10 | 1.611 | 1.576 | -0.035 |
| Average | **1.407** | **1.367** | **-0.039** |

## RAAF BMD (g.cm$^2$)

### *THORACIC SPINE*

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 0.967 | 1.041 | 0.074 |
| 2 | 0.982 | 1.031 | 0.049 |
| 3 | 0.858 | 0.873 | 0.015 |
| 4 | 0.747 | 0.762 | 0.015 |
| 5 | 0.971 | 1.013 | 0.042 |
| 6 | 0.907 | 0.951 | 0.044 |
| 7 | 0.847 | 0.767 | -0.080 |
| 8 | 0.703 | 0.803 | 0.100 |
| 9 | 1.016 | 1.031 | 0.015 |
| Average | **0.889** | **0.919** | **0.030** |

### *LUMBAR SPINE*

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 1.303 | 1.318 | 0.015 |
| 2 | 1.190 | 1.257 | 0.067 |
| 3 | 1.008 | 1.024 | 0.016 |
| 4 | 0.910 | 0.771 | -0.139 |
| 5 | 1.440 | 1.297 | -0.143 |
| 6 | 1.149 | 1.183 | 0.034 |
| 7 | 1.012 | 0.967 | -0.045 |
| 8 | 0.985 | 1.055 | 0.070 |
| 9 | 1.202 | 1.276 | 0.074 |
| Average | **1.133** | **1.128** | **-0.006** |

### *PELVIS*

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 1.679 | 1.586 | -0.093 |
| 2 | 1.590 | 1.558 | -0.032 |
| 3 | 1.253 | 1.275 | 0.022 |
| 4 | 1.319 | 1.291 | -0.028 |
| 5 | 1.423 | 1.442 | 0.019 |
| 6 | 1.345 | 1.376 | 0.031 |
| 7 | 1.344 | 1.326 | -0.018 |
| 8 | 1.278 | 1.238 | -0.040 |
| 9 | 1.477 | 1.472 | -0.005 |
| Average | **1.412** | **1.396** | **-0.016** |

## CONTROL BMD ($g.cm^2$)

### ARMS

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 0.757 | 0.79 | 0.033 |
| 2 | 0.922 | 0.873 | -0.049 |
| 3 | 0.845 | 0.884 | 0.039 |
| 4 | 0.936 | 0.929 | -0.007 |
| 5 | 0.809 | 0.797 | -0.012 |
| 6 | 0.876 | 0.885 | 0.009 |
| 7 | 0.904 | 0.934 | 0.03 |
| 8 | 0.907 | 0.911 | 0.004 |
| 9 | 0.789 | 0.799 | 0.01 |
| 10 | 0.916 | 0.884 | -0.032 |
| Average | | | **0.0025** |

### LEGS

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 1.192 | 1.083 | -0.109 |
| 2 | 1.382 | 1.462 | 0.08 |
| 3 | 1.296 | 1.36 | 0.064 |
| 4 | 1.644 | 1.698 | 0.054 |
| 5 | 1.277 | 1.363 | 0.086 |
| 6 | 1.334 | 1.367 | 0.033 |
| 7 | 1.317 | 1.295 | -0.022 |
| 8 | 1.669 | 1.818 | 0.149 |
| 9 | 1.186 | 1.233 | 0.047 |
| 10 | 1.51 | 1.433 | -0.077 |
| Average | | | **0.0305** |

## RAAFBMD ($g.cm^2$)

### ARMS

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 0.929 | 0.935 | 0.006 |
| 2 | 0.902 | 0.897 | -0.005 |
| 3 | 0.809 | 0.771 | -0.038 |
| 4 | 0.86 | 0.867 | 0.007 |
| 5 | 1.062 | 1.035 | -0.027 |
| 6 | 0.934 | 0.932 | -0.002 |
| 7 | 0.846 | 0.826 | -0.02 |
| 8 | 0.784 | 0.744 | -0.04 |
| 9 | 0.995 | 0.98 | -0.015 |
| Average | | | **-0.014889** |

### LEGS

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 1.419 | 1.445 | 0.026 |
| 2 | 1.632 | 1.601 | -0.031 |
| 3 | 1.406 | 1.362 | -0.044 |
| 4 | 1.387 | 1.423 | 0.036 |
| 5 | 1.508 | 1.485 | -0.023 |
| 6 | 1.67 | 1.704 | 0.034 |
| 7 | 1.441 | 1.462 | 0.021 |
| 8 | 1.336 | 1.383 | 0.047 |
| 9 | 1.633 | 1.501 | -0.132 |
| Average | | | **-0.007333** |

## CONTROL BMD FOR INDIVIDUAL CERVICAL VERTEBRAE ($g.cm^2$)

| | | c4 | | | | c5 | |
|---|---|---|---|---|---|---|---|
| SUBJECT | pre | post | diff | SUBJECT | pre | post | diff |
| 1 | 0.713 | 0.680 | -0.033 | 1 | 0.712 | 0.716 | 0.004 |
| 2 | 0.747 | 0.732 | -0.015 | 2 | 0.683 | 0.712 | 0.029 |
| 3 | 0.698 | 0.728 | 0.030 | 3 | 0.668 | 0.682 | 0.014 |
| 4 | 0.880 | 0.937 | 0.057 | 4 | 0.942 | 0.961 | 0.019 |
| 5 | 0.720 | 0.667 | -0.053 | 5 | 0.647 | 0.565 | -0.082 |
| 6 | 0.715 | 0.772 | 0.057 | 6 | 0.626 | 0.698 | 0.072 |
| 7 | 0.856 | 0.885 | 0.029 | 7 | 0.900 | 0.761 | -0.139 |
| 8 | 0.712 | 0.760 | 0.048 | 8 | 0.714 | 0.745 | 0.031 |
| 9 | 0.528 | 0.486 | -0.042 | 9 | 0.535 | 0.511 | -0.024 |
| 10 | 0.883 | 0.979 | 0.096 | 10 | 0.851 | 0.828 | -0.023 |
| Average | | | **0.017** | Average | | | **-0.010** |

| | | c6 | | | | c7 | |
|---|---|---|---|---|---|---|---|
| SUBJECT | pre | post | dif | SUBJECT | pre | post | diff |
| 1 | 0.718 | 0.699 | -0.019 | 1 | 0.589 | 0.631 | 0.042 |
| 2 | 0.685 | 0.725 | 0.040 | 2 | 0.649 | 0.609 | -0.040 |
| 3 | 0.610 | 0.586 | -0.024 | 3 | 0.671 | 0.590 | -0.081 |
| 4 | 0.867 | 0.862 | -0.005 | 4 | 0.841 | 0.830 | -0.011 |
| 5 | 0.604 | 0.522 | -0.082 | 5 | 0.544 | 0.593 | 0.049 |
| 6 | 0.599 | 0.525 | -0.074 | 6 | 0.469 | 0.503 | 0.034 |
| 7 | 0.814 | 0.644 | -0.170 | 7 | 0.787 | 0.605 | -0.182 |
| 8 | 0.680 | 0.683 | 0.003 | 8 | 0.781 | 0.799 | 0.018 |
| 9 | 0.537 | 0.510 | -0.027 | 9 | 0.465 | 0.424 | -0.041 |
| 10 | 0.798 | 0.776 | -0.022 | 10 | 0.784 | 0.784 | 0.000 |
| Average | | | **-0.038** | Average | | | **-0.021** |

## RAAF BMD FOR INDIVIDUAL CERVICAL VERTEBRAE ($g.cm^2$)

| | | c4 | | | | c5 | |
|---|---|---|---|---|---|---|---|
| SUBJECT | pre | post | diff | SUBJECT | pre | post | diff |
| 1 | 0.789 | 0.763 | -0.026 | 1 | 0.728 | 0.759 | 0.031 |
| 2 | 0.703 | 0.767 | 0.064 | 2 | 0.671 | 0.728 | 0.057 |
| 3 | 0.623 | 0.679 | 0.056 | 3 | 0.603 | 0.680 | 0.077 |
| 4 | 0.690 | 0.683 | -0.007 | 4 | 0.583 | 0.595 | 0.012 |
| 5 | 0.824 | 0.773 | -0.051 | 5 | 0.741 | 0.752 | 0.011 |
| 6 | 0.675 | 0.694 | 0.019 | 6 | 0.669 | 0.697 | 0.028 |
| 7 | 0.589 | 0.572 | -0.017 | 7 | 0.668 | 0.540 | -0.128 |
| 8 | 0.536 | 0.618 | 0.082 | 8 | 0.517 | 0.578 | 0.061 |
| 9 | 0.796 | 0.840 | 0.044 | 9 | 0.737 | 0.745 | 0.008 |
| Average | | | **0.018** | Average | | | **0.017** |

| | | c6 | | | | c7 | |
|---|---|---|---|---|---|---|---|
| SUBJECT | pre | post | diff | SUBJECT | pre | post | diff |
| 1 | 0.755 | 0.802 | 0.047 | 1 | 0.751 | 0.806 | 0.055 |
| 2 | 0.684 | 0.771 | 0.087 | 2 | 0.626 | 0.722 | 0.096 |
| 3 | 0.588 | 0.726 | 0.138 | 3 | 0.543 | 0.569 | 0.026 |
| 4 | 0.487 | 0.518 | 0.031 | 4 | 0.510 | 0.534 | 0.024 |
| 5 | 0.745 | 0.777 | 0.032 | 5 | 0.741 | 0.818 | 0.077 |
| 6 | 0.635 | 0.657 | 0.022 | 6 | 0.628 | 0.620 | -0.008 |
| 7 | 0.564 | 0.533 | -0.031 | 7 | 0.535 | 0.597 | 0.062 |
| 8 | 0.477 | 0.486 | 0.009 | 8 | 0.443 | 0.416 | -0.027 |
| 9 | 0.820 | 0.812 | -0.008 | 9 | 0.655 | 0.695 | 0.040 |
| Average | | | **0.036** | Average | | | **0.038** |

**CONTROLS**

***TOTAL FAT MASS (g)***

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 13975.70 | 8909.80 | -5065.90 |
| 2 | 11248.60 | 11014.40 | -234.20 |
| 3 | 4667.70 | 4381.00 | -286.70 |
| 4 | 6422.30 | 8063.20 | 1640.90 |
| 5 | 19064.40 | 18257.70 | -806.70 |
| 6 | 7940.70 | 9044.20 | 1103.50 |
| 7 | 9278.70 | 7025.70 | -2253.00 |
| 8 | 10427.60 | 8830.90 | -1596.70 |
| 9 | 9919.90 | 11077.80 | 1157.90 |
| 10 | 9681.10 | 12099.20 | 2418.10 |
| Average | **10262.67** | **9870.39** | **-392.28** |

***TOTAL LEAN MASS (g)***

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 61136.20 | 60373.80 | -762.40 |
| 2 | 55930.10 | 56941.90 | 1011.80 |
| 3 | 62306.00 | 61669.70 | -636.30 |
| 4 | 61660.10 | 61939.50 | 279.40 |
| 5 | 59259.70 | 58935.20 | -324.50 |
| 6 | 53794.90 | 54749.90 | 955.00 |
| 7 | 55759.70 | 54825.60 | -934.10 |
| 8 | 71882.30 | 72374.40 | 492.10 |
| 9 | 53913.60 | 52998.10 | -915.50 |
| 10 | 58293.30 | 60154.00 | 1860.70 |
| Average | **59393.59** | **59496.21** | **102.62** |

***% FAT***

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 18.00 | 12.40 | -5.60 |
| 2 | 16.10 | 15.60 | -0.50 |
| 3 | 6.70 | 6.40 | -0.30 |
| 4 | 9.00 | 11.00 | 2.00 |
| 5 | 23.40 | 22.80 | -0.60 |
| 6 | 12.20 | 13.50 | 1.30 |
| 7 | 13.60 | 10.80 | -2.80 |
| 8 | 12.10 | 10.40 | -1.70 |
| 9 | 15.00 | 16.70 | 1.70 |
| 10 | 13.60 | 16.00 | 2.40 |
| Average | **13.97** | **13.56** | **-0.41** |

**RAAF**

***TOTAL FAT MASS (g)***

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 11361.40 | 9083.80 | -2277.60 |
| 2 | 9374.20 | 8990.40 | -383.80 |
| 3 | 11778.00 | 9511.20 | -2266.80 |
| 4 | 12905.30 | 13521.70 | 616.40 |
| 5 | 11481.70 | 11258.80 | -222.90 |
| 6 | 7645.90 | 7776.20 | 130.30 |
| 7 | 14338.80 | 15737.10 | 1398.30 |
| 8 | 12374.00 | 13303.90 | 929.90 |
| 9 | 8825.40 | 8068.70 | -756.70 |
| Average | **11120.52** | **10805.76** | **-314.77** |

***TOTAL LEAN MASS (g)***

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 64798.20 | 62354.70 | -2443.50 |
| 2 | 63517.10 | 60810.90 | -2706.20 |
| 3 | 55603.00 | 53326.60 | -2276.40 |
| 4 | 69004.60 | 68487.10 | -517.50 |
| 5 | 65169.90 | 65189.40 | 19.50 |
| 6 | 60340.50 | 59157.40 | -1183.10 |
| 7 | 62604.80 | 61172.20 | -1432.60 |
| 8 | 60446.50 | 61163.80 | 717.30 |
| 9 | 63781.00 | 64587.30 | 806.30 |
| Average | **62807.29** | **61805.49** | **-1001.80** |

***% FAT***

| SUBJECT | PRE | POST | DIFF |
|---|---|---|---|
| 1 | 14.30 | 12.10 | -2.20 |
| 2 | 12.30 | 12.30 | 0.00 |
| 3 | 16.80 | 14.50 | -2.30 |
| 4 | 15.20 | 15.90 | 0.70 |
| 5 | 14.30 | 14.10 | -0.20 |
| 6 | 10.70 | 11.10 | 0.40 |
| 7 | 18.00 | 19.80 | 1.80 |
| 8 | 16.40 | 17.20 | 0.80 |
| 9 | 11.60 | 10.60 | -1.00 |
| Average | **14.40** | **14.18** | **-0.22** |

# Appendix E

# Reliability Study Data and Calculations

## Reliabilty Study: Hologic QDR 4500: Cervical Spine

| SUBJECT | SCAN 1 | SCAN 2 | DIFFERENCE | DIFF $^2$ |
|---|---|---|---|---|
| | Total BMD | Total BMD | | |
| 1 | 0.618 | 0.62 | 0.002 | 0.00000 |
| 2 | 0.646 | 0.634 | -0.012 | 0.00014 |
| 3 | 0.675 | 0.673 | -0.002 | 0.00000 |
| 4 | 0.681 | 0.692 | 0.011 | 0.00012 |
| 5 | 0.645 | 0.656 | 0.011 | 0.00012 |
| 6 | 0.731 | 0.737 | 0.006 | 0.00004 |
| 7 | 0.609 | 0.611 | 0.002 | 0.00000 |
| 8 | 0.569 | 0.555 | -0.014 | 0.00020 |
| 9 | 0.573 | 0.56 | -0.013 | 0.00017 |
| 10 | 0.75 | 0.753 | 0.003 | 0.00001 |
| 11 | 0.7 | 0.706 | 0.006 | 0.00004 |
| 12 | 0.823 | 0.812 | -0.011 | 0.00012 |
| 13 | 0.704 | 0.691 | -0.013 | 0.00017 |
| 14 | 0.729 | 0.718 | -0.011 | 0.00012 |
| 15 | 0.67 | 0.683 | 0.013 | 0.00017 |
| Mean | **0.6749** | **0.6734** | | **0.001424** |

Mean of 30 values **0.67415**

**RESULTS**

**$Sw^2$=** 0.001424/30 **0.0000475**

**ME=** **0.019g.cm$^2$**

**CV%** **1.02%**